Laser-SR synchronization system for ultrafast x-ray diffraction at SPring-8

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－Outline－

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1. Introduction
   Snapshot by ps TR-XRD at SPring-8

2. SR-Laser synchronization
   2-1. Synchronization procedure
   2-2. Picosecond timing control in SPring-8
   2-3. Control of the repetition rate
   2-4. Optical switching of X-rays by using lattice expansion of single crystal

3. Sub-picosecond TR-XRD

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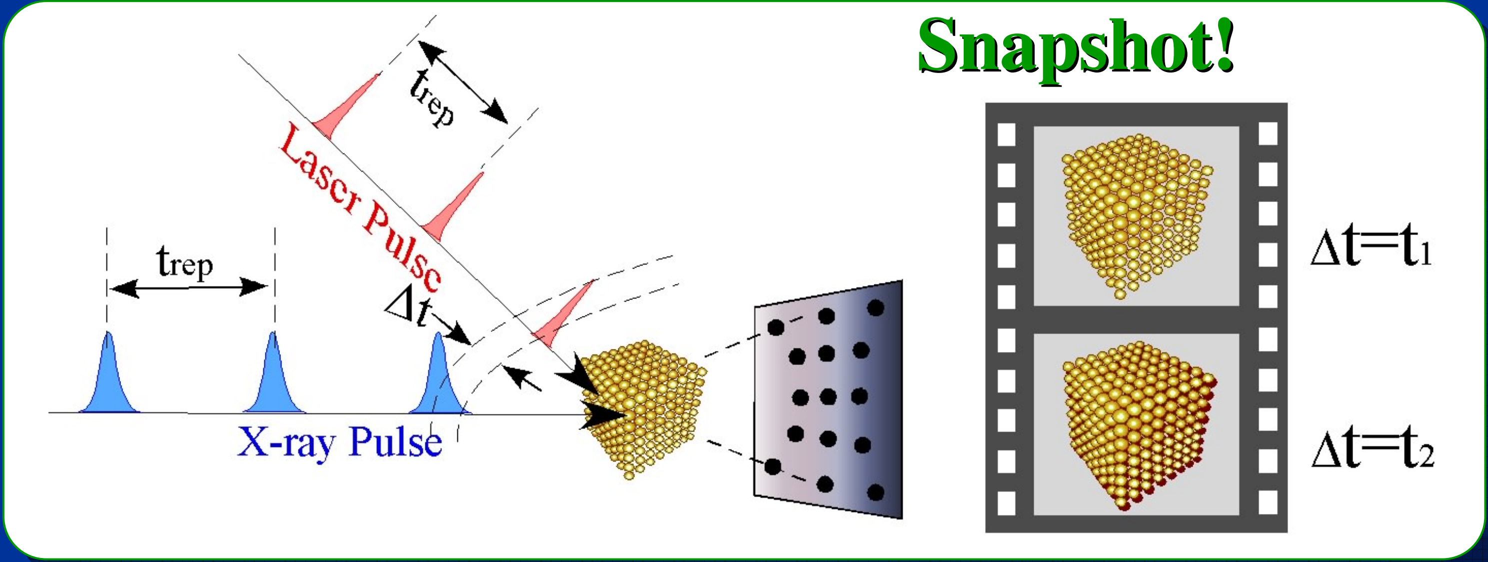
1. Introduction

Picosecond time-resolved X-ray diffractometry

Pump and probe method

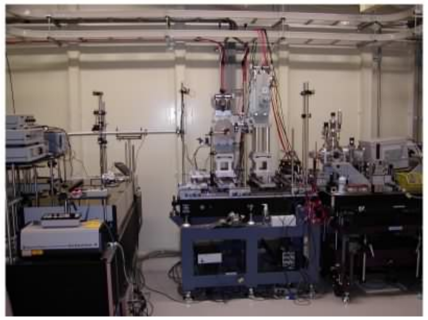


Synchronization between Laser and SR X-ray pulses is required for taking a "snapshot".

SR-Laser synchronization systems in SPring-8

BL29XUL
1km-long beamline

BL19LXU
27m-long undulator



BL17SU
Soft x-ray beamline

BL40XU
CREST beamline

Coming soon

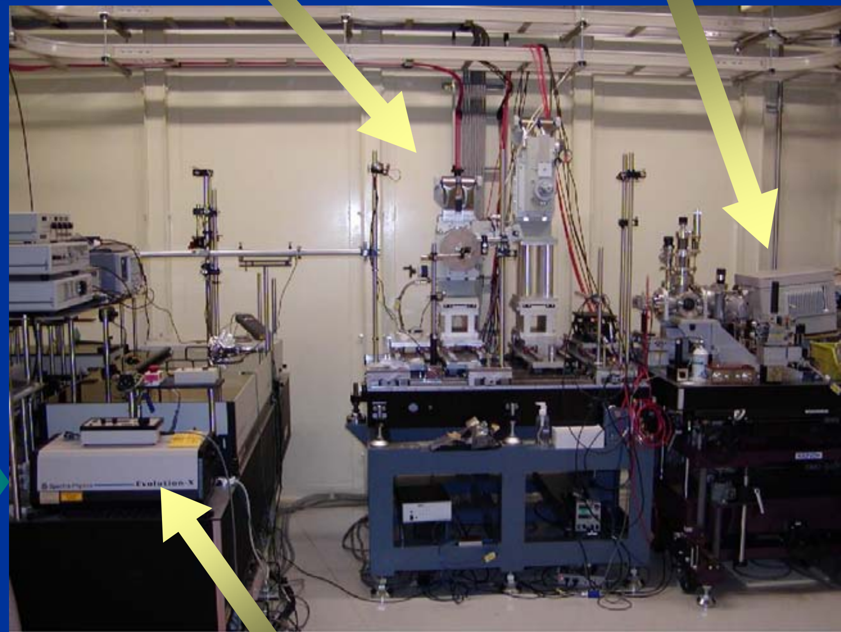
Picosecond time-resolved X-ray diffraction station @BL19LXU/SPring-8

