특론: 가속기 실험실습 I

(NUCE719P-01/PHYS715P-01, 정모세)

광자빔 진단
(Streak Camera & SR Interferometer)

김 창 범

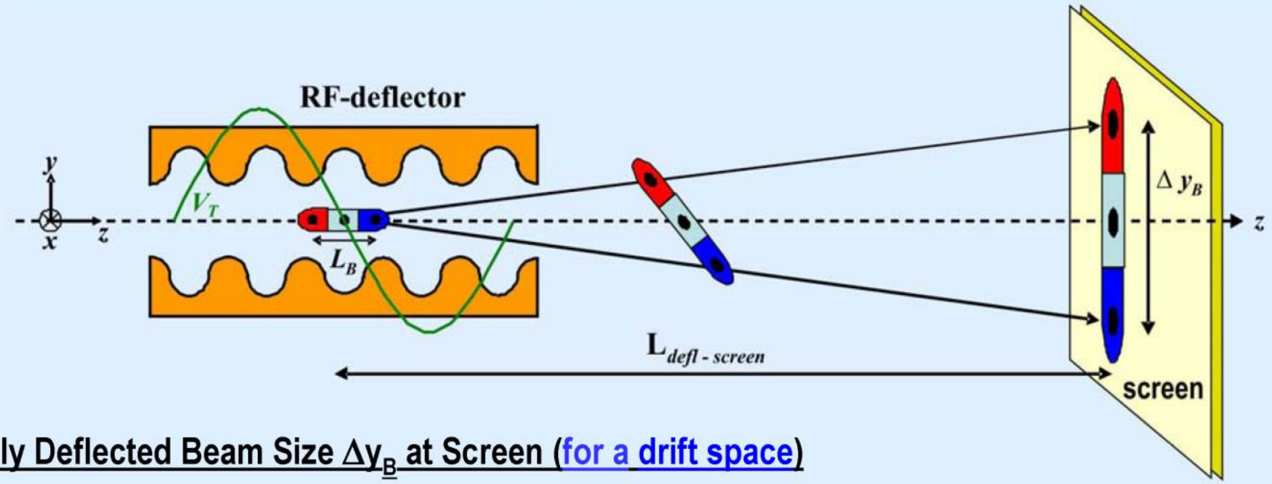
포항가속기연구소
PLS-II 가속장치부

Diagnostics for PAL-XFEL

Parameter	Instruments	Number	Resolution
Beam Position & Beam Energy	Stripline BPM	160	< 5 um
	Cavity BPM	49	< 1 um
Beam Size	Screen Monitor	54	< 10 um
	Wire Scanner	9	< 10 um
Bunch Length	Coherent Radiation Monitor	4	-
	Transverse Deflecting Cavity	3	< 10 fs
Beam Charge	Turbo ICT	10	< 1 pC
Beam Arrival Time	Beam Arrival Time Monitor	10	< 30 fs
Beam Loss	Beam Loss Monitor	26	-

Bunch Length Monitor

Principle of Bunch Length Measurement with RF Deflector



Transversely Deflected Beam Size Δy_B at Screen (for a drift space)

$$\Delta y_B = \frac{\omega_{RF} V_T}{2c\, E/e} \cos(\varphi_{RF}) \quad L_B \, \Delta L_{def-screen}$$

Assuming...:

- φ_{RF} = 0° at the center of the bunch results in shearing of particle density distribution without changing mean particle position
- longitudinal stability (bunch arrival time vs. RF phase) must be high in case of averaging of measurements
- pencil-like beam (zero-emittance)
- no beam offset in the RF deflector

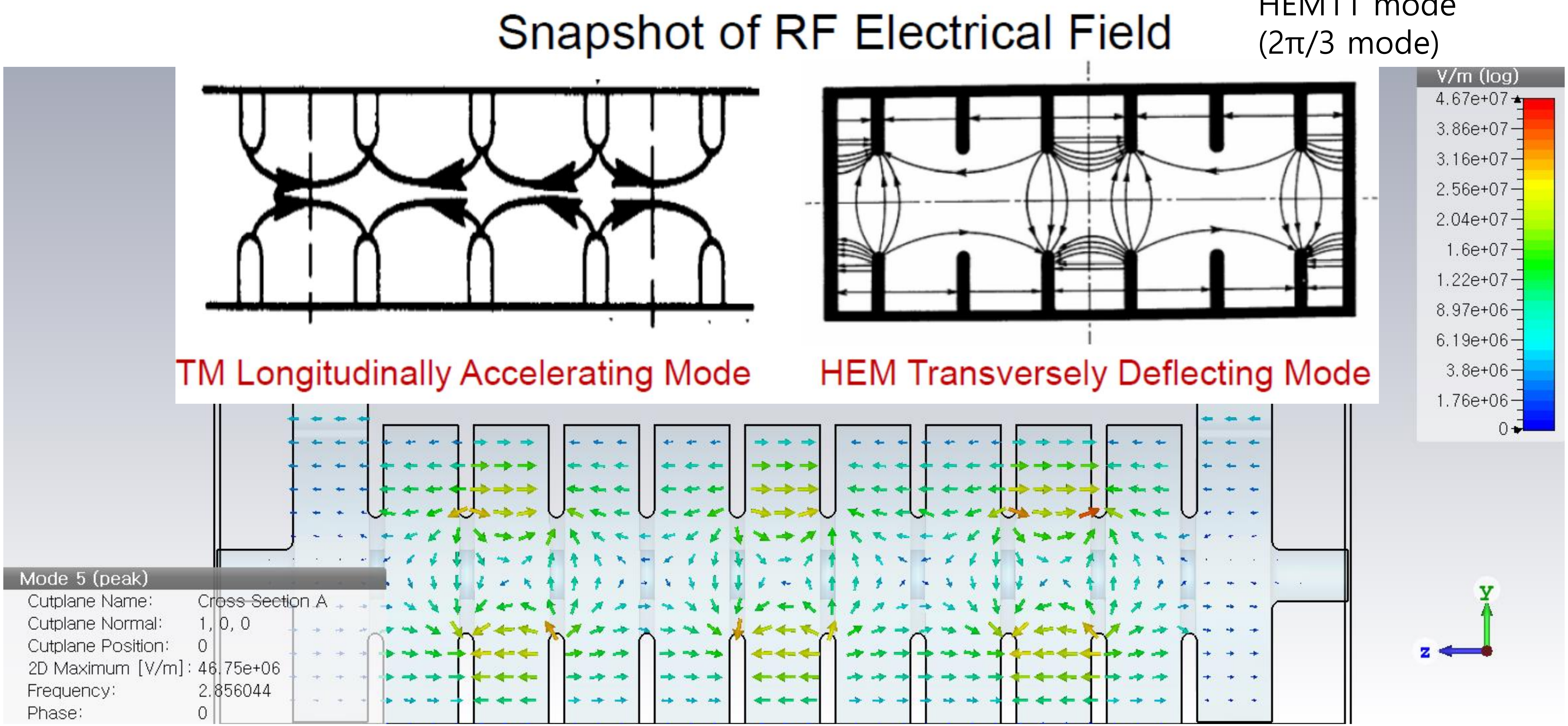
Example:

