Temporal characteristics of the UVSOR storage ring FEL

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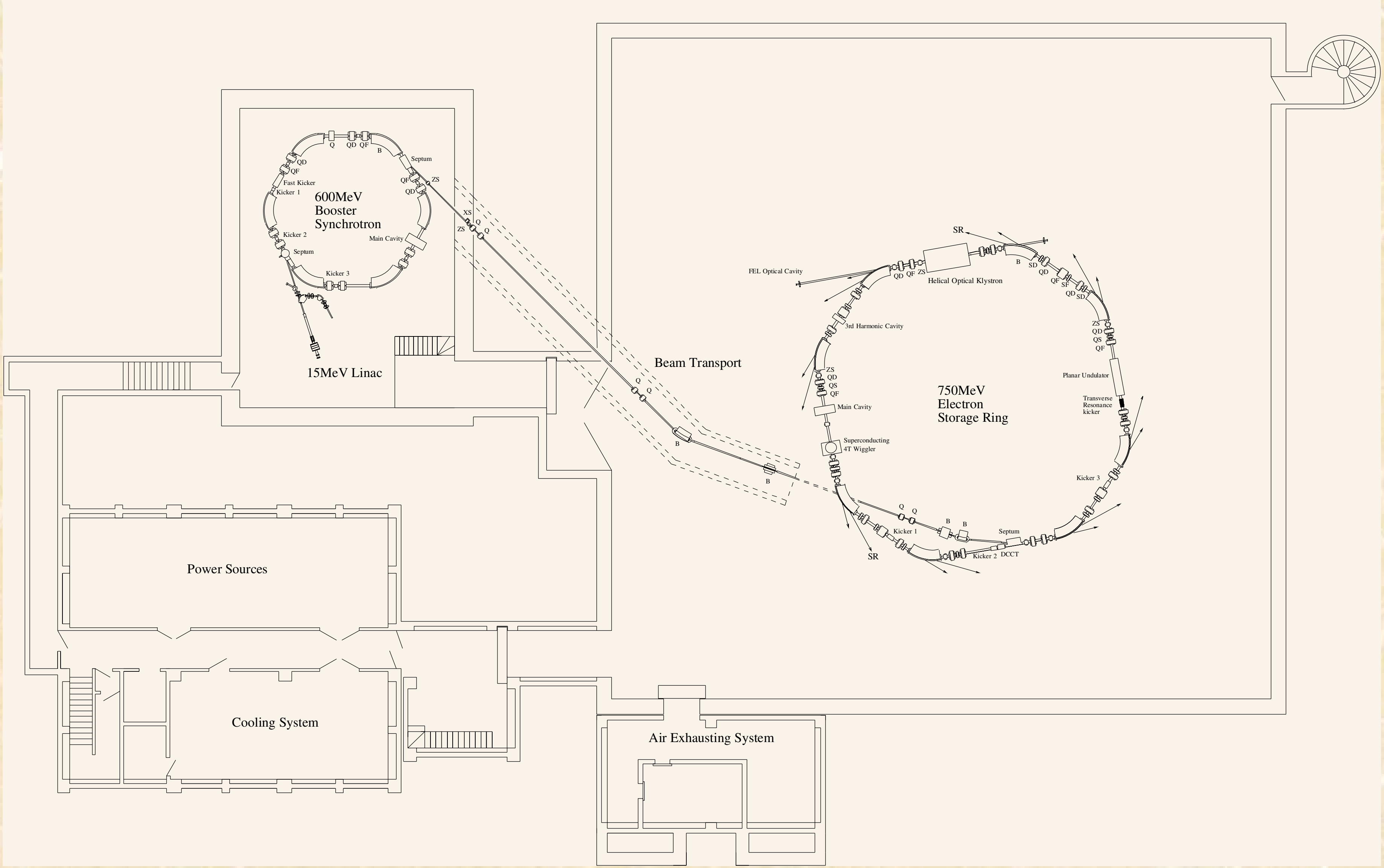
- Introduction of UVSOR storage ring
- Storage ring free electron laser experiment at UVSOR
- User experiment of UVSOR-FEL
- Temporal characteristics of SR-FEL
- Future plane of UVSOR-FEL

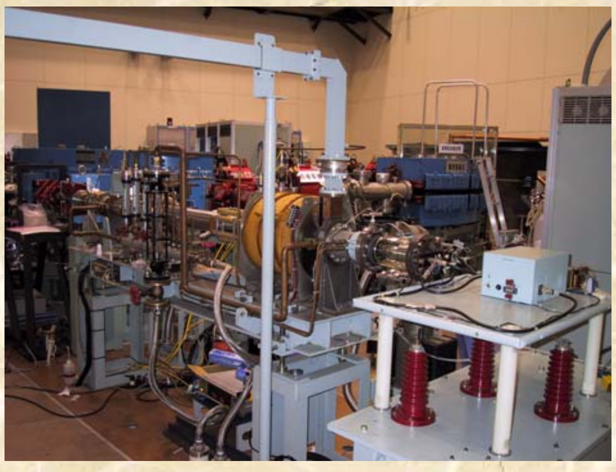
UVSOR-II storage ring since 2003

Circumference	53.2 m
Beam Energy	750 MeV
Critical Photon Energy	425 eV
RF Frequency	90 MHz
Harmonic Number	16
RF Voltage	55 kV
Emittance	27.5 nmrad

UVSOR accelerator complex

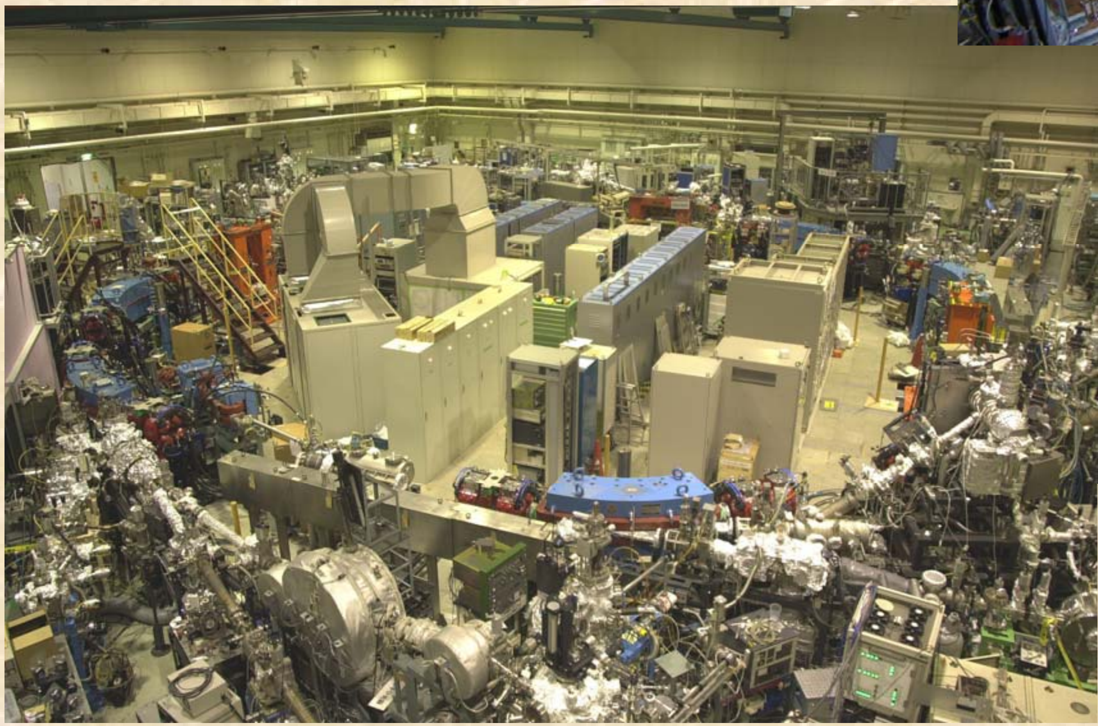
Plane view of the UVSOR Facility





Injection 15 MeV-linac

Booster 600 MeV-Synchrotron



750 MeV Storage Ring

Storage ring free electron laser experiment at UVSOR

History of UVSOR-FEL

1993 First Lasing

1996 Installation of a helical optical klystron

Lasing of 239 nm

Gamma ray via Compton backscattering

2000 1st User experiment

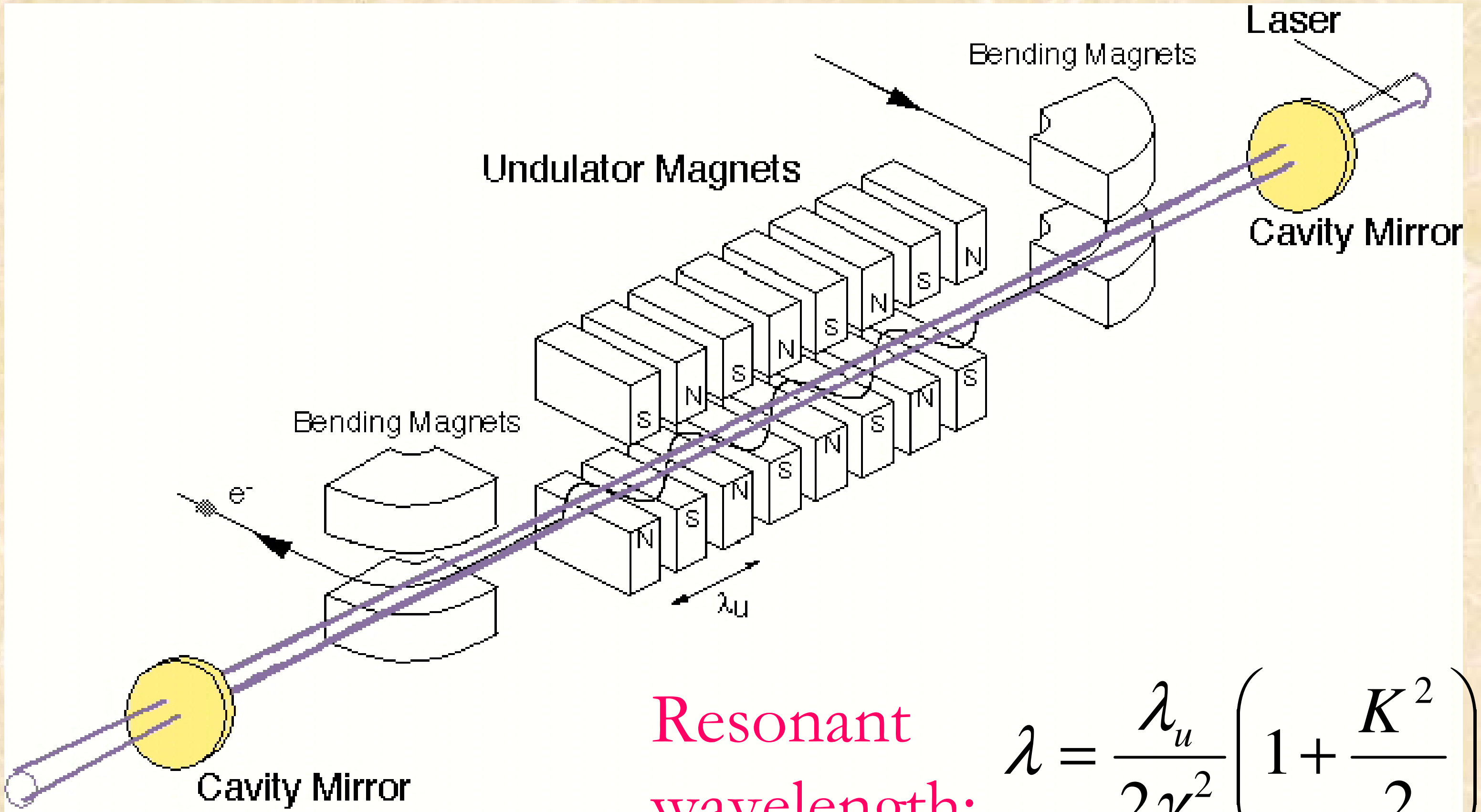
2001 FEL Power 1.2 W (λ=570 nm)