27 m-long
in-vacuum undulator

BL19LXU EH2

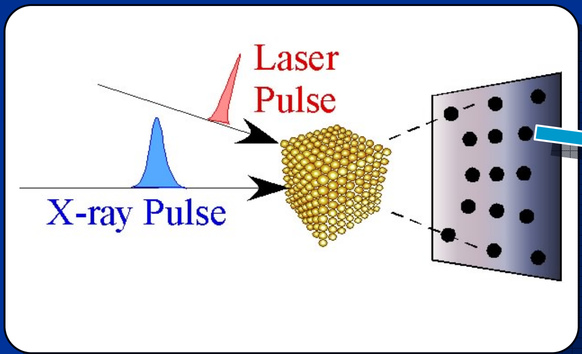
Diffractometer

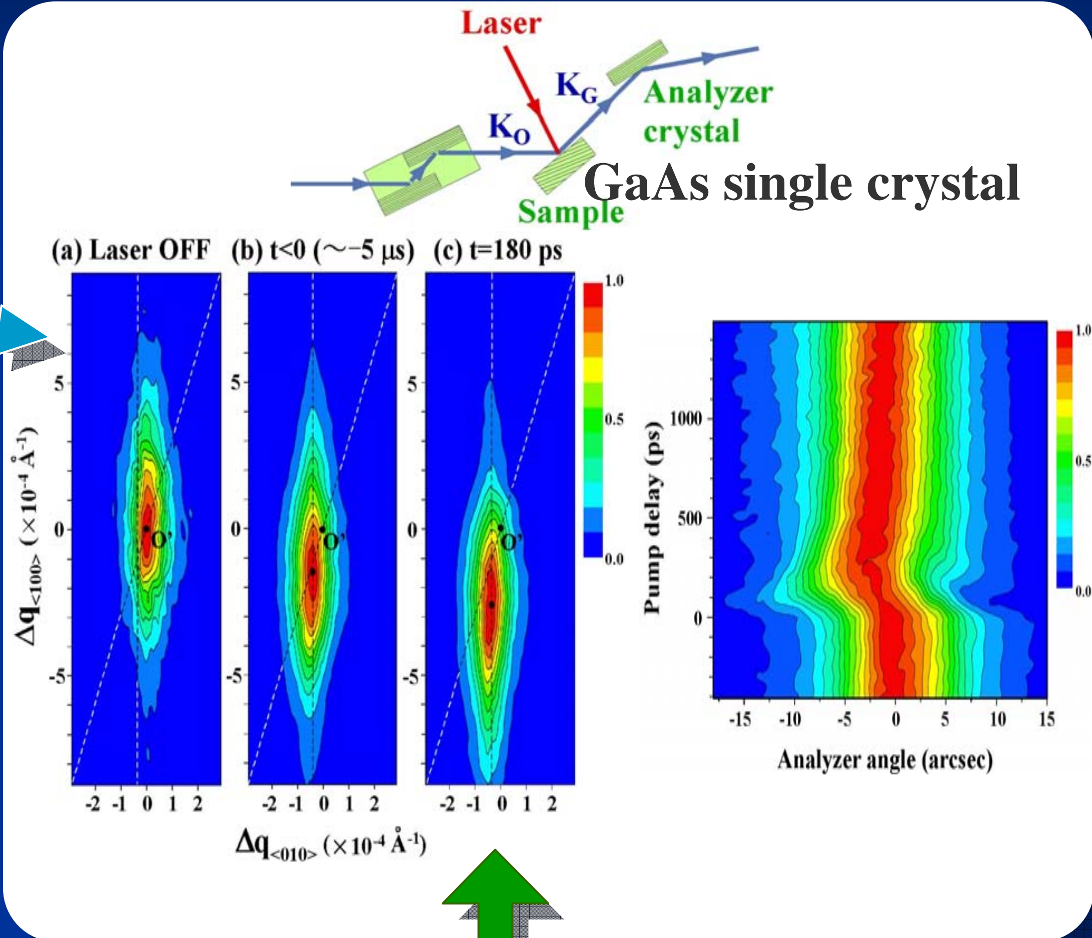
X-ray streak camera



Femtosecond pulse laser system

Example of pump-probe experiment at SPring-8





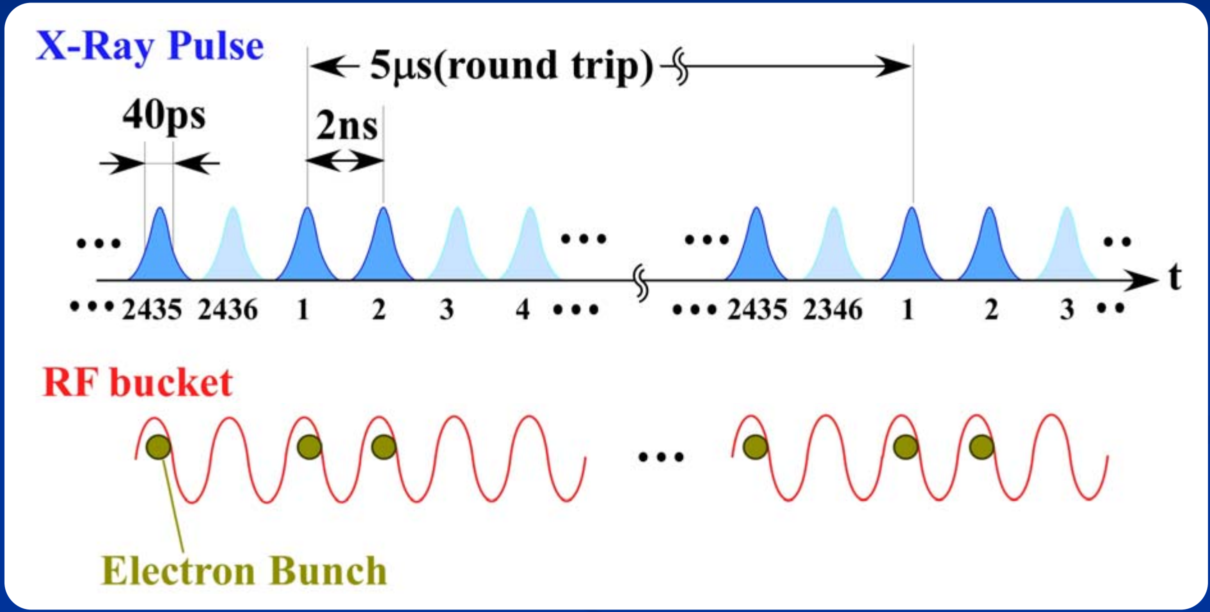
Snap shot !

2. SR-Laser Synchronization

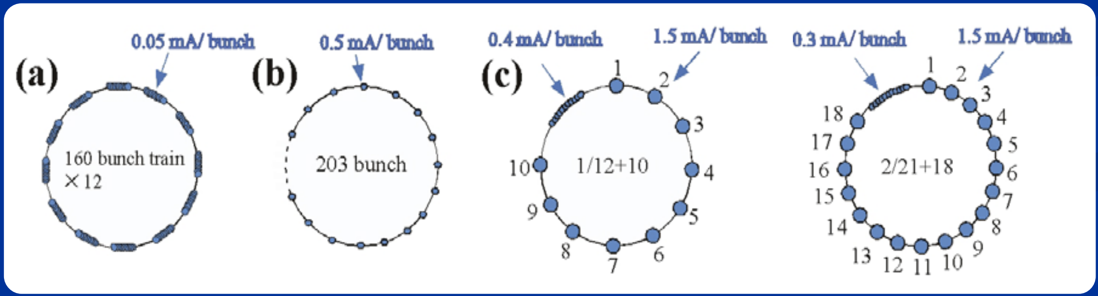
2-0. Time structure of SRs in SPring-8

X-ray pulse width:
40 ps (FWHM)

Rep. rate:
200 kHz-509MHz

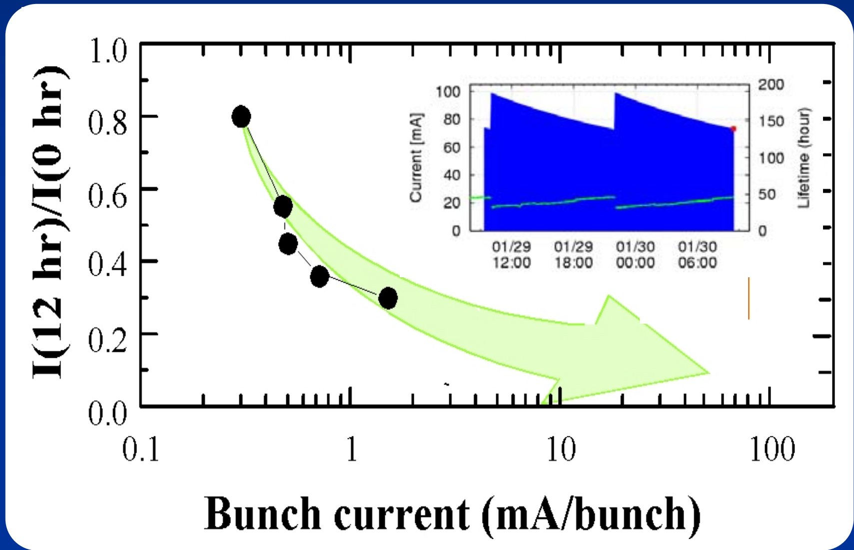


Examples of filling pattern

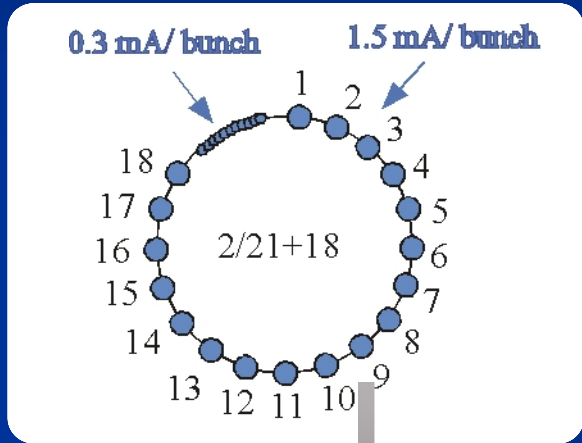


Top-up operation

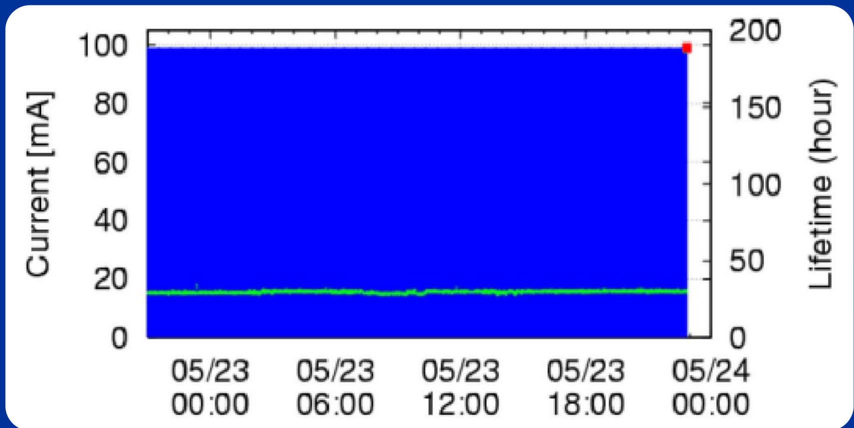
Bunch current 12 hrs. after injection

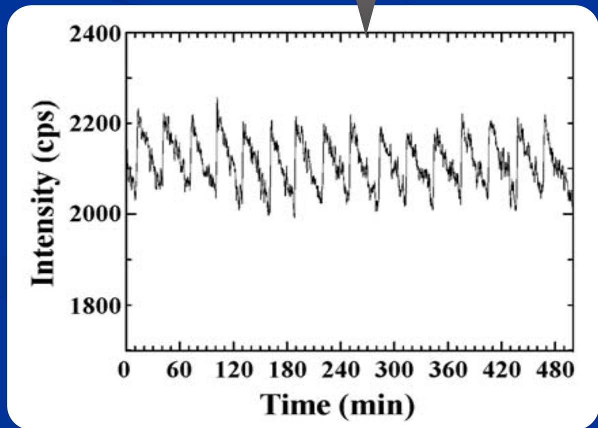


Bunch mode: 2/21+18single



Top-up operation (from May 19, 2004)