Parameters for 250 MeV PSI FEL Injector Test Facility

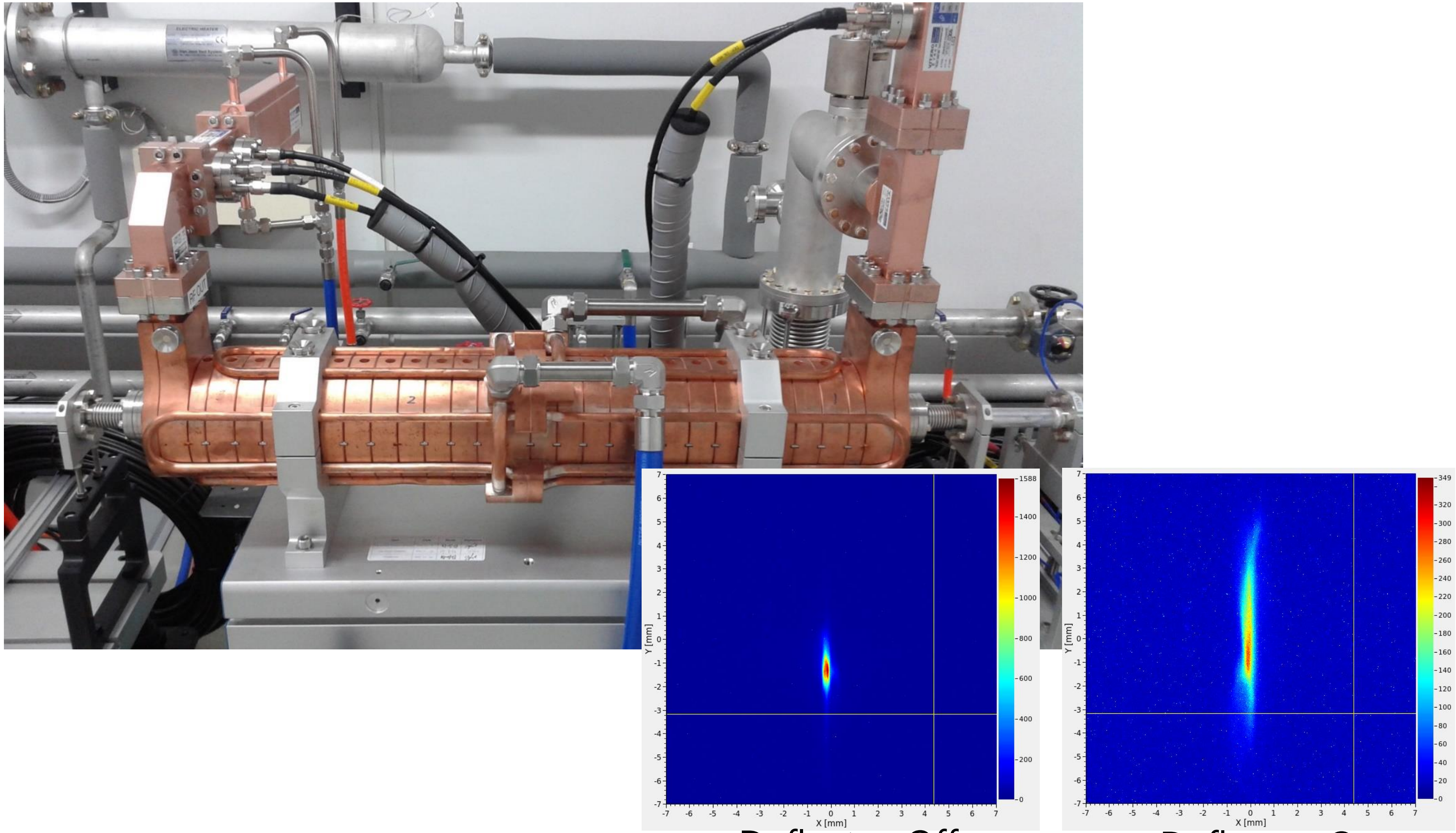
ω_{RF}	=	$2\pi \cdot 3$	GHz
V_T	=	2.5	MV
c	=	$3 \cdot 10^8$	ms^{-1}
E	=	250	MeV
L_B (FWHM)	=	600	fs
	=	200	µm
$\Delta L_{def-screen}$	=	12.25	m
Δy_B	=	770	µm

Transverse Deflection Mode

HEM11 mode
(2π/3 mode)



