X-ray Free Electron Laser

(Accelerator Based X-ray Laser)

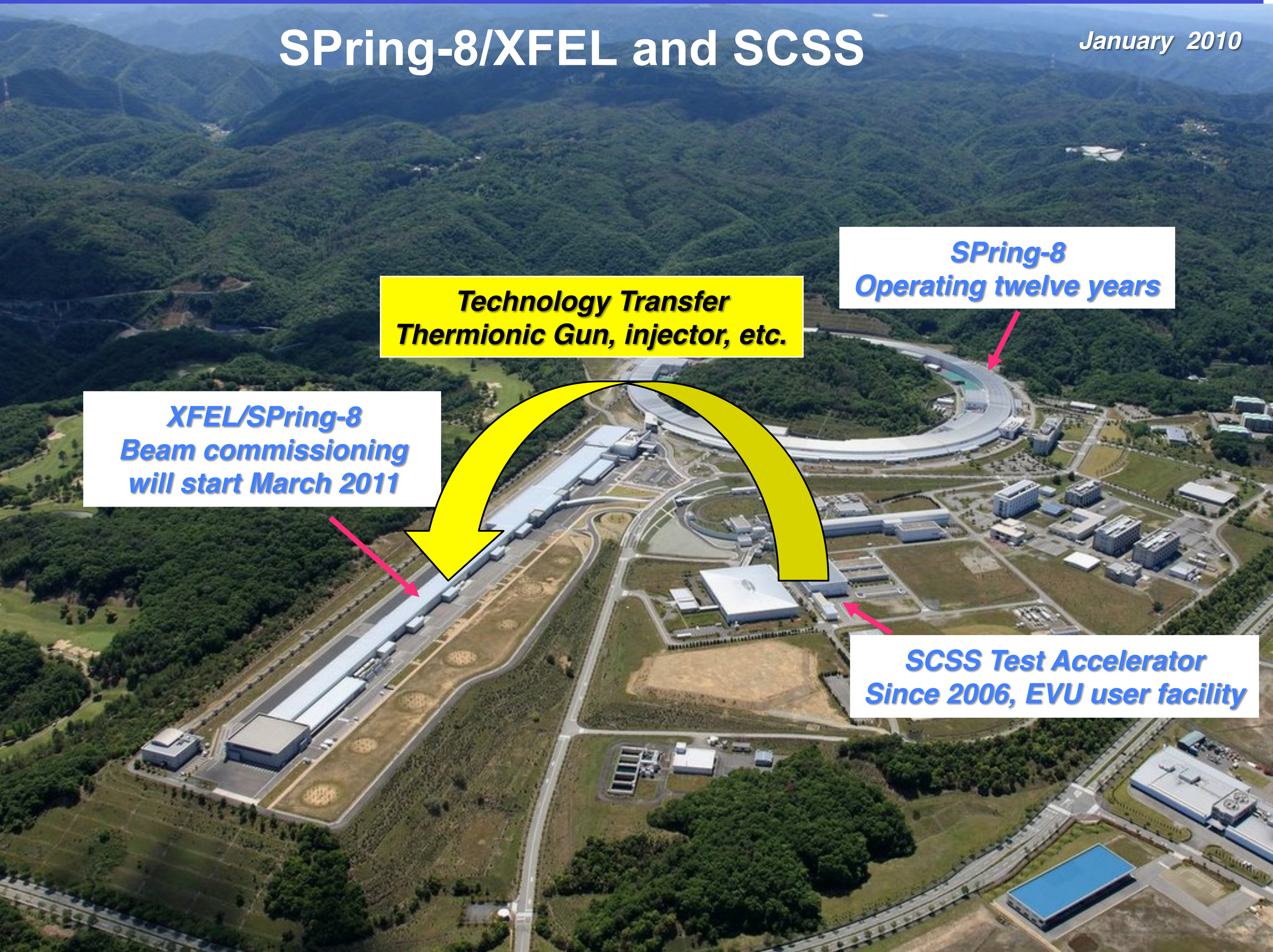
Tsumoru Shintake

RIKEN/SPring-8

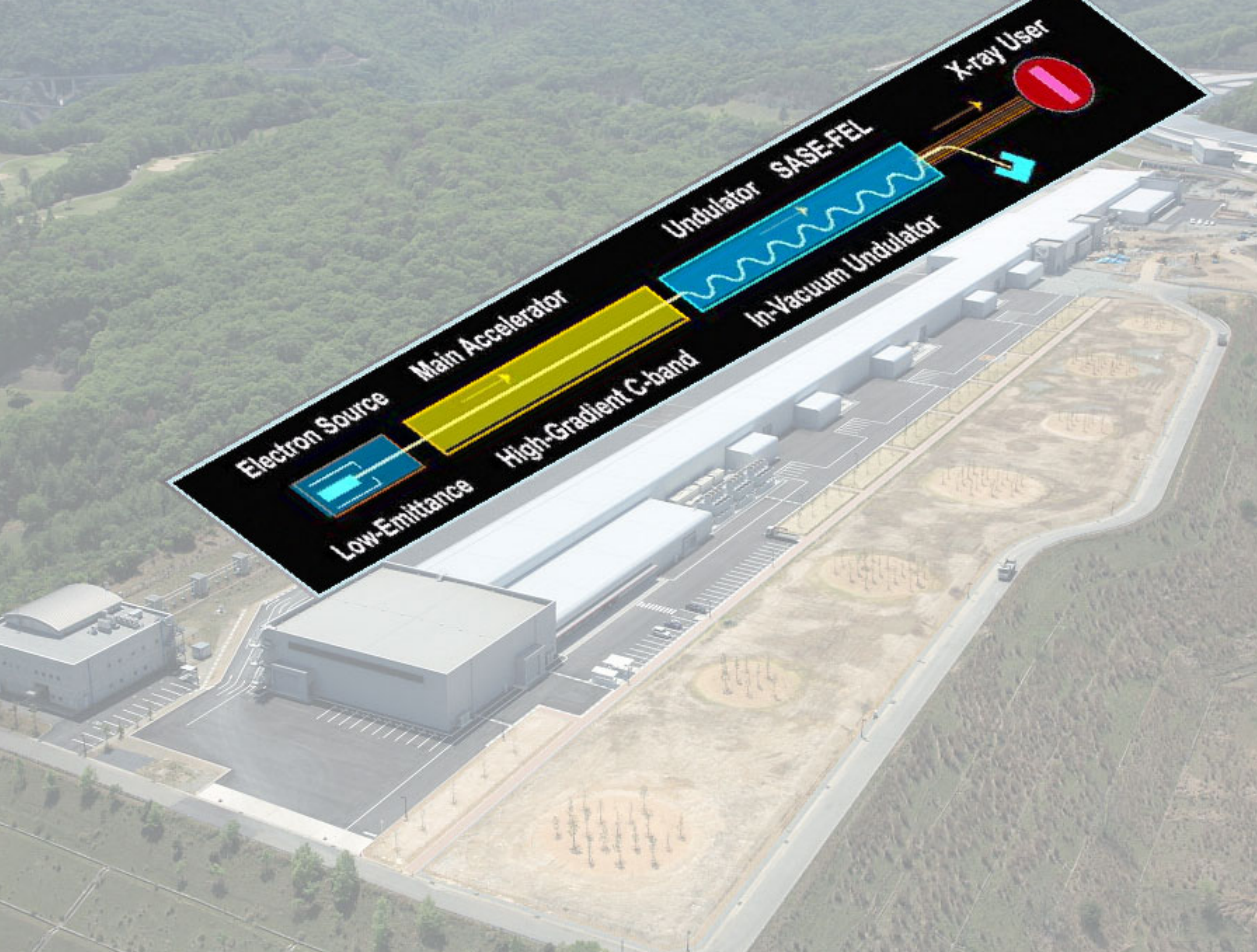
How does it work?
How to use?

Contens

- Free Electron Laser Basic
- About our SCSS & XFEL/SPring-8
- Diffraction Imaging

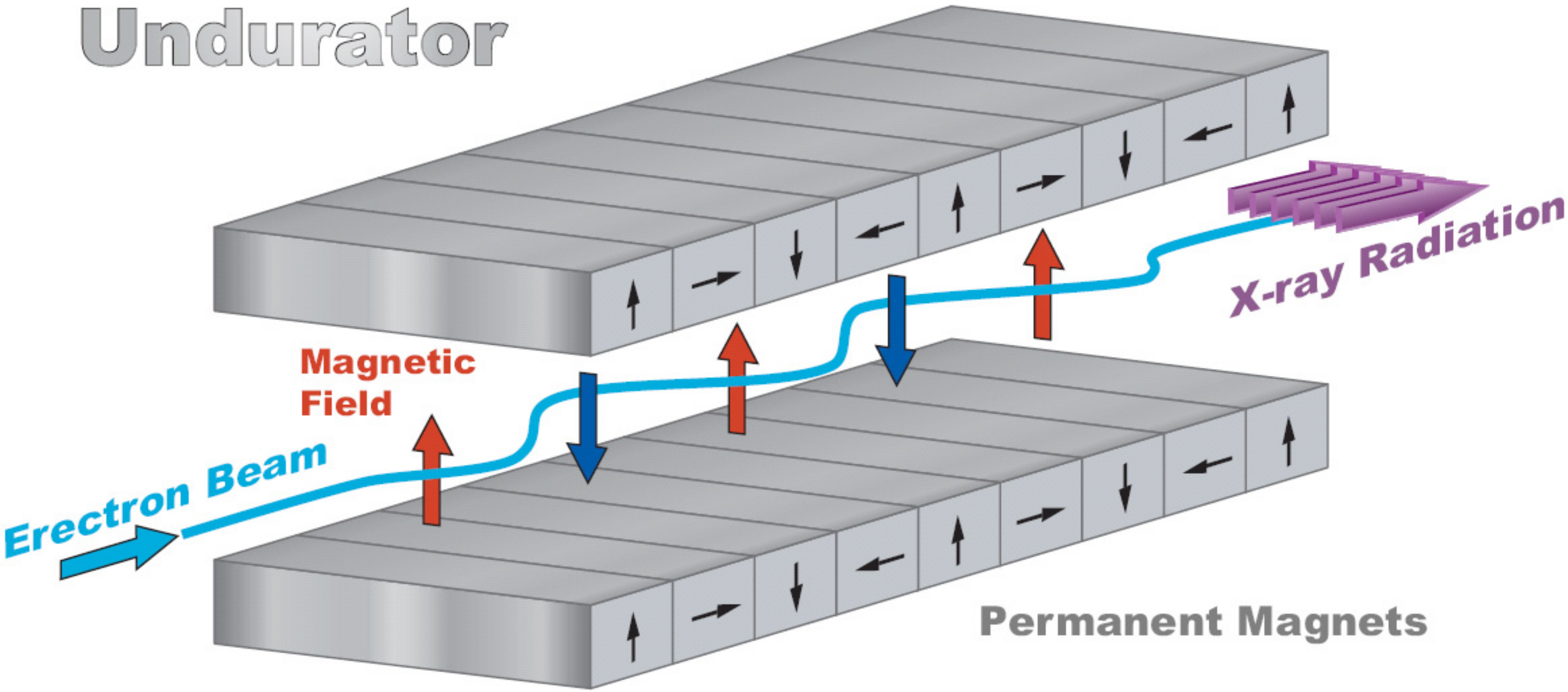

SPring-8/XFEL and SCSS
January 2010
SPring-8
Operating twelve years
Technology Transfer
Thermionic Gun, injector, etc.
XFEL/SPring-8
Beam commissioning
will start March 2011
SCSS Test Accelerator
Since 2006, EVU user facility


Beam commissioning will start next year.
Expecting First FEL X-ray Lasing in 2011.
Experimental Hall
250 m Undulator Hall
400 m Linear Accelerator
Klystron Gallery
You are here
Machine Assembly Hall
klystron, modulators,
accelerating structures,



X-ray User
SASE-FEL
Undulator
In-Vacuum Undulator
Main Accelerator
High-Gradient C-band
Electron Source
Low-Emittance

Undulator = Periodic Magnetic Device



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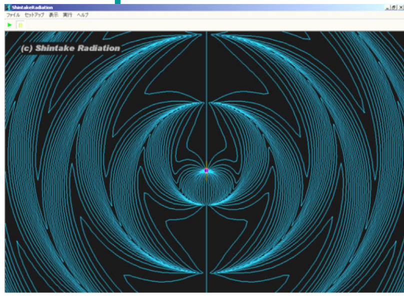
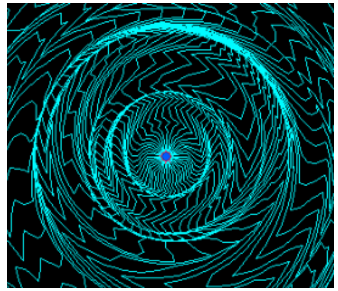
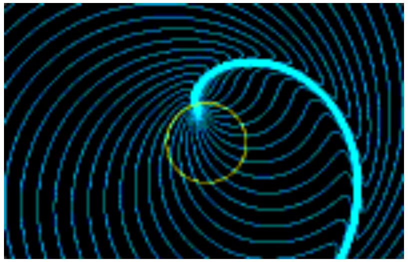
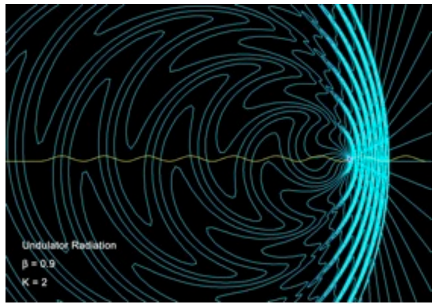
Understanding Radiation

- Free download “Radiation2D” from http://ShintakeLab.com
- Basic physics of radiation.
  - Radio-wave(dipole radiation)
  - Thermal radiation.
  - Synchrotron Radiation
  - Undulator Radiation
- Free Electron Laser Basic









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We need very high energy

Doppler shift

$$\lambda_x = ct - \lambda_u$$

$$= \left(c/\overline{u}_z - 1\right)\lambda_u$$

$$= (1/\overline{\beta}_z - 1)\,\lambda_u$$

$$= \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

Traveling time for one wavelength

$$t = \lambda_u / \overline{u}_z$$

$$1/\overline{\beta}_z - 1 \approx 1 - \overline{\beta}_z$$

$$= (1 - \overline{\beta}_z) \times \frac{1 + \overline{\beta}_z}{1 + \overline{\beta}_z}$$

$$\approx \frac{1 - \overline{\beta}_z^{\,2}}{2} = \frac{1 - \beta^2 + \overline{\beta}_y^{\,2}}{2}$$

$$= \frac{1}{2\gamma^2}\left(1 + (\gamma\overline{\beta}_y)^2\right)$$

$$= \frac{1}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$\gamma = E/m_0c^2 = 8\ \mathrm{GeV}/\,0.51\ \mathrm{MeV} = 15600$$

$$\beta = \sqrt{1 - 1/\gamma^2} \approx 1 - 1/2\gamma^2 = 1 - 2.05 \times 10^{-9}$$

$$= 0.9999999998$$

$$K = 0.1 \times \lambda_u(cm) \times B_x(kG)$$

$$= 0.1 \times 2cm \times 10kG)$$

$$= 2$$

$$\lambda_x = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$= \frac{2cm}{2(15600)^2}(1 + 2^2/2) = 0.4\dot{A} \times 3 = 1.2\dot{A}$$

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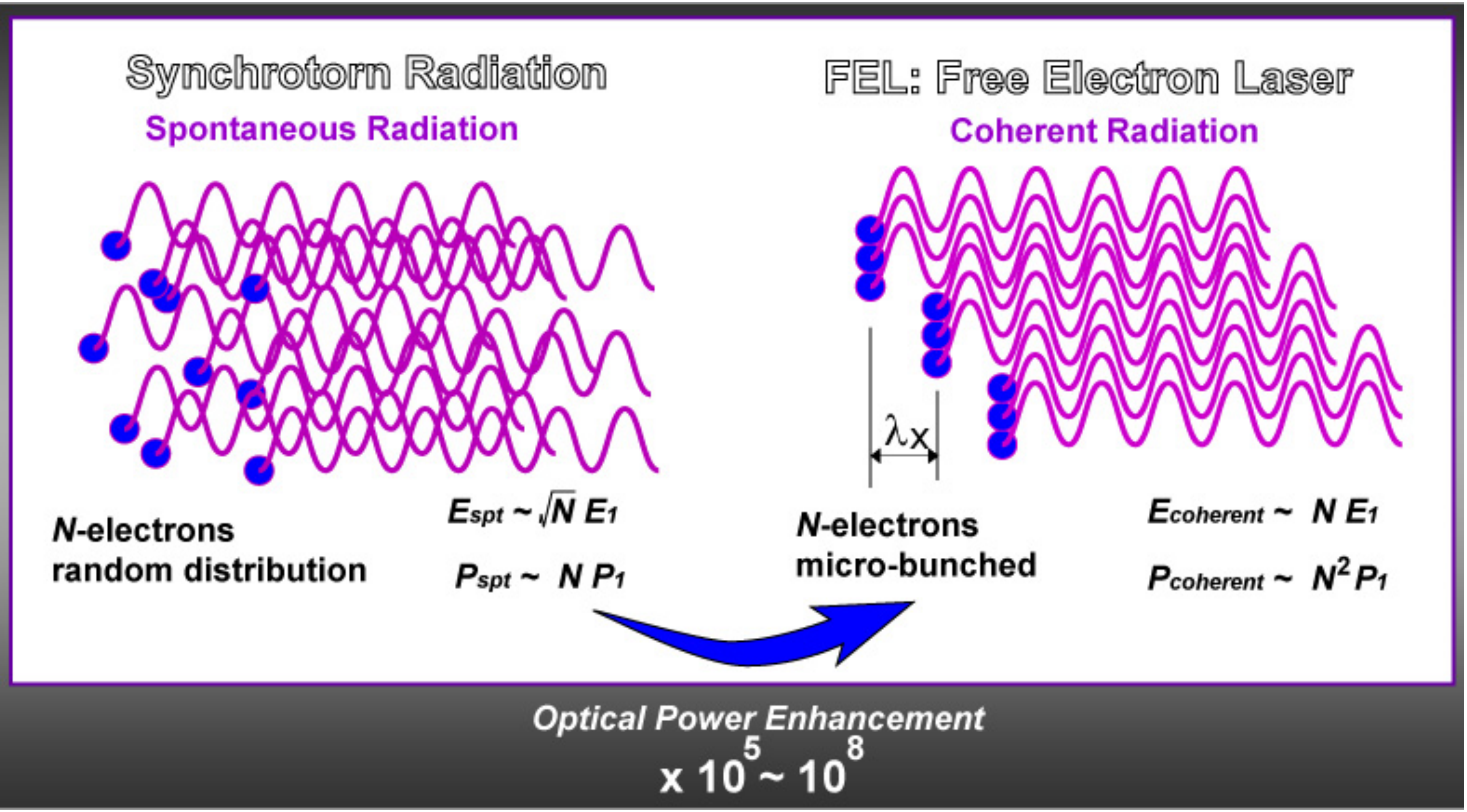
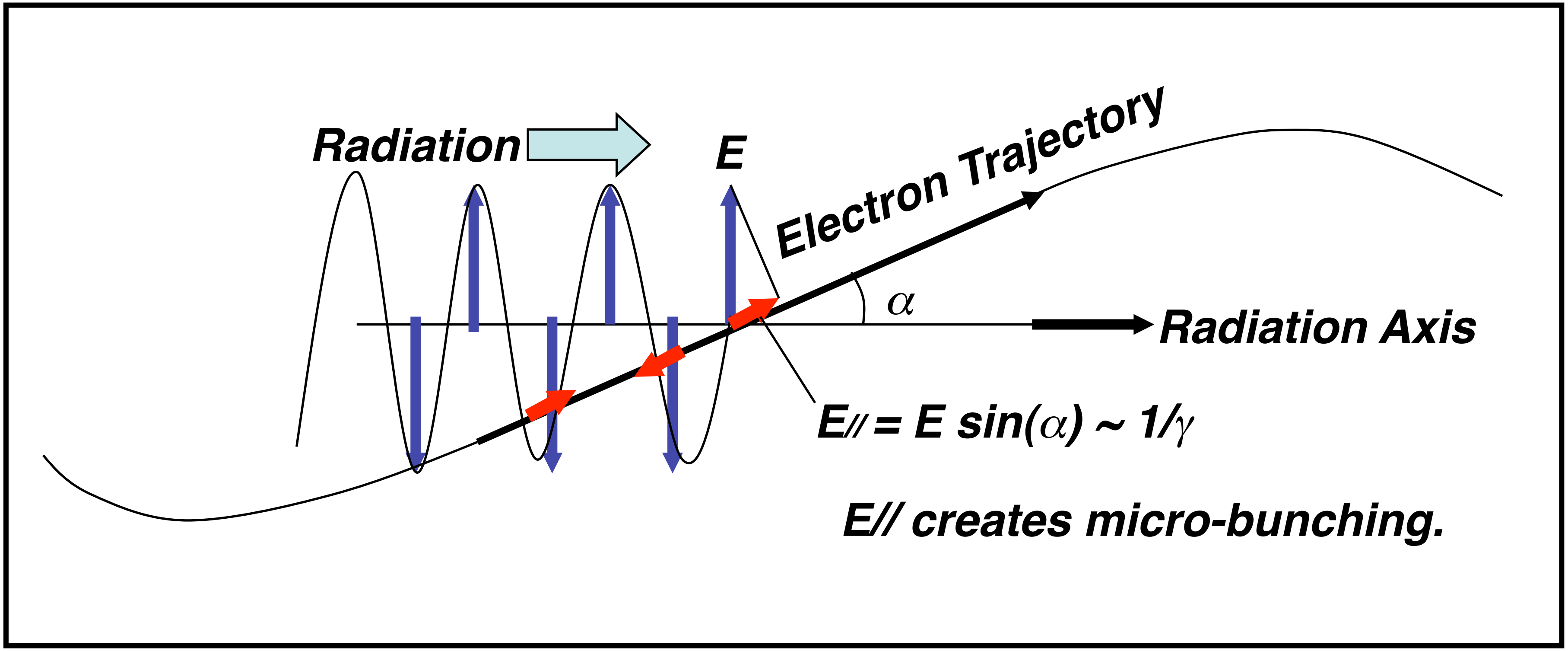
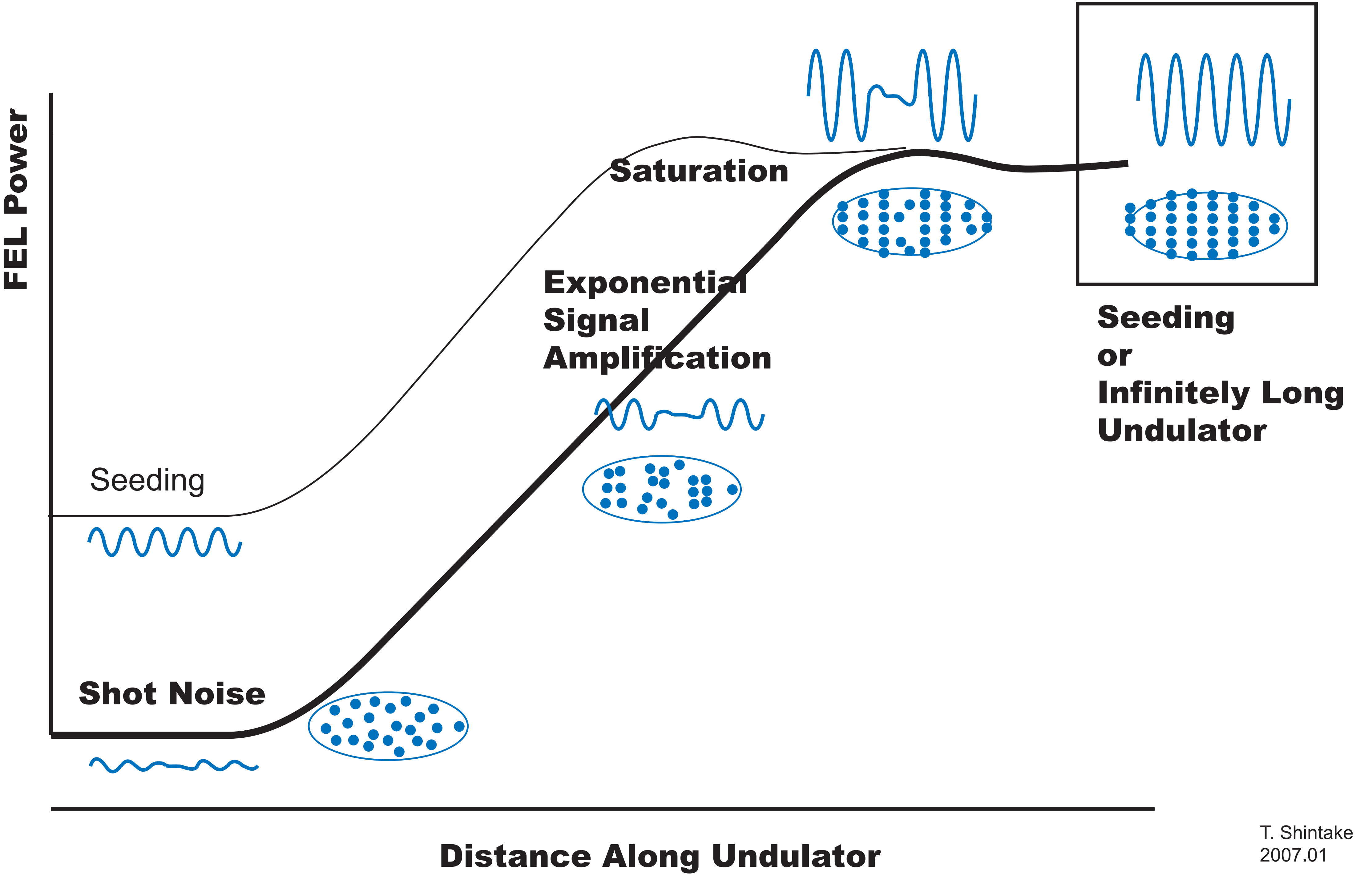
FEL = Coherent Undulator Radiation