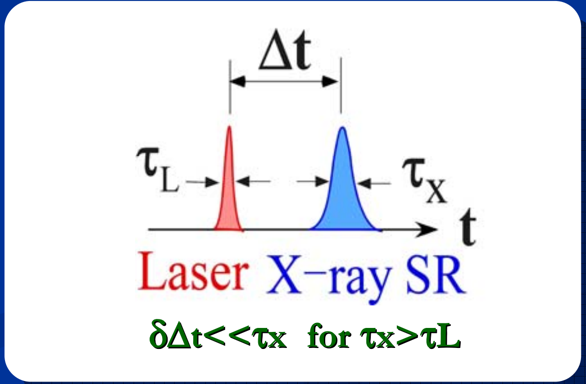




2-1. Procedure for SR-Laser synchronization

STEP I : Precise timing (phase) control

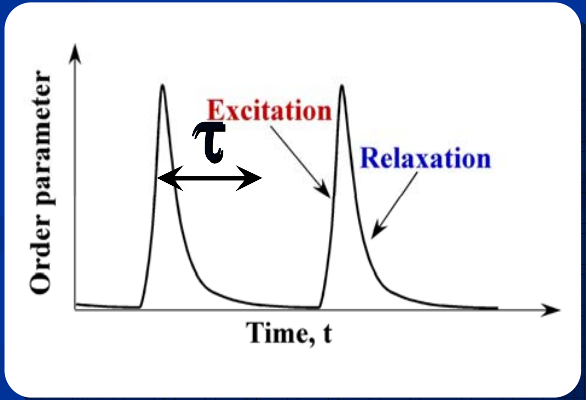
- Required precision <<40ps



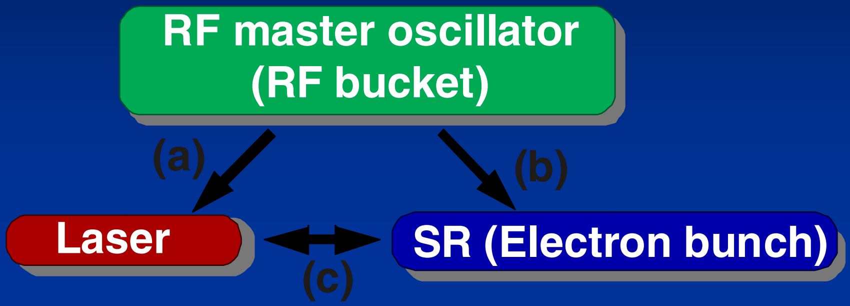
STEP II : Repetition rate control

- Dependent on recovery time in target phenomenon

$1/f_{rep} > \tau \quad \sim 1$ ms



2-2. Picosecond timing control



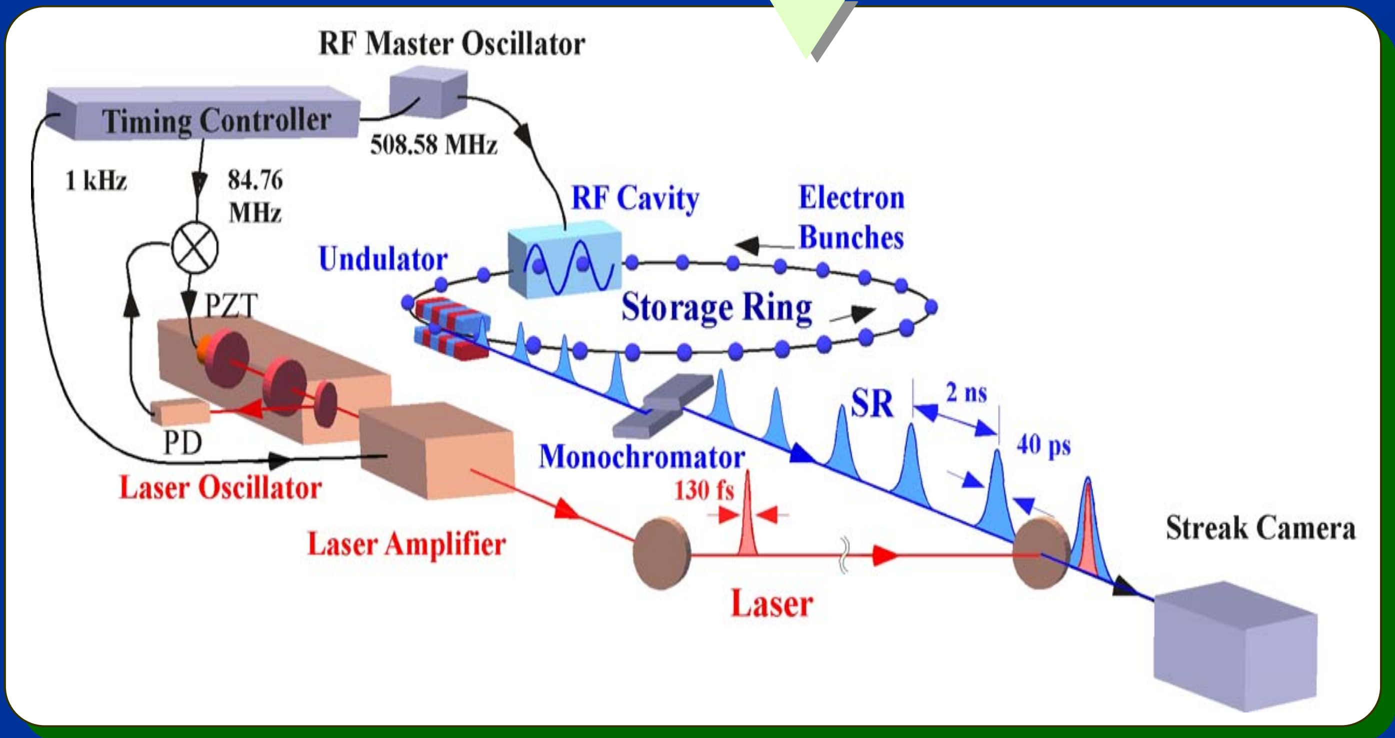
Synchronization scheme

- **Mode-locked Ti:sapphire laser with external trigger from a RF master oscillator of the ring**

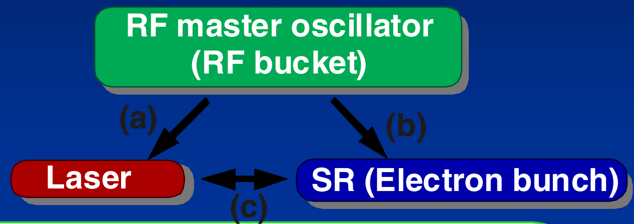
$$\text{Cavity length} = \frac{1}{2} \cdot \frac{c}{(f_0/6)}, \quad f_0\text{: Frequency of RF master oscillator}$$

- **Output timing of amplified laser pulses is controlled with a counter and a delay pulse generator**