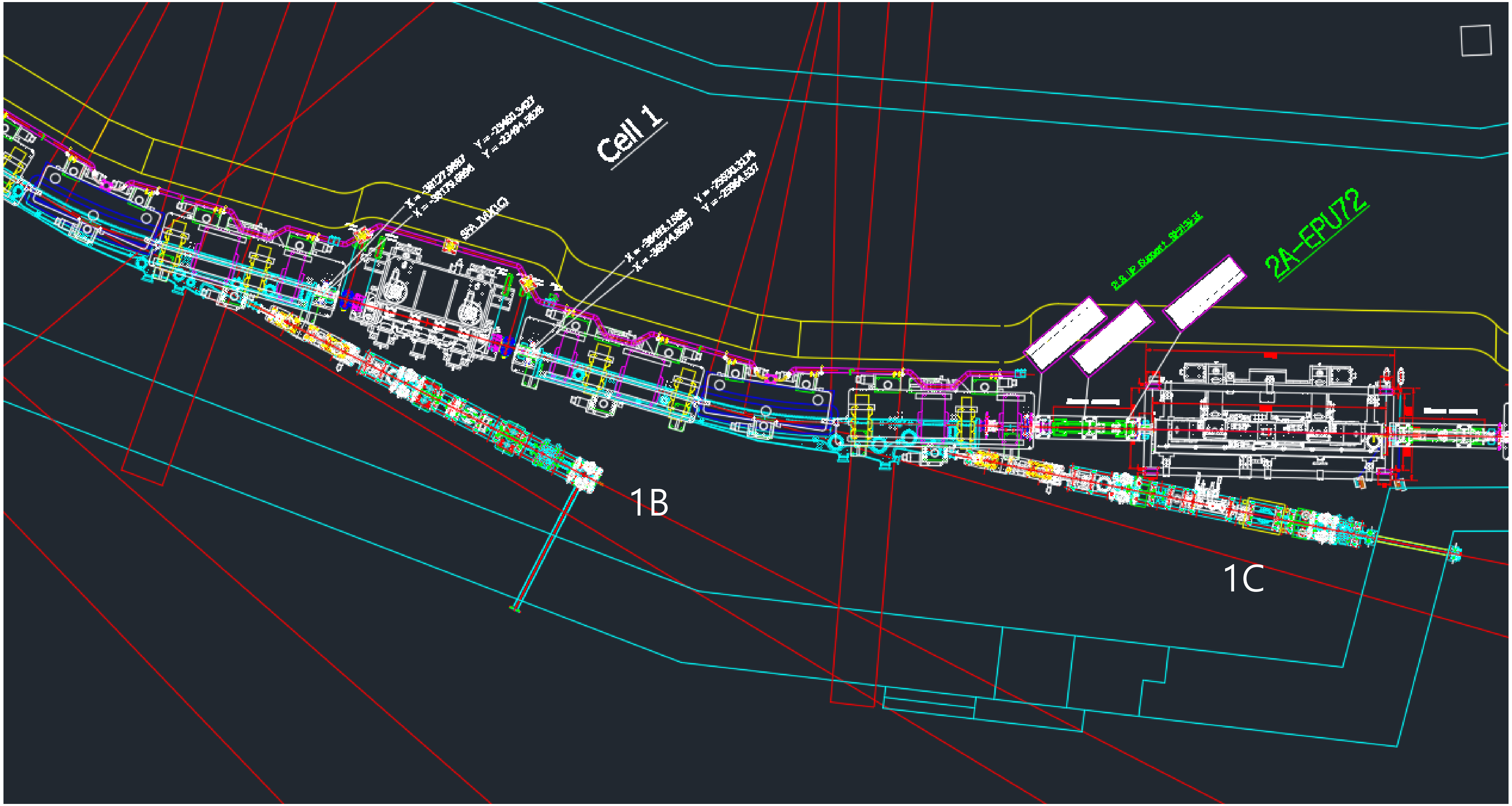
Transverse Deflecting Cavity



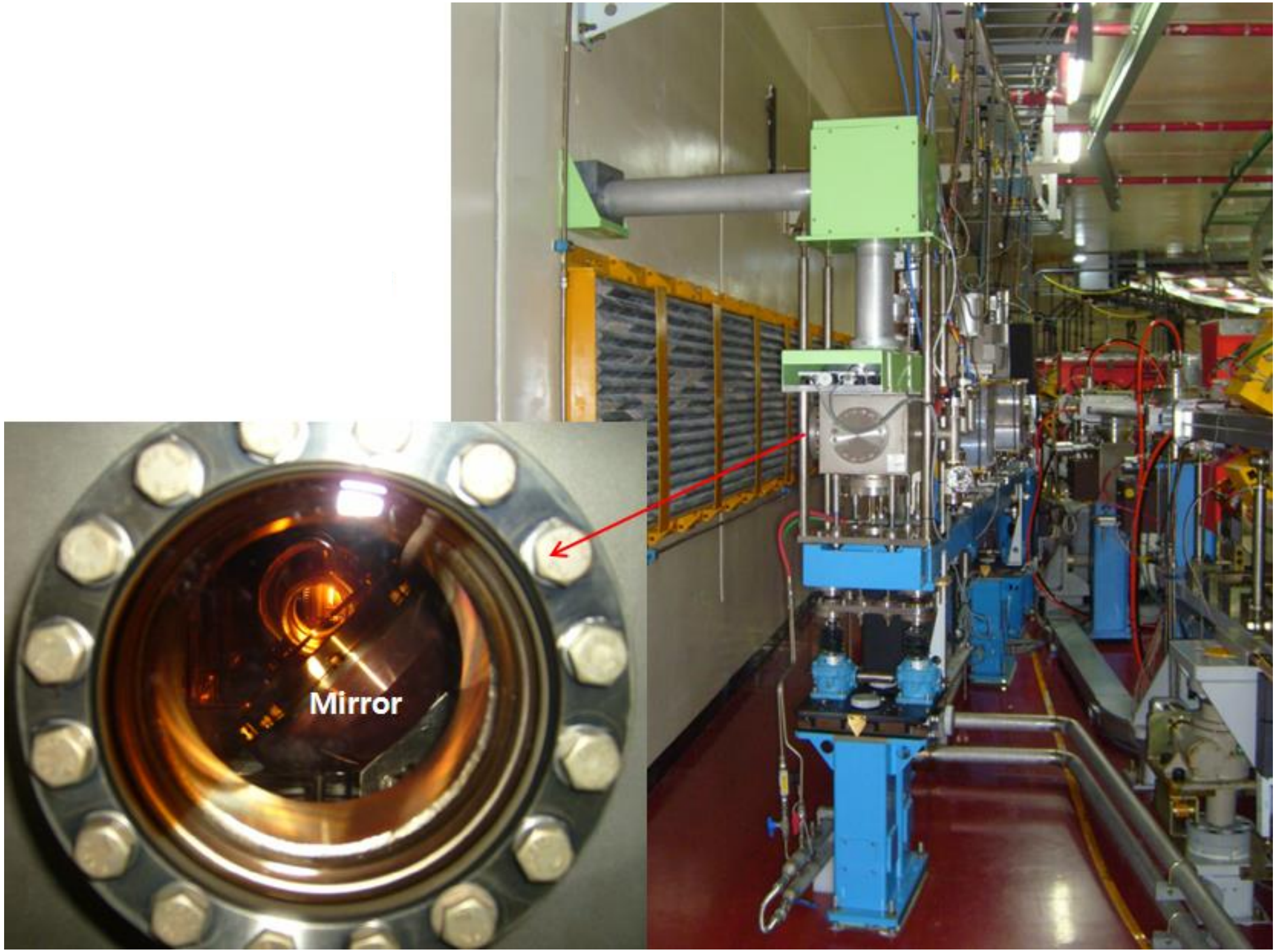
Deflector Off