2003 Upgrade of the UVSOR storage ring

2004 P > 0.2 W (λ=250 nm)

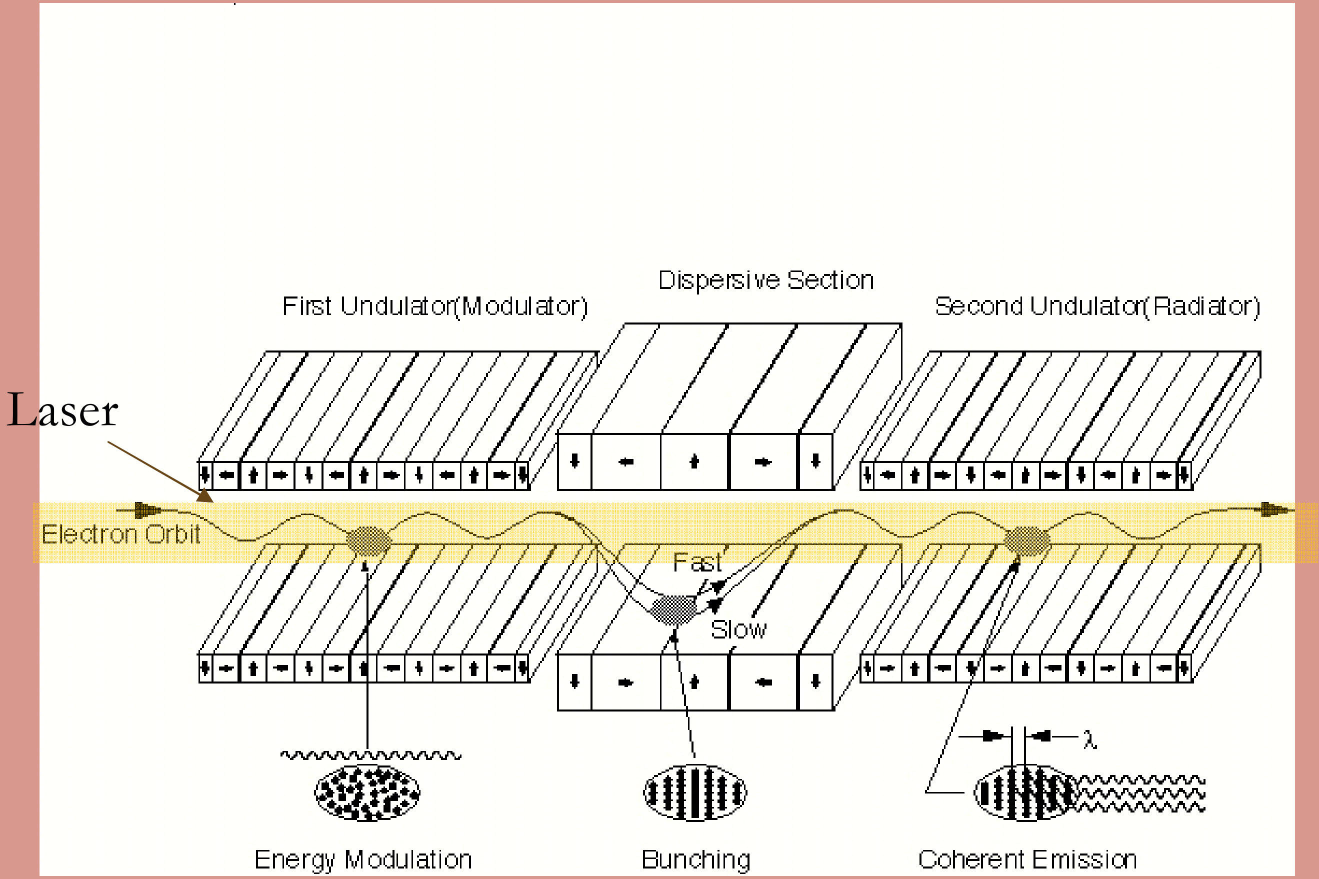
What is Free Electron Laser ?

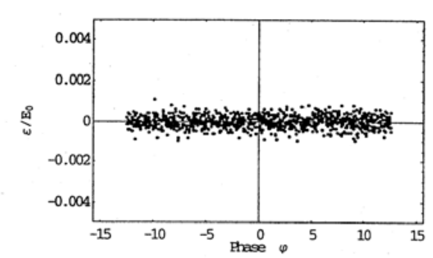
Schematic of FEL system



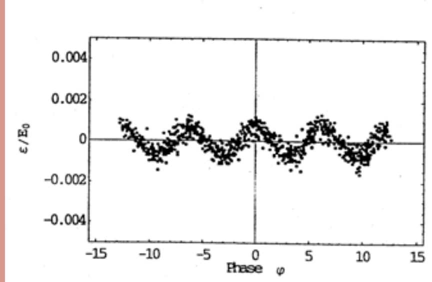
Resonant wavelength: $\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$