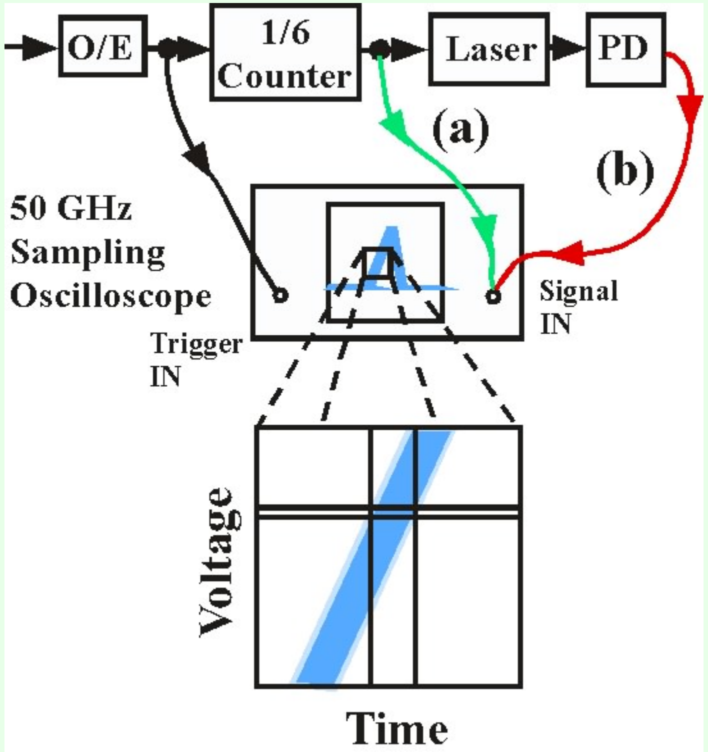
$$\left(\text{Repetition rate} = \frac{1}{2436 \times 209} f_0 \sim 1\ \text{kHz}\right)$$

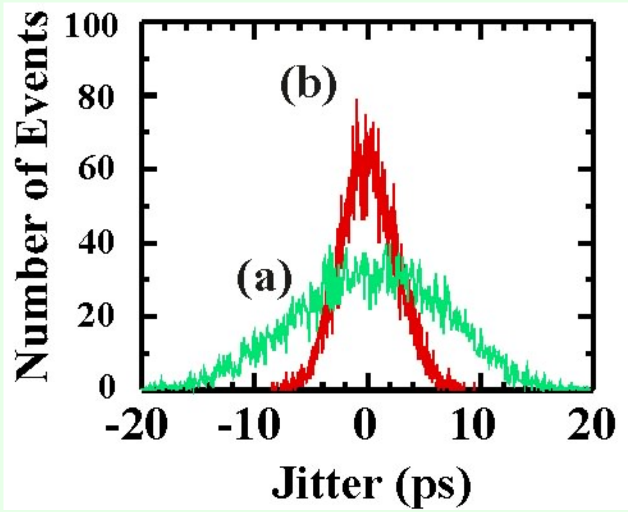


Performance of SR-Laser Synchronization in SPring-8



(a) Laser to RF master oscillator



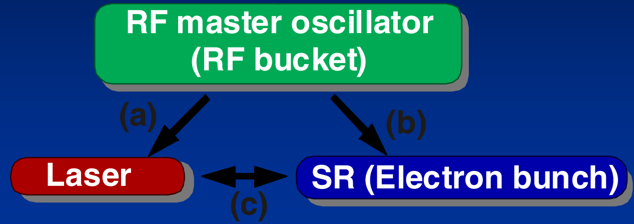


(a) $\sqrt{(\Delta t^{(a)})^2 - (\Delta t^{(0)})^2} = \sqrt{15^2 - 4.4^2} = 14$ ps (FWHM)

(b) $\sqrt{(\Delta t^{(b)})^2 - (\Delta t^{(0)})^2} = \sqrt{5.0^2 - 4.4^2} = 2.4$ ps (FWHM)

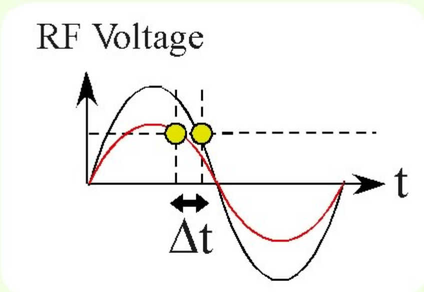
$\Delta t^{(0)}$: Oscilloscope jitter (FWHM)

Performance of SR-Laser Synchronization in SPring-8



(b) RF master oscillator vs. SR

- Beam loading effect



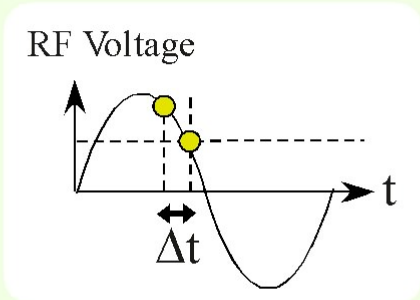
Phase is stable and is dependent on the address of RF bucket

↓

Output timing control of amplified laser pulses, as

repetition rate = $\frac{1}{2436 \times 209} f_0$

- Electron energy loss



Dependent on the undulator power

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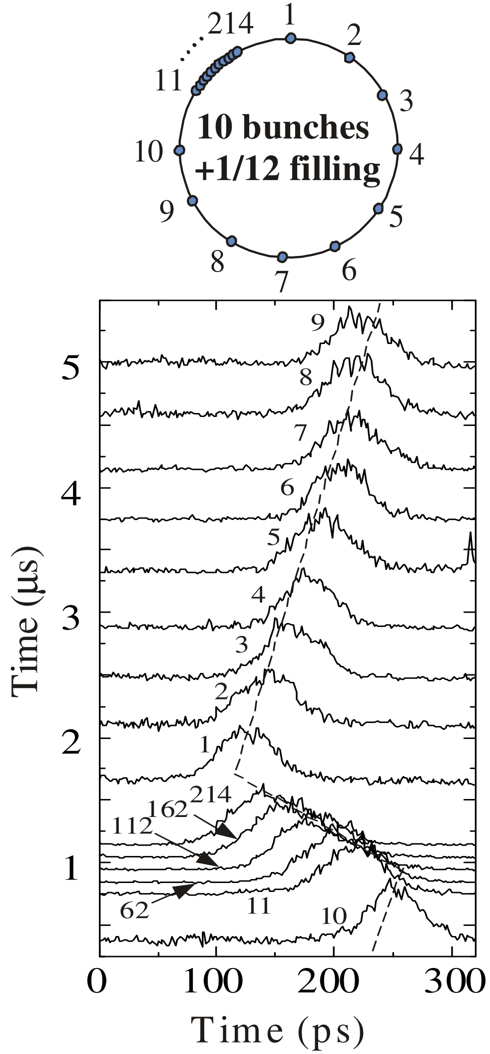
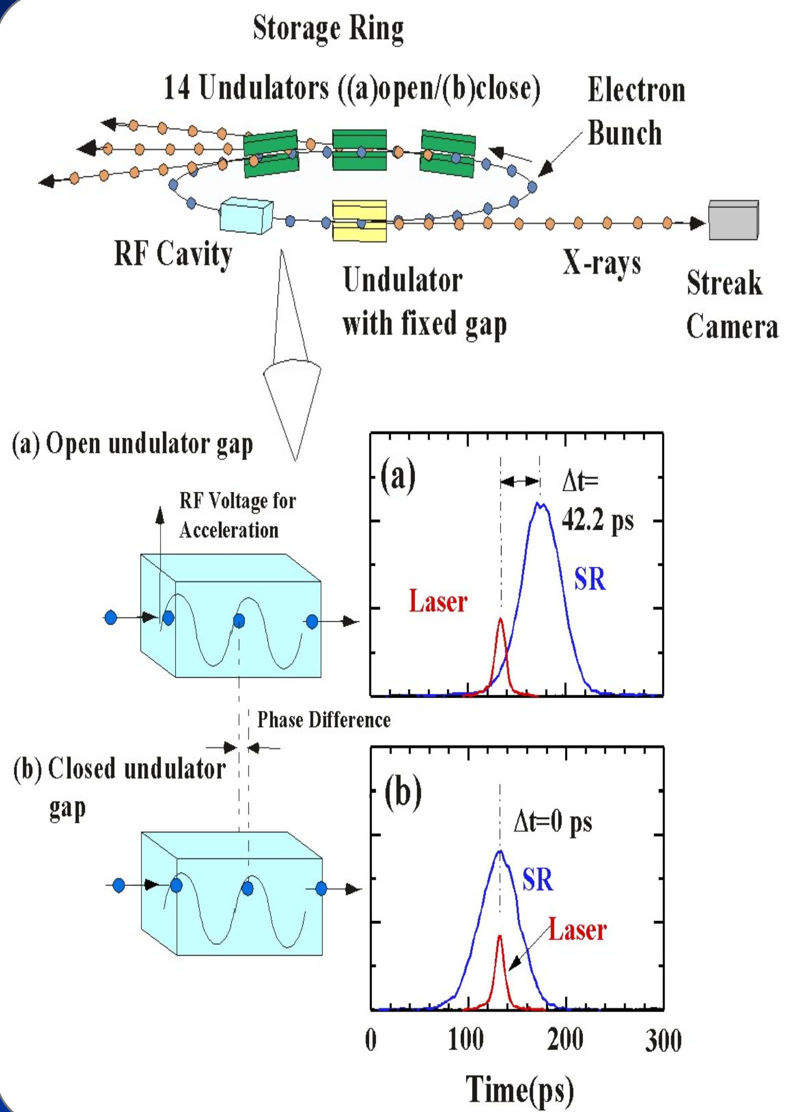
Max. 2 ps-shift for 1 undulator