Deflector On

Diagnostic Beamline of PLS-II (1B)

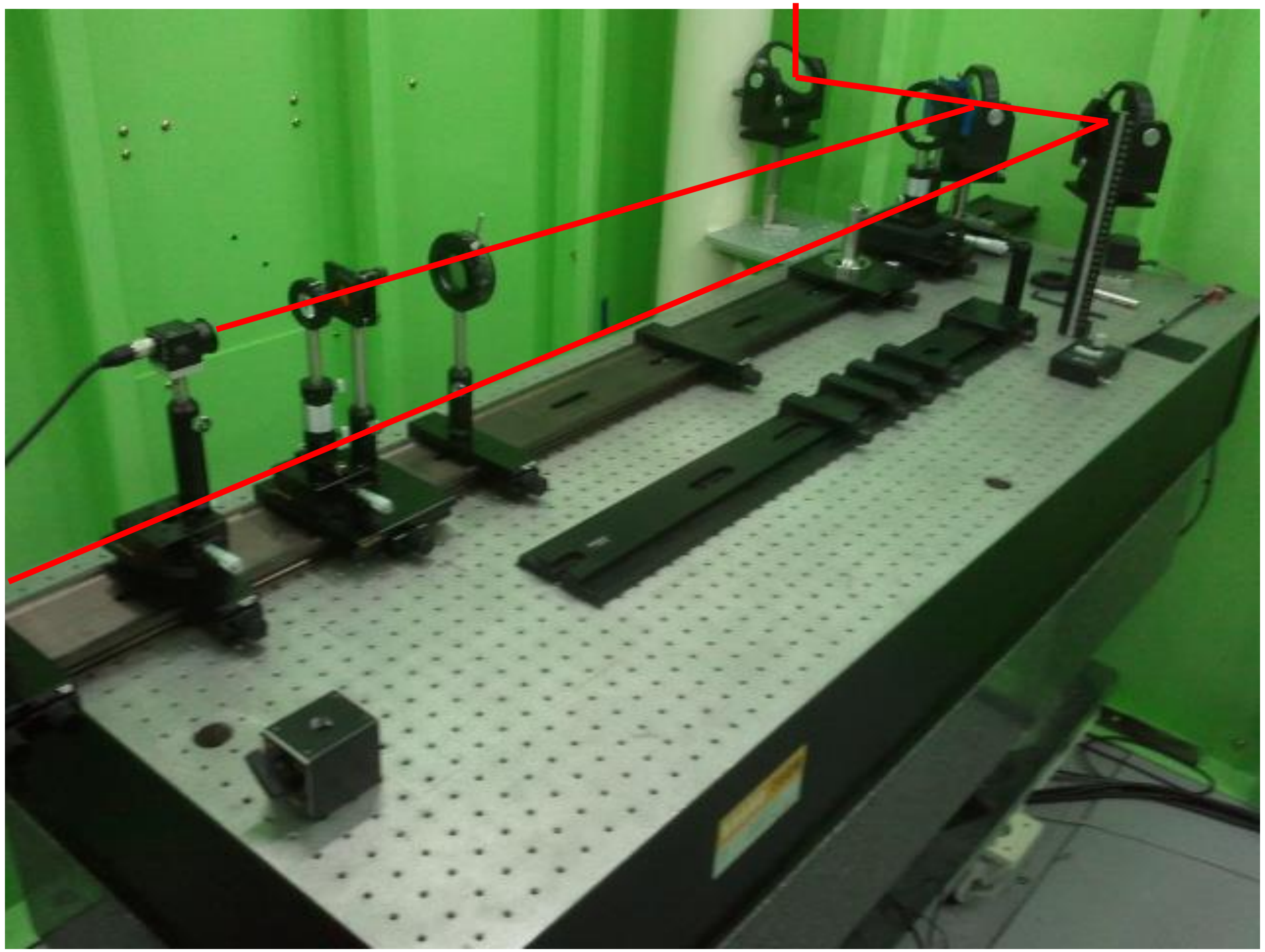


Diagnostic Beamline of PLS-II (1B)