Gain Mechanism of FEL using an Optical Klystron

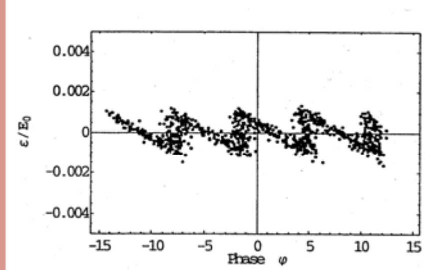




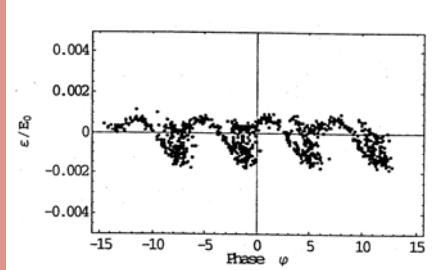
(a) Initial distribution



(b) Energy modulation

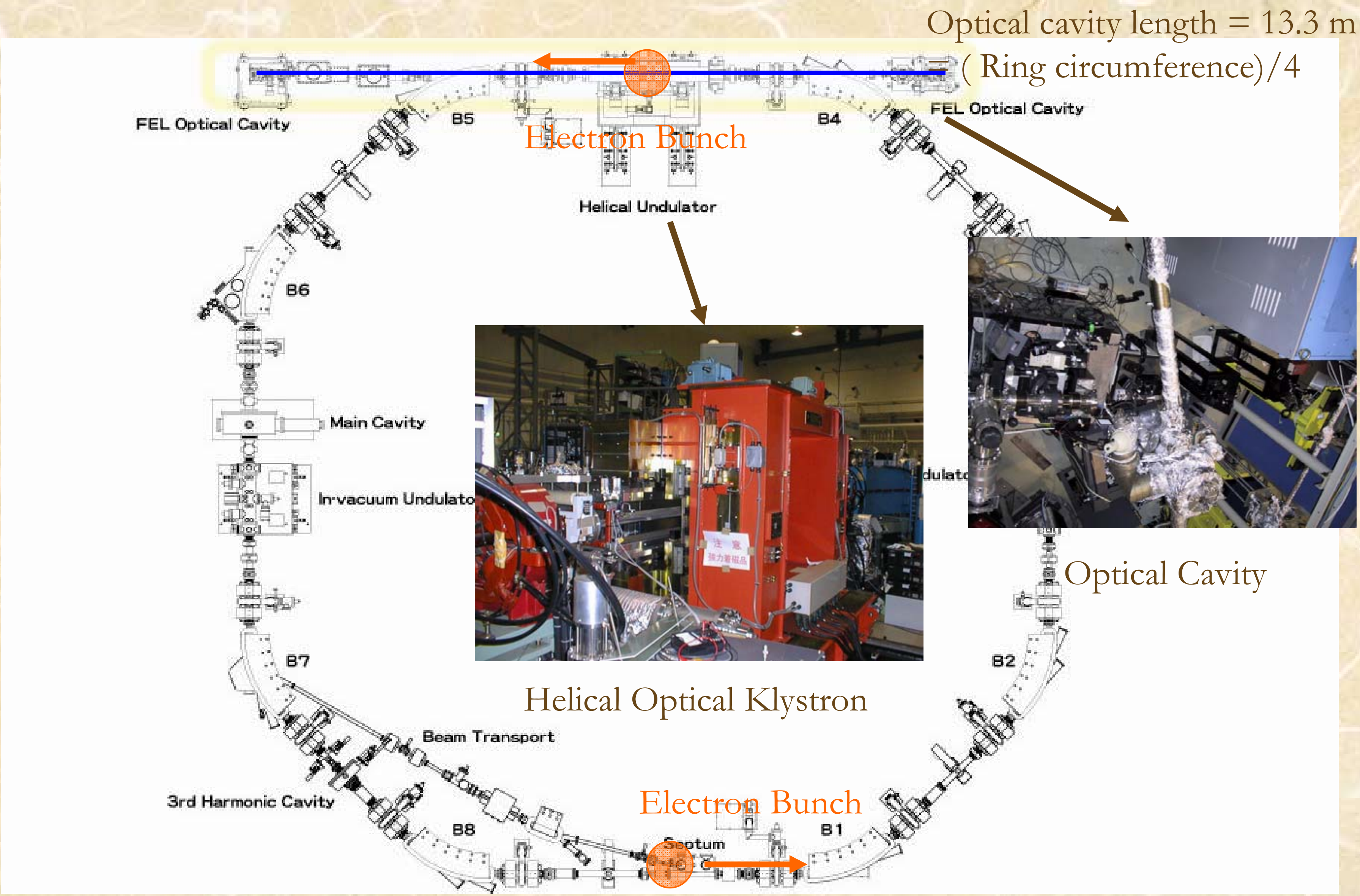


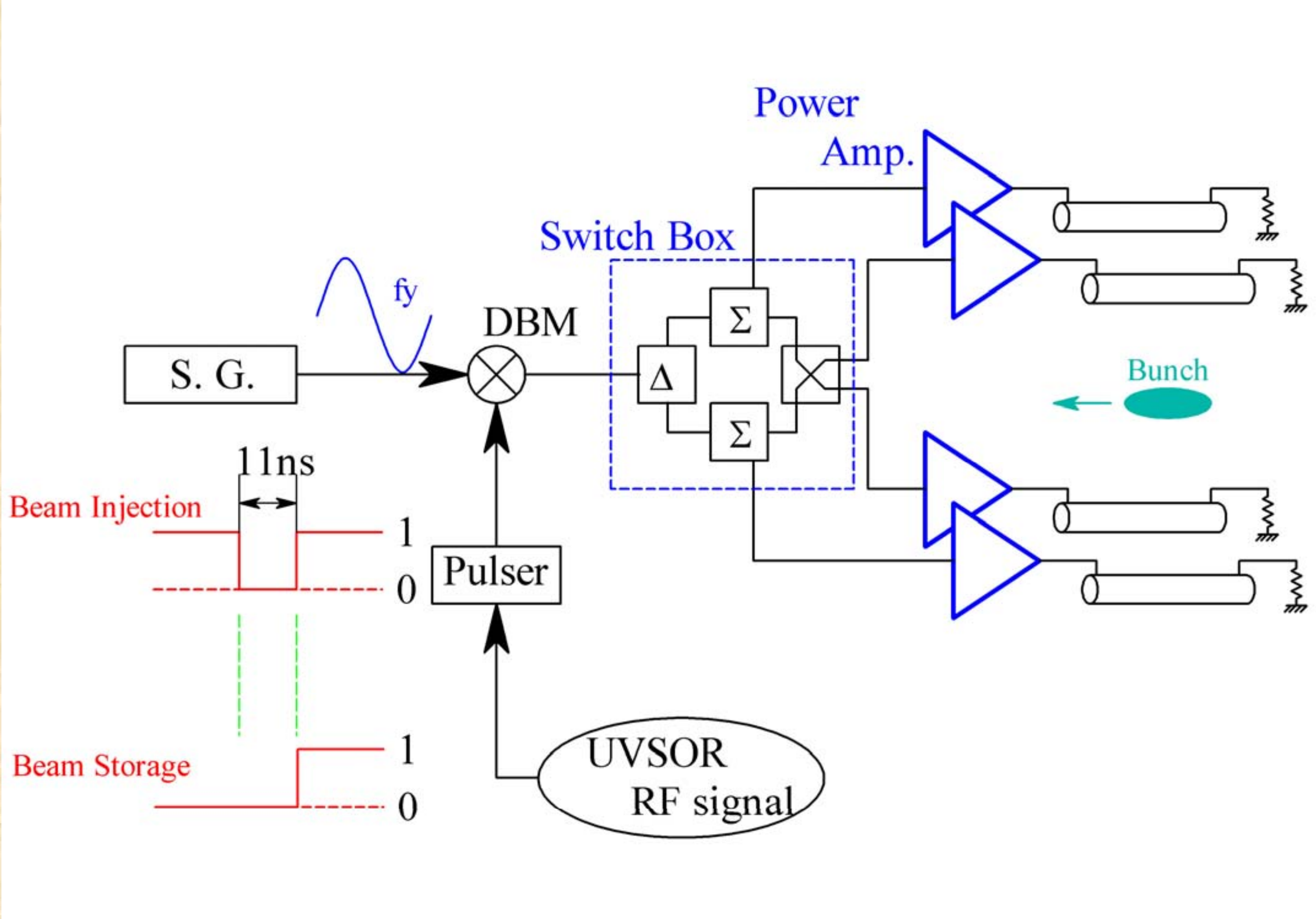
(c) Density modulation



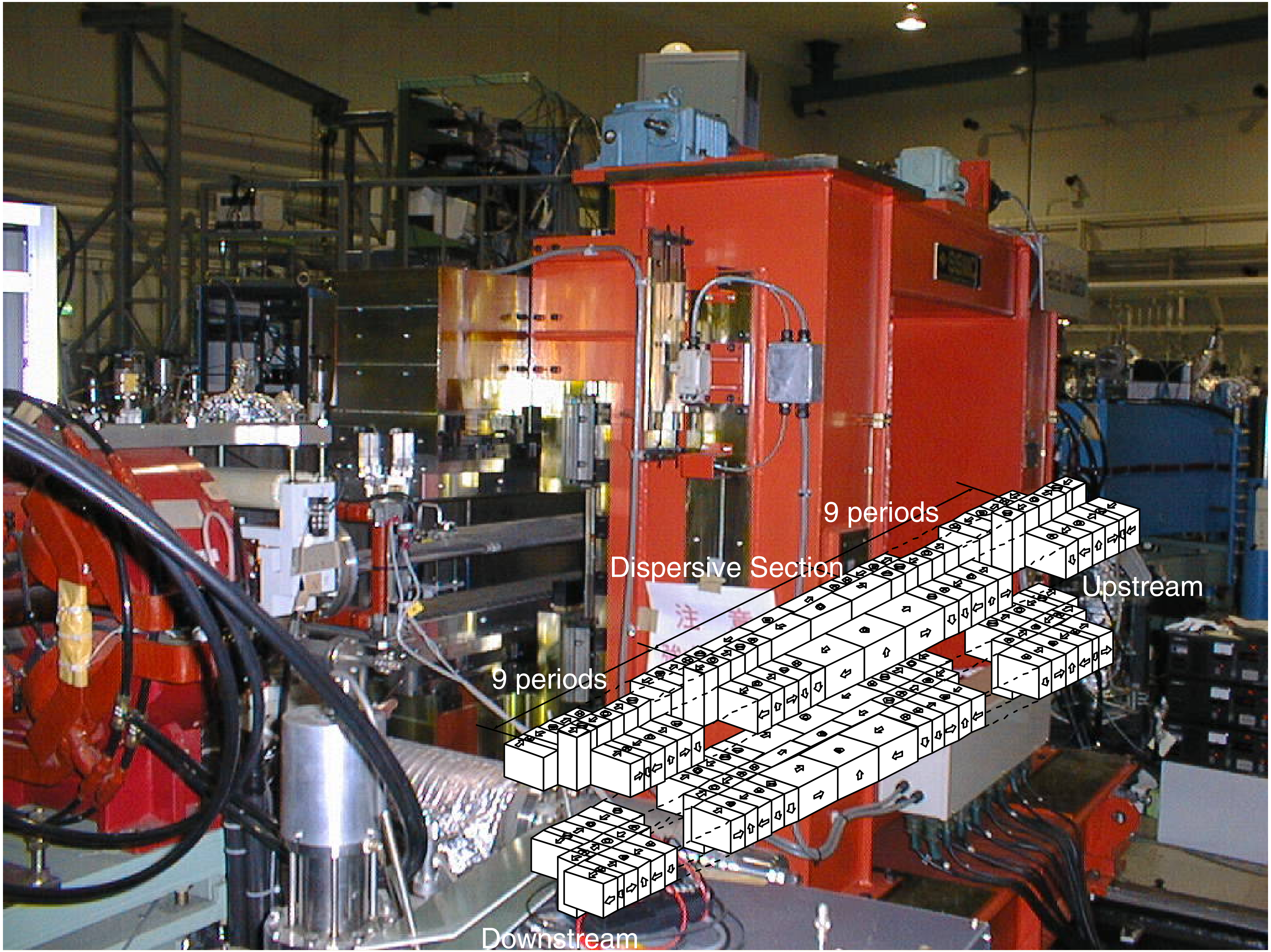
(d) Coherent radiation

Storage ring FEL experiment at UVSOR





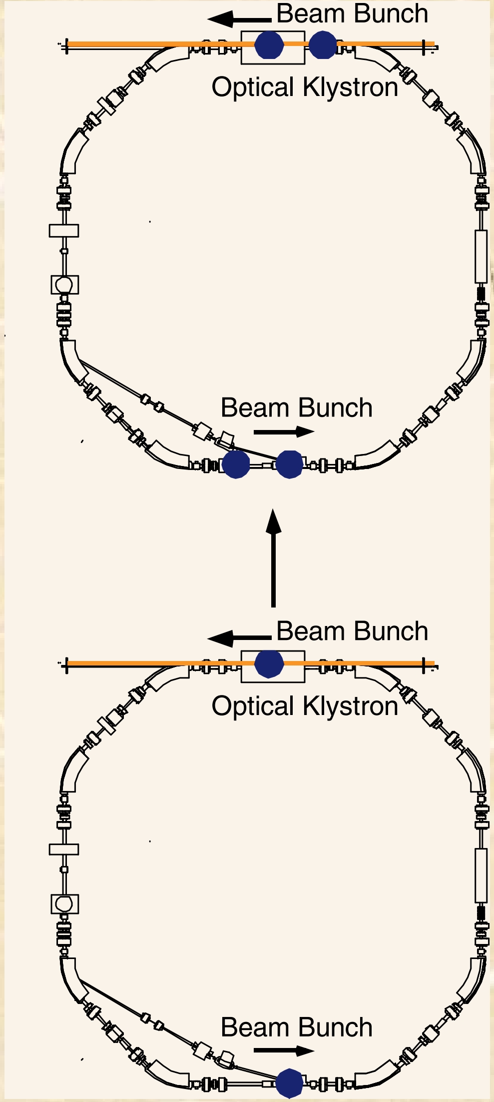
RF knock out system for single bunch operation