Feedback circuit according to the total undulator power

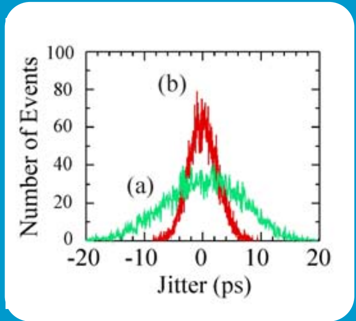
(b)-1 Beam loading effect



(b)-2 Radiation power dependence

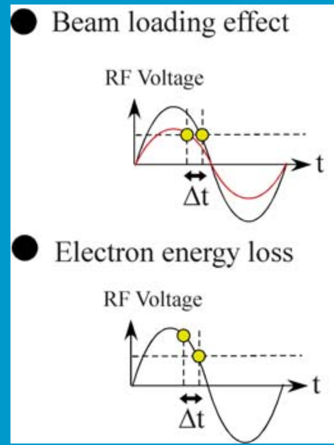


Performance of SR-Laser Synchronization in SPring-8



$\Delta t_{jitter} < 3$ ps

RF master oscillator (RF bucket)

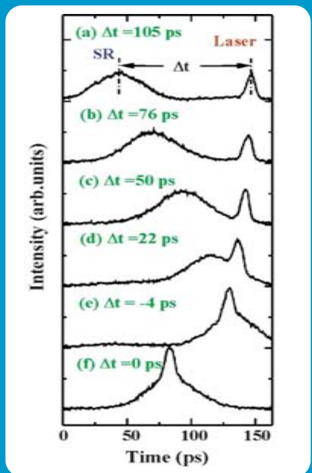


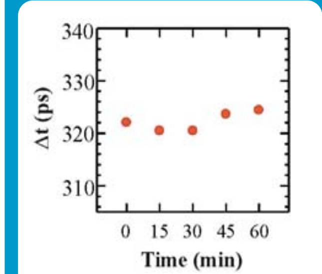
$\Delta t_{drift} < 2$ ps

Laser

$\Delta t < 5$ ps

SR (Electron bunch)





Long-term stability
< ± 2 ps

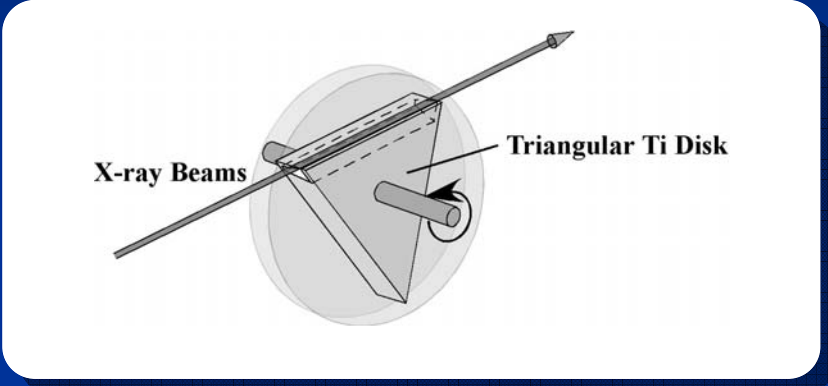
cf.) Y.Tanaka, T.Hara, H.Kitamura, T.Ishikawa, Rev.Sci.Instrum., 71, 1268 (2000)