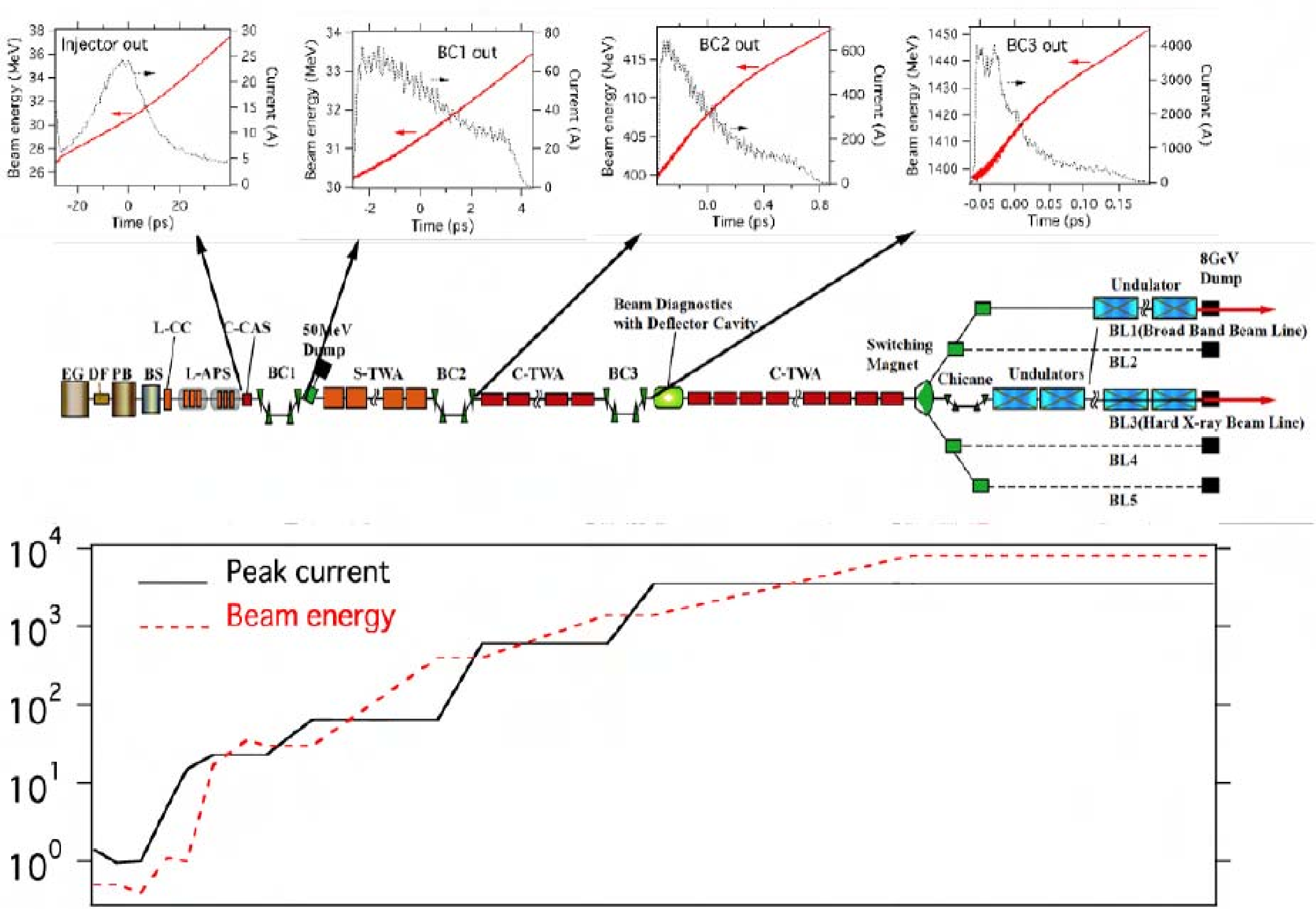
Physical Origin of Micro-bunching (FEL Action)

- Undulator field produces curved trajectory. From this slope, the tangential component of EM wave creates longitudinal field.



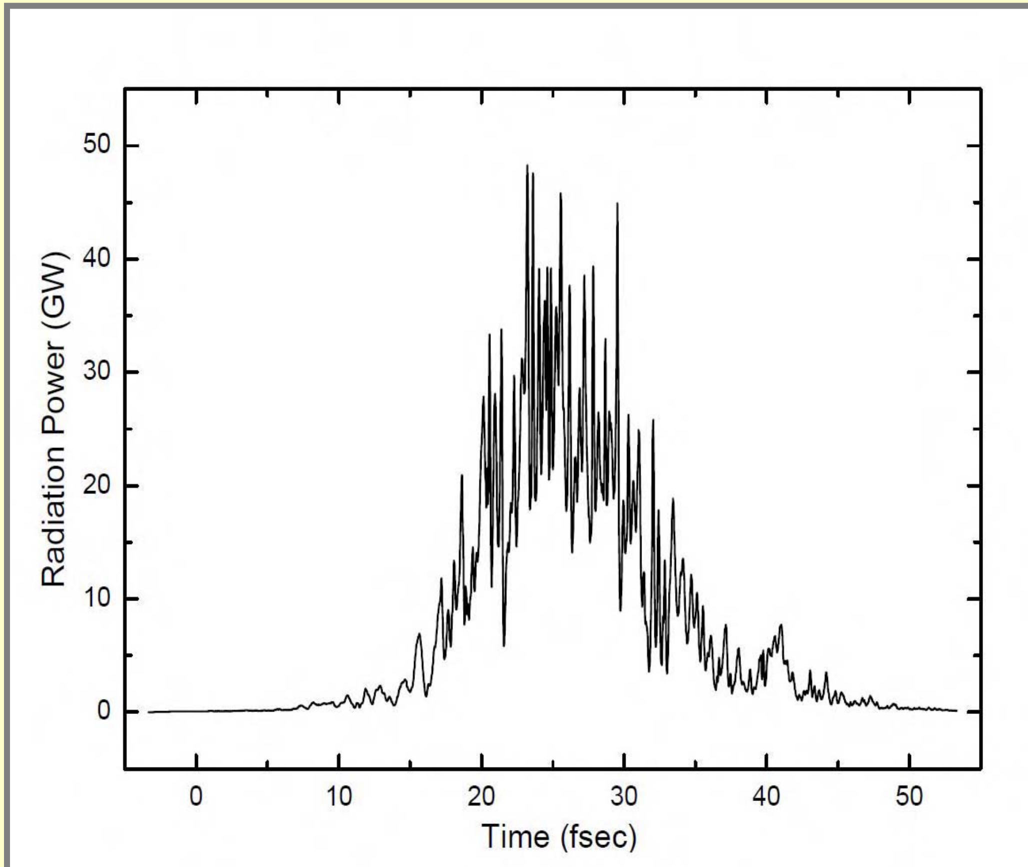

FEL Power
Saturation
Exponential
Signal
Amplification
Seeding
or
Infinitely Long
Undulator
Seeding
Shot Noise
Distance Along Undulator
T. Shintake
2007.01

Basic Machine Layout of XFEL/SPring-8



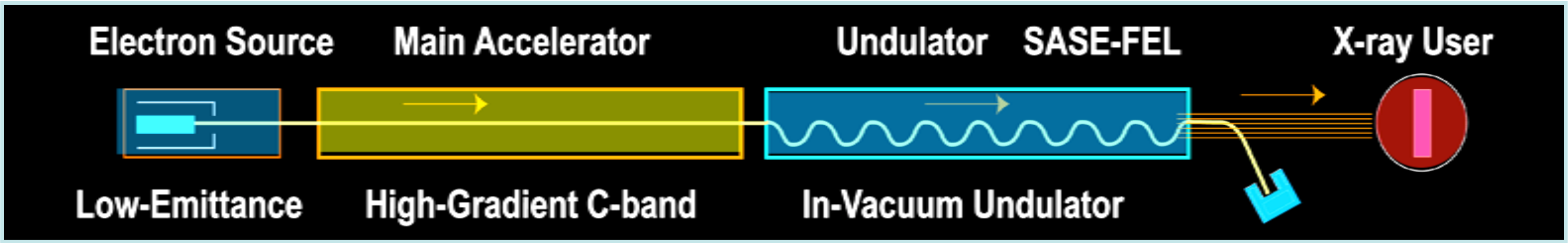
Expected Performance of XFEL/SPring-8

Wavelength	**< 0.1 nm**
Peak Power	**~ 20 GW**
X-ray Pulse Length	**200 fs ~ 20 fs**
X-ray Pulse Energy	**Max 0.4 mJ**
Photon Flux	**2 x 10^{11} p/pulse**
Peak Brightness	**1 x 10^{33} p/mm^2/mrad^2/0.1% BW**
X-ray Pulse Repetition	**10 ~ 3000 pps (50 bunch x 60 Hz)**
Bunch per Pulse	**1 ~ 50 (4.2 nsec spacing)**
e Beam	**8 GeV x 0.3 nC 0.8 πmm.mrad, 3 kA**



Expected X-ray pulse of 0.1 nm
(SIMPLEX simulation)

SCSS : SPring-8 Compact SASE Source



- **Short Period Undulator** → **Lower Beam Energy**

In-Vacuum Undulator : λu= 18 mm, K=1.9, λx < 1 Å → E= 8 GeV,

SLAC-LCLS : λu= 30 mm, K=3.7, λx~ 1.5 Å → E= 14 GeV

Euro-XFEL : λu= 36 mm, K=3.3, λx < 1 Å → E= 17.5 GeV

- **High Gradient Accelerator** → **Short Accelerator Length**

8 GeV, C-band 35 MV/m → 230 m

SLAC-LCLS : S-band 19 MV/m → 740 m

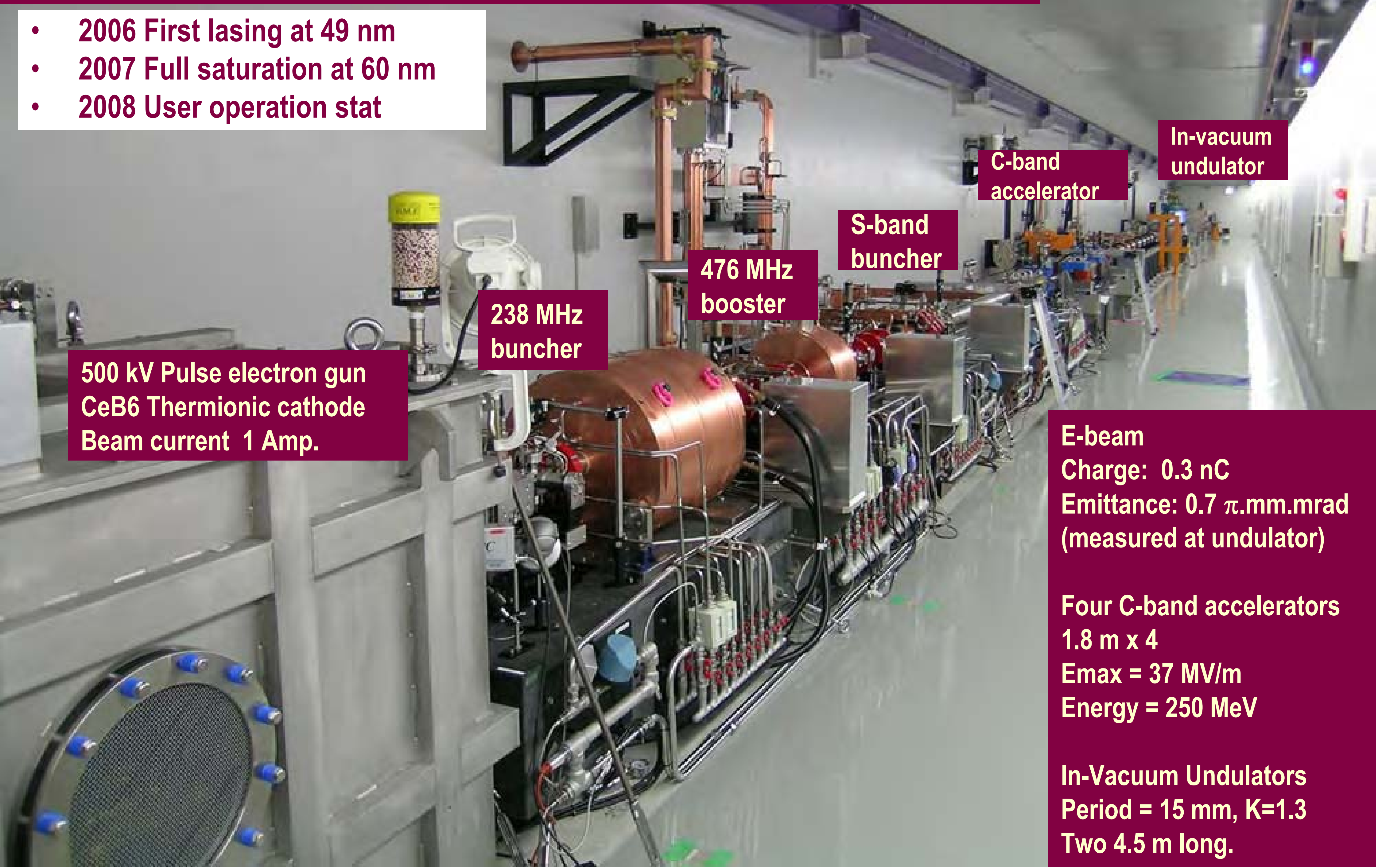
- **Thermionic Electron Source** → **Short Saturation Length**

Thermionic gun + velocity bunching → 0.8 π.mm.mrad @ 3k A, 8GeV

→ multi-bunch operation, smooth & quiet beam for seeding

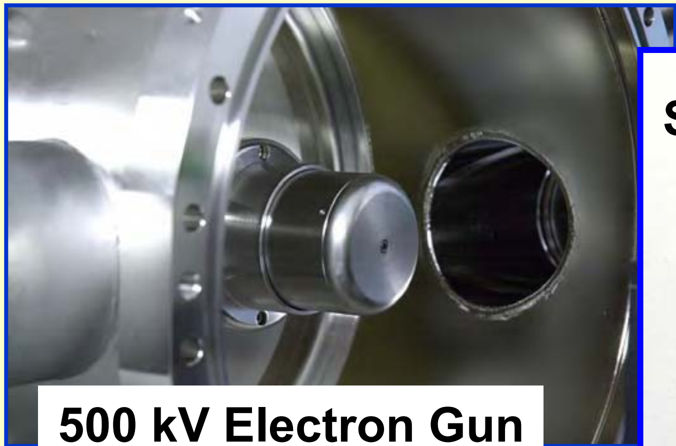
SCSS Test Accelerator Performance

- 2006 First lasing at 49 nm
- 2007 Full saturation at 60 nm
- 2008 User operation stat

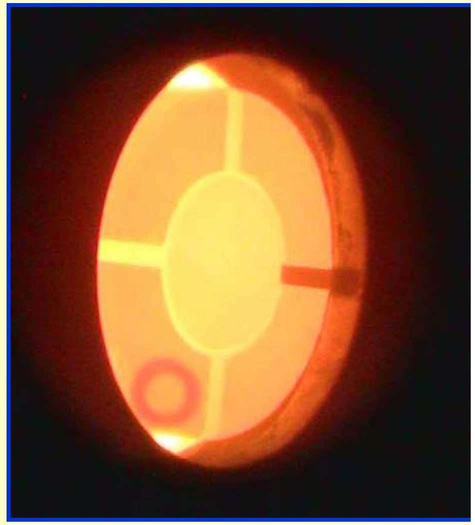


Single-crystal CeB_6 Cathode for the SCSS Low-emittance Injector

***No HV breakdown
for 4 years daily operation***



***After 20,000 hours operation
1 crystal changed.***



Heating Cathode

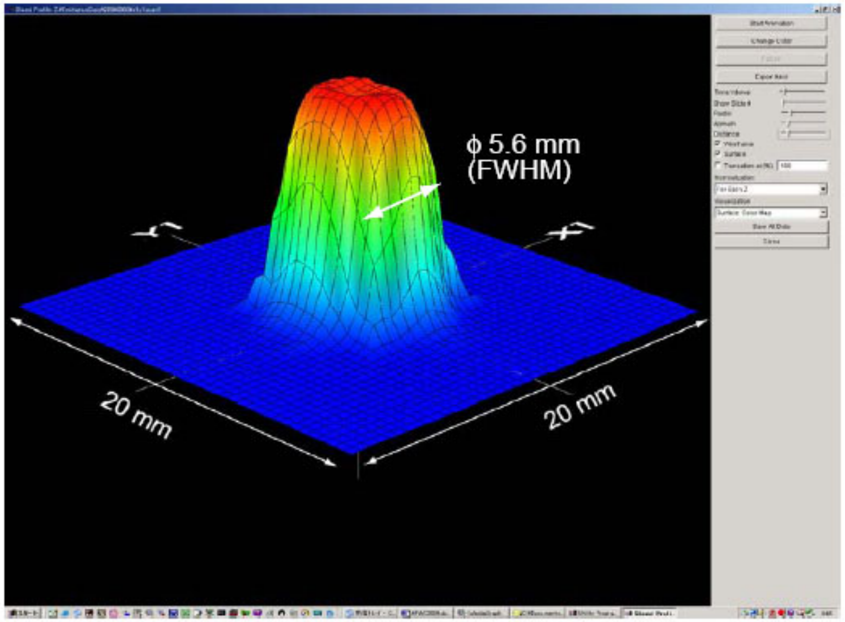
Diameter : ϕ3 mm
Temperature : ~1500 deg.C
Beam Voltage : 500 kV
Peak Current : 1 A
Pulse Width : ~2 μs

CeB6 cathode after 20,000 hour use.

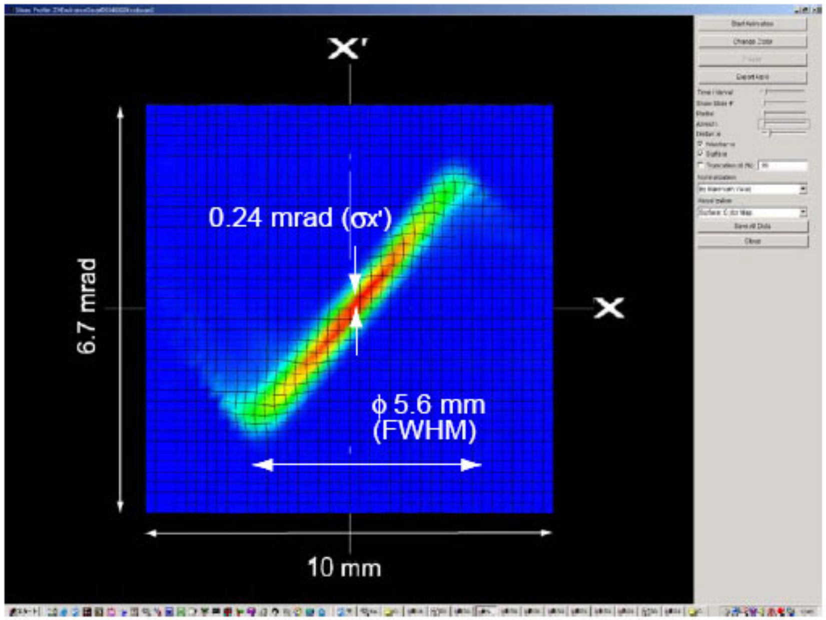
It was found the cathode surface became concave of 0.2 mm deep from the initial flat surface.
It corresponds to evaporation speed of 10 nm/hour (10 nm/h x 20,000 h = 200 micron-meter)
Concave geometry made beam slightly focusing, but did not break emittance.
Electron microscope study showed (1) Surface is fairly smooth, (2) covered by carbon contamination (lowered electron emission).

Measured Emittance at the Gun

Beam Profile



Phase Space Profile



Beam energy	500 keV
Peak current	1 A
Pulse width (FWHM)	3 μs
Repetition rate	10 Hz
Normalized emittance (rms, 100% electrons)	1.1π mm mrad
Normalized emittance (rms, 90% electrons)	0.6π mm mrad

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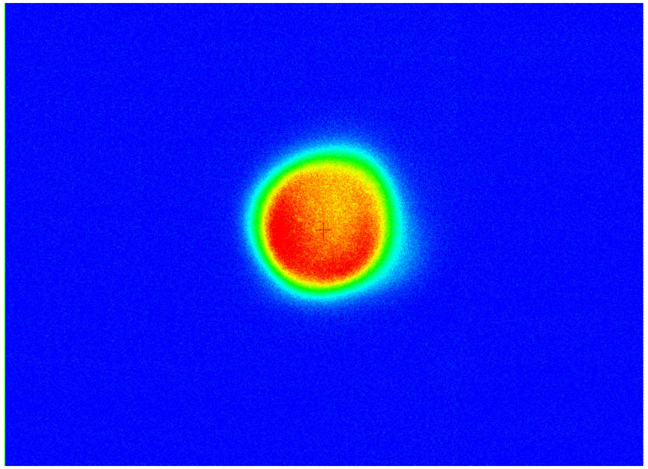
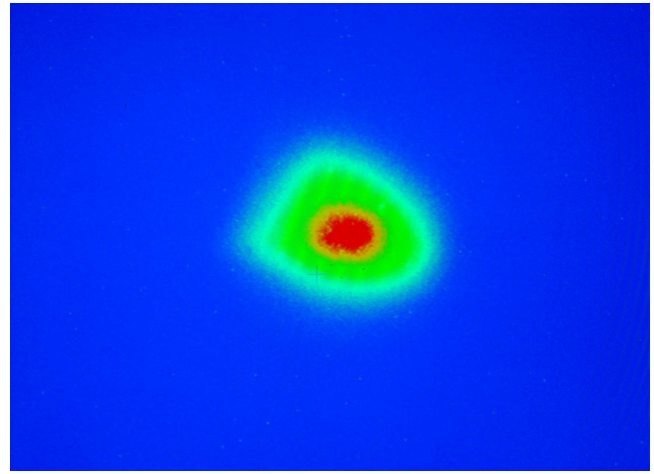
CeB_6 Thermionic Gun provides stable beam.

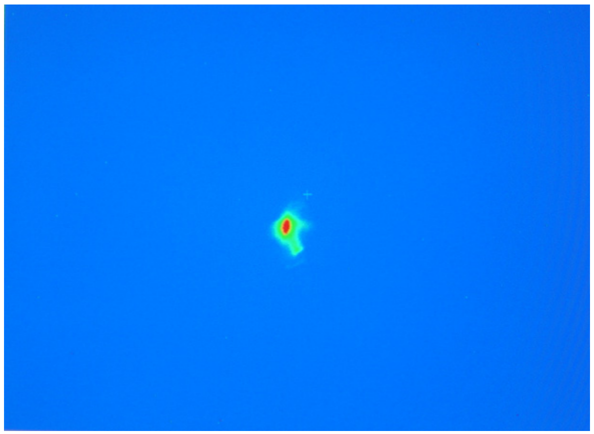
Beam Profile
CCD Image
Scale 10 mm



500 kV Gun

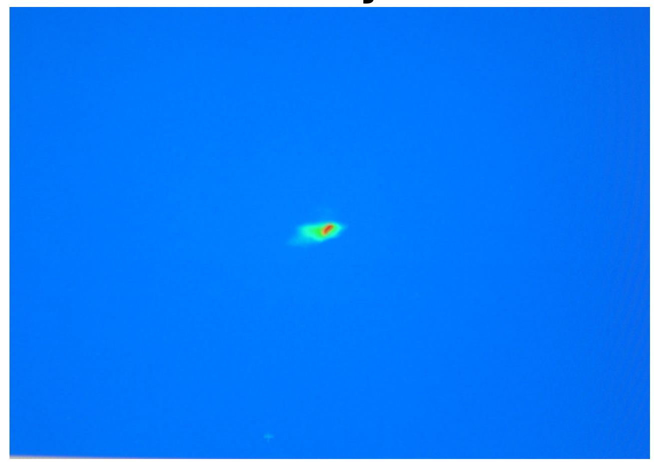


50 MeV Injector Out



250 MeV Compressor

Undulator Input

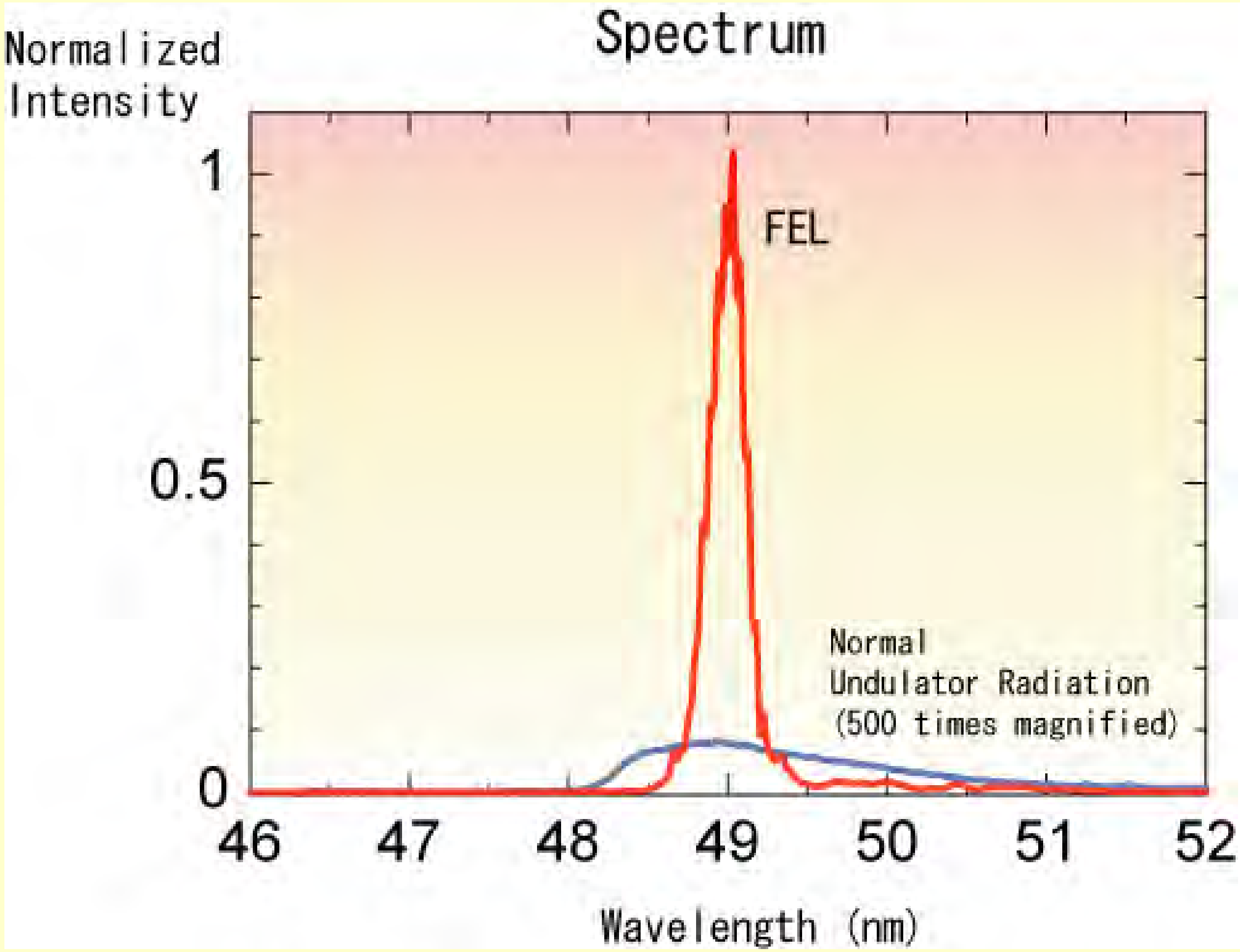


Undulator Output

First Lasing at SCSS Prototype Accelerator.