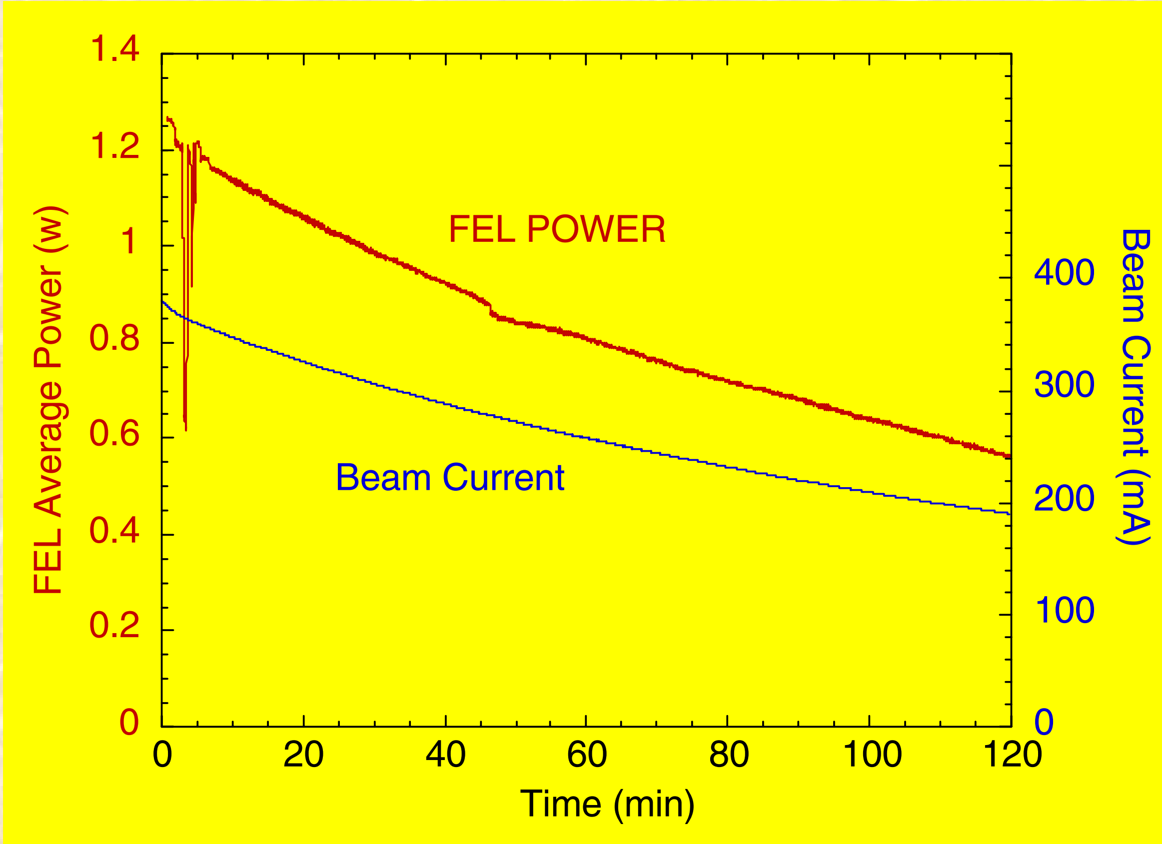

9 periods
Dispersive Section
Upstream
9 periods
Downstream

Parameter of the FEL experiment

Storage ring	
Beam Energy	600 MeV (ordinary operation 750 MeV)
Emittance	18 nm-rad (108 nm-rad before the upgrade)
Beam current	100 mA/bunch (Max)
Operation	Single bunch, 2 bunch, 4 bunch
Optical klystron	
Type	Helical/Linear
Number of period	9+9
Period length	110 mm
K-value	4.6>(Helical)/8.5>(linear)
Optical Cavity	
Type	Fabry-Perot
Length	13.3 m
Mirror	Multi-layers (HfO_2/SiO_2, Ta_2O_5/SiO_2)

High power operation





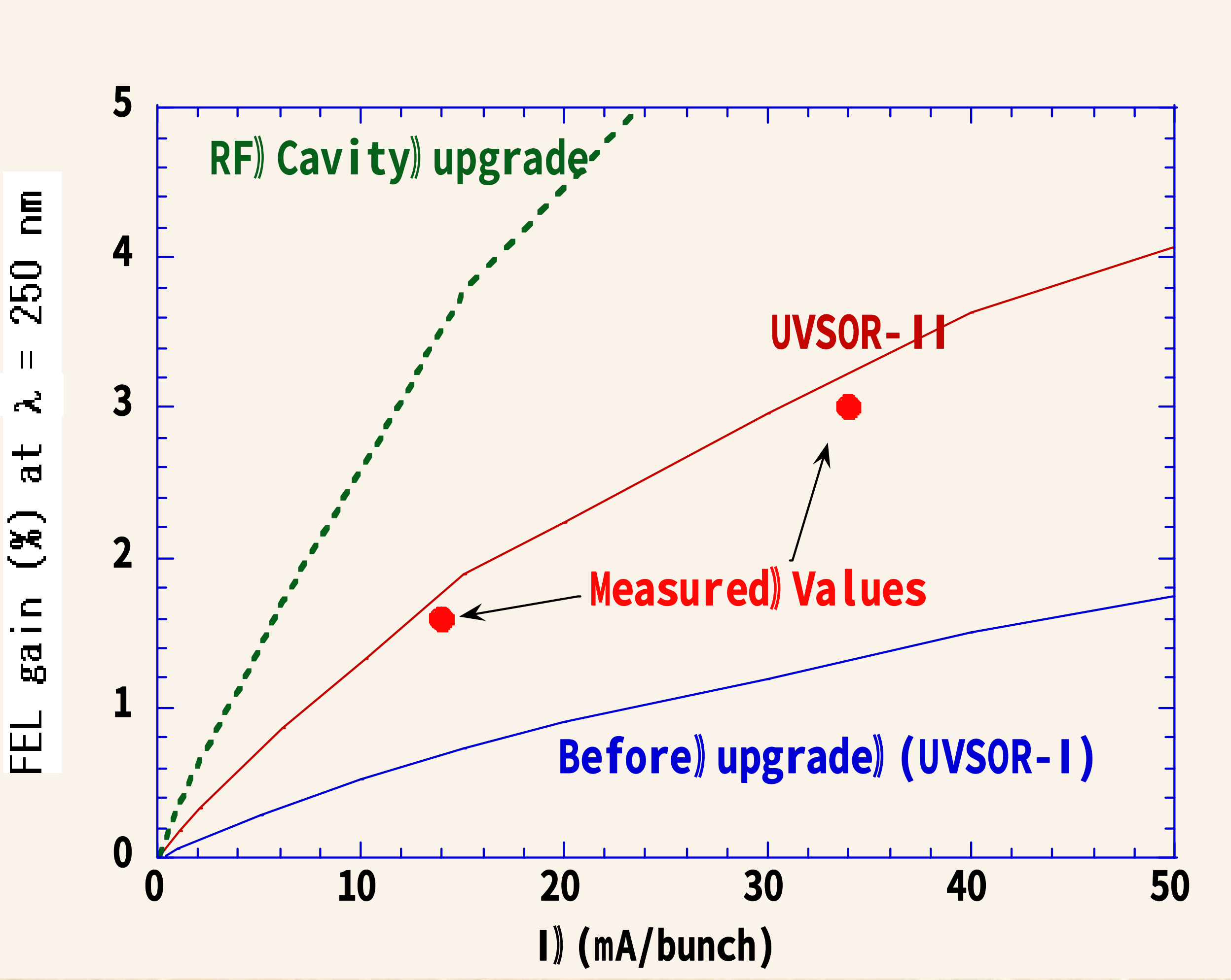
- High beam current (~100mA/bunch)
- Optimization of cavity mirrors
- 4 bunch operation

FEL with upgraded UVSOR-II storage ring

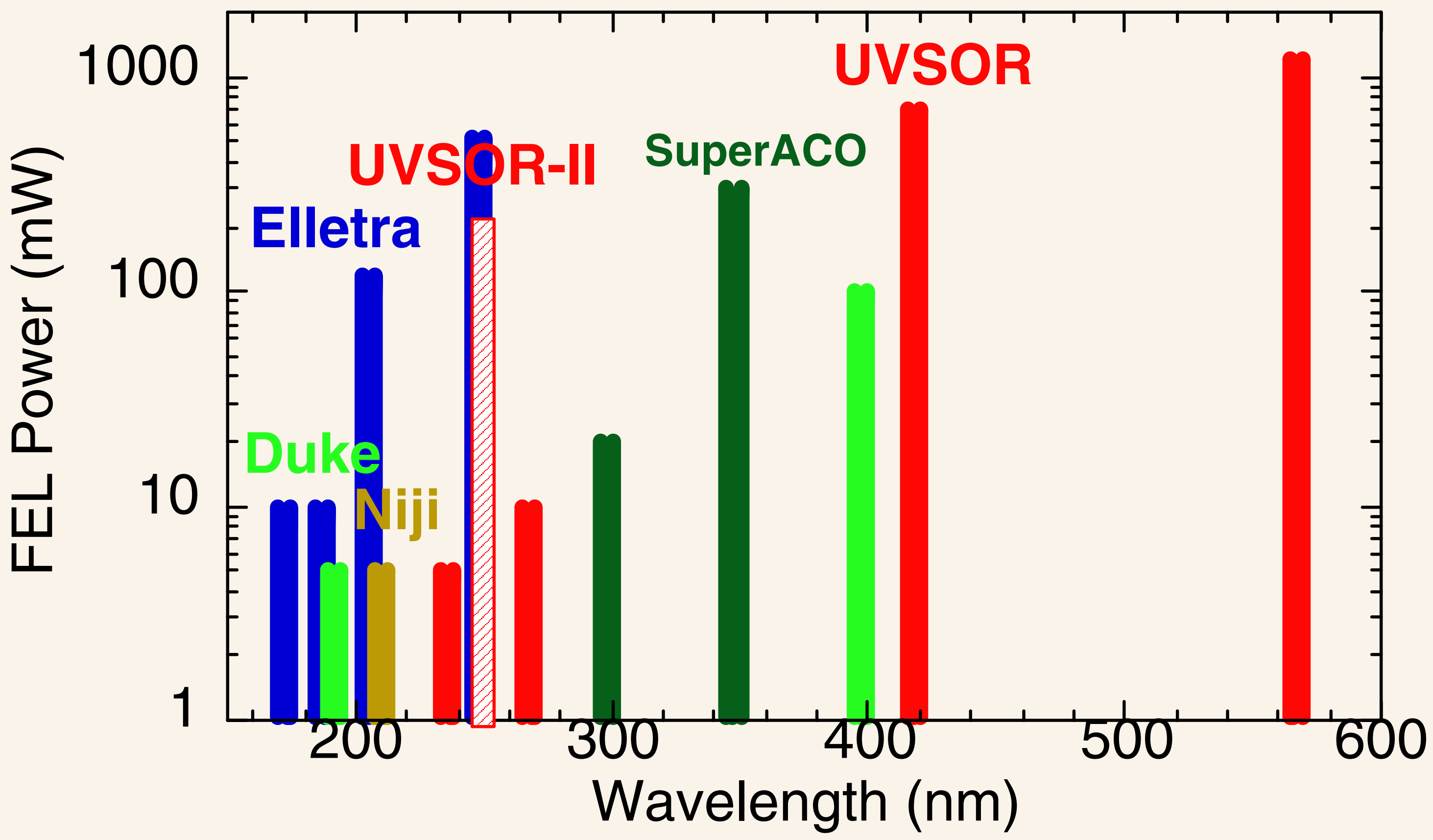
Upgrade of UVSOR (2003).