2-3. How to adjust the repetition rate

－Extraction of X-ray pulses with appropriate rep. rate－

(a) Pulse selection by mechanical chopper

Gate > 400 ns



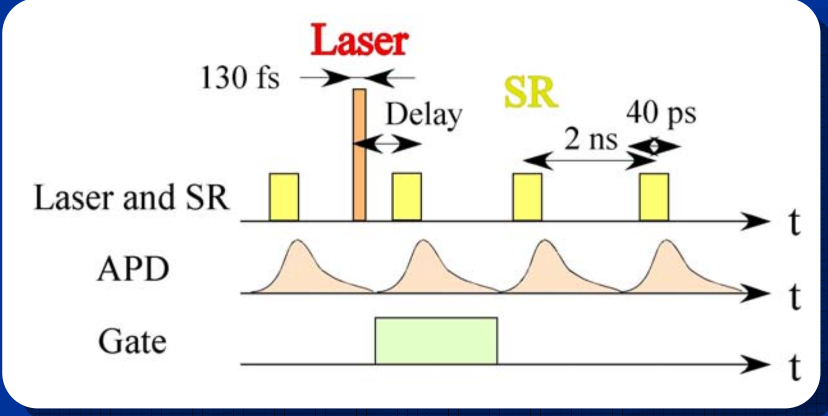
(b) By electronic gate

- Avalanche photodiode

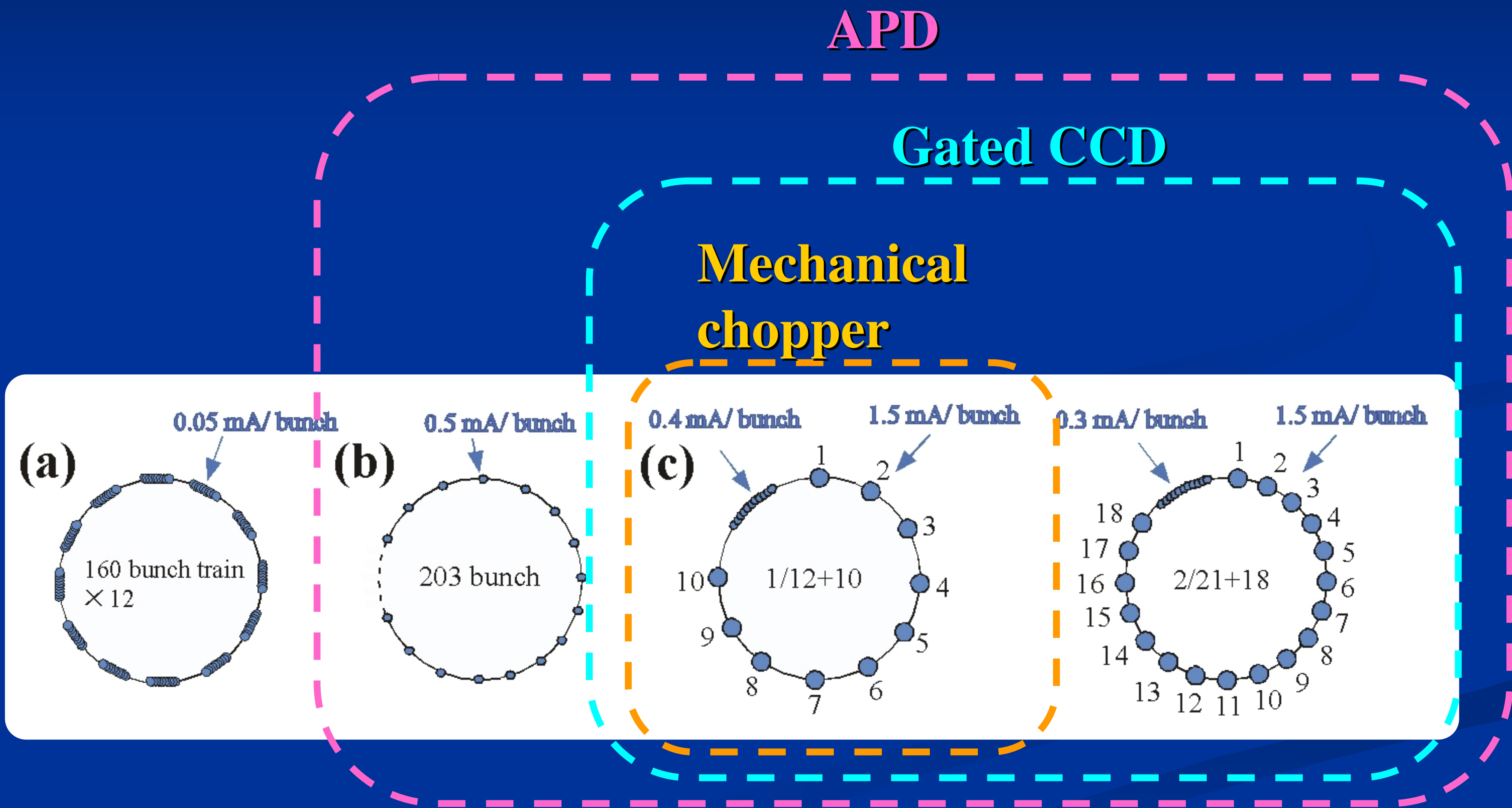
  Gate > 5 ns

- Gated CCD camera

  Gate > 100 ns

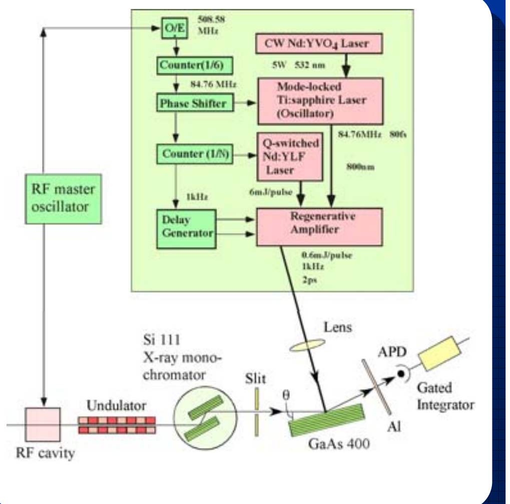


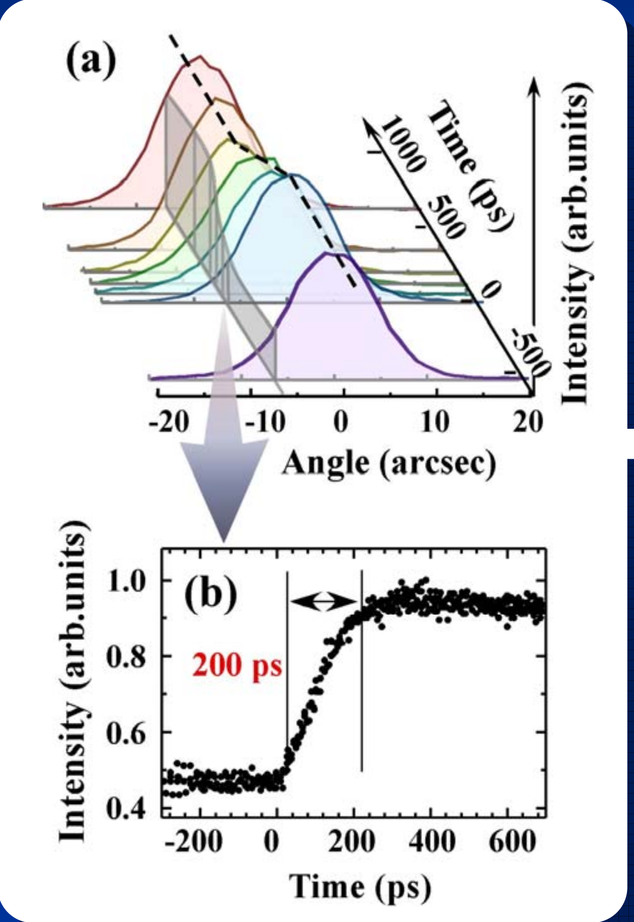
The filling pattern available for the pulse selection



Filling patterns in SPring-8

2-4. Optical switching of X-rays by using lattice expansion in GaAs





Bragg condition

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

Relation between Bragg peak shift and lattice spacing

$$\Delta\theta = -(\Delta d/d)\tan\theta_B$$

Peak shift to smaller angle

↓

Lattice constant : larger

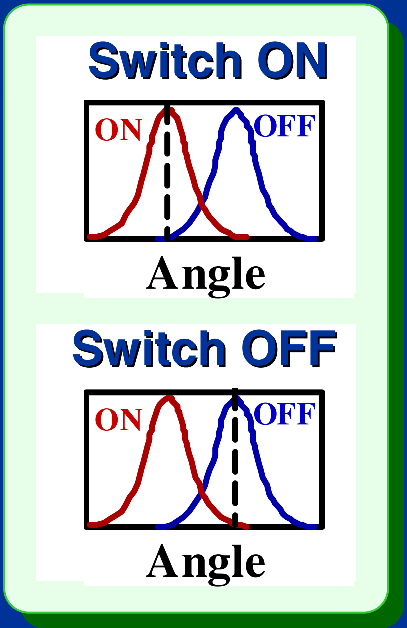
↓

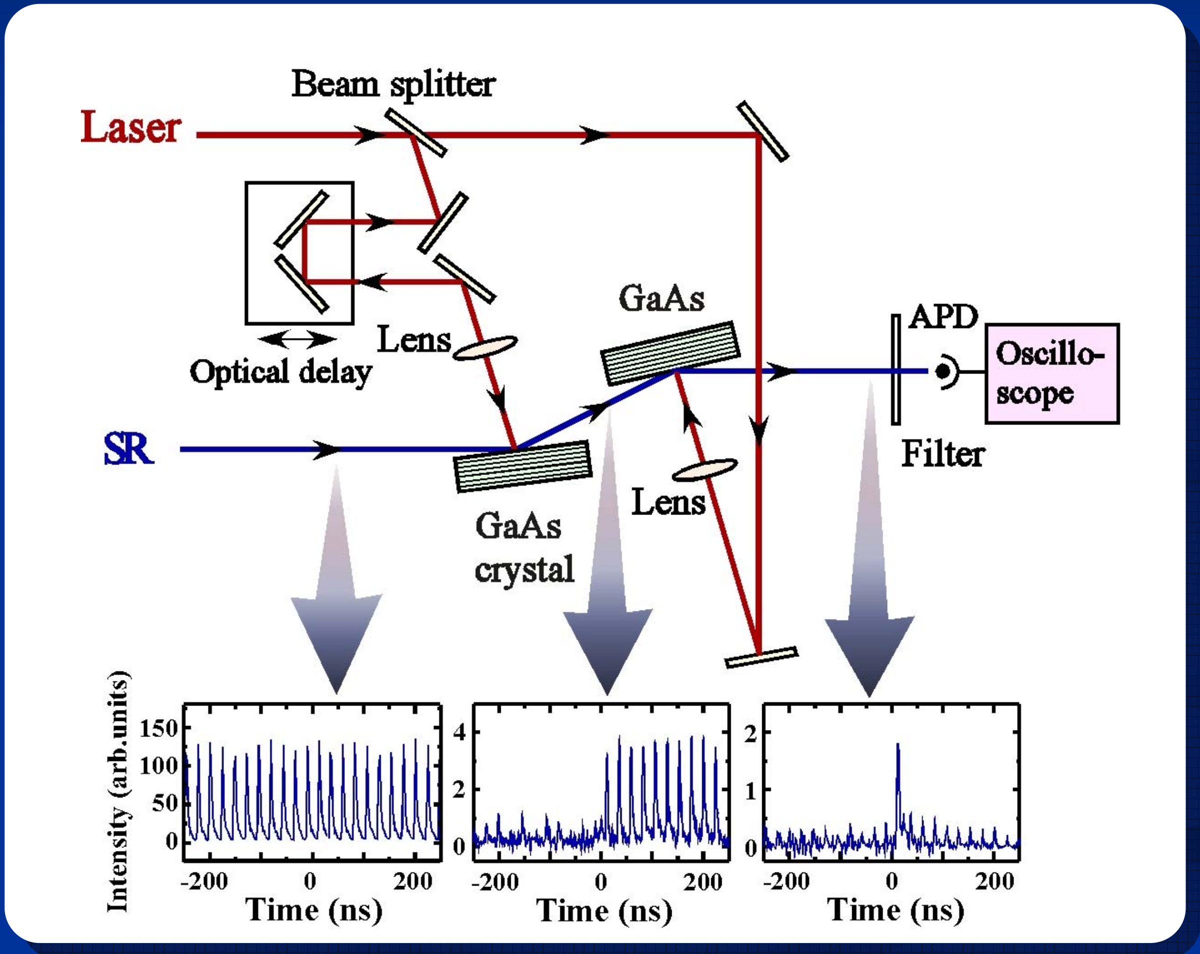
Lattice expansion with a response time of 200ps