June 15, 2006

First Lasing at SCSS Prototype Accelerator.



- **The first lasing: 49 nm**
- **E-beam energy : 250 MeV**
- **Bunch charge: 0.25 nC**
- **Bunch length: (< 1 pse)**
- **Peak Current (> 300 A)**

- **At moment spectrum width 0.5 nm is dominated by e-beam energy fluctuation ~ 0.2%.**

Thinking big. Tsumoro Shintake with a prototype XFEL at SPring-8.

MATERIALS SCIENCE

Japanese Latecomer Joins Race To Build a Hard X-ray Laser

X-ray free-electron lasers are the next big thing in high-energy probes of matter. With U.S. and European machines in the works, Japan wants into the club

SAYO, HYOGO PREFECTURE, JAPAN—It's the scientific version of keeping up with the Joneses. Once researchers in one region plan a big, new experimental device, researchers everywhere want their own. The latest example: x-ray free-electron lasers (XFELs), which promise beams that are vastly brighter and with higher energy and shorter pulses than today's workhorse synchrotron x-rays.

These "hard" x-ray wavelengths—down to 0.1 nanometer—promise to reveal the struc-

broad interest for science, it is no surprise that [researchers] in three regions of the world want to have a facility of their own," says Reinhard Brinkmann, who leads the European effort based at the German Electron Synchrotron (DESY) research center in Hamburg. "Free-electron lasers are amazing things which herald a new era in photon science," says Janos Hajdu, a synchrotron radiation specialist at Uppsala University in Sweden.

XFELs rely on new approaches to gener-

or oscillating in lockstep—a quality missing from synchrotron light.

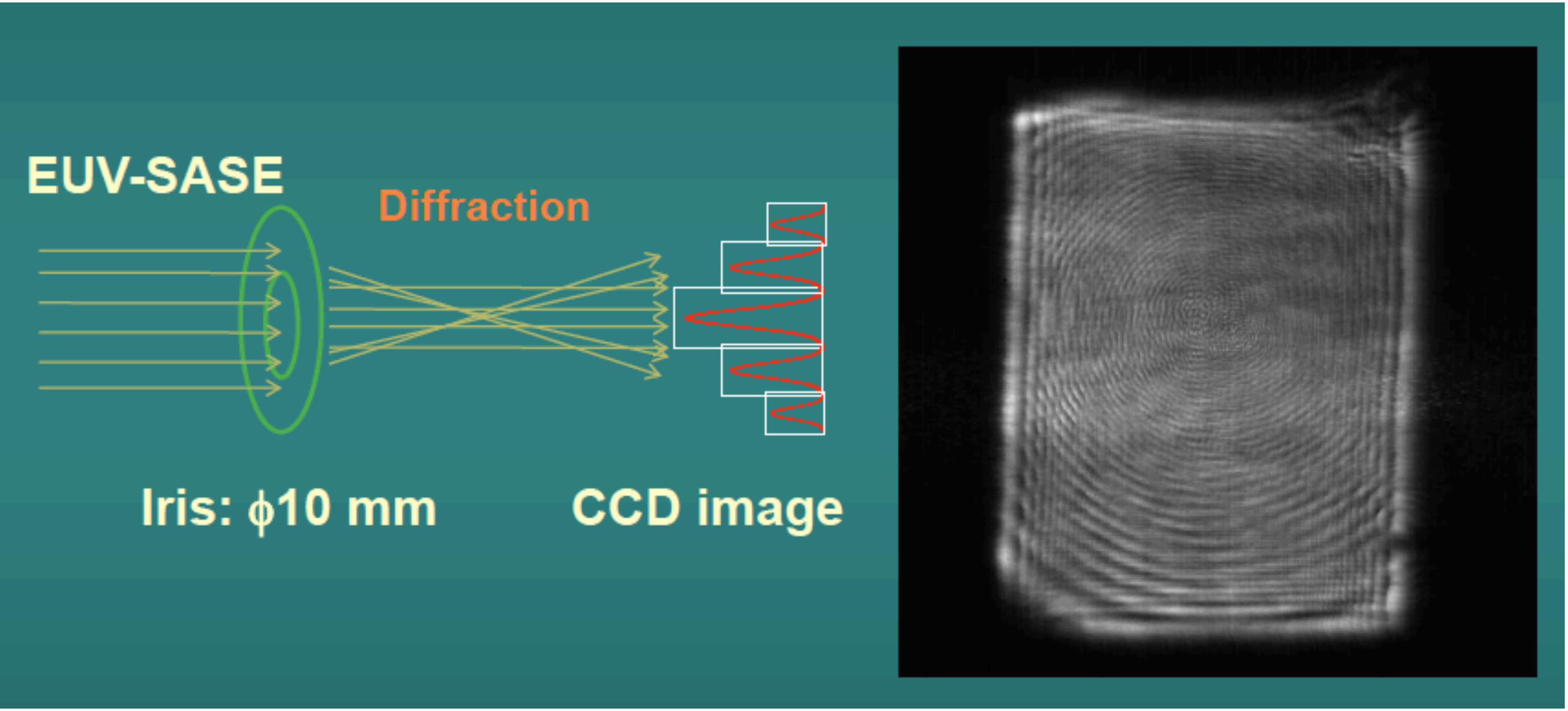
Although all three planned systems share the same basic setup, subtle differences give each of them strengths and weaknesses. "The final targets of the XFEL projects are the same, but the means are different," says Tsumoru Shintake, who heads accelerator development for Japan's XFEL.

The first project to come online will be Stanford's LCLS. Much of the key research underpinning XFELs was done at SLAC beginning in the early 1990s. And SLAC got a head start by using a 1-kilometer stretch of its now-idled linear accelerator, or linac. The SLAC group estimates that reusing its linac has saved more than $300 million, giving a total construction cost of $379 million. LCLS will have one undulator providing hard and soft x-rays to up to six experimental stations. Galayda says the group expects to generate its first x-rays by July 2008 and to start experiments by March 2009.

Japan's entry is the SPring-8 Compact SASE Source (SCSS), just now getting under construction here. Latecomers to the field, the team is using some homegrown technology to cut cost and size. "We're taking the first step toward making XFELs smaller and cheaper so more [institutions] can consider developing their own," boasts SCSS project leader Tetsuya Ishikawa. Whereas the other two machines will generate electrons by firing a laser at a metal target, the SCSS heats a cathode to produce electrons. Eliminating the laser simplifies the system but requires careful compression of the cloud of electrons before they go into the linac.

The wavelength of the output x-rays is a tradeoff between the energy of the electrons

It's laser light at EUV



60 nm, courtecy of Nishino.

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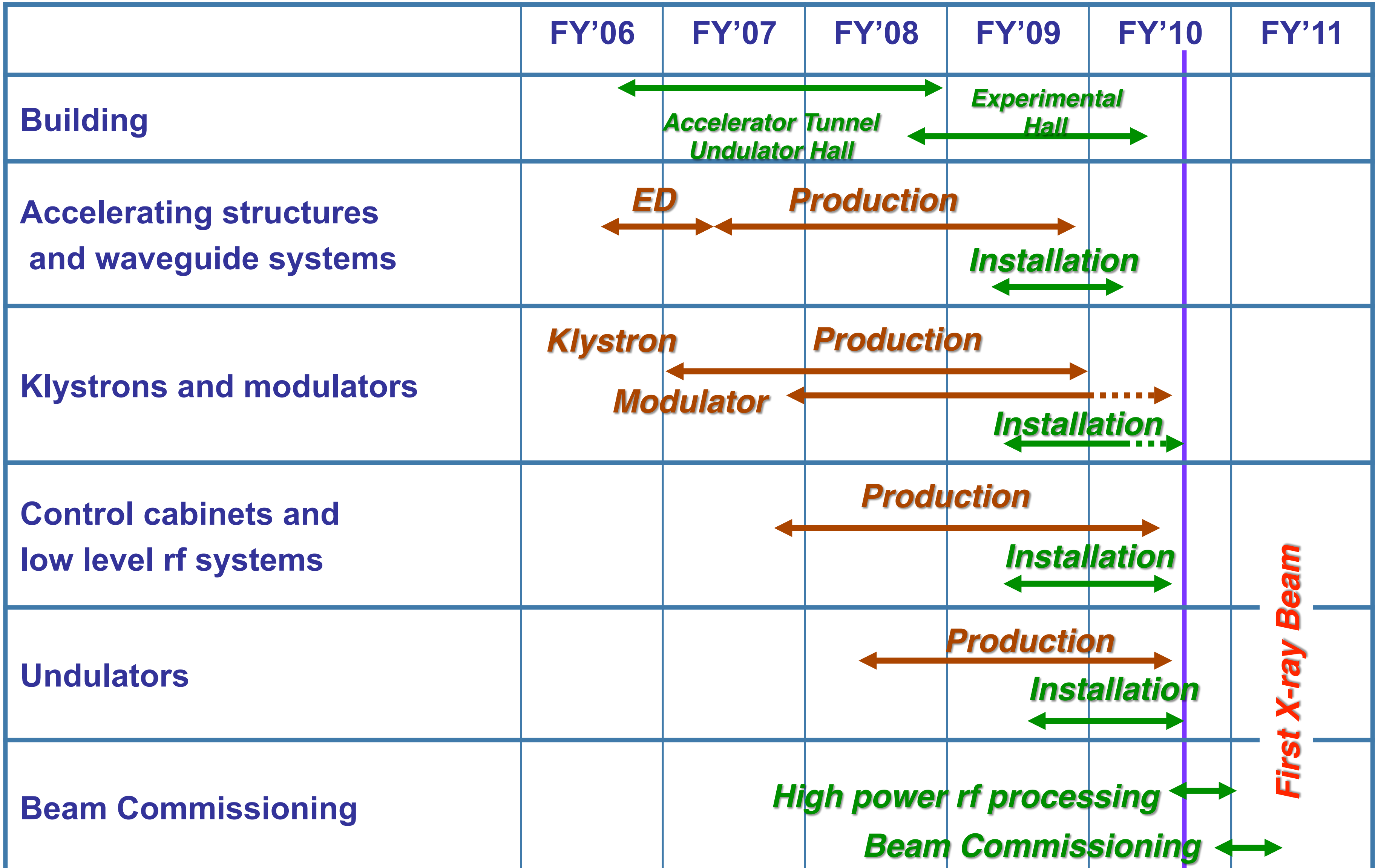
Status of XFEL/SPring-8 Construction



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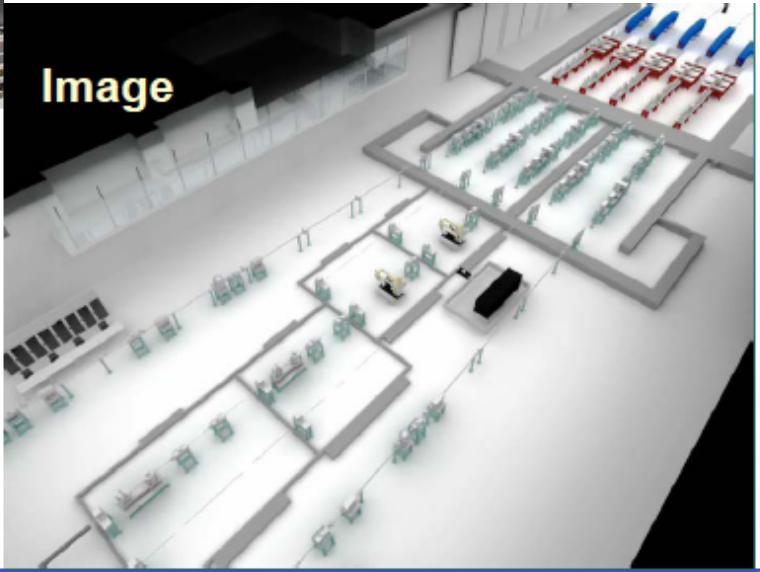
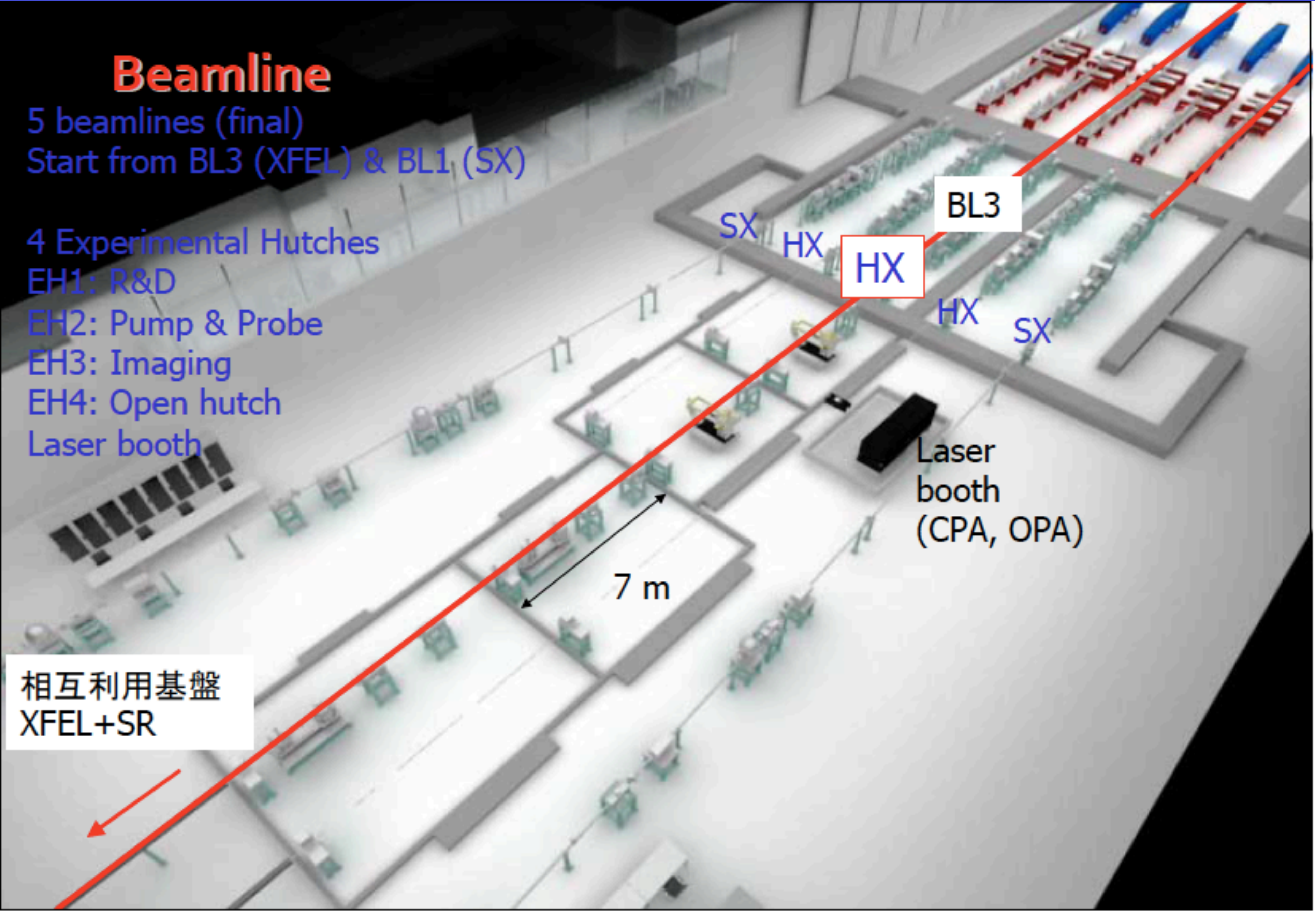
50 m Experimental Hall
200 m Undulator Hall
400 m Accelerator Tunnel
Klystron Gallery
Machine Assembly Hall

Experimental Hall



Beam Lines


Beamline
5 beamlines (final)
Start from BL3 (XFEL) & BL1 (SX)
4 Experimental Hutches
EH1: R&D
EH2: Pump & Probe
EH3: Imaging
EH4: Open hutch
Laser booth
SX
HX
HX
BL3
HX
SX
Laser
booth
(CPA, OPA)
7 m
相互利用基盤
XFEL+SR

Accelerator installation

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2009 Aug


2009 Aug

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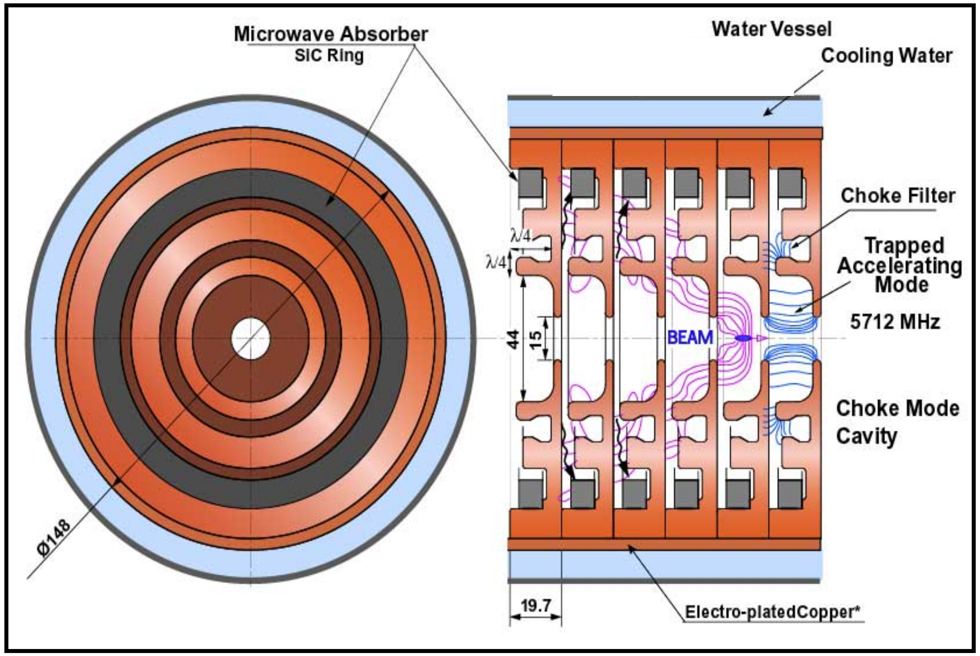
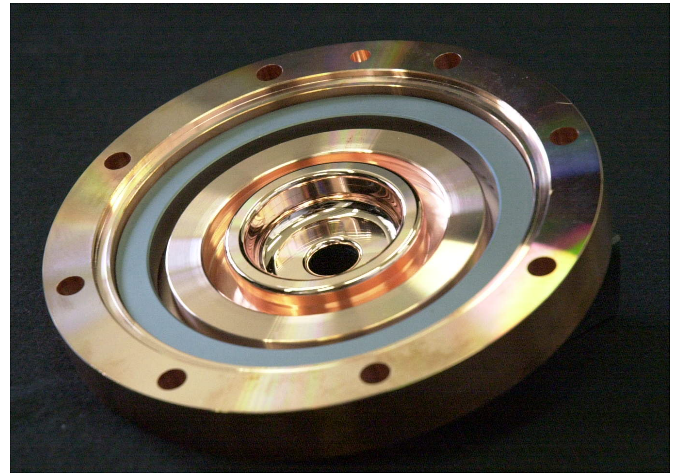
C-band Accelerator for Multi-bunch Option





13,000 cells are under mass production.

T. Shintake, "Choke Mode Cavity",
Jpn. J. Appl. Phys. Vol. 31 pp. L1567-L1570, November 1

Sadao Miura, MITSUBISHI Heavy Ind, April 2008

Higher Order Mode Damping for Multi-bunch operation.
Maximum 50 bunches x 1 nC, at 4.2 nsec spacing

X-ray 4.2 nsec x 50 bunches will be key for
Single bio-molecule imaging to improve Luminosity.

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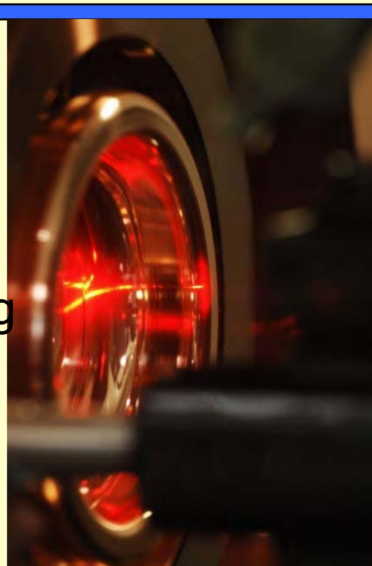
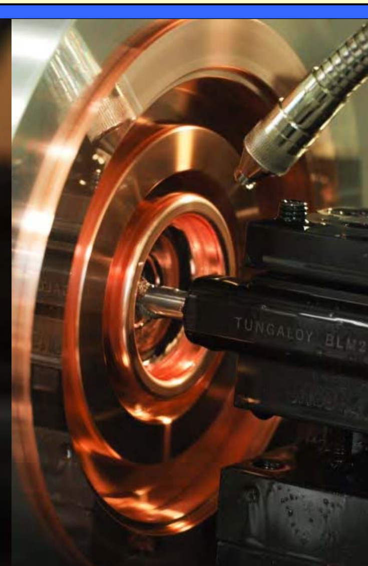
HITACHI Cable Co. completed mass production of C-band cell. June 2009

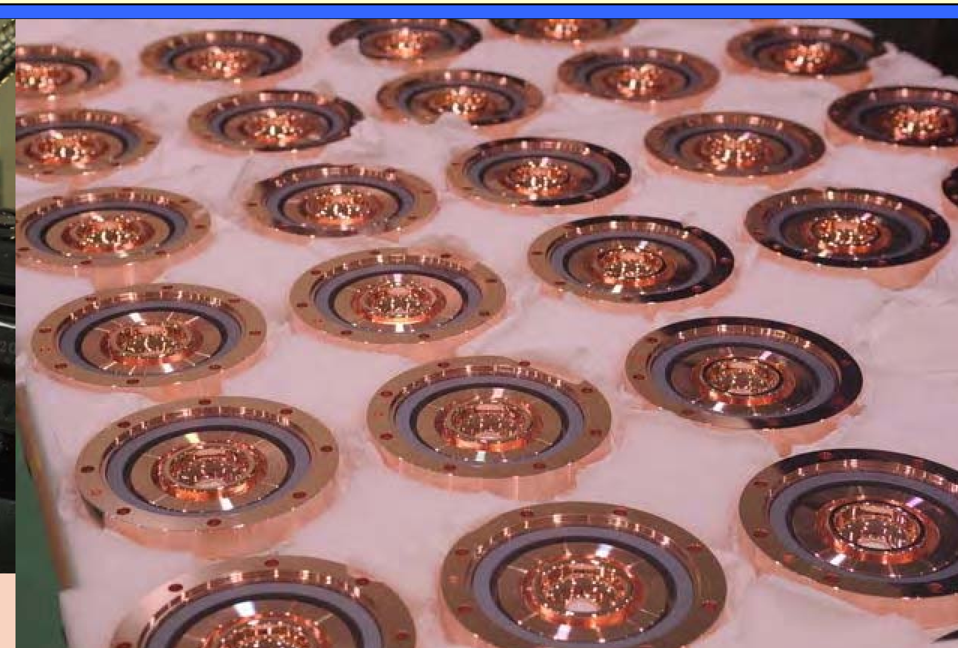
We made 13,000 pieces of C-band accelerator cell.