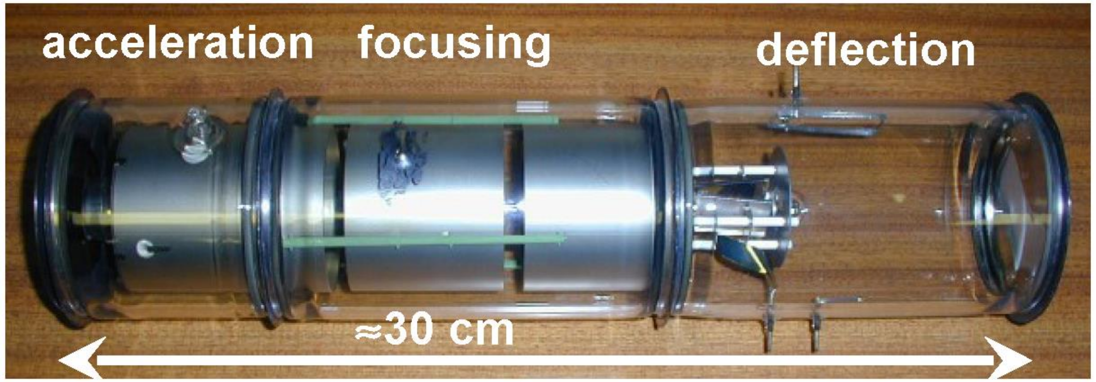


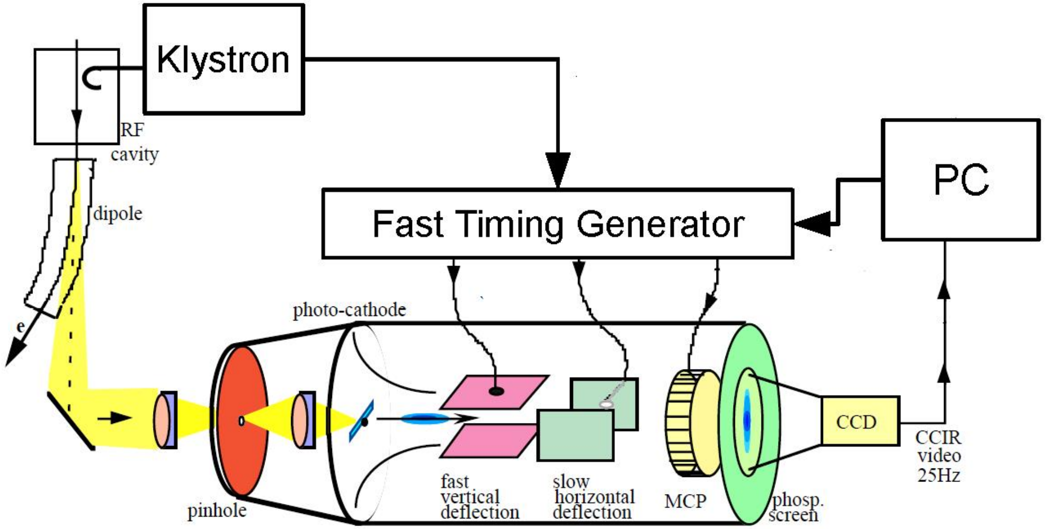
Inside of Diagnostic Beamline Hutch (1B)