(a) Time-resolved rocking curves

(b) Time-dependence of diffraction intensity

Extraction of single X-ray pulse from SR pulse train by fast X-ray shutter

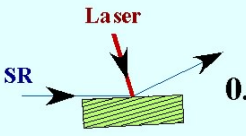
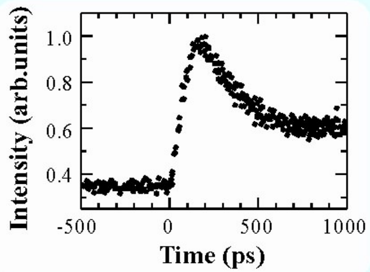
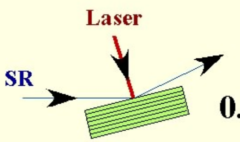
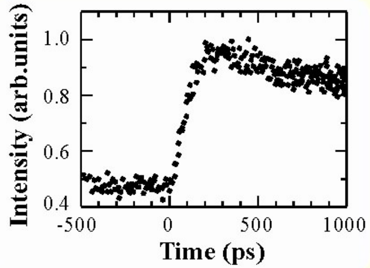
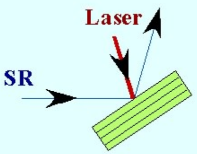
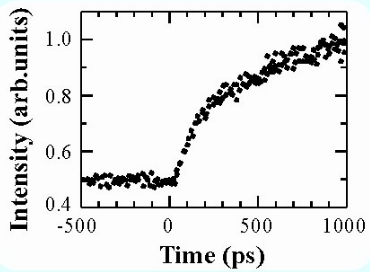


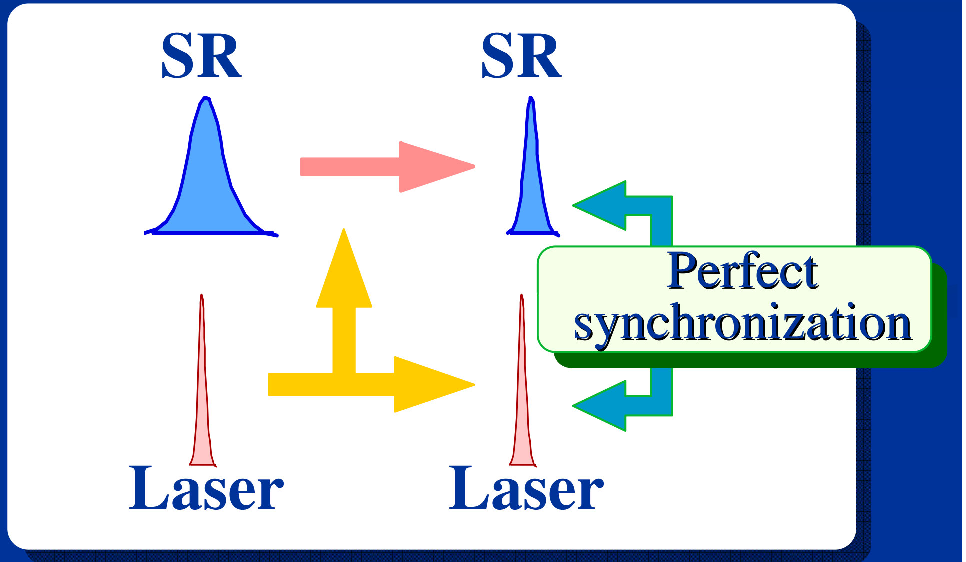


Ref: Y.Tanaka, T.Hara, H. Yamazaki, H.Kitamura, T.Ishikawa, J. Synchrotron Rad., 9, 96 (2002)

Extinction depth-dependence of time-response of X-ray diffraction

Development of faster X-ray shutter → Generation of short X-ray pulses

	回折面	消衰距離(l_{ext})	回折強度の時間応答
(a)	 GaAs 620 G ╳ n	0.41μm	
(b)	 GaAs 400 G // n	0.73μm	
(c)	 GaAs 800 G // n	2.98μm	



Y. Tanaka, T. Hara, H. Kitamura, T. Ishikawa:
The Review of Laser Engineering , 30(9), 525-530 (2002).

3. Sub-ps TRXRD

Forthcoming ultrashort pulsed x-ray sources

- Free electron laser (TESLA, Stanford, SPring-8…)

  SASE=(Self Amplification of Spontaneous Emission)

  SPPS (SLAC) SPPS=(Sub-Picosecond Photon Source)

  width:80fs(fwhm) jitter:260fs(rms)
- Slicing (LBNL)
- Crab cavity (SPring-8)
- Switching (APS, SPring-8, …)
- Energy recovery linac (Cornell, KEK…)

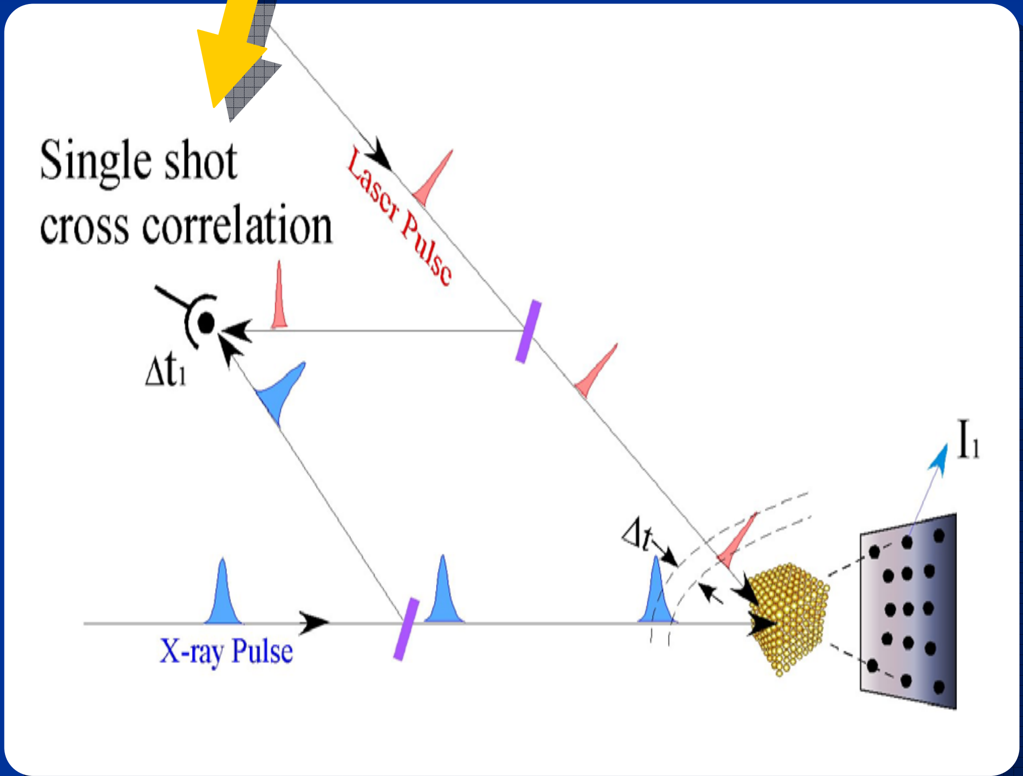
How about the synchronization for sub-ps pulses ?

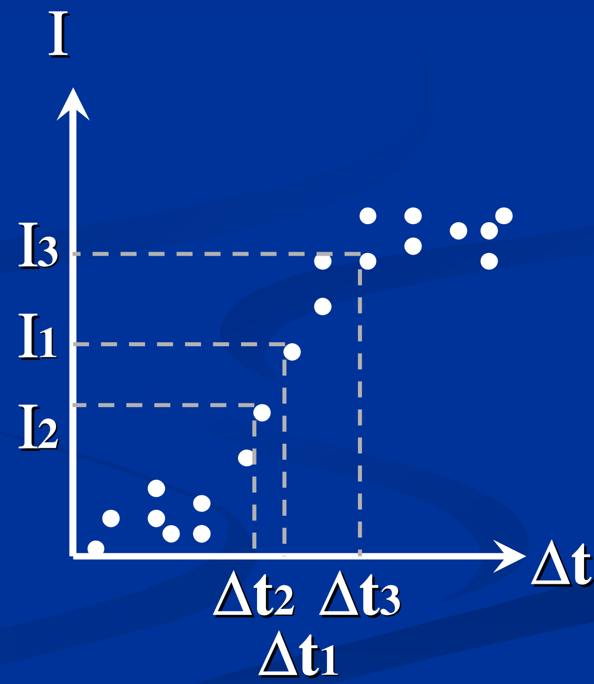
････Synchronization of two lasers with 28 fs precision
(Miura et al. Appl. Phys. B75(2002)19)

We will give up sub-ps synchronization・・・!?