Mass Production of C-band Accelerator at MITSUBISHI Heavy Ind. 2007 ~ 2009

Laser Guided Precision Machining







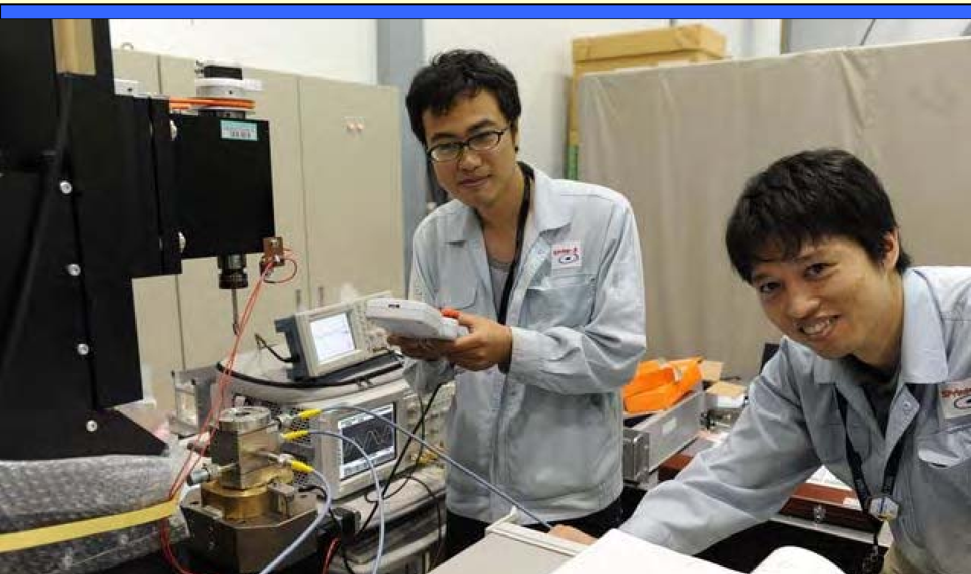
MITSUBISHI-Team completed 100 tubes (out of 128) C-band Accelerator. Photo March 2009

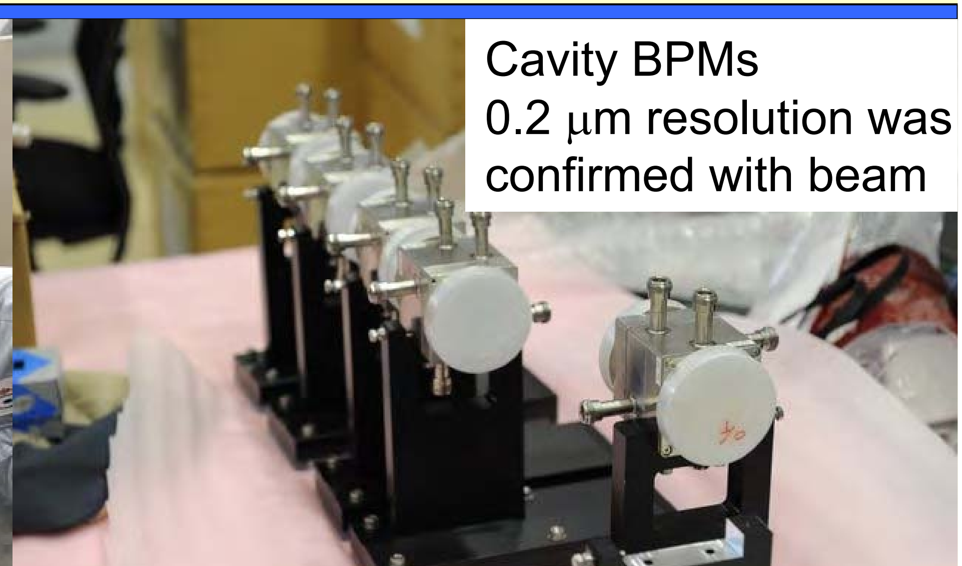
Testing Modulator & Klystron


May 2010

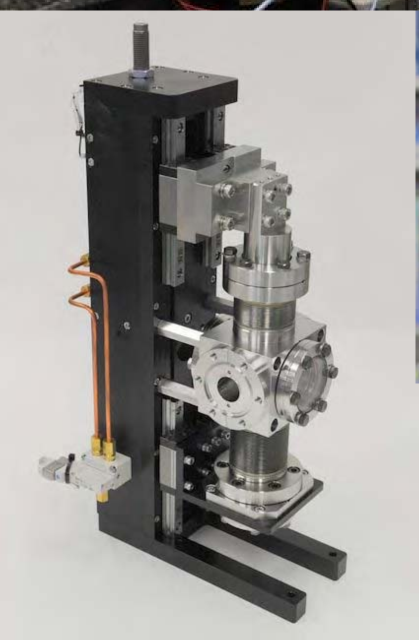
Beam Monitor Devices

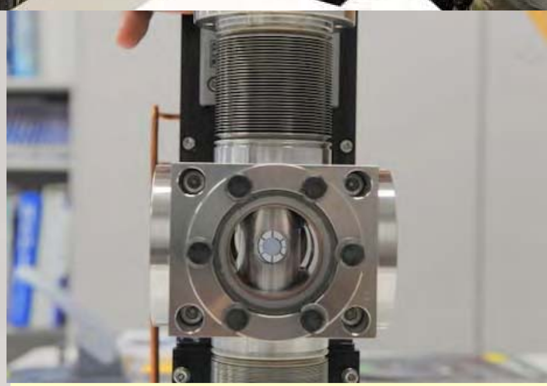
By Y. Otake team.





Cavity BPMs
0.2 μm resolution was confirmed with beam





OTR Radiator

All undulators (18) have been installed in Augost

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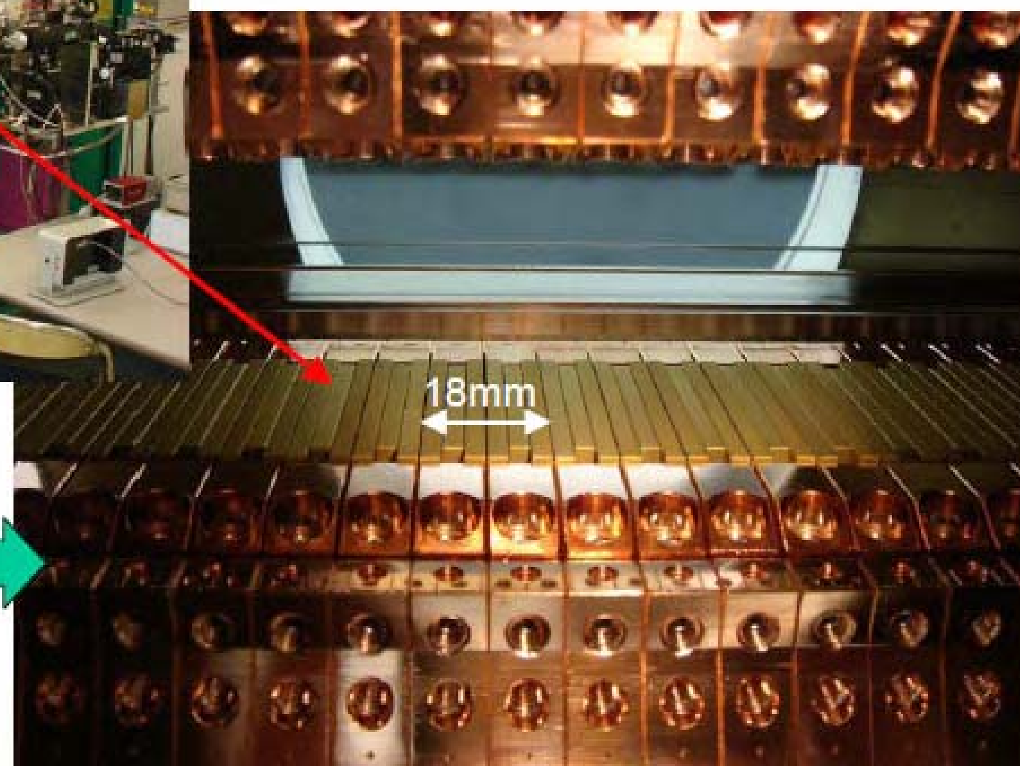
Undulator is ready for mass production.

Undulator for XFEL/SPring-8

Outlook of 5 m long in-vacuum undulator for X-ray FEL.



NeFeB magnet array, undulator period is 18 mm.

Undulator for XFEL/SPring-8

Undulator Type		In-Vacuum Planer Undulator
Active Length		5 m
Undulator Period		18 mm
Magnetic Circuit		Hybrid (NdFeB+Permendur)
Peak Field	Maximum	1.31 T
	Nominal	1.13 T
K	Maximum	2.2
	Nominal	1.9
Gap	Minimum	3.5 mm
	Nominal	4.5 mm
Maximum Attractive Force		~ 6 ton

Why we are constructing XFELs?

- Realize dream of laser at X-ray wavelength.
- Very high peak power 2 GW, high photon flux.
- Very short pulse length. < 100 fsec
- Widely tunable wavelength.

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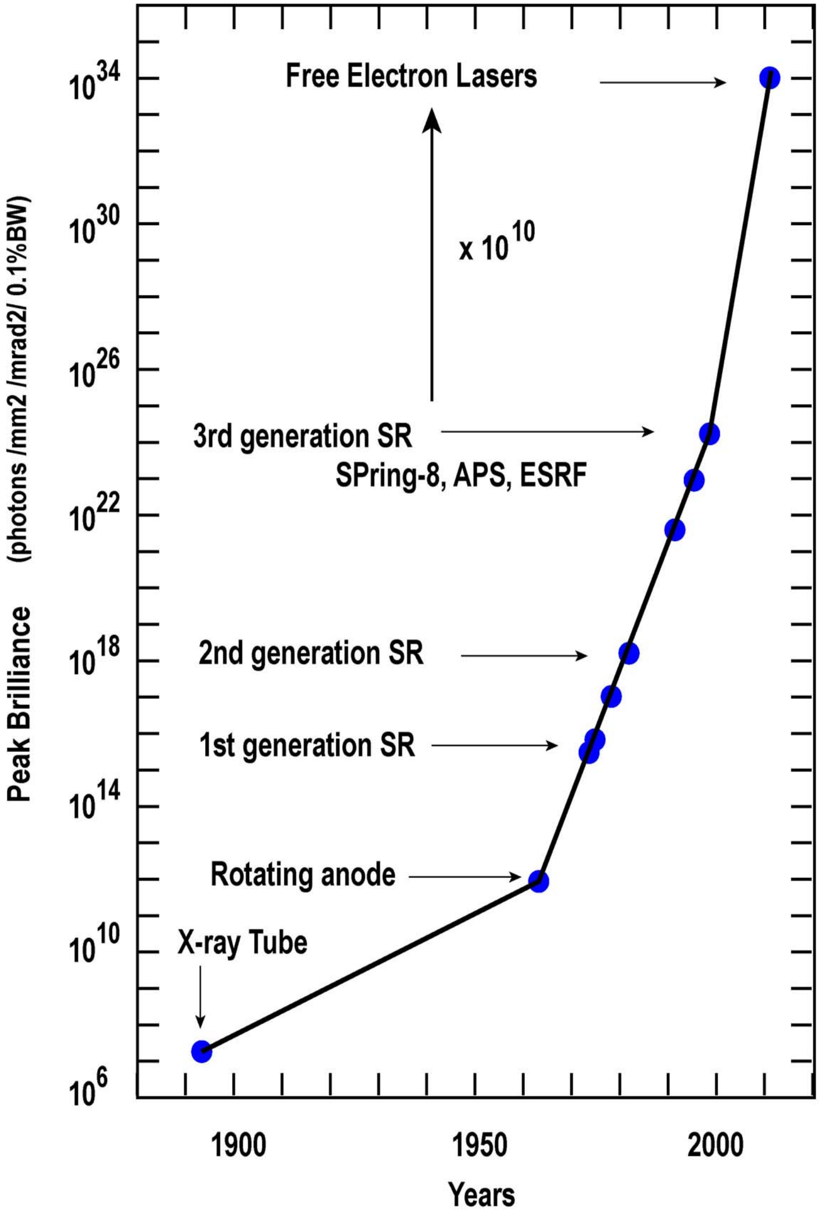
Peak Brilliance Evolution



- Peak brilliance will be enhanced by factor of 10^{10} from 3rd generation SR to XFEL.
- $10^{10} = 10^1 \times 10^1 \times 10^1 \times 10^7$

  = peak current by factor 10
  x lowered emittance by 10
  x energy spread lowered by 10
  x interference effect 10^7 by micro-bunching formation.

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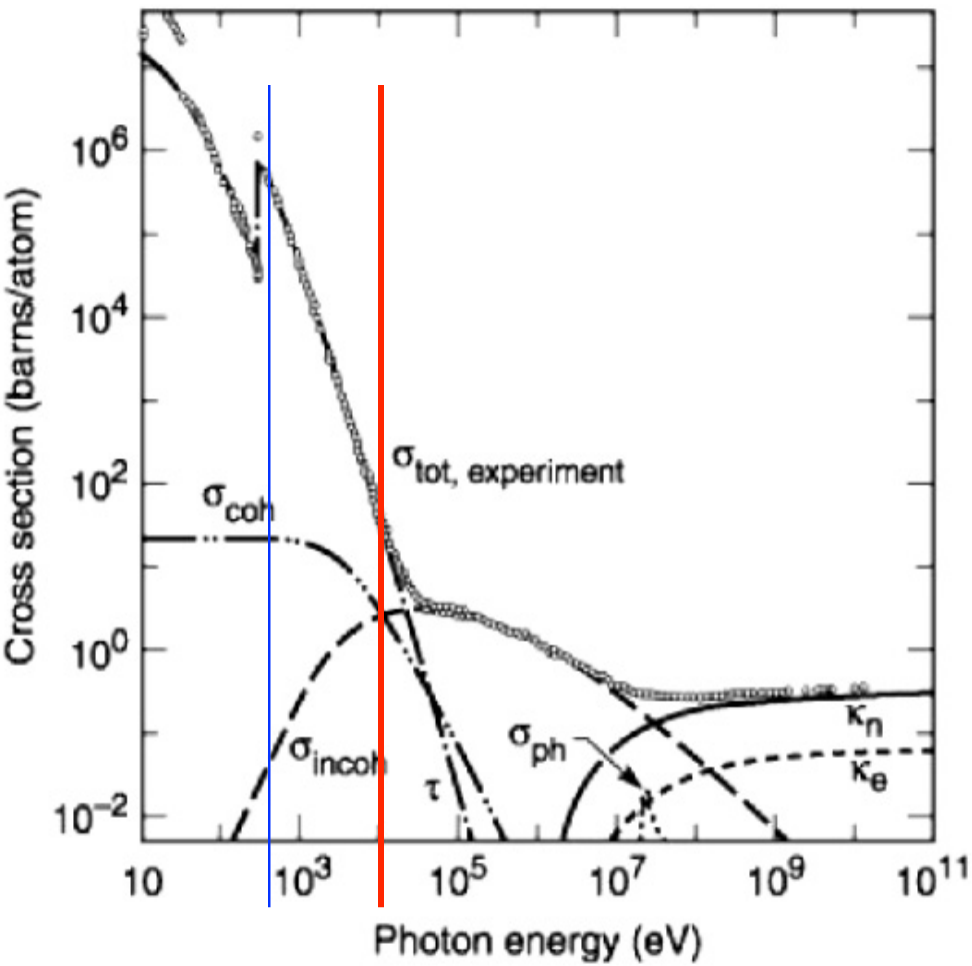
XFEL Radiation Characteristics

- High Peak Power ~ GW
  → high field non linear physics
  → high flux photons for single shot diffraction imaging
  single molecular structural analysis

- Short Pulse   10 ~ 100 fsec
  → Time resolving experiment (Pump probe)
  Chemical reaction

- Coherent
  → Holography, Coherent Imaging

Why 1 Angstrom?



- Photo-ionization becomes lower as X-ray energy.
- Around 1 A, 8 keV, photo-ionization becomes low enough to see coherent scattering.
- Spatial resolution becomes a few Angstrom, which resolves macromolecular crystal in biology.

  → Imaging, crystallography

- **water window** (2.3-4.4nm light) is also another candidate.

(a few micron-meter thick water)

Cross-section of X-ray with Carbon

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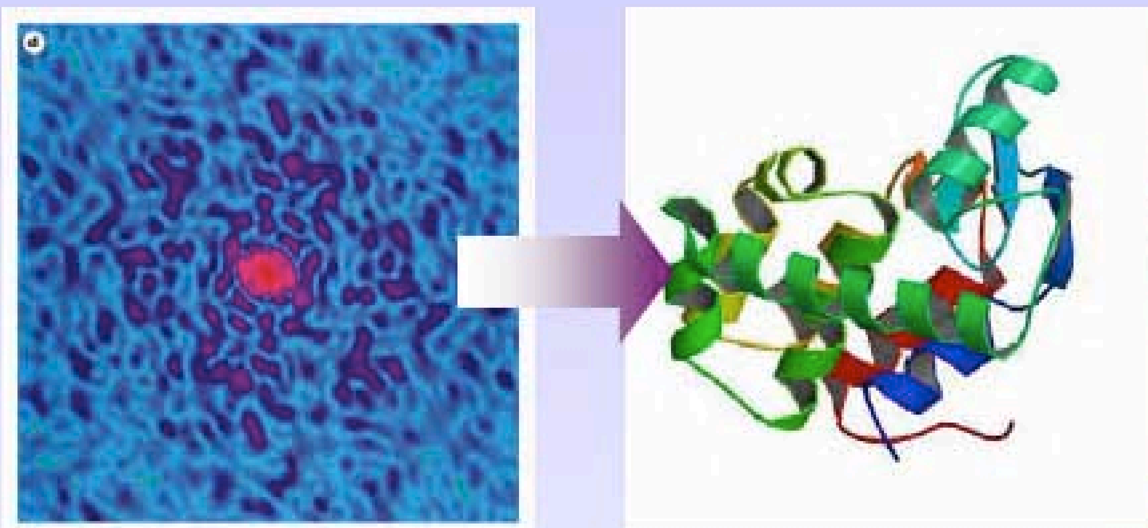
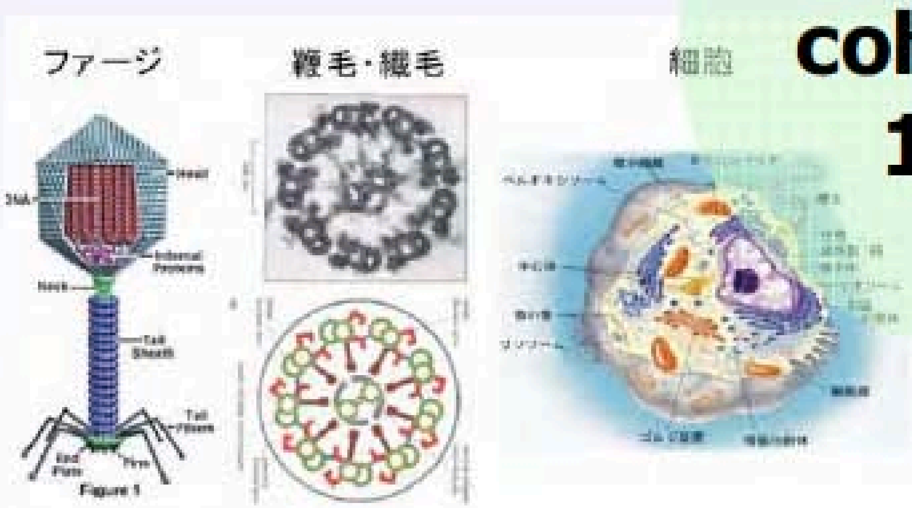
shintake@spring8.or.jp

Science with X-ray Free Electron Laser



Atomically-resolved imaging for non-crystalline objects



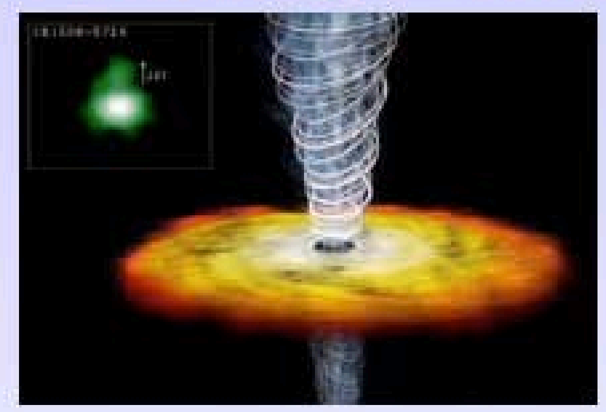
High brilliance
x10^9

XFEL

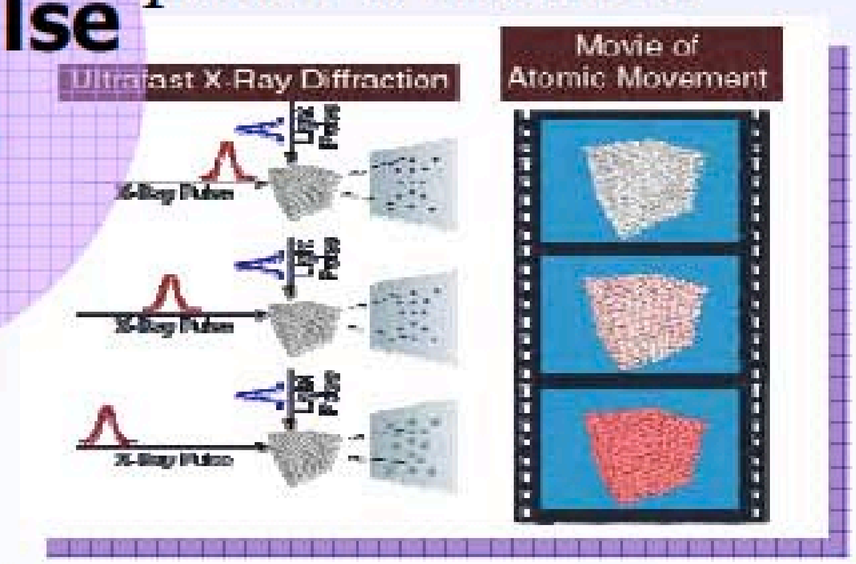
Spatial coherence 100%

Ultrafast pulse < 100 fs

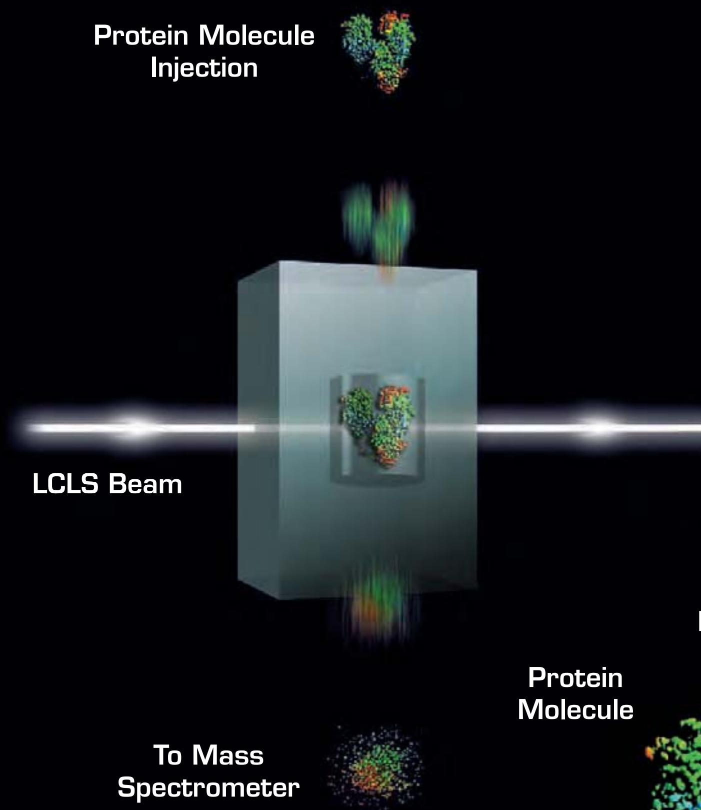
Generation of extreme state

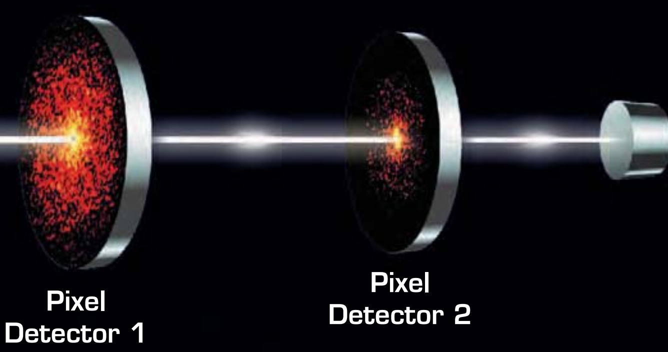


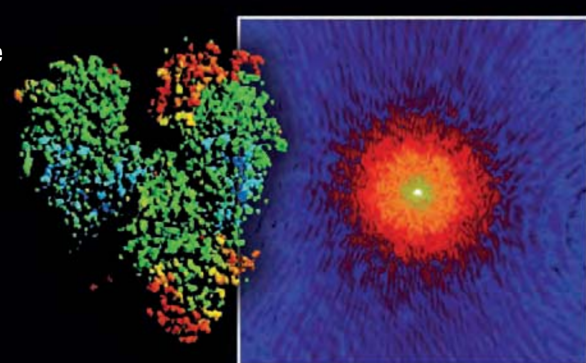
Probing of ultrafast chemical reaction & phase transition



With its fast "shutter" speed and super brightness, LCLS could take pictures of an important class of proteins that cannot be x-rayed any other way.