Streak Camera



Streak Camera





Working Principle of Streak Camera

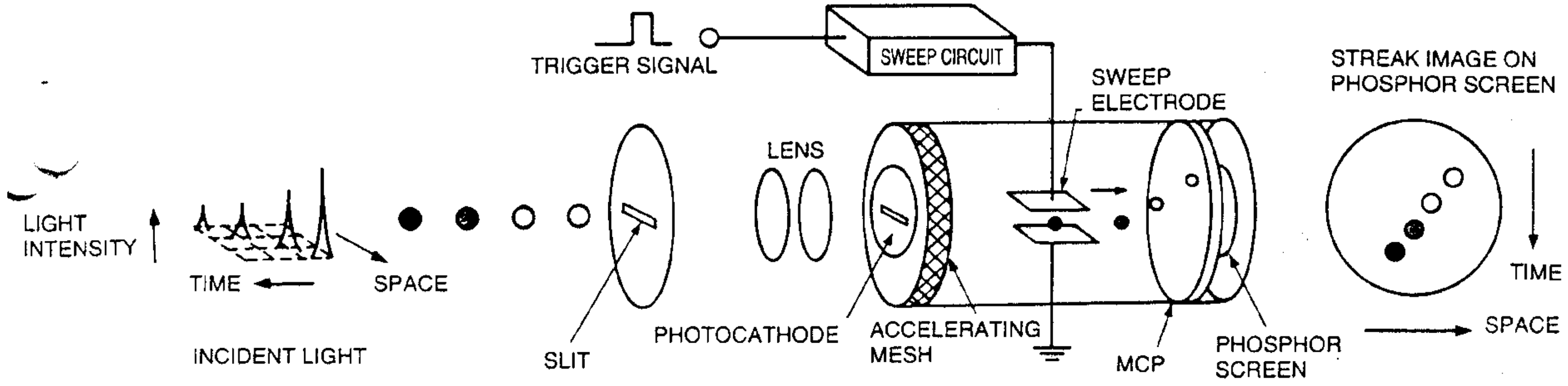


Fig.1 Operating Principle of the Streak Tube

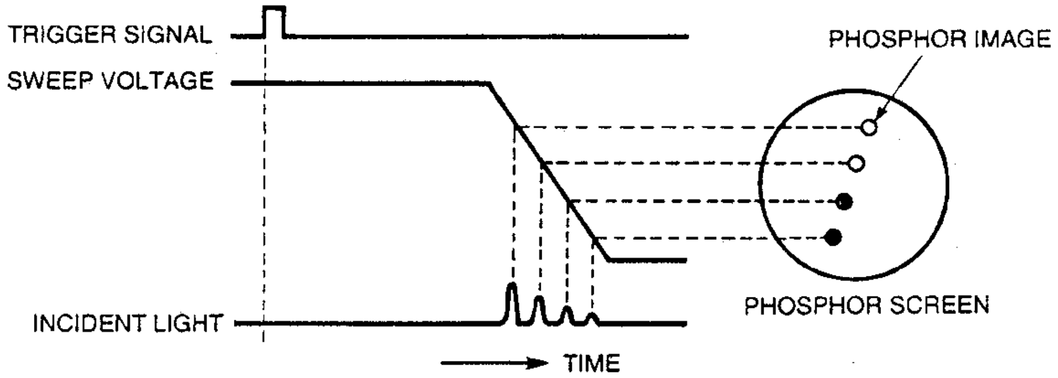
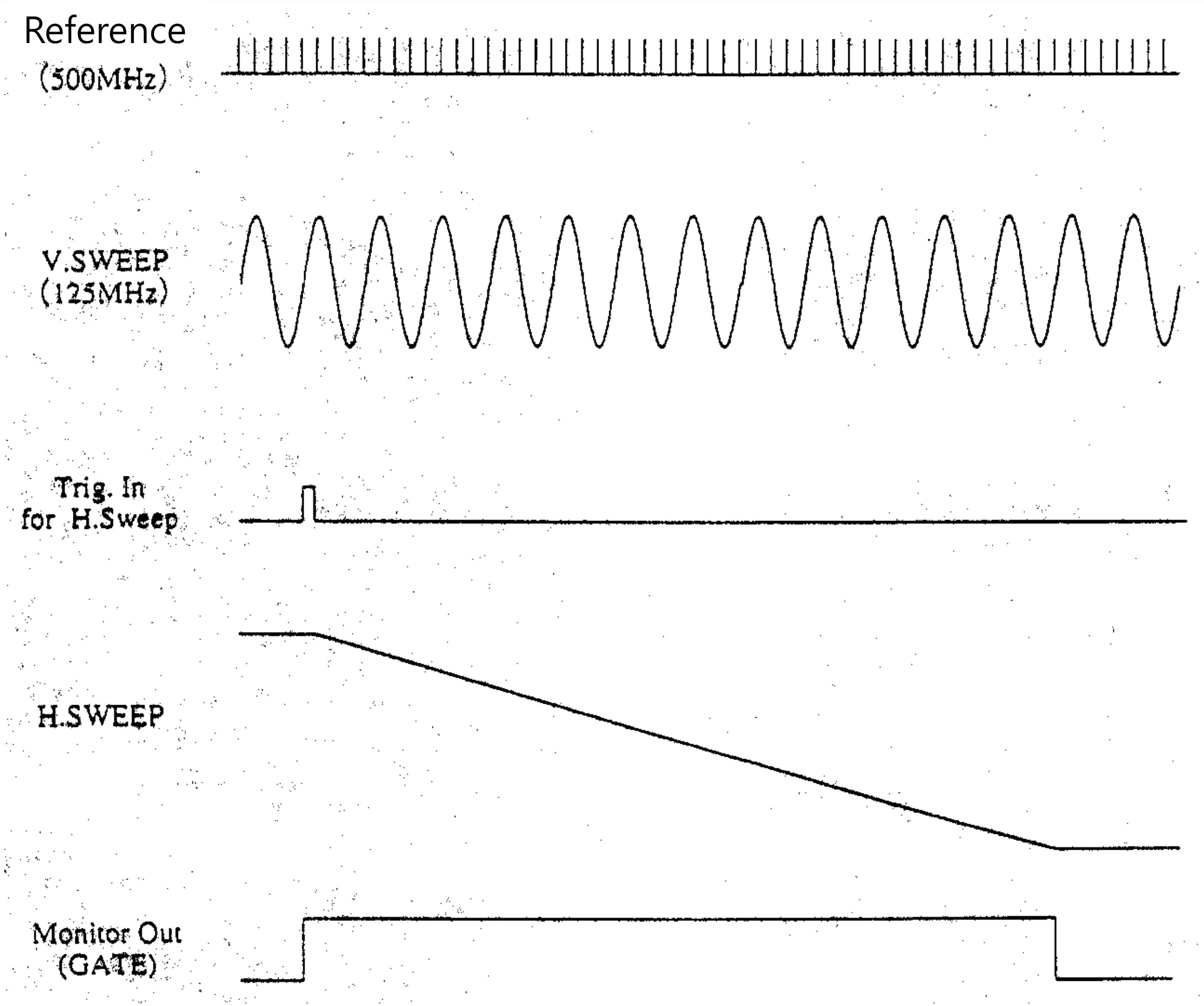
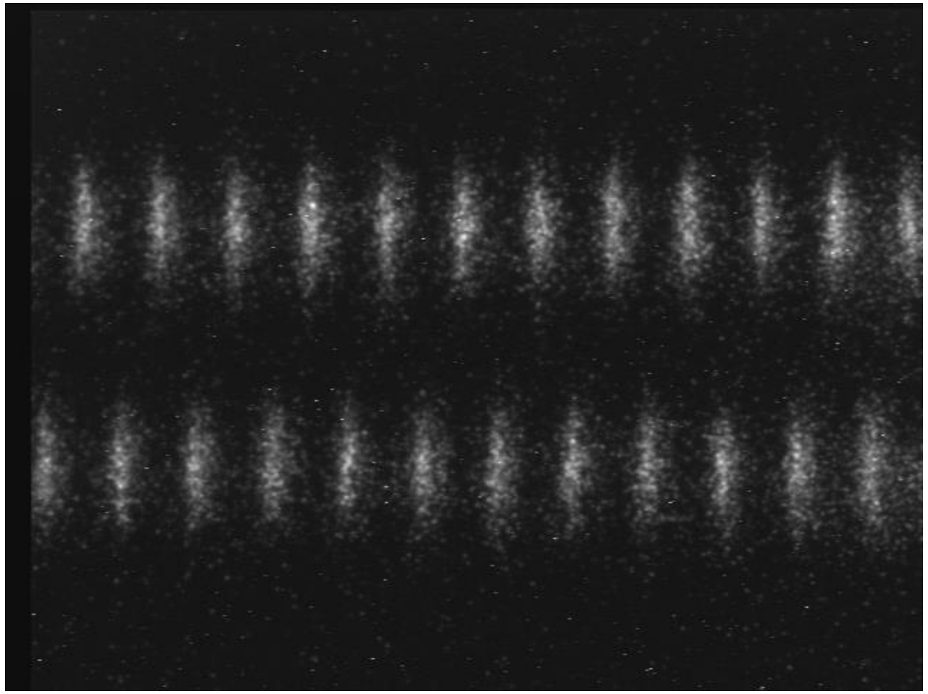