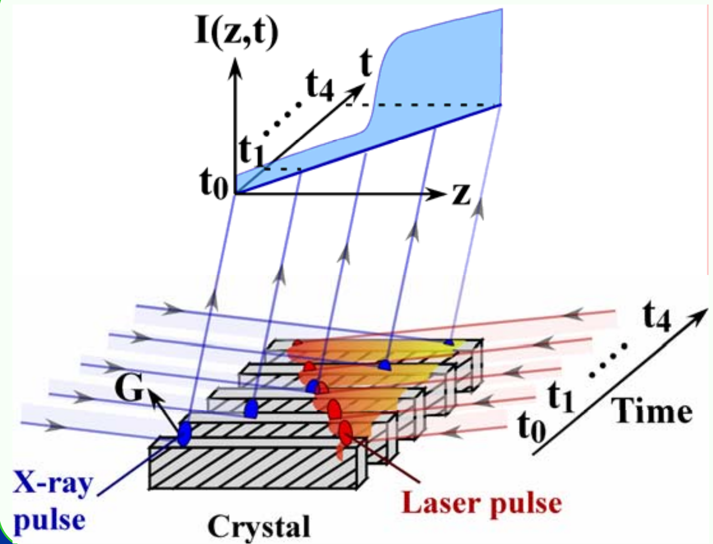
Post Processing

Record of shot-by-shot timing





Time-to-space converter (TSC) for shot-by-shot timing measurement

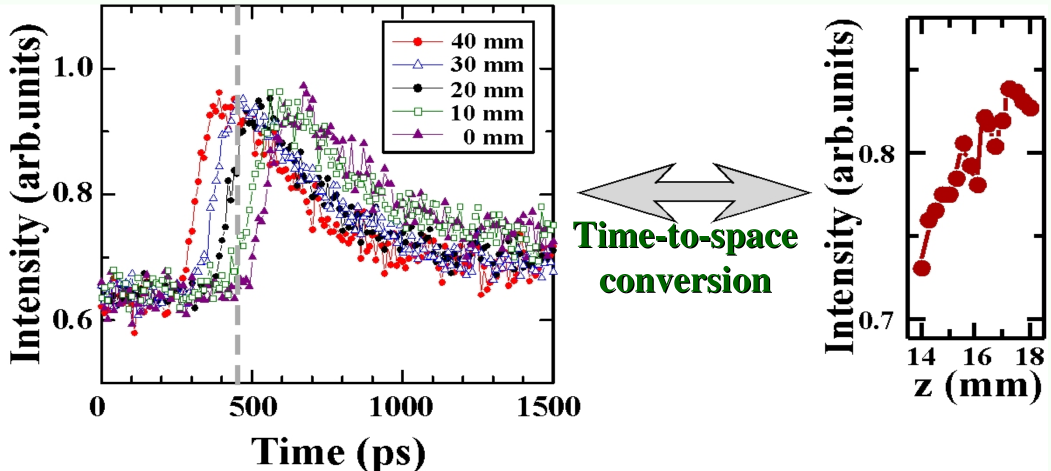


$$\Delta t=(z/c)[\sin 2\theta_B/\sin(\theta_B+\alpha)][\cos(\theta_B-\alpha)+\cos\theta_L]$$

θ_B=19.0 deg.
θ_L =9.4 deg.
α =18.4 deg.

$\Delta t=(z/c)\times 2.01$

4 mm×2 = c・27 ps

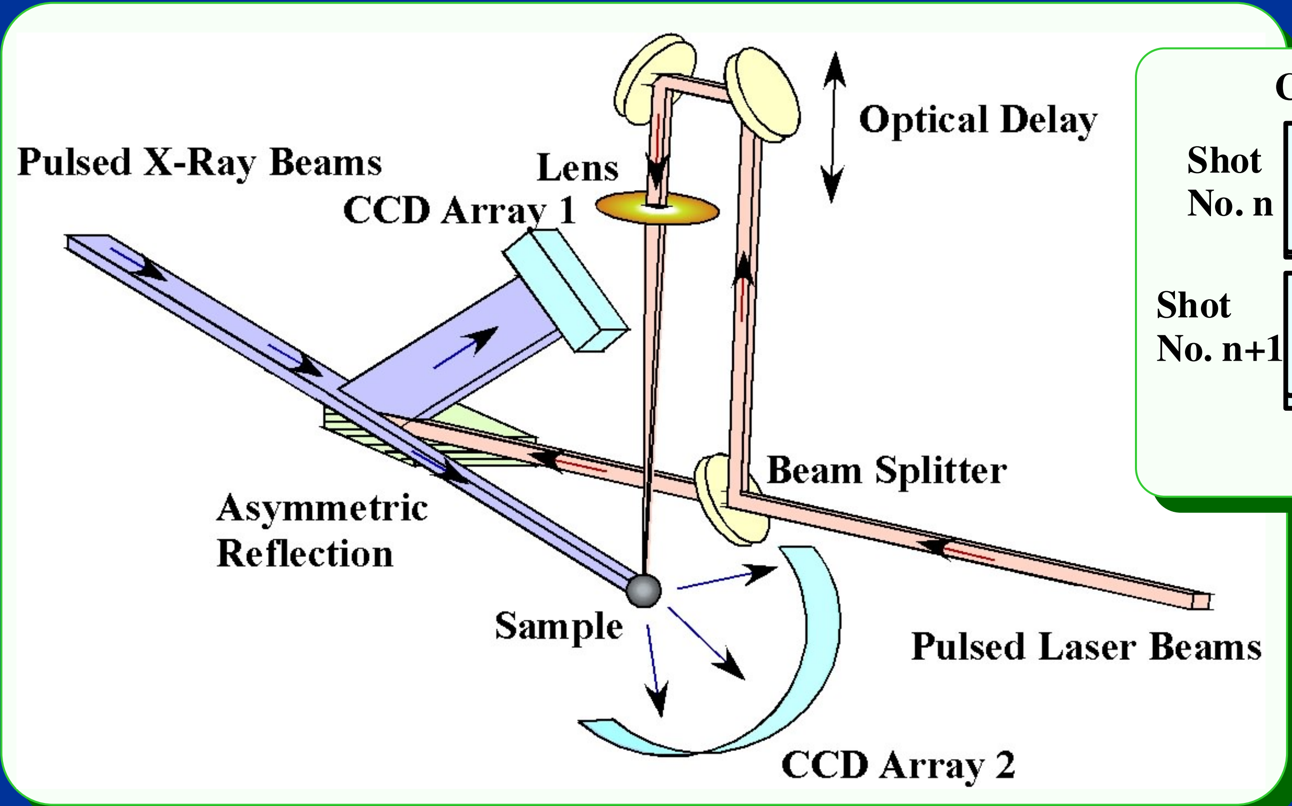


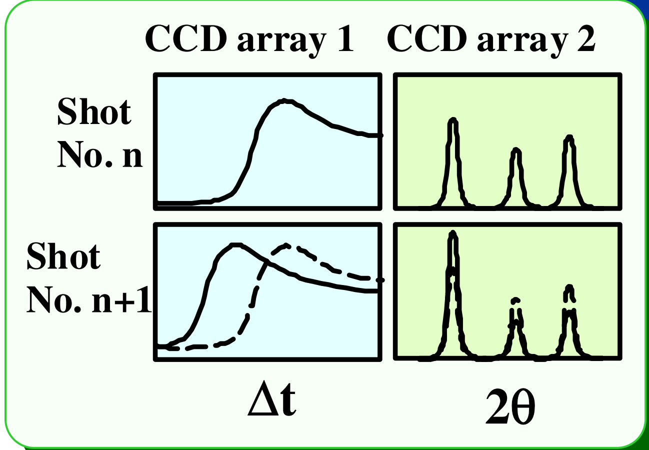
Y.Tanaka, S.Muraki, T.Hara, H.Kitamura, and T.Ishikawa, AIP conference proceedings **705** (2004) 1379.

Post Processing using TSC

---Correlation between timing and diffraction intensity---

Record of shot-by-shot timing





4. Summary

Light sources

Time-resolved measurements

SR-X-rays
(Storage ring)

+

Short pulse laser

→ ps synchronization →

Laser-induced lattice dynamics,

Phase transition,

100ps :
:
:

↓

<1ps

Sub-ps X-rays by optical shutters

← Shutter

→ Sub-ps synchrnization →

Sub-ps X-rays from new sources

→ Post processing →

Ultrafast X-ray diffraction method was now proposed !

Waiting for success of ultrashort pulse generation at SPring-8・・・・

－－－＞ Nakazato-san’s talk

Thank you for your attention