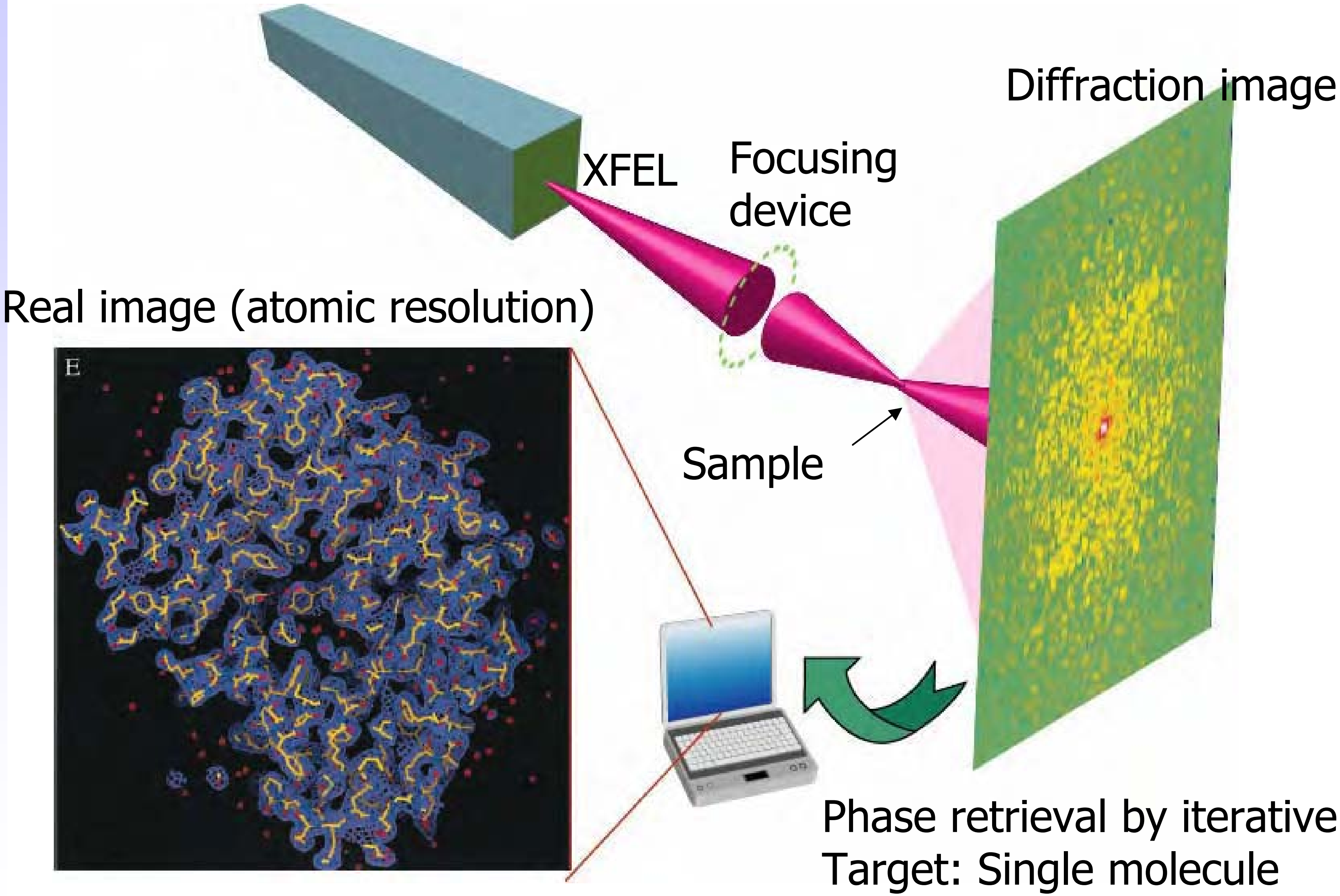




X-ray Diffraction Pattern

Operating with ultrafast pulses, LCLS will take images of molecules dropped into the x-ray beam. Scientists will merge the series of diffraction patterns of the molecules in many different positions. The resulting three-dimen sional reconstruction will reveal the structures of pro teins that cannot be crystallized and thus studied any other way.

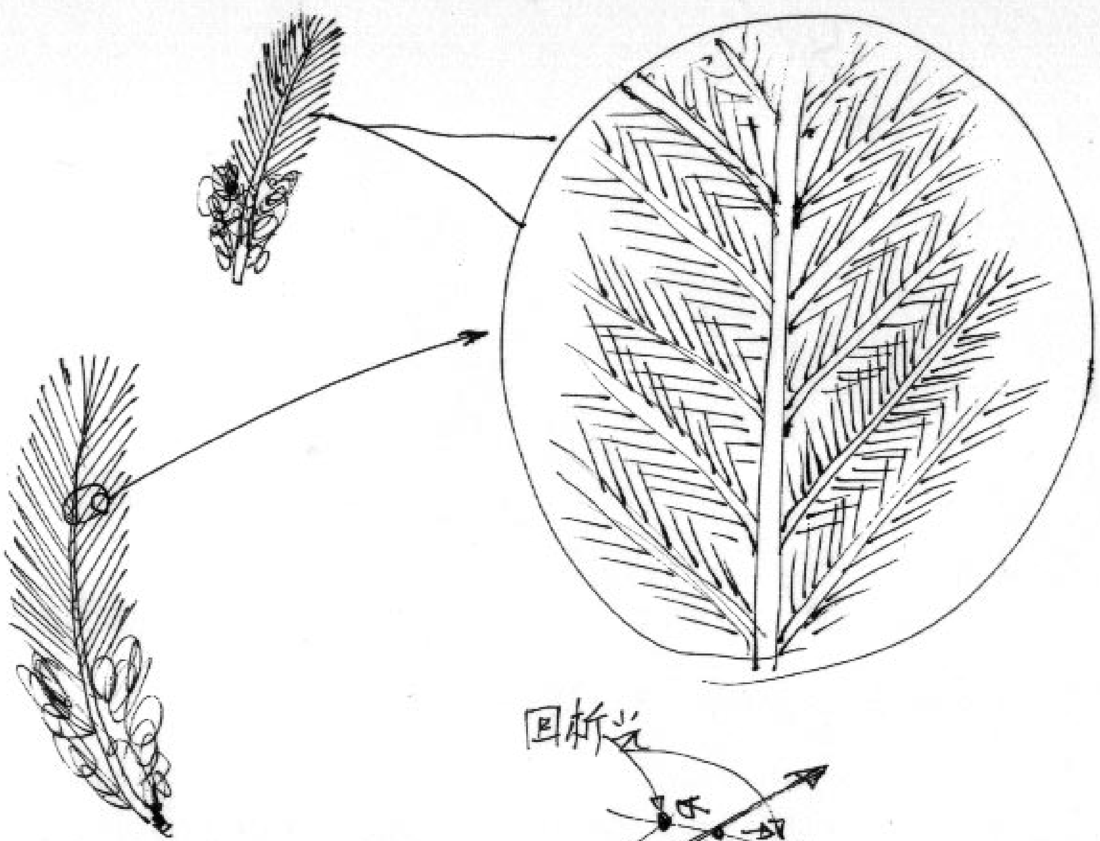
Coherent diffraction imaging

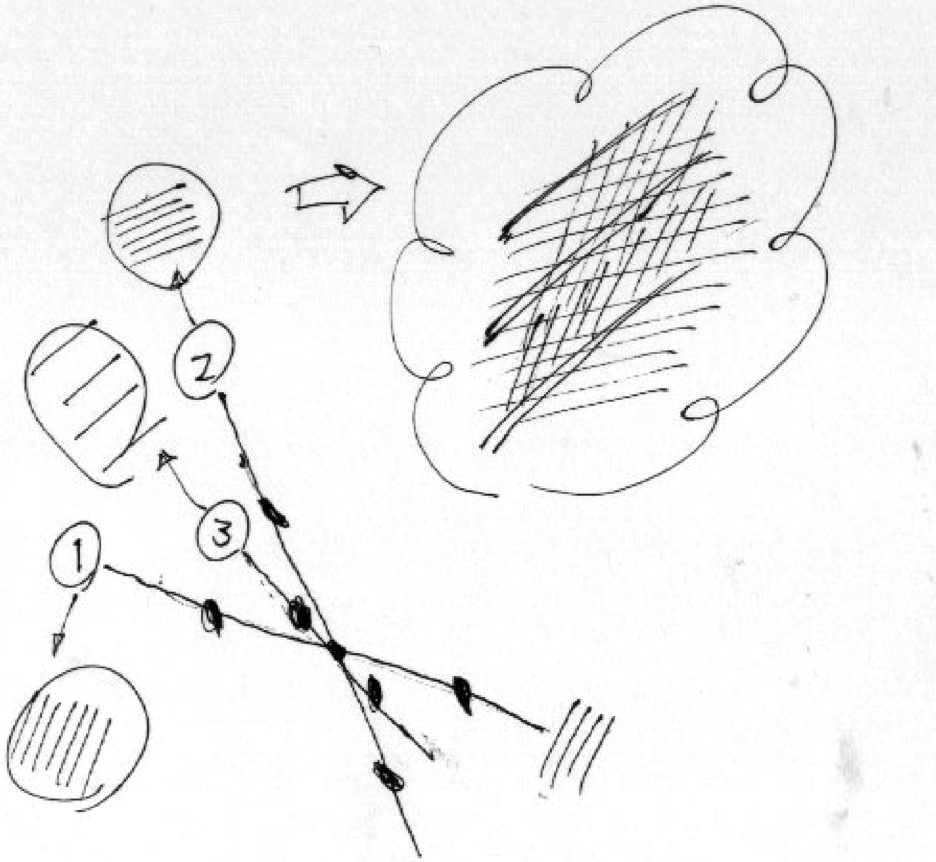


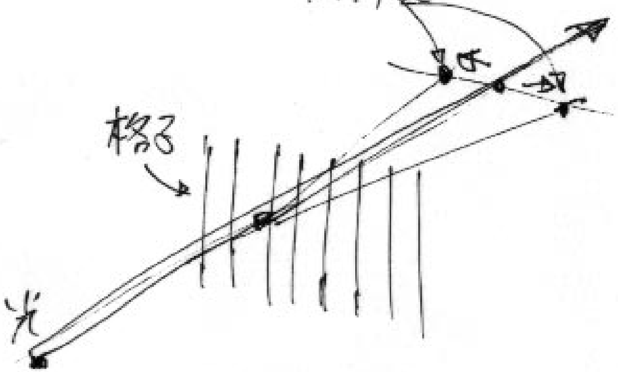
Phase retrieval by iterative algorithm
Target: Single molecule

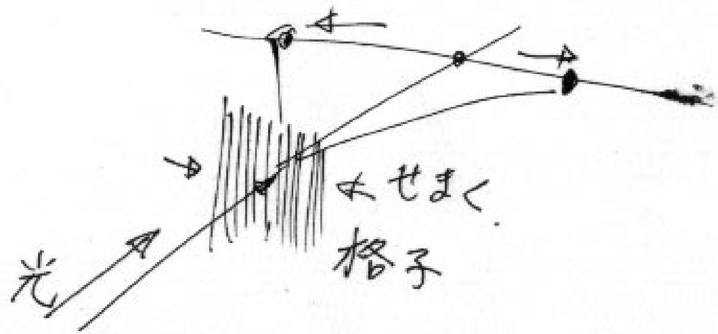
Shintake

鳥の羽根，回析





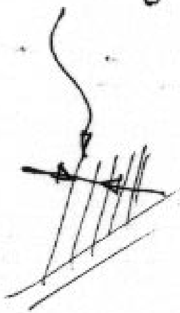




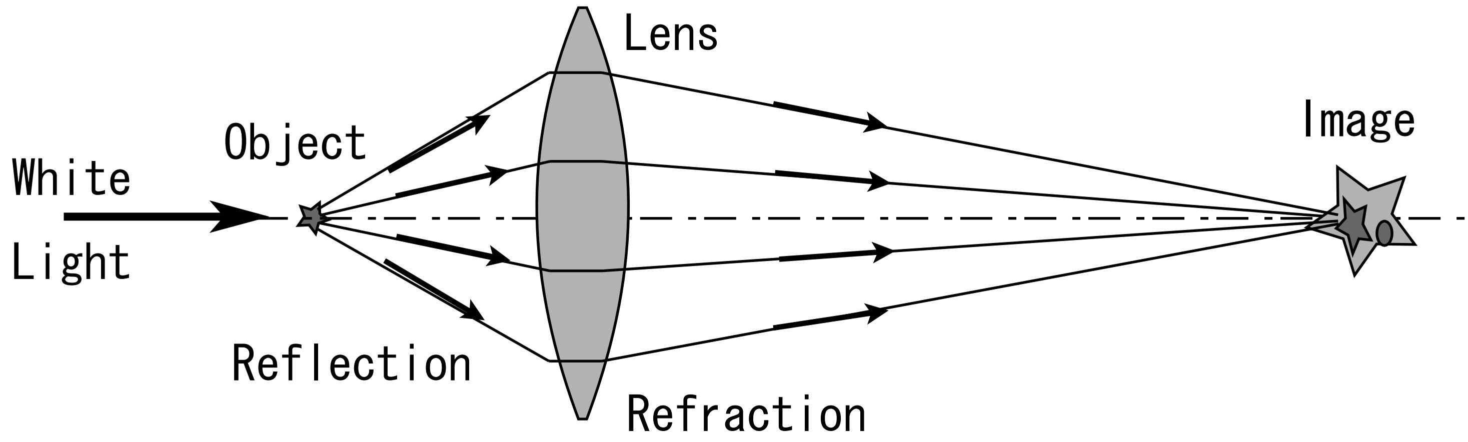
$$\theta = \frac{4\,\mathrm{cm}}{1\,\mathrm{m}} = 40\,\mathrm{mrad}$$

$$P = \frac{\lambda}{\theta} = \frac{532\,\mathrm{nm}}{0.04}$$

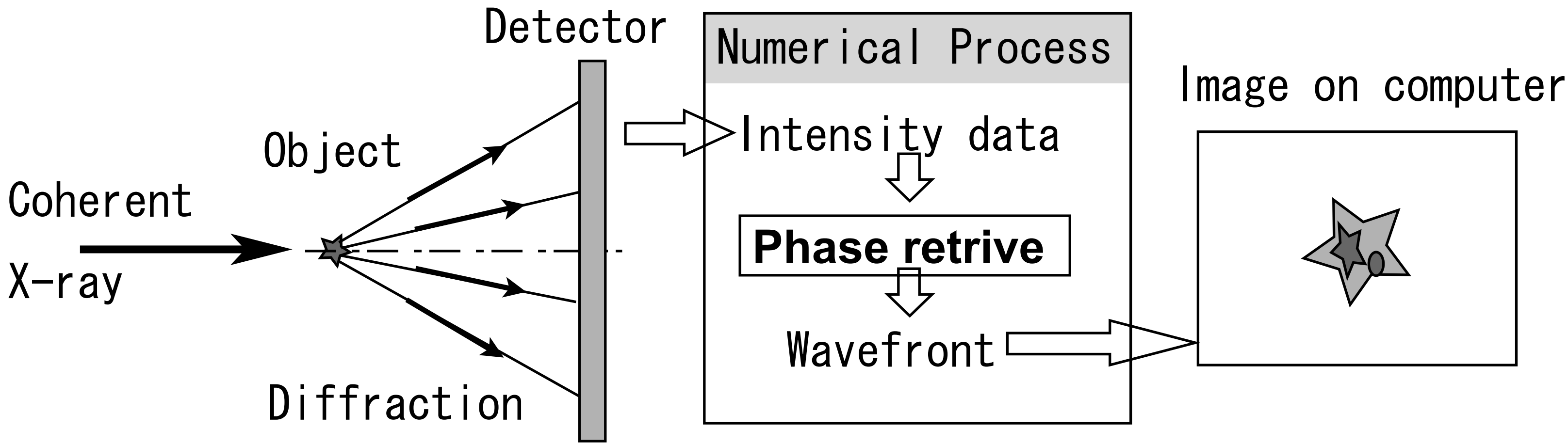
$$= 13\,\mu\mathrm{m}$$



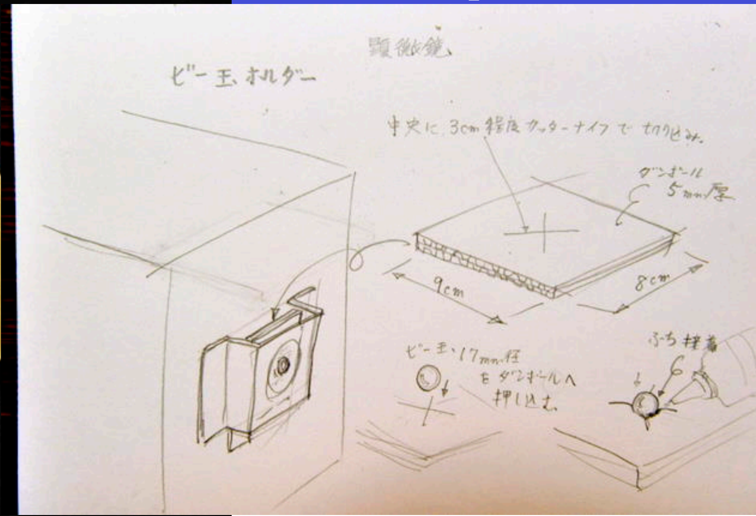
Optical Microscope



Lensless Diffraction Microscope



Glass Bead (Single Lens) does Microsope



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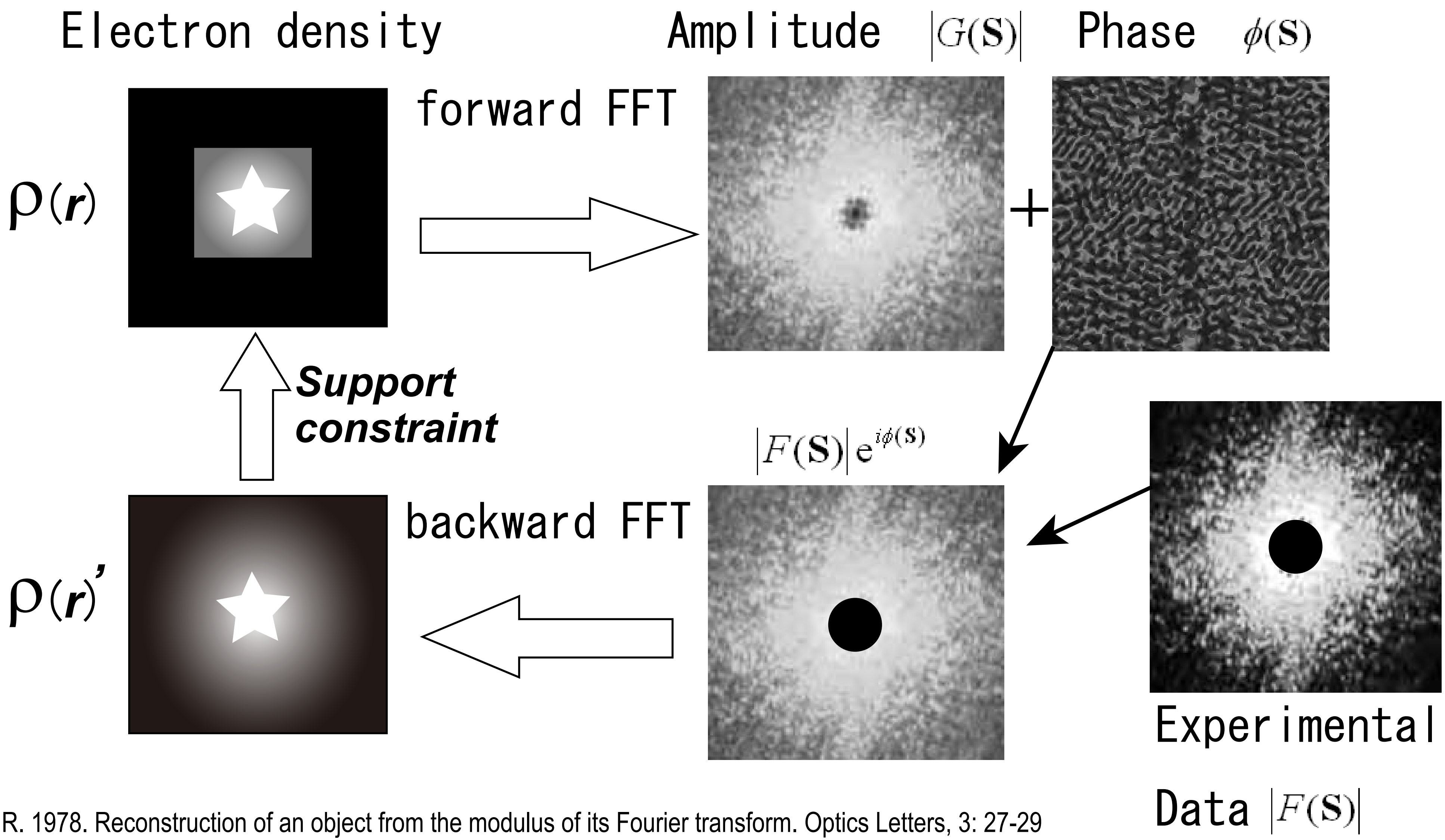
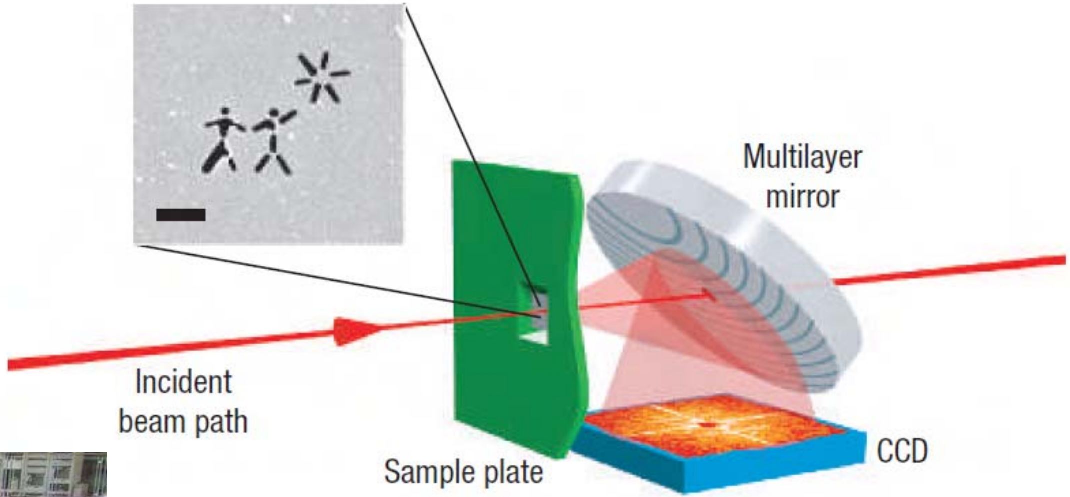
Iterative Phase Retrieval

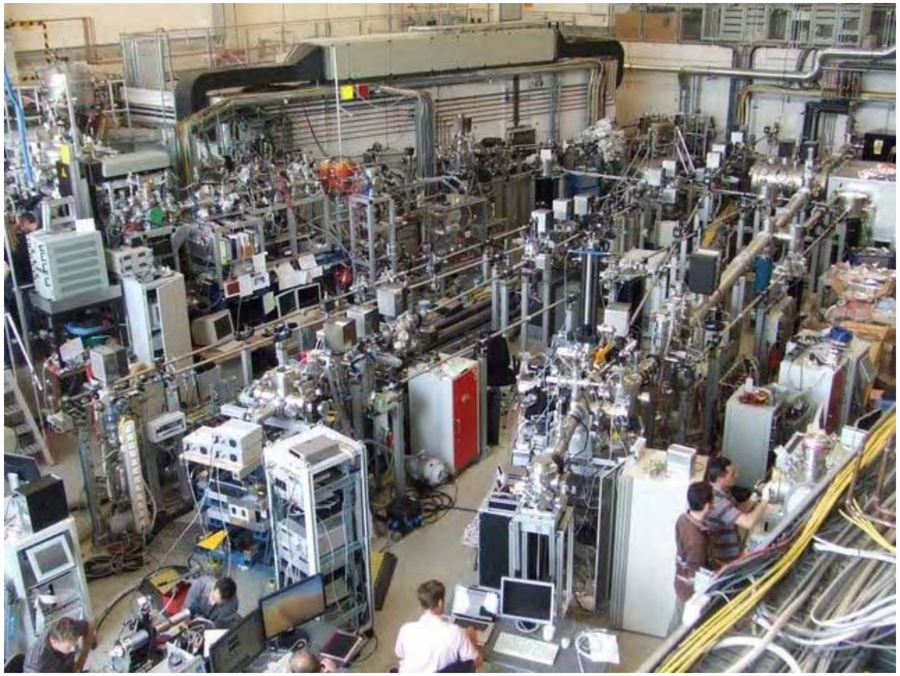


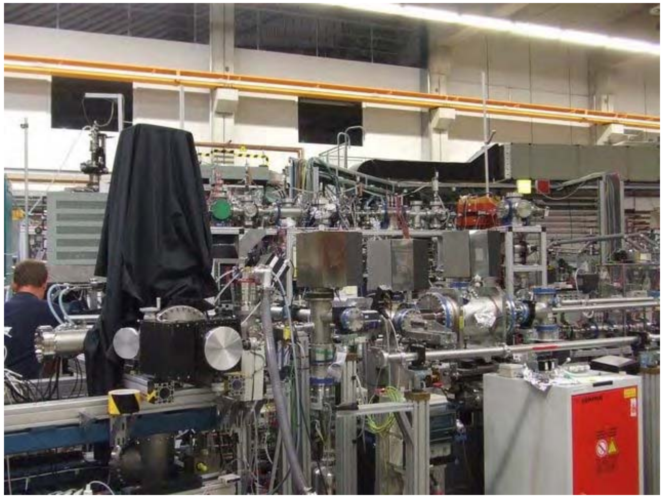
Fienup, J.R. 1978. Reconstruction of an object from the modulus of its Fourier transform. Optics Letters, 3: 27-29

Demonstration Experiments

DESY FLASH VUV FEL







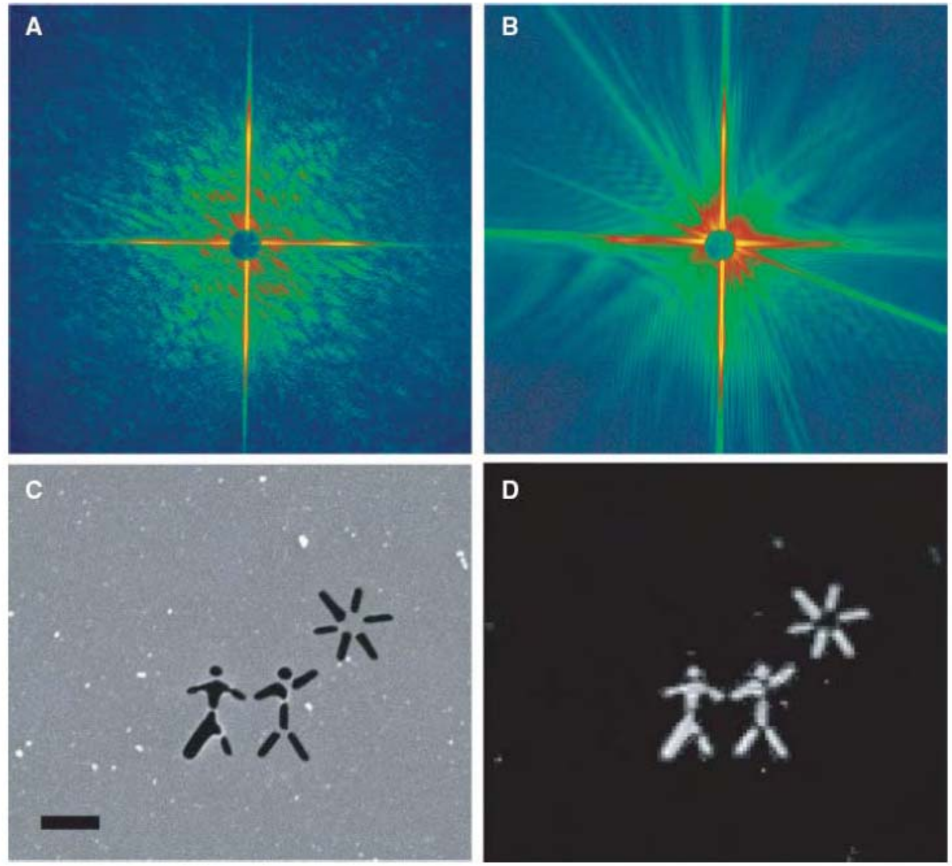


Fig. 3. (**A**) Diffraction pattern recorded with a single FEL pulse from a test object placed in the 20-μm focus of the beam (*8*). (**B**) The diffraction pattern recorded with a second FEL pulse selected with a fast shutter, showing diffraction from the hole in the sample created by the first pulse. (**C**) Scanning electron microscope image of the test object, which was fabricated by ion-beam milling a 20-nm-thick silicon nitride membrane. The scale bar denotes 1 μm. (**D**) The image reconstructed from the single-shot diffraction pattern shown in (A).