Beam emittance
110 nmrad ⟶ 18 nmrad

More than 2 times higher gain



Storage ring FEL in the world



User experiment of the UVSOR-FEL

Advantages of UVSOR-FEL

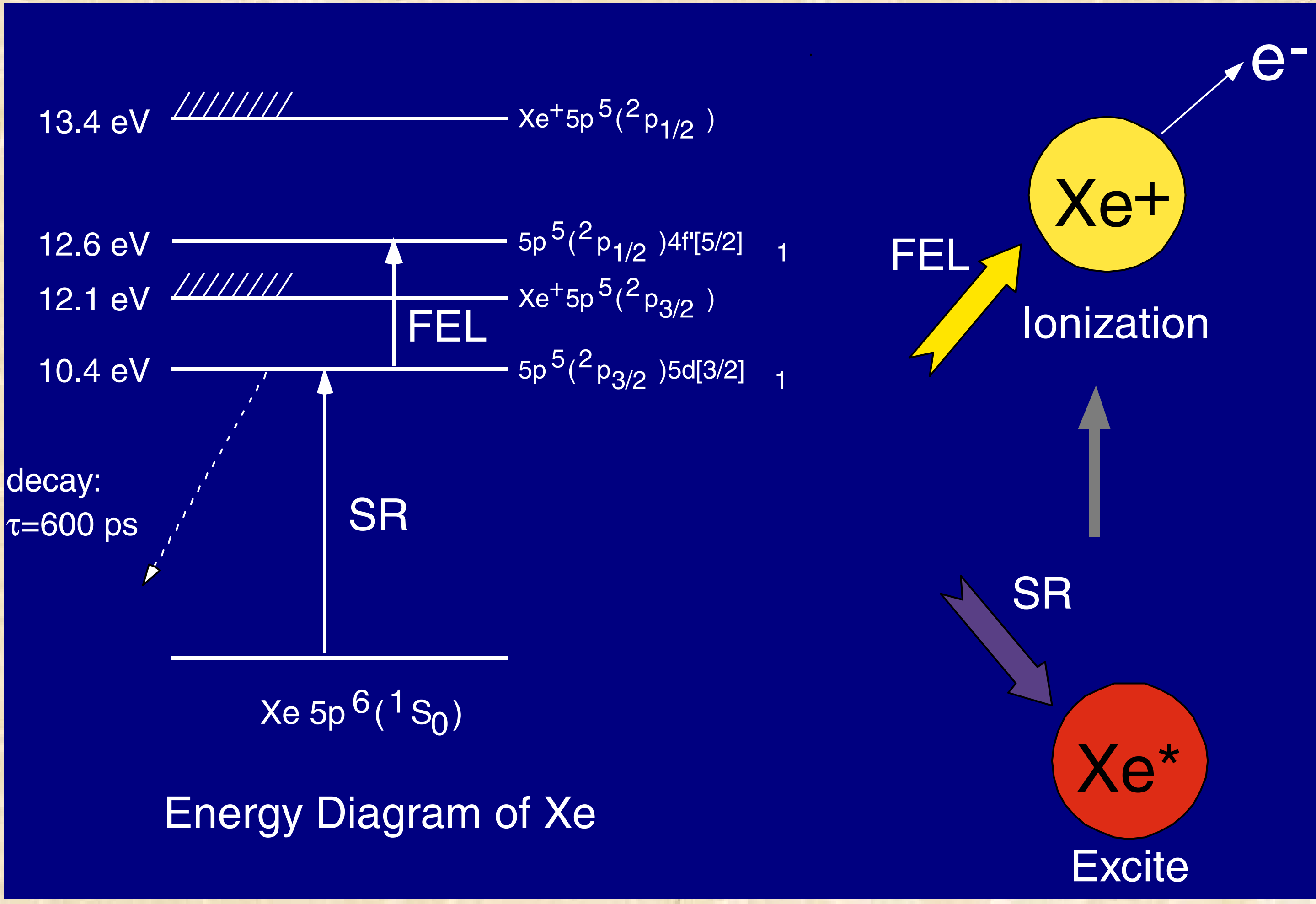
- Natural synchronization with SR pulse
- Good temporal features (σ_τ<10ps)
- Good coherence ($\Delta\lambda/\lambda$~1/5000)
- Covering a wide range of wavelength (Infra-red ~ UV)
- High power (~1W)
- Switch polarization (right circular, left circular, liner)
- High intra-cavity power (~ kW)