Fig. 2 Operation Timing (at time of sweep)

Bunch Length Measurement

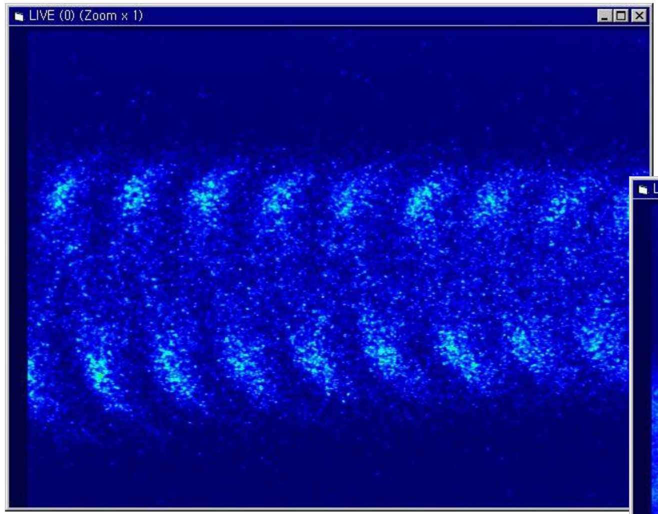




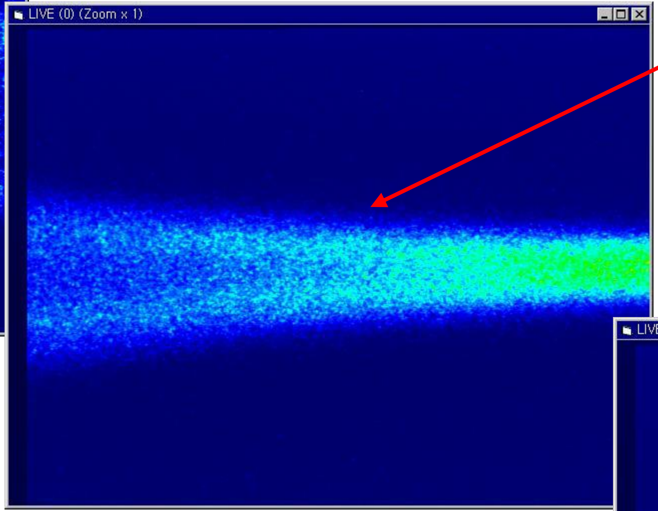
Each bunches in the storage ring are shown.
The time scale of horizontal axis is 100 ns.
The vertical one is 500 ps.

Synchrotron Damping

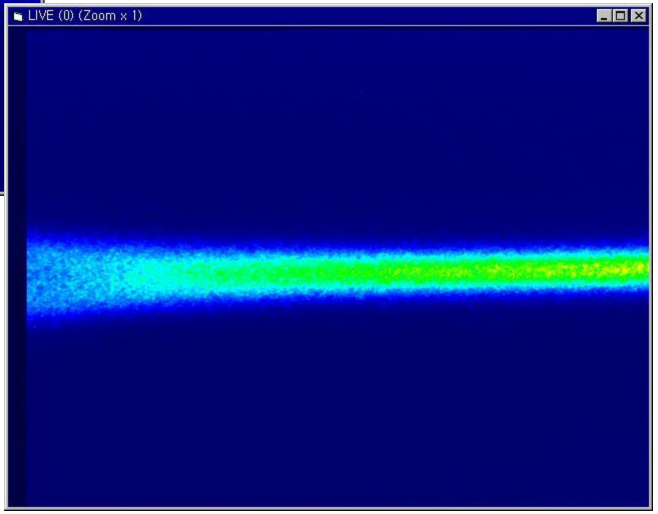
Synchrotron damping



Horizontal scale: 1 ms



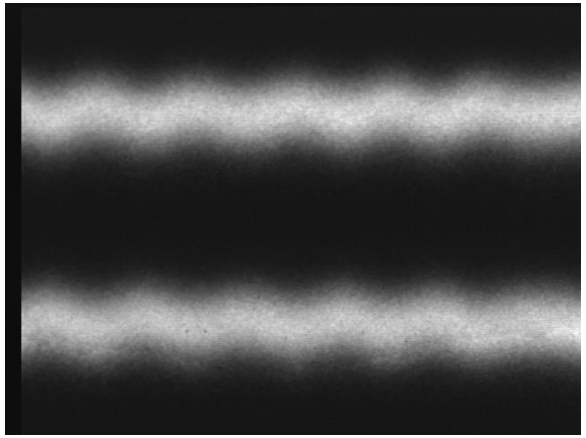
Horizontal scale: 5 ms

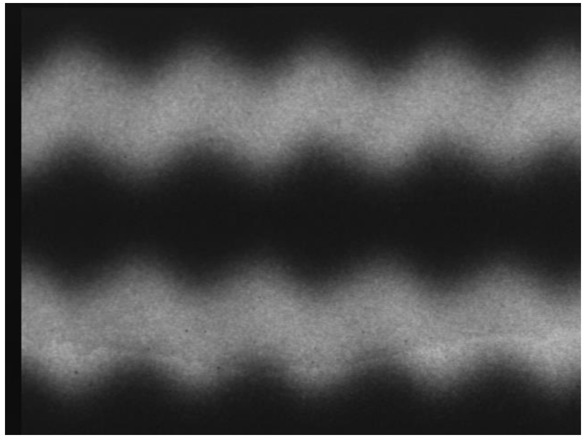


Horizontal scale: 10 ms

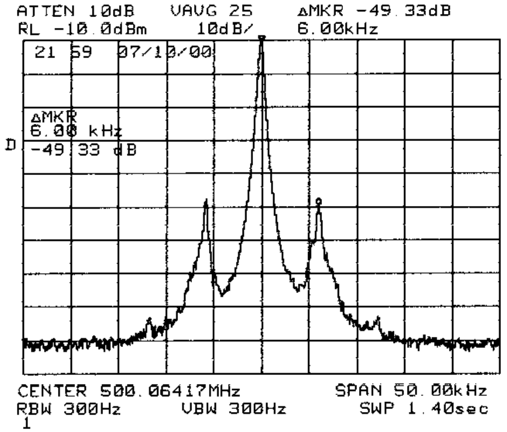
Injected electron beam
Vertical scale: 2 ns
Streak camera delay: 0 sec