Chapman, H.N., A. Barty and M. Bogan et al. 2006. Femtosecond diffractive imaging with a soft-X-ray free-electron laser, Nature Physics 2: 839-843

PHYSICAL REVIEW E **78**, 041906 (2008)

Possibility of single biomolecule imaging with coherent amplification of weak scattering x-ray photons

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(Received 23 April 2008; revised manuscript received 21 August 2008; published 3 October 2008)

The number of photons produced by coherent x-ray scattering from a single biomolecule is very small because of its extremely small elastic-scattering cross section and low damage threshold. Even with a high x-ray flux of 3×10^{12} photons per 100-nm-diameter spot and an ultrashort pulse of 10 fs driven by a future x-ray free electron laser (x-ray FEL), it has been predicted that only a few 100 photons will be produced from the scattering of a single lysozyme molecule. In observations of scattered x rays on a detector, the transfer of energy from wave to matter is accompanied by the quantization of the photon energy. Unfortunately, x rays have a high photon energy of 12 keV at wavelengths of 1 Å, which is required for atomic resolution imaging. Therefore, the number of photoionization events is small, which limits the resolution of imaging of a single biomolecule. In this paper, I propose a method: instead of directly observing the photons scattered from the sample, we amplify the scattered waves by superimposing an intense coherent reference pump wave on it and record the resulting interference pattern on a planar x-ray detector. Using a nanosized gold particle as a reference pump wave source, we can collect 10^4-10^5 photons in single shot imaging where the signal from a single biomolecule is amplified and recorded as two-dimensional diffraction intensity data. An iterative phase retrieval technique can be used to recover the phase information and reconstruct the image of the single biomolecule and the gold particle at the same time. In order to precisely reconstruct a faint image of the single biomolecule in Angstrom resolution, whose intensity is much lower than that of the bright gold particle, I propose a technique that combines iterative phase retrieval on the reference pump wave and the digital Fourier transform holography on the sample. By using a large number of holography data, the three-dimensional electron density map can be assembled.

DOI: 10.1103/PhysRevE.78.041906 PACS number(s): 87.85.Ng, 42.30.Rx, 07.85.Tt, 42.40.Ht

Physical Origin of Difficulty

- In observations of scattered X-rays on a detector, the transfer of energy from wave to matter is accompanied by the quantization of the photon energy. Unfortunately, X-rays have a considerably high photon energy of 12 keV at wavelengths of 1 Å, which is required for atomic resolution imaging.

- Therefore, the number of photoionization events is considerably less, which limits the resolution of the imaging of a single biomolecule.

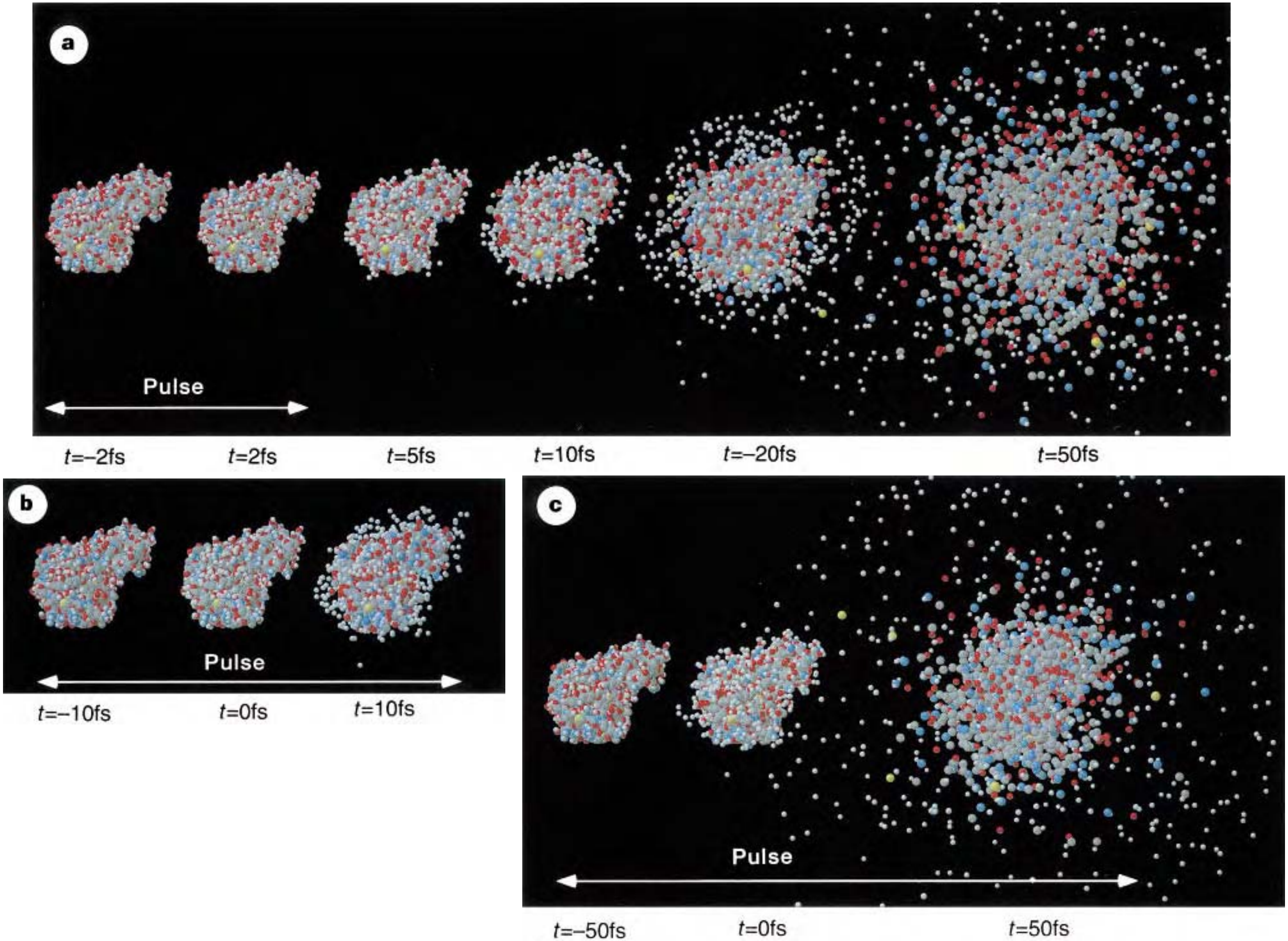


Figure 2 Explosion of T4 lysozyme (white, H; grey, C; blue, N; red, O; yellow, S) induced by radiation damage. The integrated X-ray intensity was 3×10^{12} (12 keV) photons per 100-nm diameter spot (3.8×10^{6} photons per Å^{2}) in all cases. **a**, A protein exposed to an X-ray pulse with an FWHM of 2 fs, and disintegration followed in time. Atomic positions in the first two structures (before and after the pulse) are practically identical at this pulse length because of an inertial delay in the explosion. $R_{nucl} = 3\%$, $R_{elec} = 11\%$ **b**, Lysozyme exposed to the same number of photons as in **a**, but the FWHM of the pulse was 10 fs. Images show the structure at the beginning, in the middle and near the end of the X-ray pulse. $R_{nucl} = 7\%$, $R_{elec} = 12\%$ **c**, Behaviour of the protein during an X-ray pulse with an FWHM of 50 fs. $R_{nucl} = 26\%$, $R_{elec} = 30\%$.

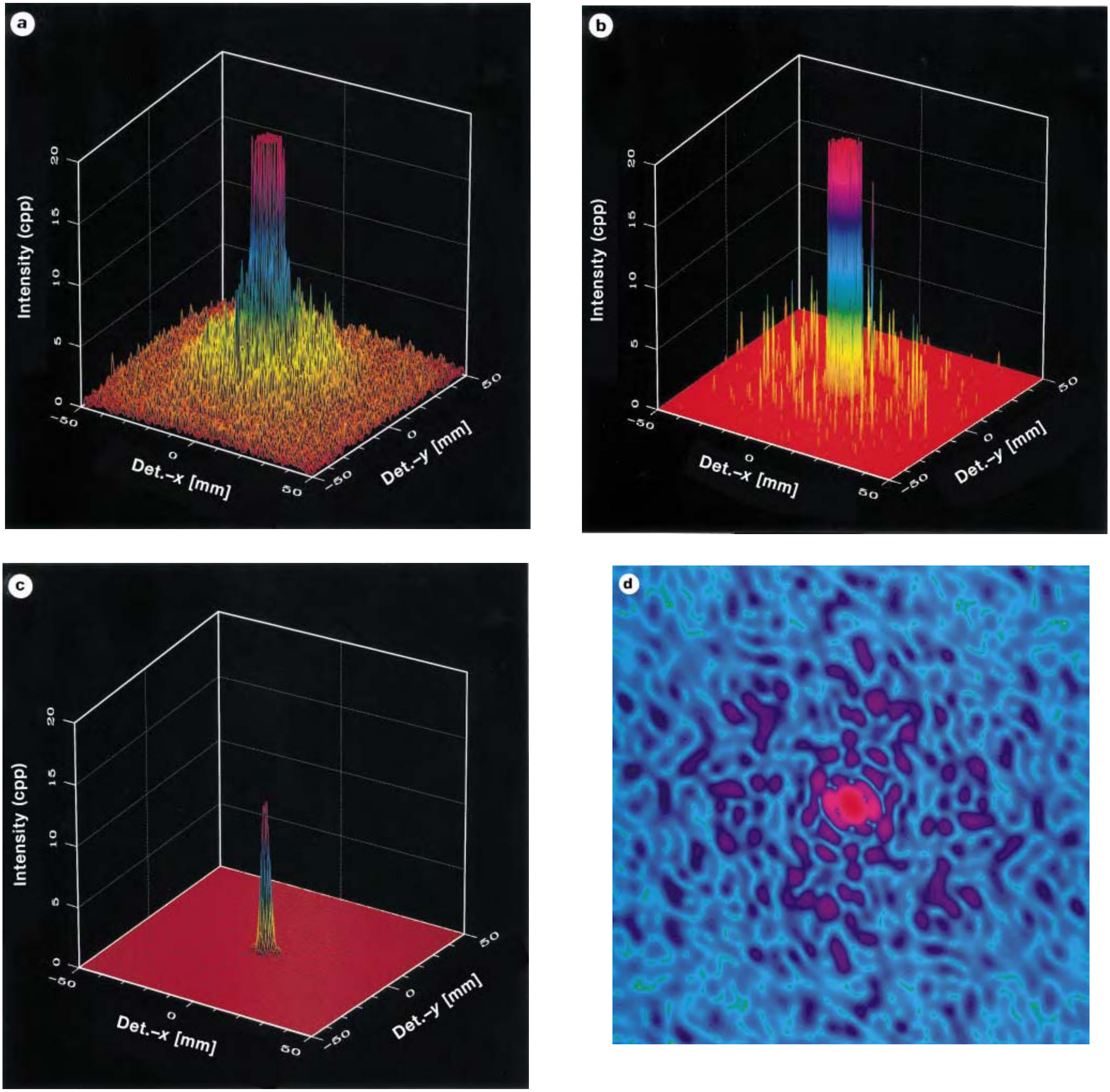


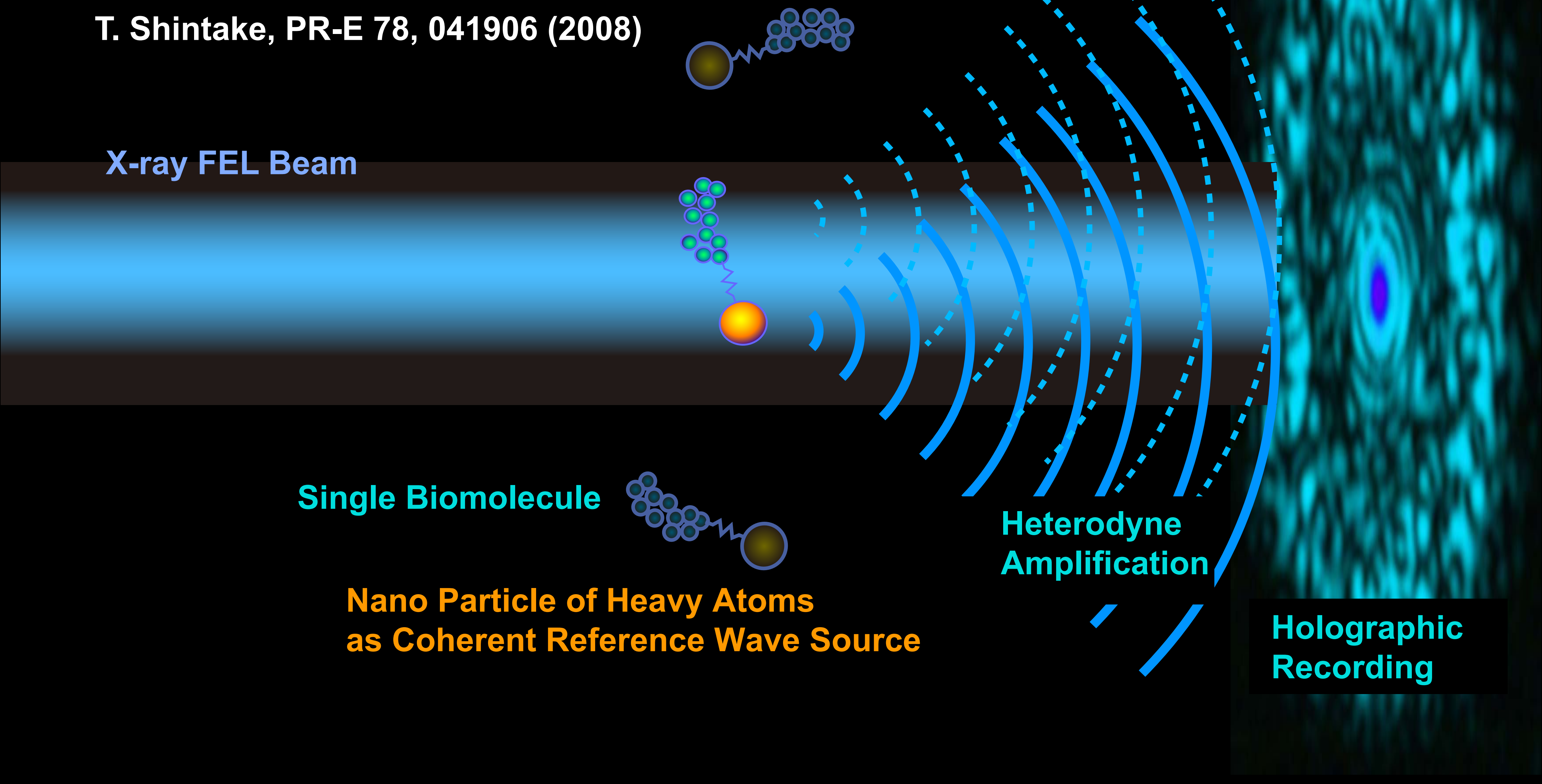
Figure 3 Elastic scattering from a variety of samples. **a**–**c**, Simulated diffraction images on a 128 × 128 pixel planar detector (100 mm × 100 mm) normal to and centred at the beam, and placed 100 mm from the sample. The background was not modelled, and 100% detective quantum efficiency was assumed. The integrated X-ray intensity was 3×10^{12} (12 keV) photons per 100-nm diameter spot (3.8×10^{6} photons per Å^2); the pulse length was 10 fs. The resolution is 2.2 Å at the rim in **a**–**c**. cpp, counts per pixel. **a**, Scattering from a single tomato bushy stunt virus capsid. **b**, Scattering from a 5 × 5 × 5 cluster of lysozyme molecules with an average r.m.s. conformational deviation of 0.2 Å to model an imperfect lattice. **c**, Scattering from a single molecule of lysozyme. **d**, A planar section through the molecular transform (that is, a simulated continuous scattering image) of a single T4 lysozyme molecule under ideal conditions without sample movement or damage. Resolution at the rim of **d** corresponds to 2.0 Å. Structure factor amplitudes are coloured logarithmically (magenta, high; green, low). The section is perpendicular to the *z* axis, and crosses through the origin at the centre of the image, revealing centric symmetry.

Single Biomolecule Imaging with XFEL

(Heterodyne Detection + Holographic Recording)

"Weak diffraction from biomolcule is amplified by 10 ~ 50 times (Heterodyne) on the coherent reference wave from nano-particle, providing 100~1000 times more photons"

T. Shintake, PR-E 78, 041906 (2008)



X-ray Heterodyne Detection

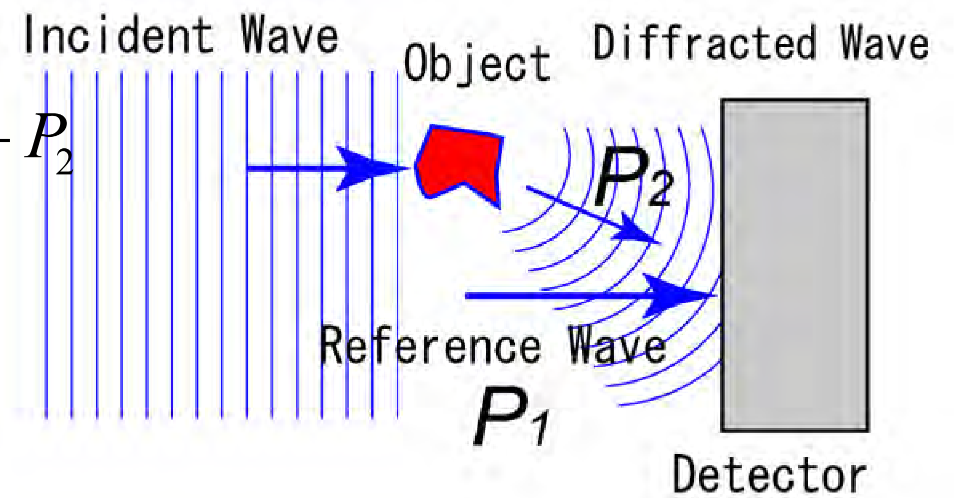
T. Shintake 2003

- *X-ray heterodyne detection using reference X-ray P_1 on the small signal P_2*

$$P_{\pm} = \left(\sqrt{P_1} \pm \sqrt{P_2}\right)^2 = P_1 \pm 2\sqrt{P_1 P_2} + P_2$$

$$= P_1\left(1 \pm 2\sqrt{P_1 / P_2} + P_1 / P_2\right)$$

$$\simeq P_1\left(1 \pm 2\sqrt{P_1 / P_2}\right)$$

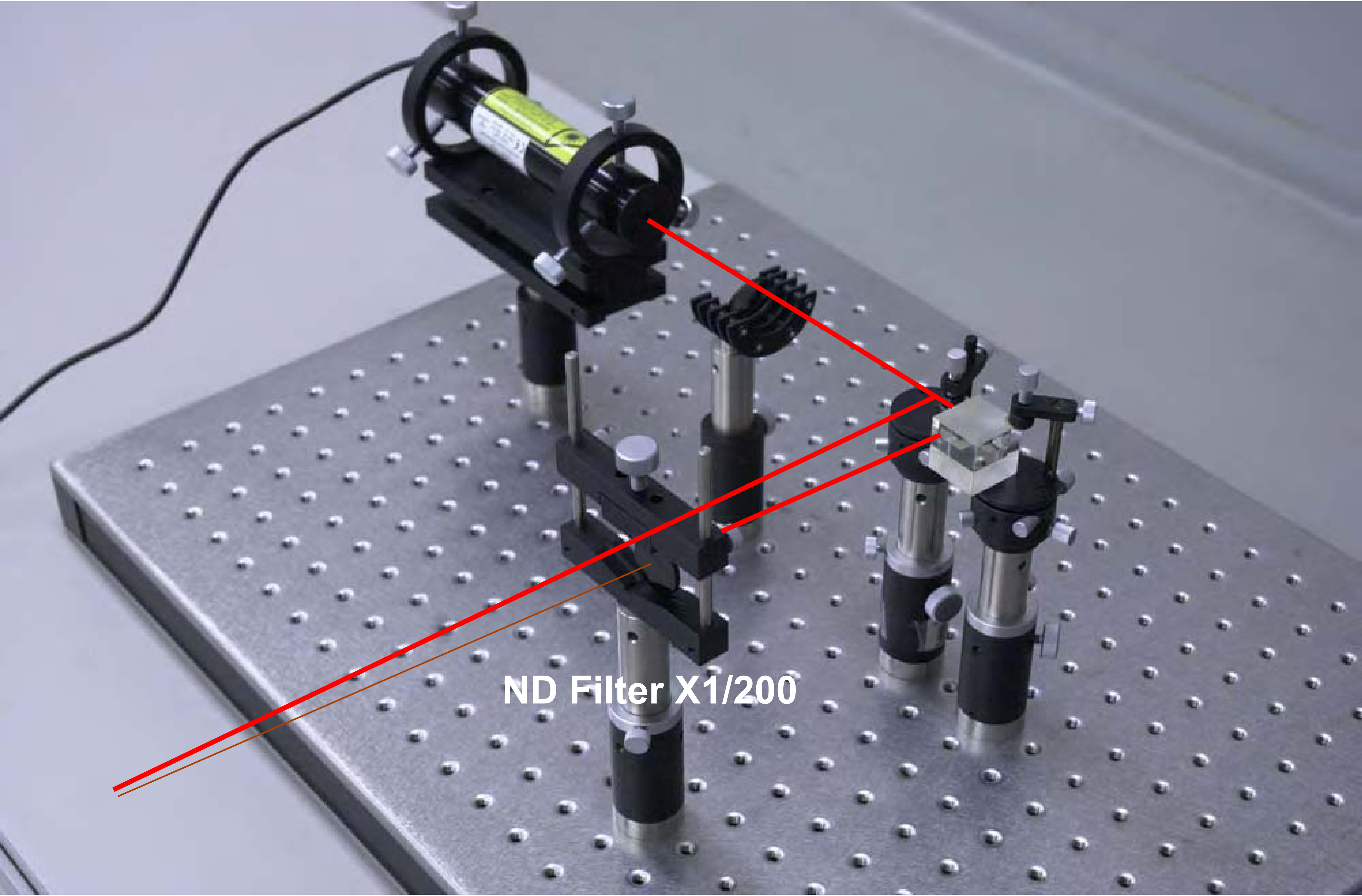


- *Even if P_2 is 10^{-6} times smaller, the signal is amplified to 10^{-3} level. This is +30 dB amplification.*

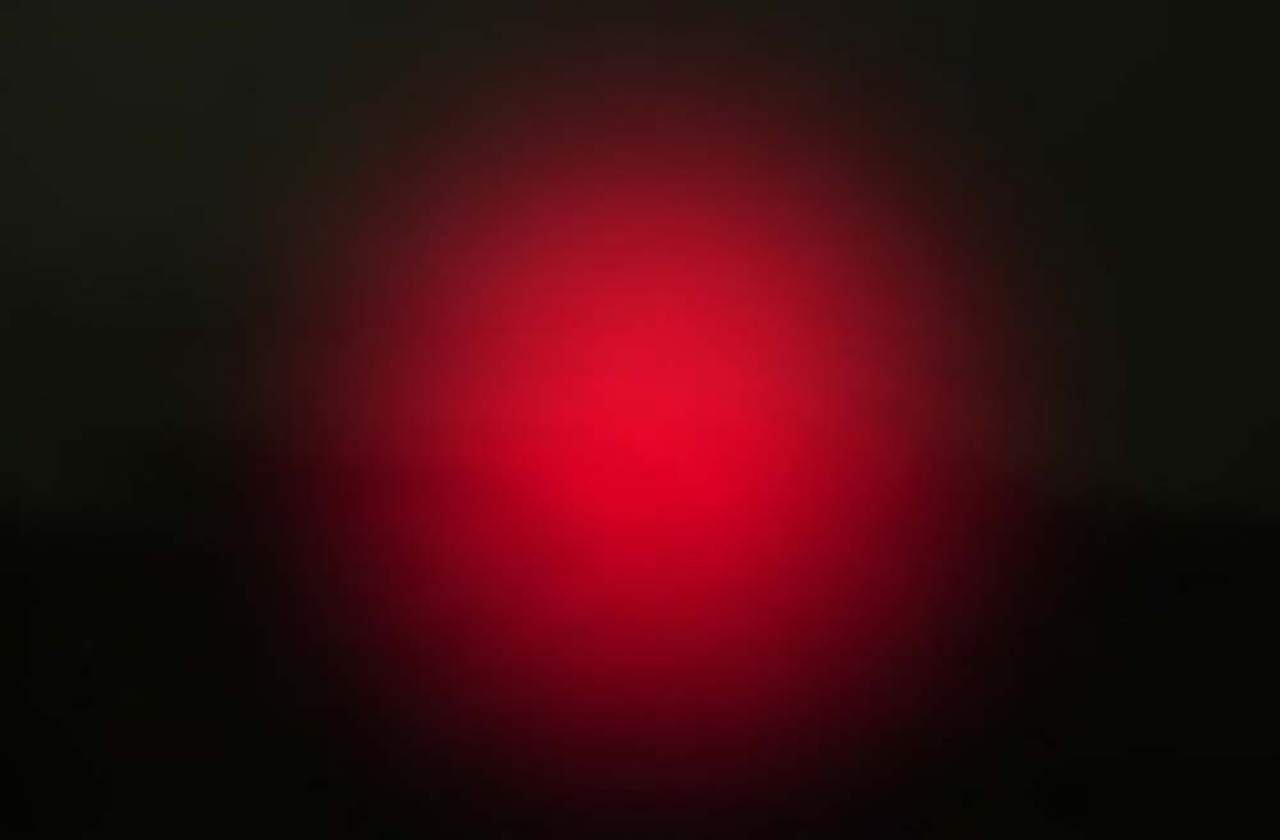
Does noise increase or decrease?