↓

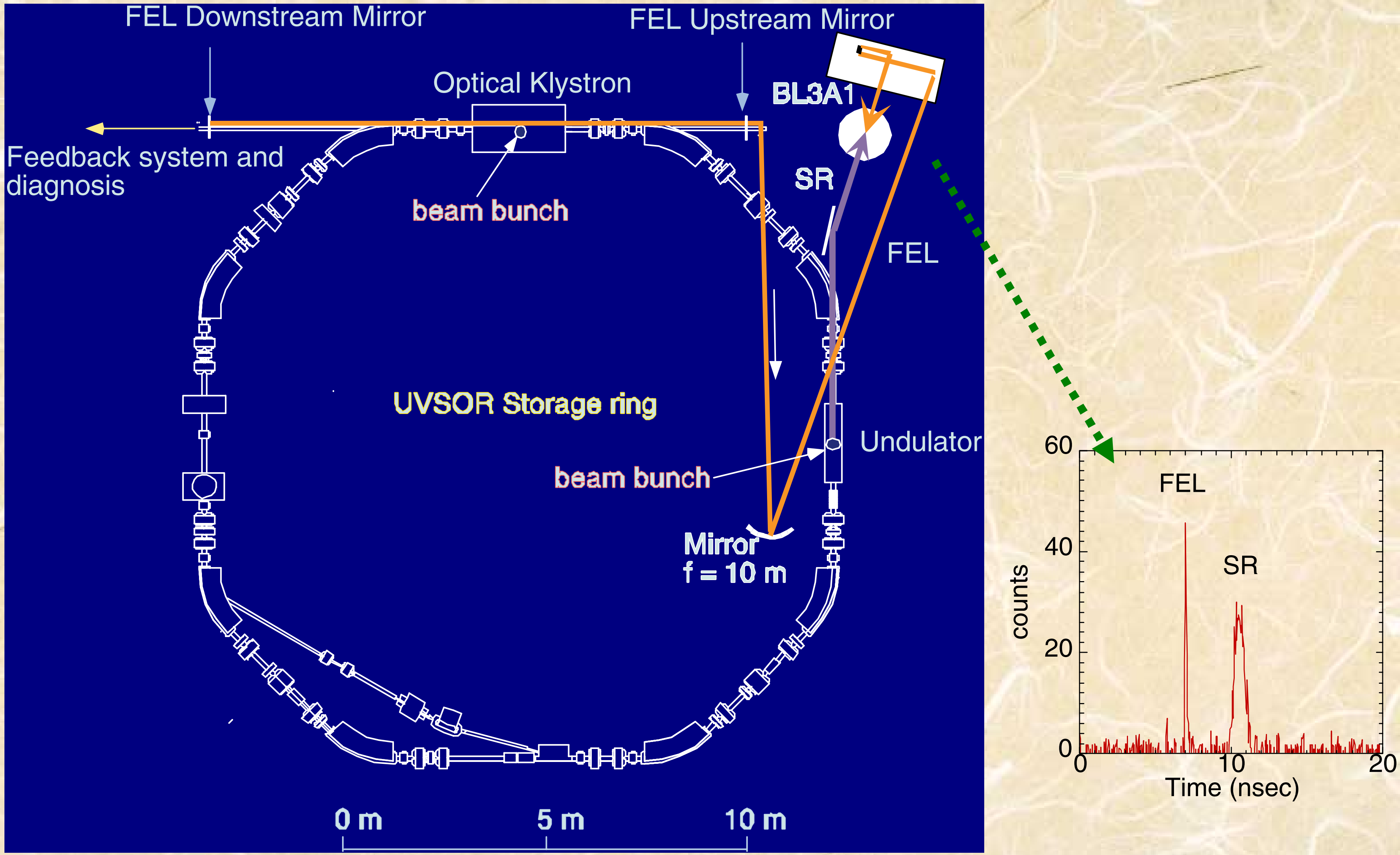
Application

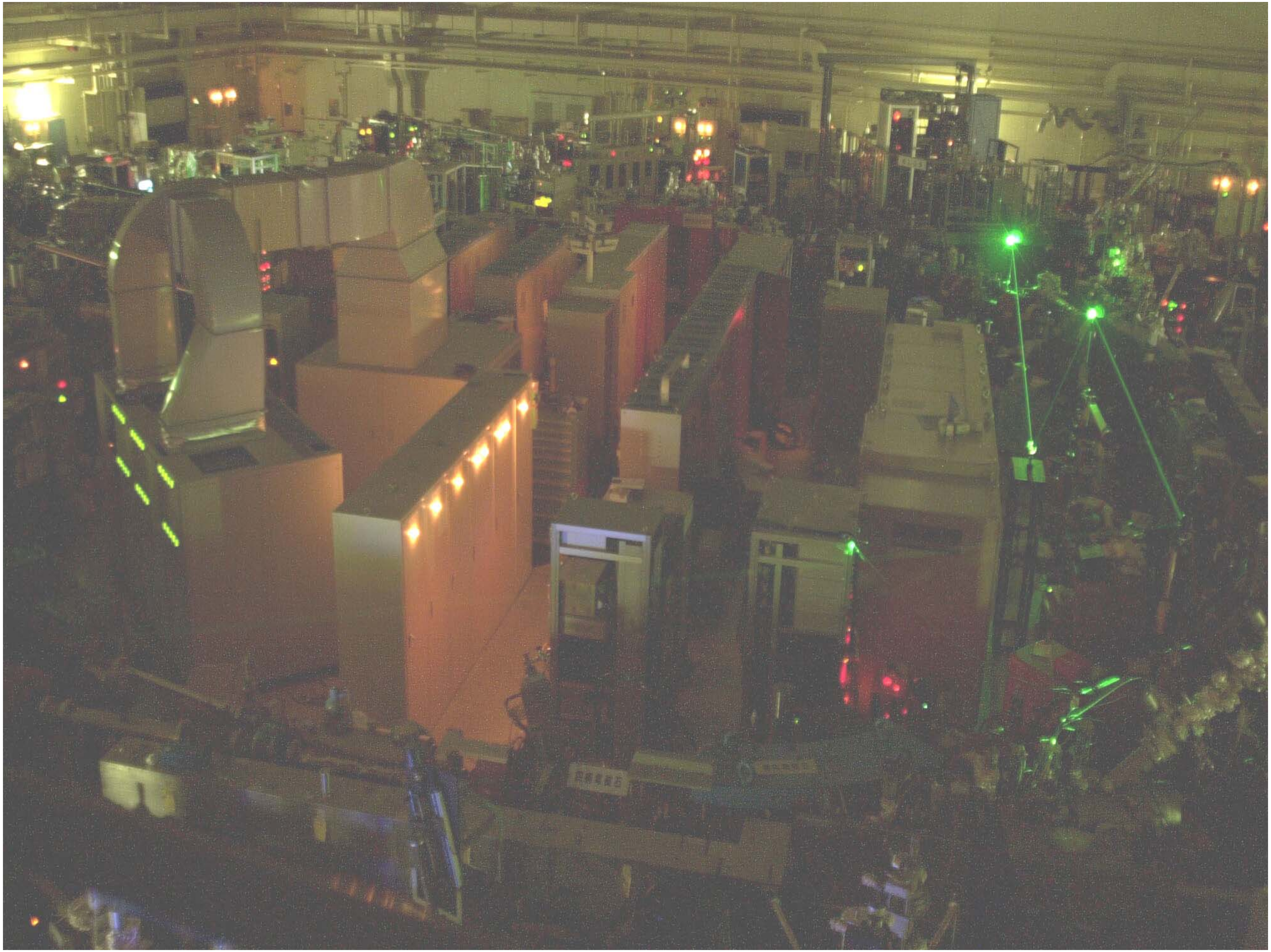
- Pump/Probe experiment
- Chirality experiment (bio-molecule)
- Production of high energy γ-ray

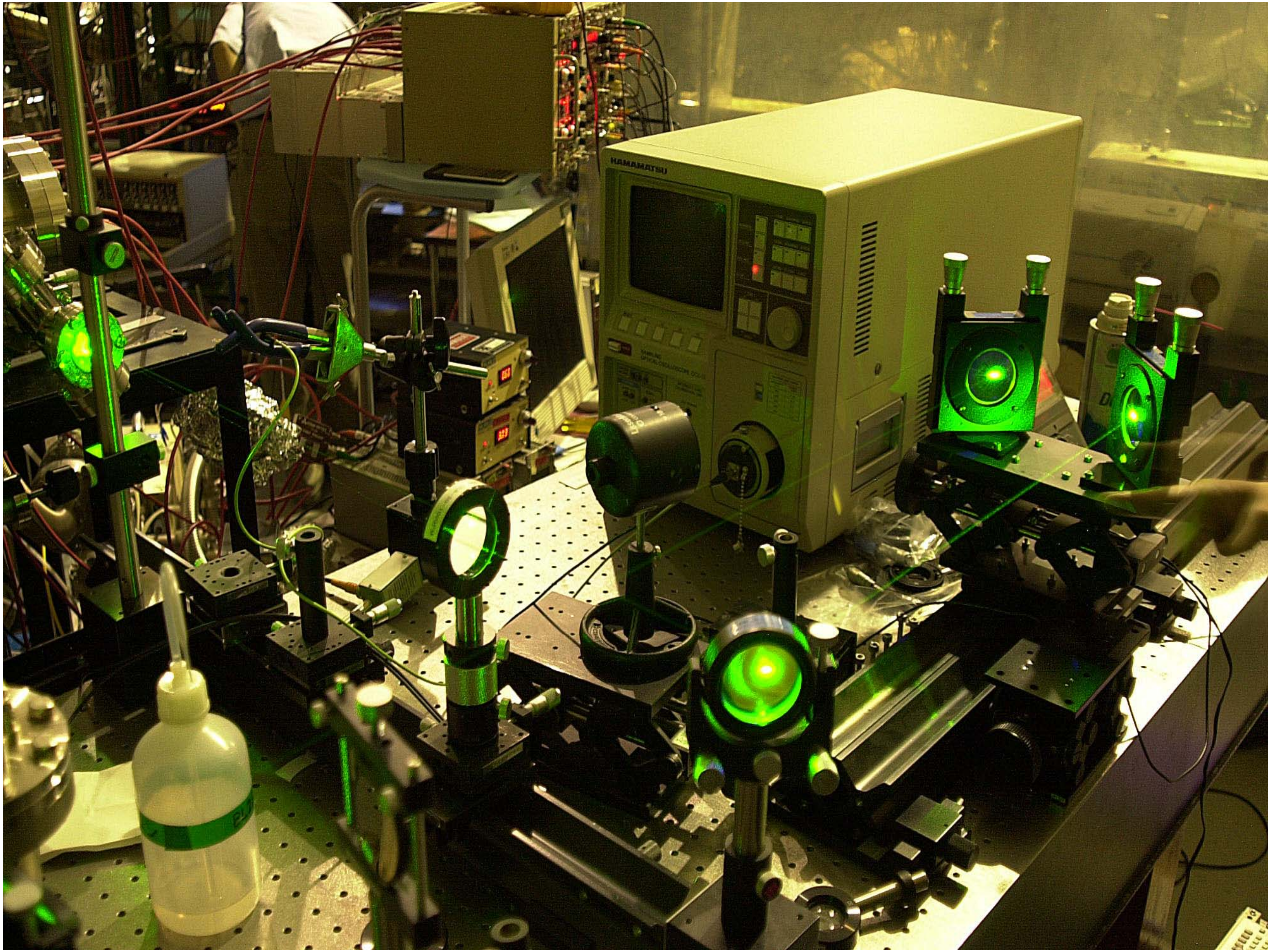
Pump/probe experiment on Xe



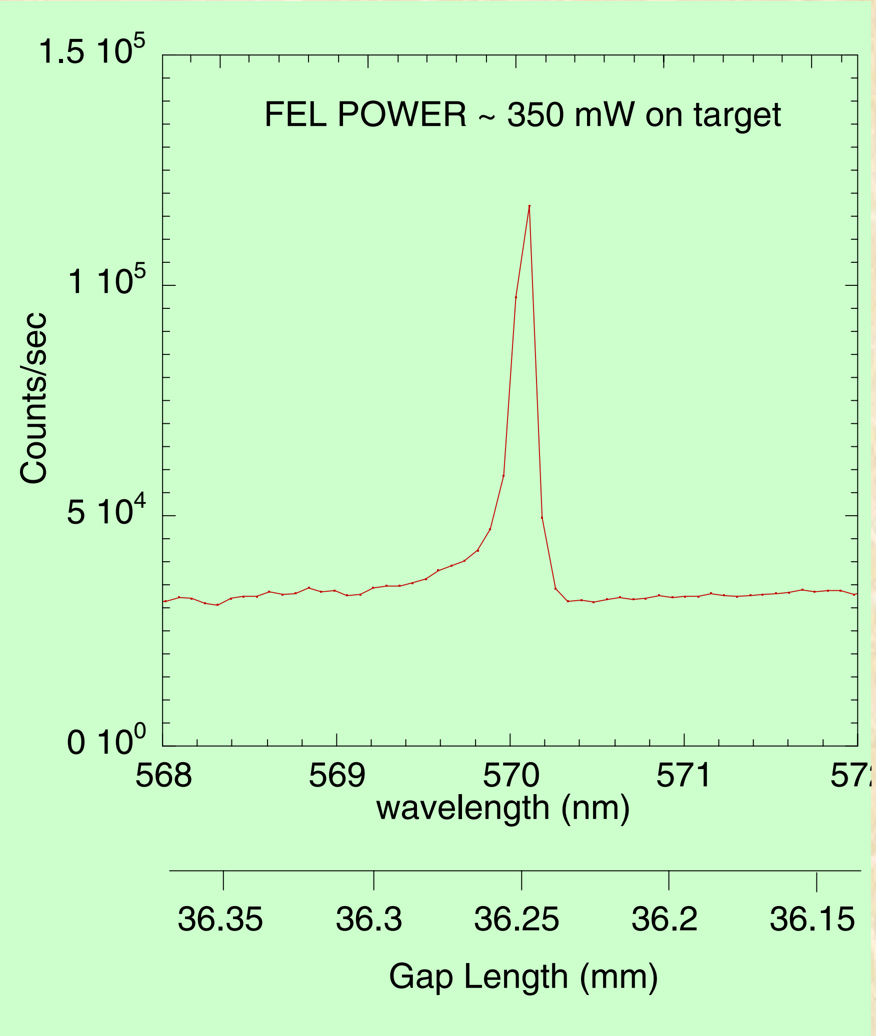
Experimental setup






HAMAMATSU

Experimental result



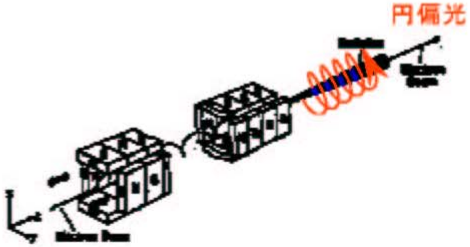
- FEL Wavelength ~ 570 nm and ~420 nm
- Ions produced in double resonant reaction are detected as a function of FEL wavelength.
- FEL wavelength is swept by changing the gap length of the optical klystron.