- S/N due to the electrical noise in detector instrument can be easily improved as the signal growing.
- Question is the statistical noise associated with quantization of energy in photo-ionization process in CCD or film detector.
- Since amplitude of the interference pattern increase as $\propto \sqrt{I}$, and statistical noise also increases as $\propto \sqrt{I}$, thus S/N becomes constant, and looks like not been improved.

$$S/N\,|_{\mathrm{holography}} = S/N\,|_{\mathrm{direct}}$$


ND Filter X1/200


Nikon
D1



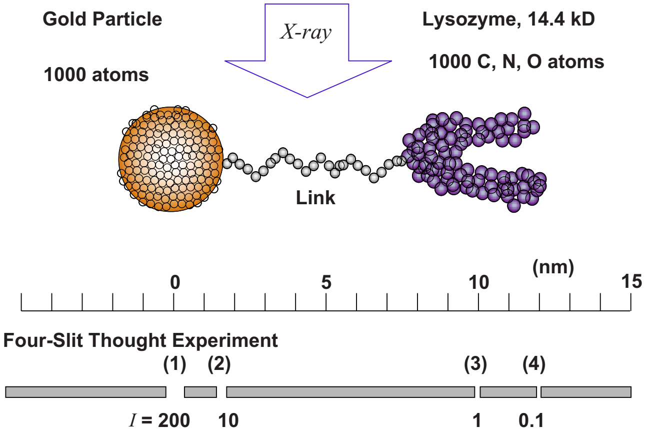


FIG. 4. (Color online) Conceptual diagram of a single lysozyme molecule linked to a gold particle (diameter of atoms is not drawn to scale). The gold particle produces 200 times more coherent x-ray scattering than the single lysozyme molecule. The bar at the bottom of the figure represents a four-slit thought experiment.

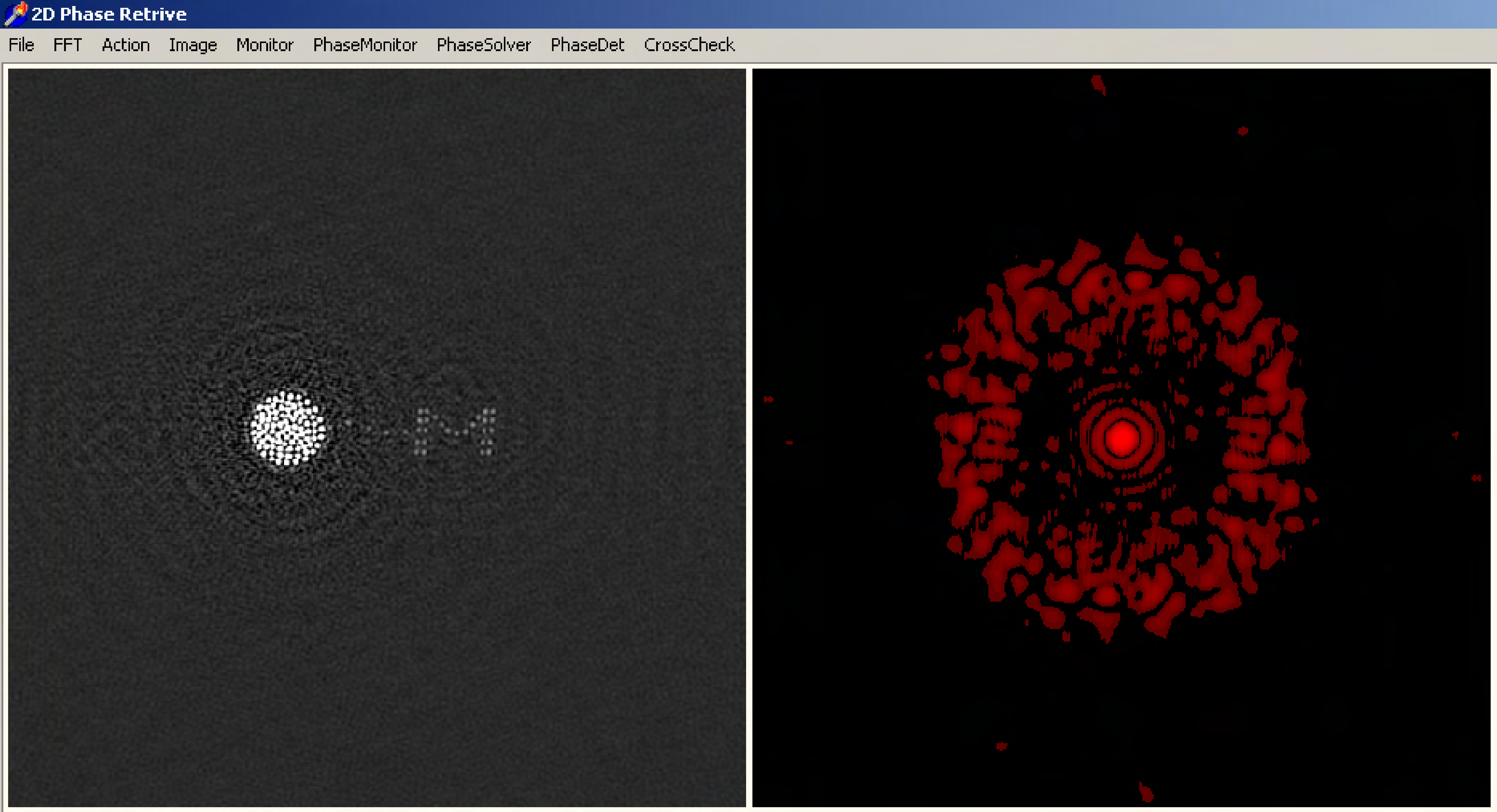
Fourier transform holography uses spherical waves as reference waves to record the phase of an object wave. The intensity of the reference wave is chosen such that it is comparable to that of the object wave to obtain the best contrast. To obtain better image quality, the size of the reference wave source should be considerably smaller than the object. The image-recovery process in Fourier transform holography is

where $\Delta\phi_{ij}=\phi_j-\phi_i$ is the phase difference given by

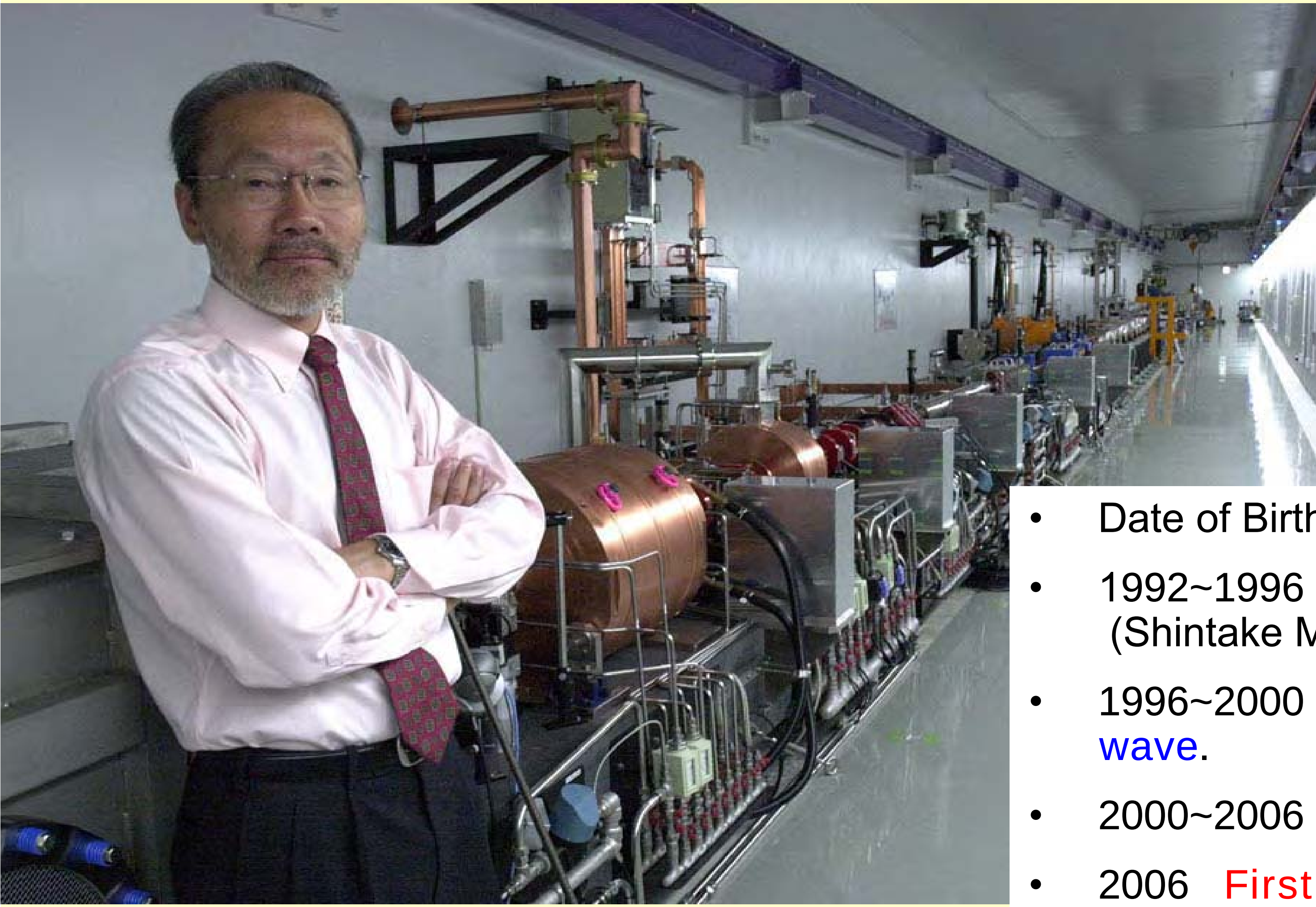
$$\Delta\phi_{ij}=\phi_j-\phi_i=\frac{2\pi d_{ij}}{\lambda}\sin(2\theta). \quad (8)$$

Here, I_i represents the flux from the ith slit, 2θ is the scattering angle (as defined in crystallography), and d_{ij} is the distance between the i and jth slits. The slit locations and flux ratio suitable for our example case shown in Fig. 4 are as follows: $d_{12}=1.5$ nm, $d_{23}=8.5$ nm, $d_{34}=2$ nm, $I_1=200$, $I_2=10$, $I_3=1$, $I_4=0.1$, and $\lambda=1$ Å. Figure 5(a) shows the flux density distribution estimated using Eq. (7). The distribution is considerably complicated because the fringes are formed by the interference of four waves.

In Fig. 5(c), the curve at the bottom indicates the scattered wave from the biomolecule when it is directly observed without using the reference pump wave. It is a very weak signal with a relative intensity of approximately 1. In practice, the signal is quantized by the photon energy, leading to a loss of detailed information. The dashed curve (magnified 10 times) also shows an interference pattern, which represents the internal structure of the biomolecule; our aim is to study this pattern. By superposition of the reference pump wave, the signal wave is amplified, and the resulting interference pattern is recorded. In order to demonstrate the amplification effect clearly, the reference pump wave is assumed to be perfect with $\psi_2=0$. In Fig. 5(c), the curve at the top shows the amplified signal, which is recorded by the


2D Phase Retrive
File
FFT
Action
Image
Monitor
PhaseMonitor
PhaseSolver
PhaseDet
CrossCheck

Who is Shintake?

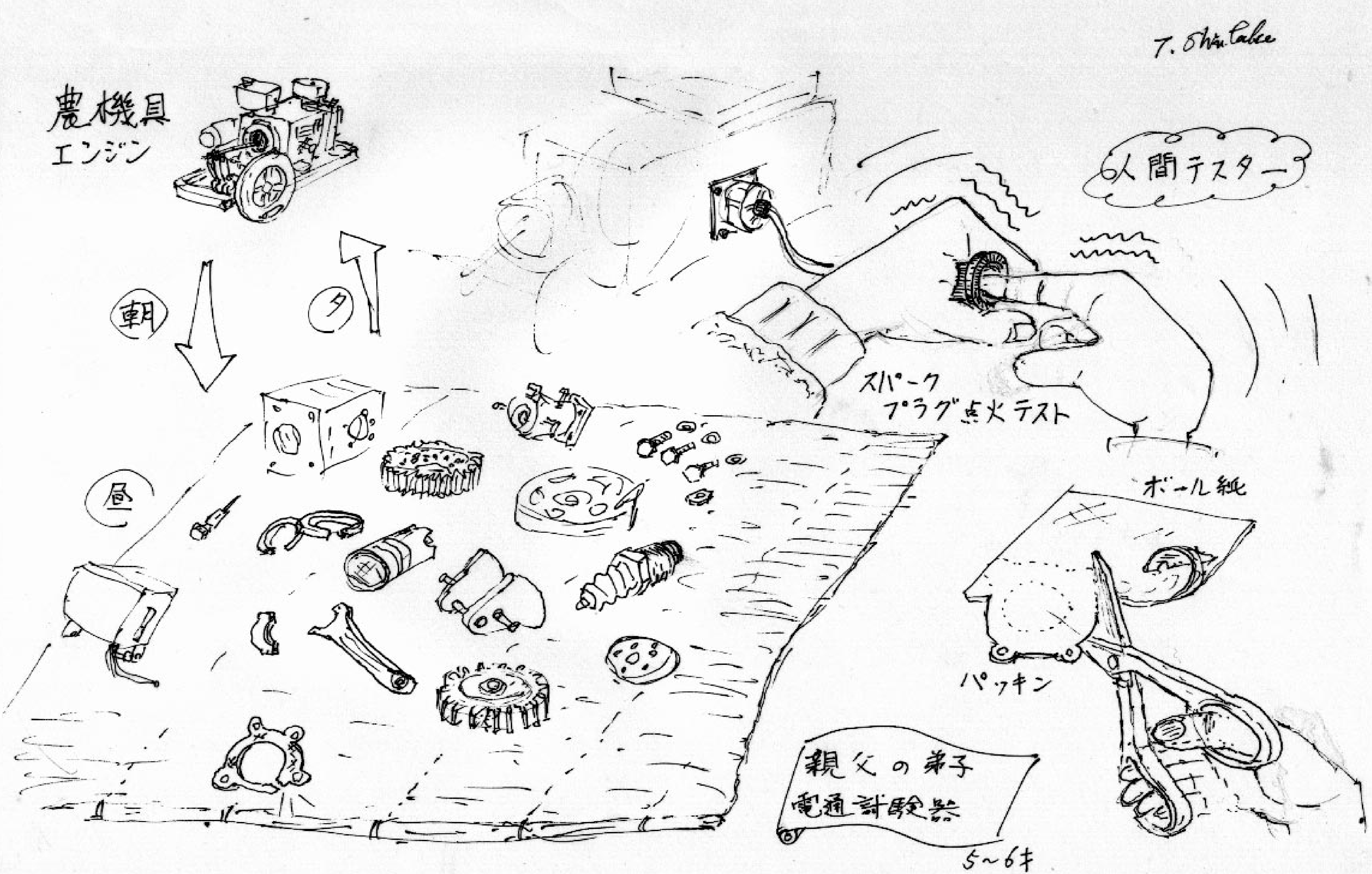


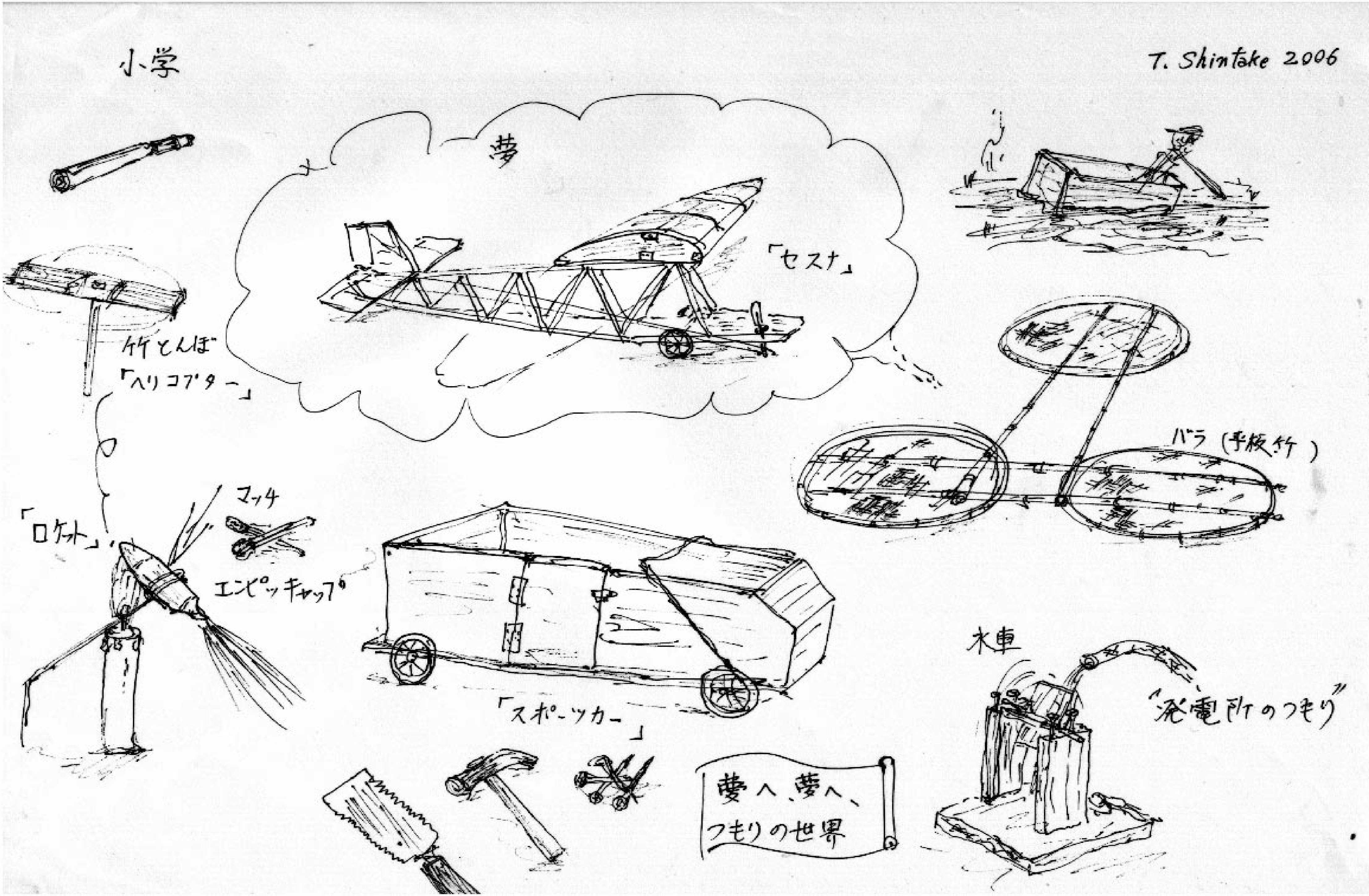
@ SCSS tunnel
Test Accelerator for XFEL

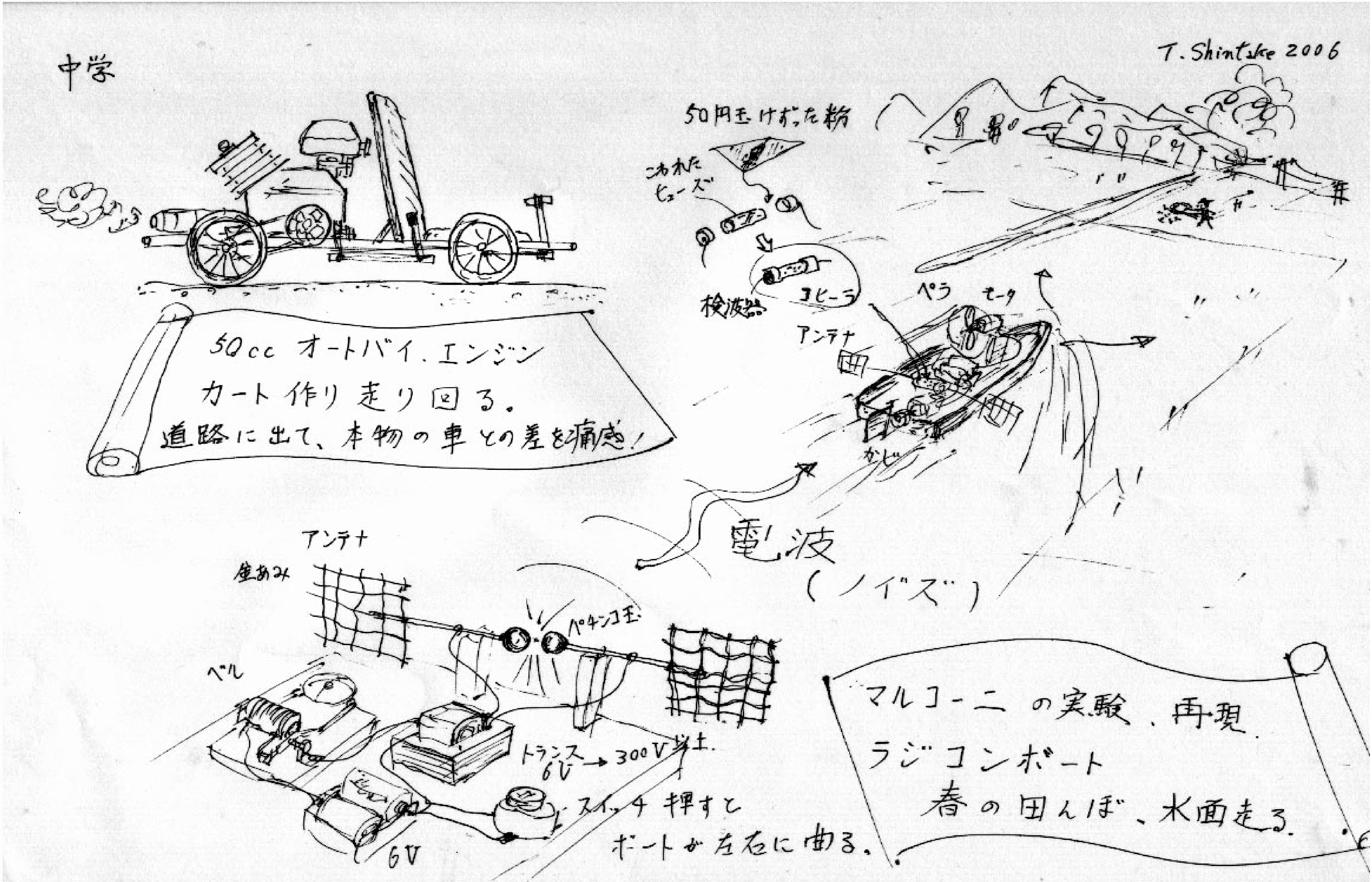
- Date of Birth 1955, Miyazaki, Kyushu Japan
- 1992~1996 FFTB – SLAC "Spot Size Monitor" (Shintake Monitor) 60 nm e with 1 μm wave
- 1996~2000 "C-band R&D" for LC at KEK 5 cm wave.
- 2000~2006 SCSS R&D Leader e- beam
- 2006 First Lasing at SCSS Prototype Accelerator 49 nm wave
- 2006~ Now constructing 8 GeV XFEL/SPring-8 for 0..1 nmm wave