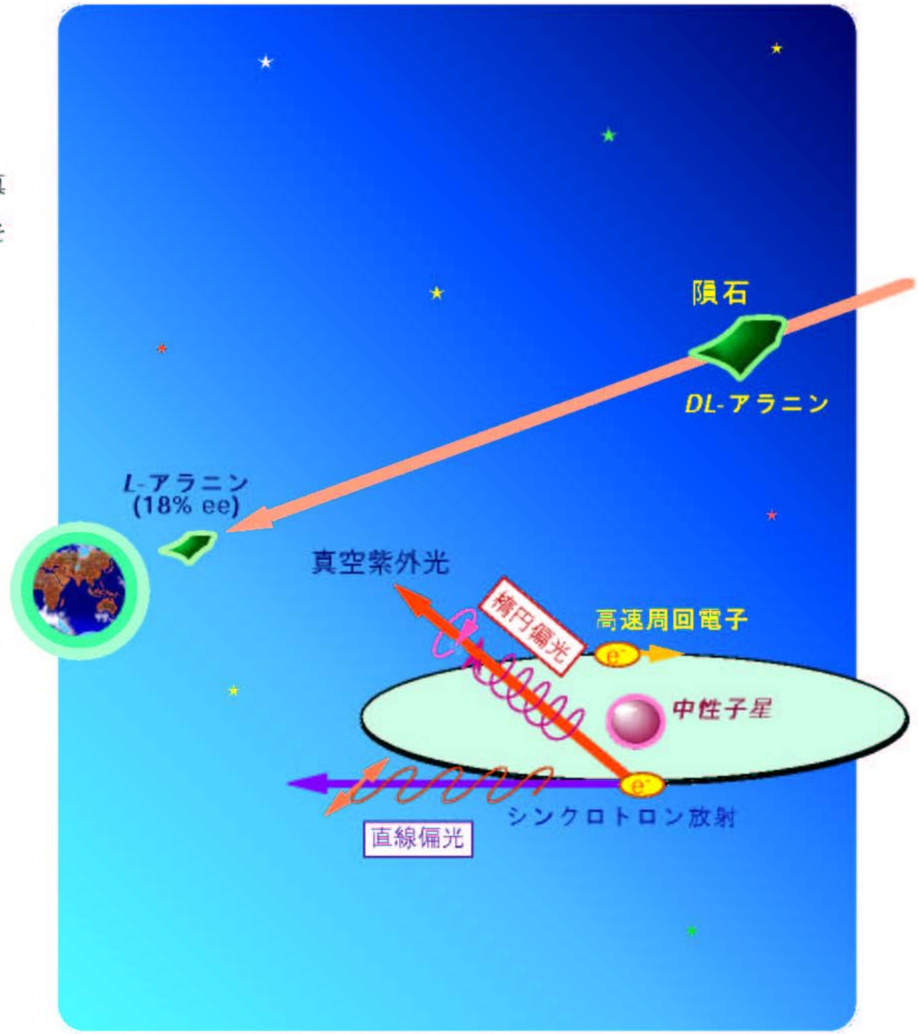
Spectrum of a doubly excited stat of Xe

Origin of biomolecular homochirality

宇宙におけるキラリティー誕生のシナリオ

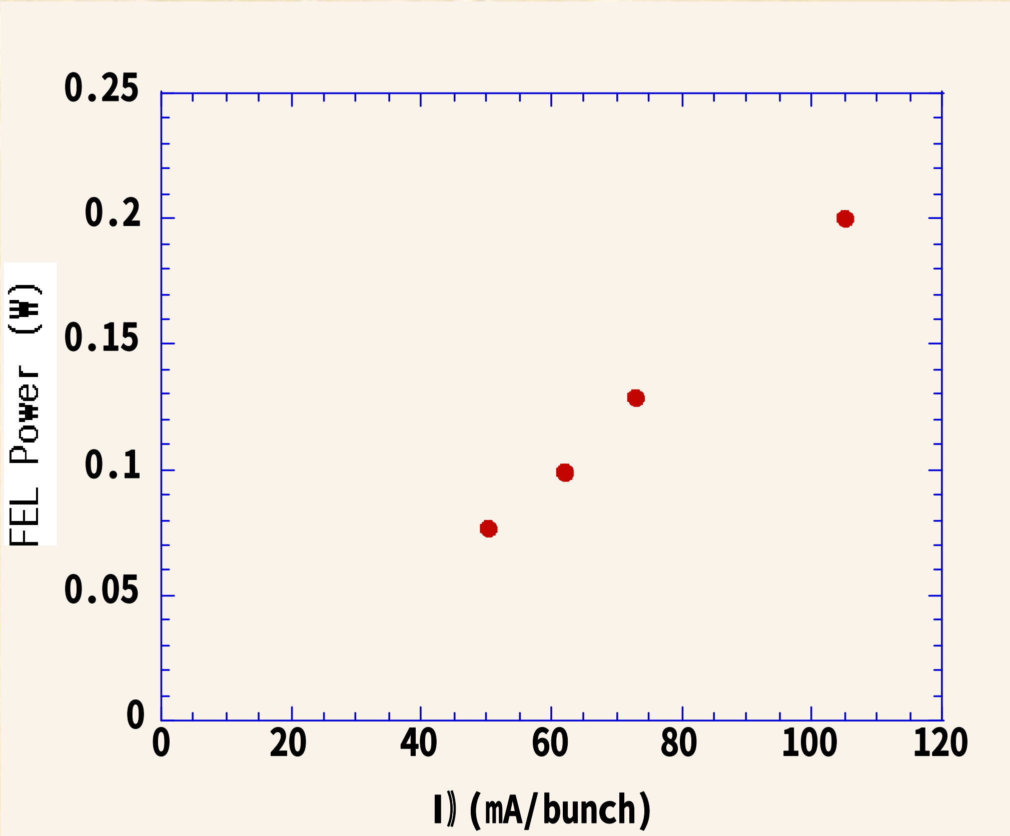
超新星爆発後に出来る中性子星を周回する高速電子からシンクロトロン放射（楕円偏光）によるる絶対不斉合成をヘリカルアンジュレータ(真空紫外円偏光発生用シンクロトロン挿入光源)を用いてシミュレートする





ICORP Entropy Control Project

Origin of biomolecular homochirality (Cont.)

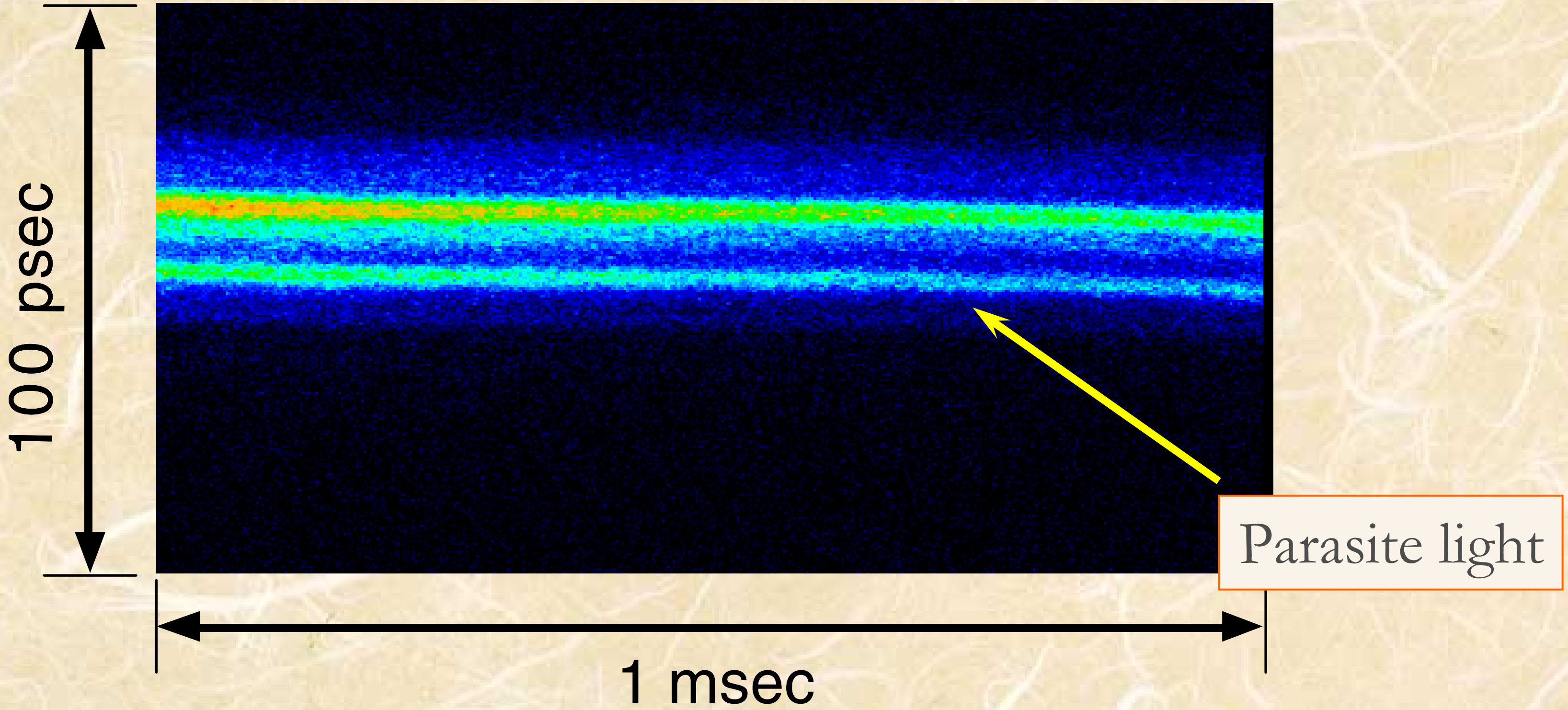


FEL power at $\lambda = 250$ nm

- Irradiate a sample with right and left circular FEL
- FEL wavelength
  (1) 250 nm (Mar. 5th 2005)
  (2) 215 nm

Temporal Characteristics of Storage ring FEL

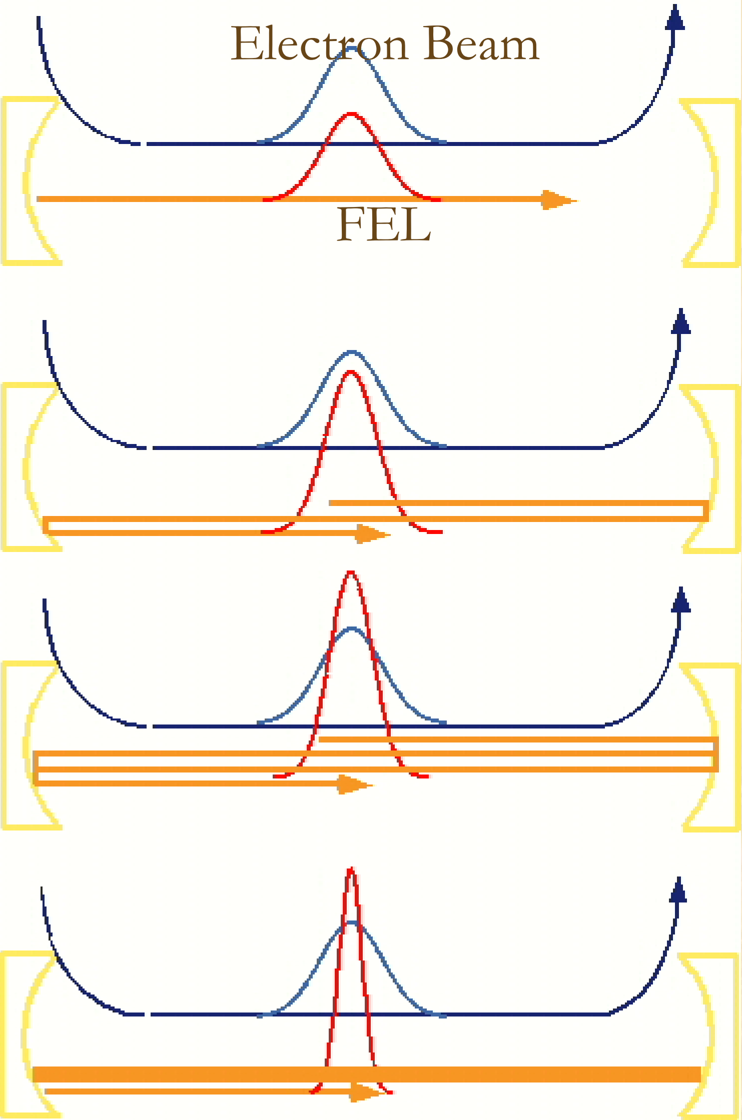
Streak camera image in the CW zone



Measured time duration ~ 3psec << Bunch Length (100 ~ 400 ps)

Why ?

Mechanism of temporal narrowing



Incoherent radiation

$I_{FEL} \propto \exp(-(\tau/\sigma_{beam})^2/2$ $\sigma_\tau = \sigma_{Beam}$,

Gain $\propto$ Beam Density

1 Round Trip

$I_{FEL} \propto \exp(-(\tau/\sigma_{beam})^2/2)^2 =$
$\exp(-(\tau/(\sigma_{beam}/2))^2/2)$

$\sigma_\tau = \sigma_{Beam}/2$,

2 Round Trip

$\sigma_\tau = \sigma_{Beam}/3$

n Round Trip

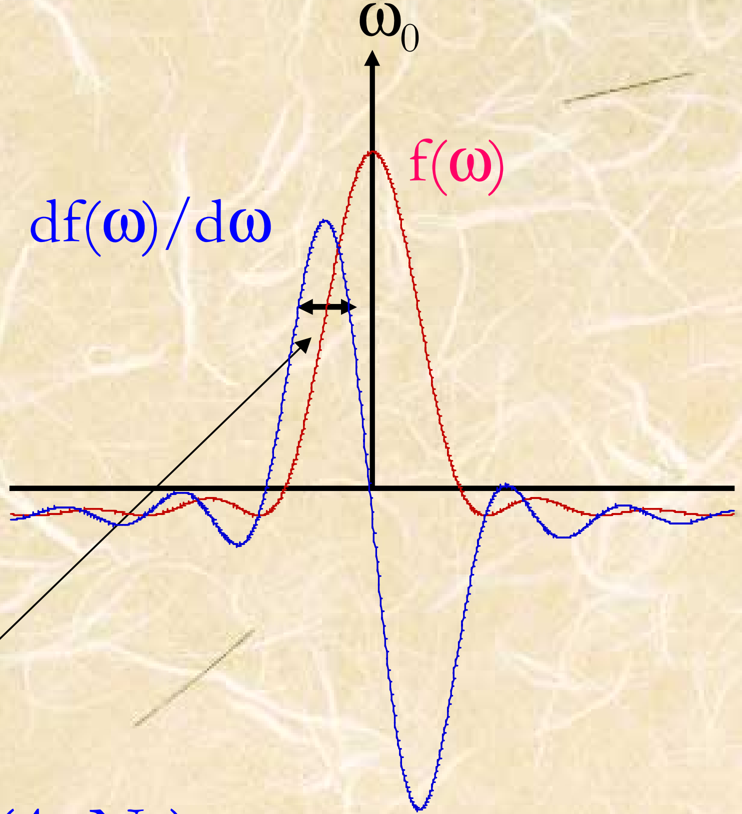
$\sigma_\tau = \sigma_{Beam}/n$,

Spectral narrowing

Mayday's theorem:

FEL gain (ω) ∝ df (ω) /d ω

f(ω): Spectrum of spontaneous radiation from undulator



1 Round trip

$$\sigma_{sp} = \Delta\omega = \omega_0/(4\pi N_u)$$

2 Round trip

$$\sigma_\omega = \Delta\omega/2$$

n-Round trip

$$\sigma_\omega = \Delta\omega/n = \omega_0/(4\pi n N_u)$$

$\Delta\omega = \omega_0/(4\pi N_u)$

N_u: Number of periods of undulator

Limitation of Narrowing

"n round trip" $\sigma_\tau = \sigma_{beam}/n$

$\sigma_\omega = \omega_0/(4\pi n N_u)$

Fourier Limit $\sigma_\tau \bullet \sigma_\omega > 1/2$

: $\sigma_\tau \bullet \sigma_\omega = \sigma_{beam}\omega_0/(4\pi N_u n^2) > 1/2$

$n = (\sigma_{beam}\omega_0/(2\pi N_u))^{1/2}$ ~100 :narrowing saturate

$\sigma_\tau = (2\pi N_u \sigma_{beam}/\omega_0)^{1/2} = (N_u \sigma_{beam}\lambda/c)^{1/2}$

$\sigma_\omega = 0.5(\omega_0/(2\pi N_u \sigma_{beam}))^{1/2}$

Supermode theory

$\sigma_\tau = 0.5(N_u \lambda \sigma_{beam}/c)^{1/2}$ $\sigma_\lambda/\lambda = (\lambda/(N_u \sigma_{beam} c))^{1/2}/\pi$

UVSOR: $N_u = N + N_d \sim 100$,
$\lambda = 520$ nm
$\sigma_{beam} = 100$ psec
$\sigma_\tau \sim 4.2$ psec (measured 4 psec)
$\sigma_\lambda/\lambda \sim 1/10000$ (measured $< 1/5000$)

For shorter pulse FEL(UVSOR case)

- Smaller number of periods of the undulator
  → Smaller gain (not realistic)
- Shorter wavelength → 200 nm
- Shorter bunch length
  low alpha, high cavity voltage → 10psec

$\sigma_\tau \sim 800$ fsec

Future plane of the UVSOR-FEL

Lasing in the VUV region (200nm ~ 150nm)

- Oxides multi-layers can not be used for mirrors (λ<190 nm)
- Fluoride (ex CaF_2/MgF_2) multi-layers

↓

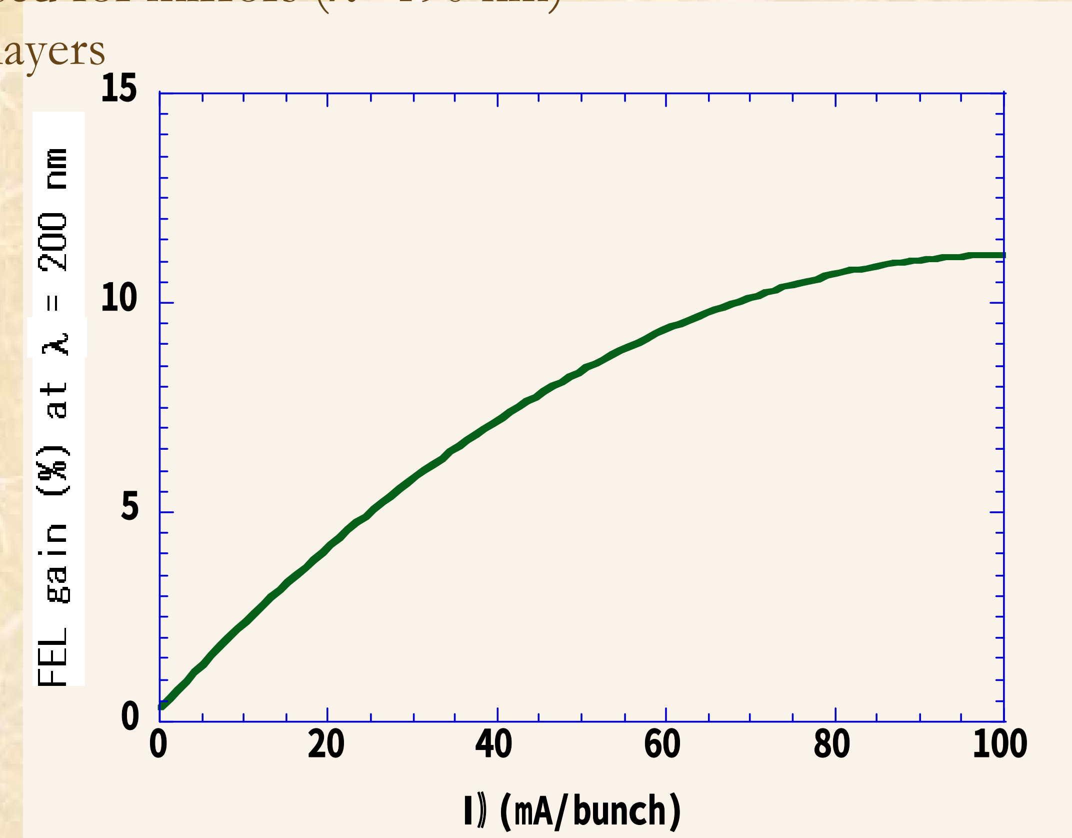
Reflectivity is small ~ 90 %

Upgrade of RF cavity

55 kV ⟶ 150 ~ 200 kV

Gain is doubled.

Lasing is possible in the VUV



Expected FEL gain with upgraded RF cavity