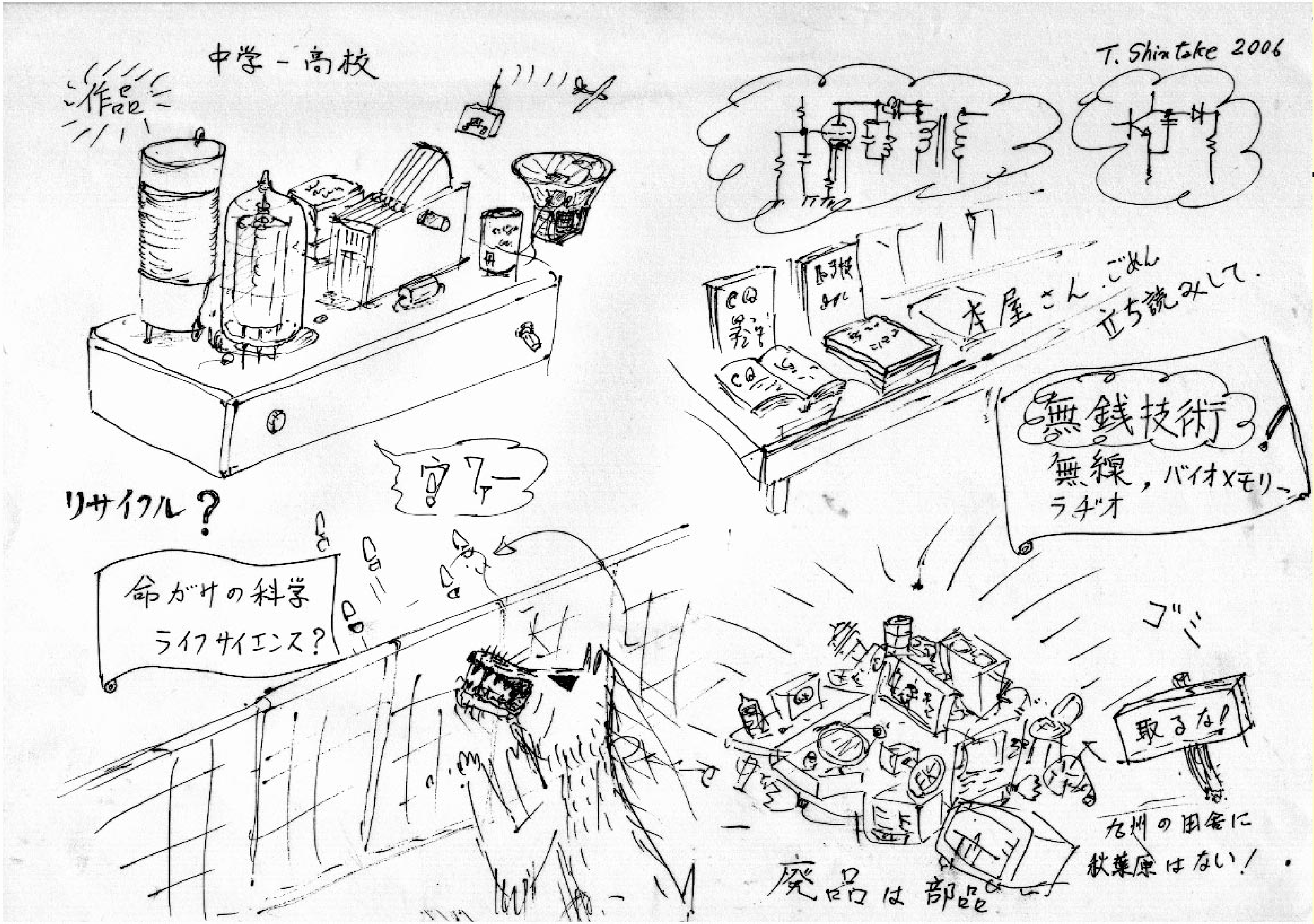
KYUSHU

MIYAZAKI

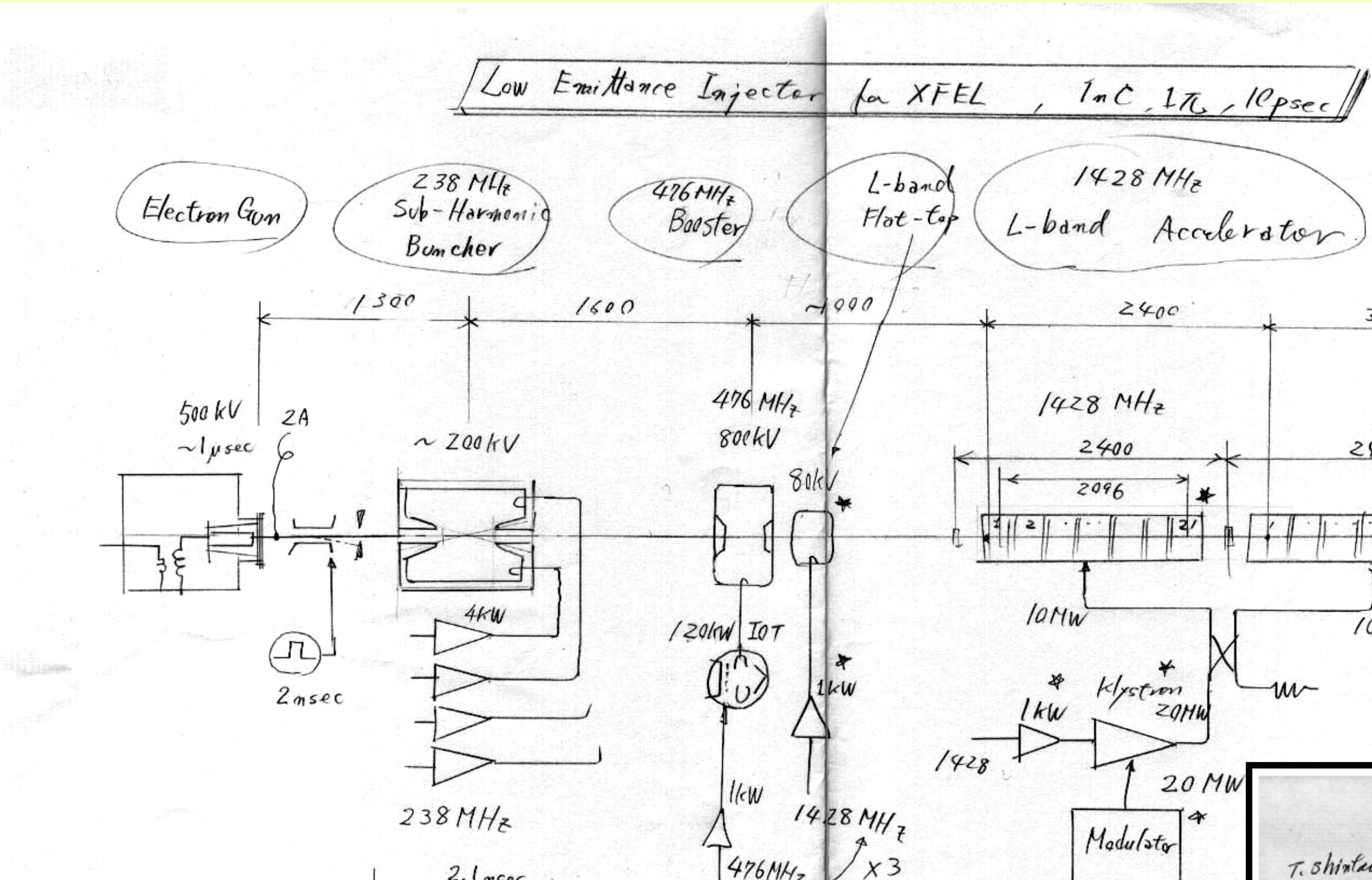

農機具
エンジン
朝
夕
昼
人間テスター
スパーク
プラグ点火テスト
ボール紙
パッキン
親父の弟子
電通試験器
5~6才

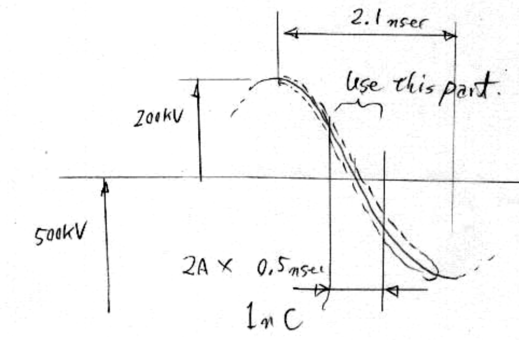

小学
T. Shintake 2006
夢
「セスナ」
竹とんぼ
「ヘリコプター」
「ロケット」
マッチ
エンピッキャップ
「スポーツカー」
バラ（手板竹）
水車
“発電所のつもり”
夢へ、夢へ、
つもりの世界

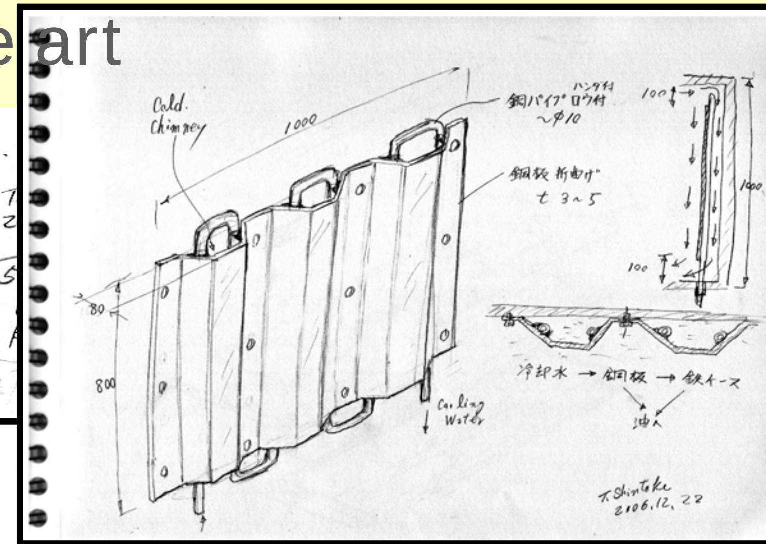

中学
T. Shintake 2006
50cc オートバイ・エンジン
カート作り走り回る。
道路に出て、本物の車との差を痛感！
50円玉けずった粉
こわれたヒューズ
コヒーラ
検波器
ペラ
モータ
アンテナ
かじ
電波
（ノイズ）
アンテナ
金あみ
パチンコ玉
ベル
トランス
6V → 300V以上
スイッチ押すと
ボートが左右に曲る。
6V
マルコーニの実験、再現
ラジコンボート
春の田んぼ、水面走る。

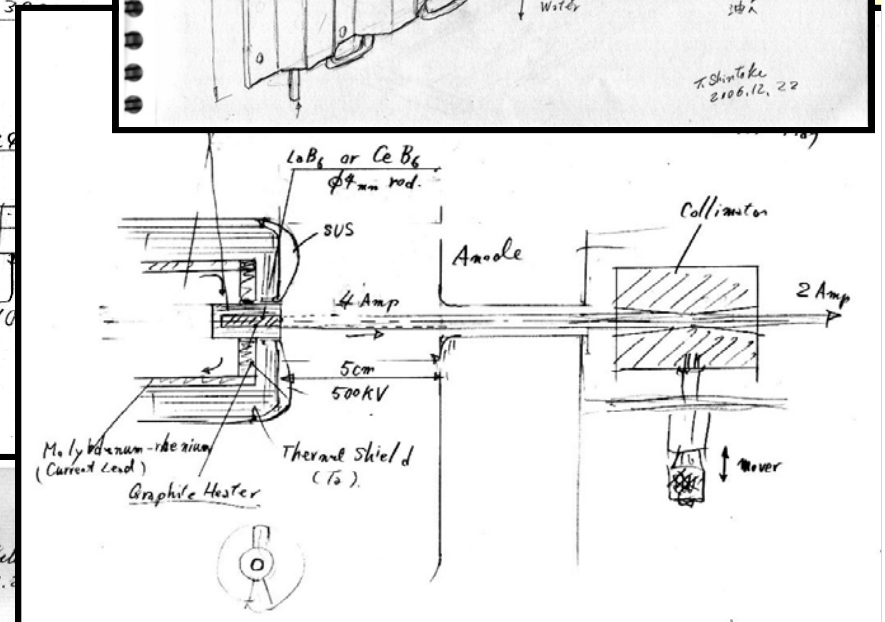

中学－高校
作品
T. Shintake 2006
本屋さん．ごめん
立ち読みして．
無銭技術！
無線，バイオメモリー
ラヂオ
リサイクル？
命がけの科学
ライフサイエンス？
ゴミ
取るな！
九州の田舎に
秋葉原はない！
廃品は部品

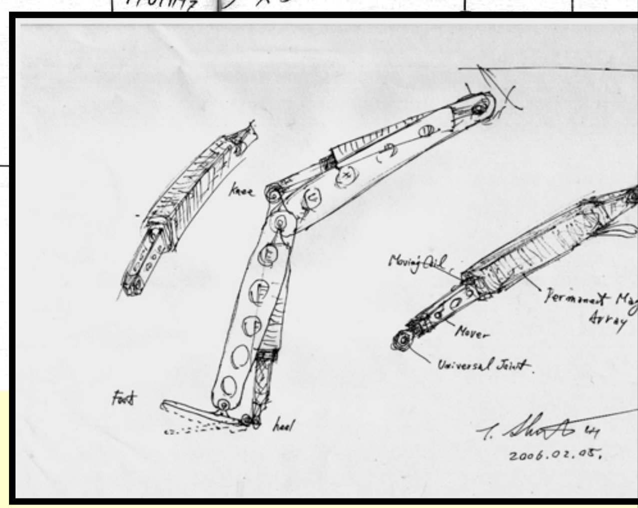
Design accelerator as creating images like art

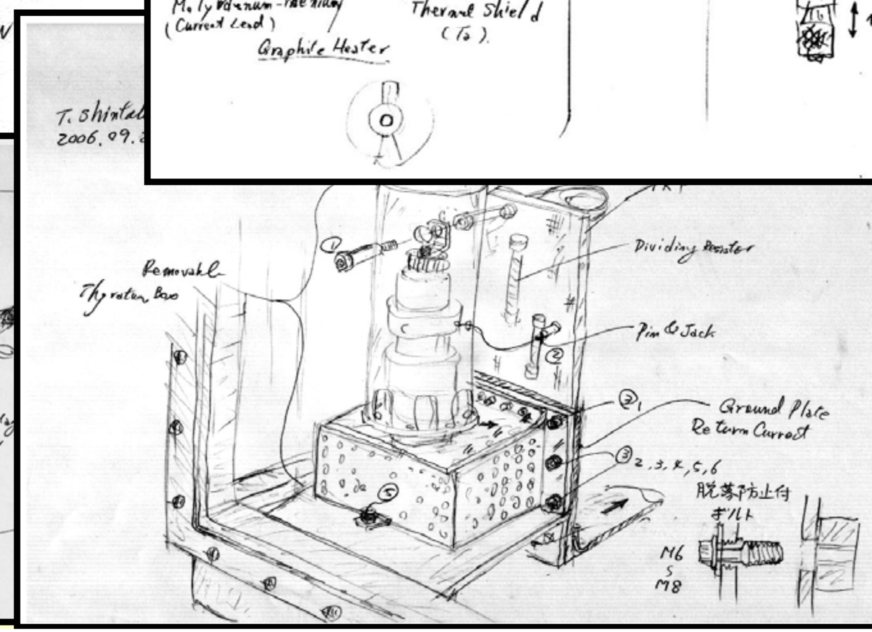




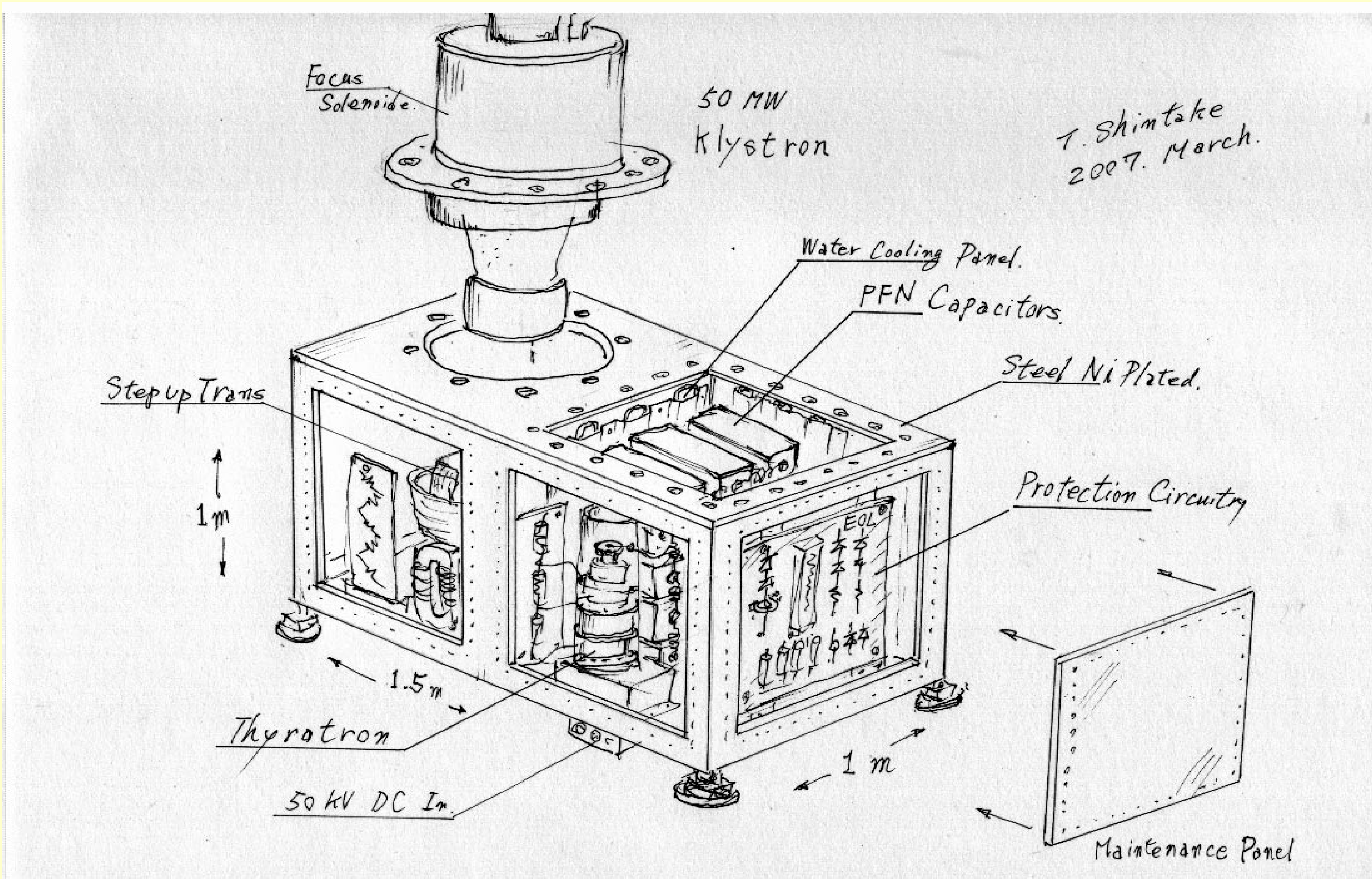






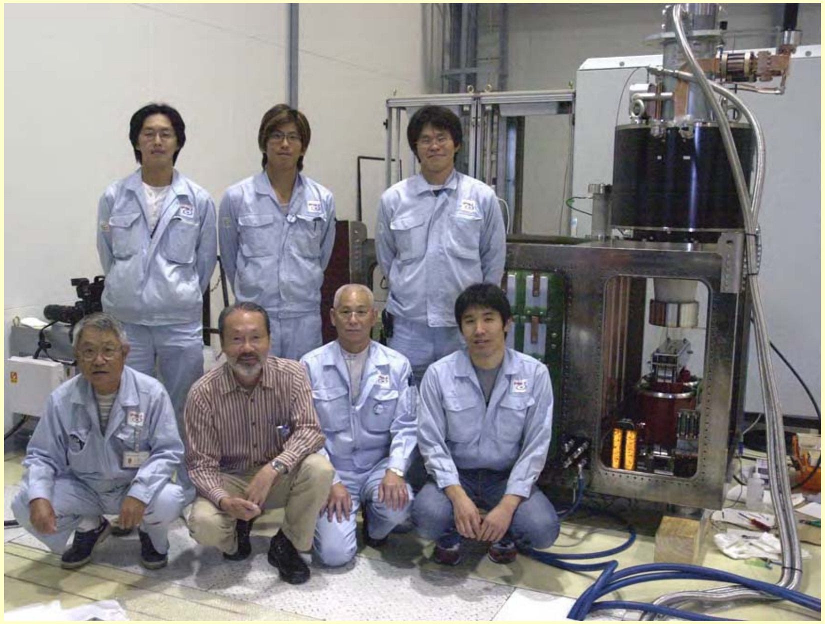


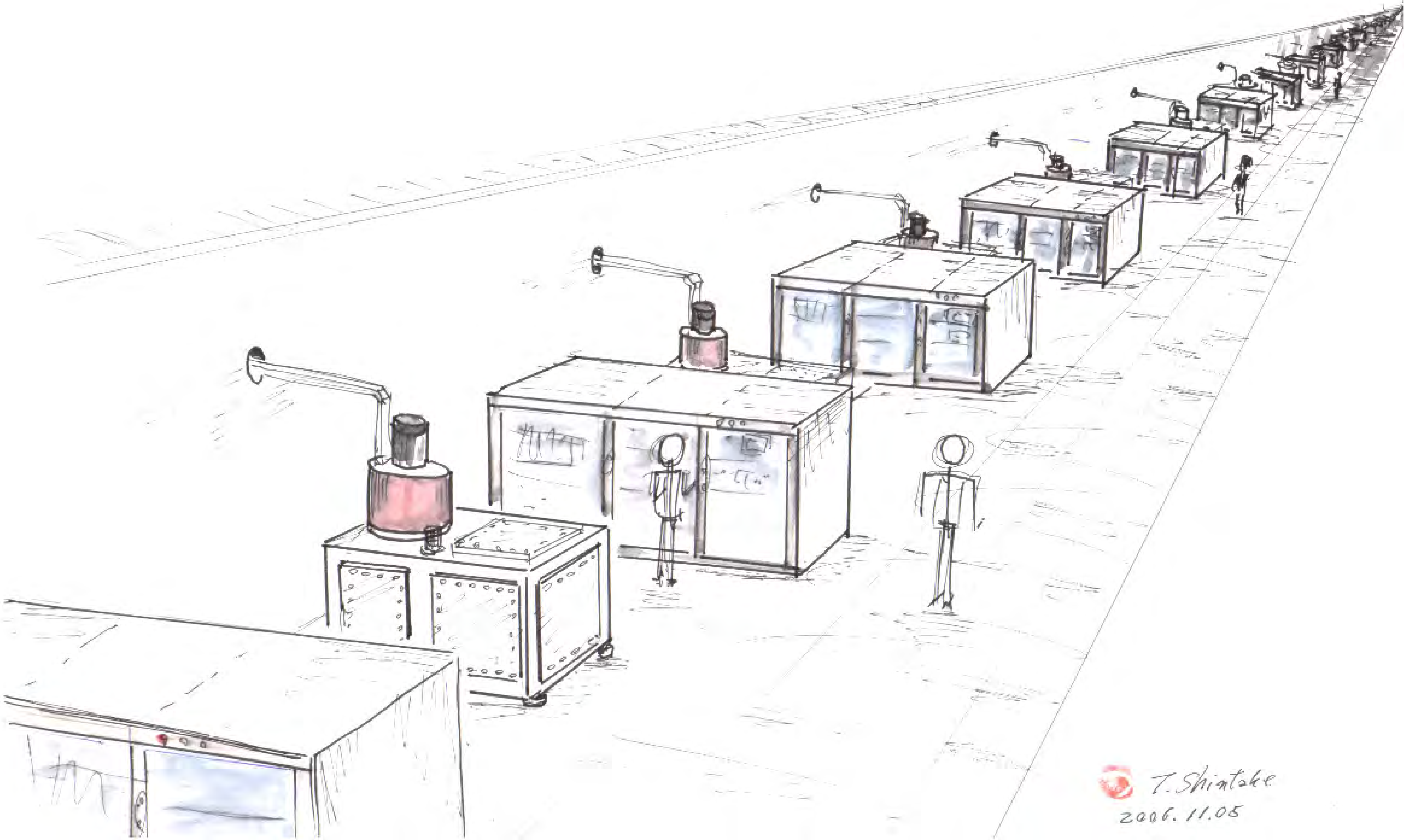
Klystron Modulator for
C-band, S-band 50 MW Klystrons



Compact Modulator for 50 MW Klystrons

- Output Power 50 MW RF x 60 pps
- 50 kV PFN, 1:16 Trans, 350 kV klystron.
- Compact 1 m x 1 m x 1.5 m,
- Very low noise
  (<10 Vpp on 200 V heater line)
- Water cooled. Max surface temp 45 deg.




T. Shintake
2006. 11. 05

Summary

- So many different efforts are coherently contributing to the project. They are almost on the time schedule.

- Building construction has been completed.
- Accelerator component installation has been started.
~ 1 year installation.

- October 2010, We start high power operation of accelerator.
- Spring 2011, we start beam commissioning.