Effects of High Harmonic RF

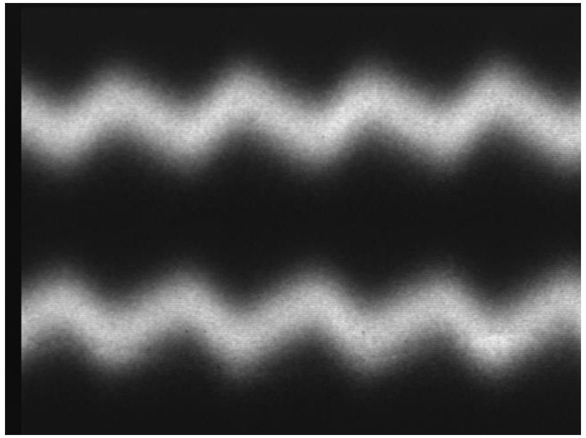


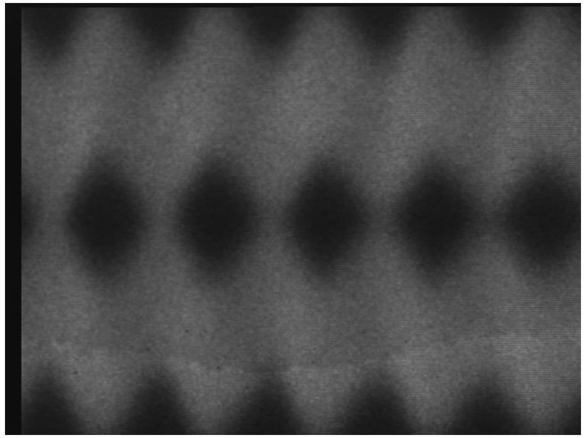


Images of 5-6 kHz oscillation when the noise of same frequency is detected from the beam position monitor. The horizontal axis is 1 ms.

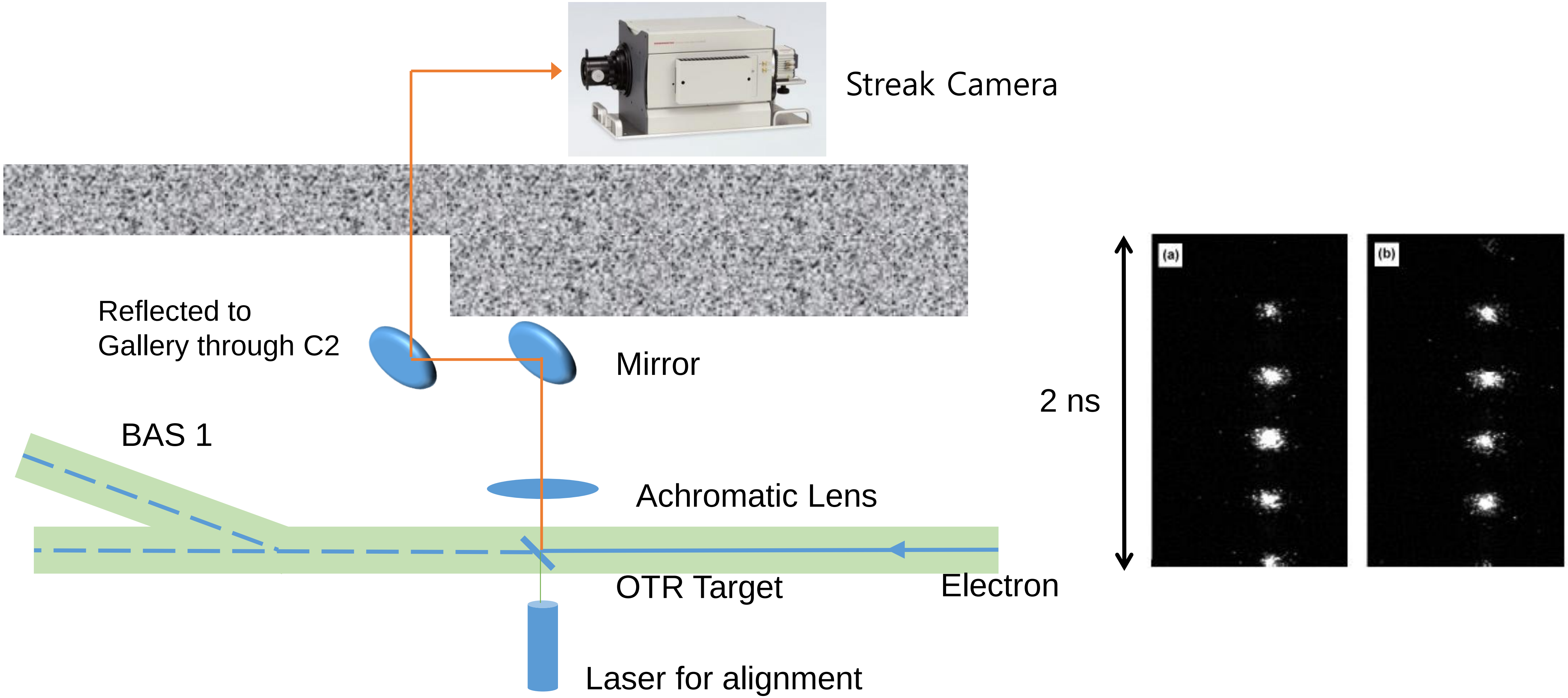


Spectrum analyzer image of 6 kHz RF noise.

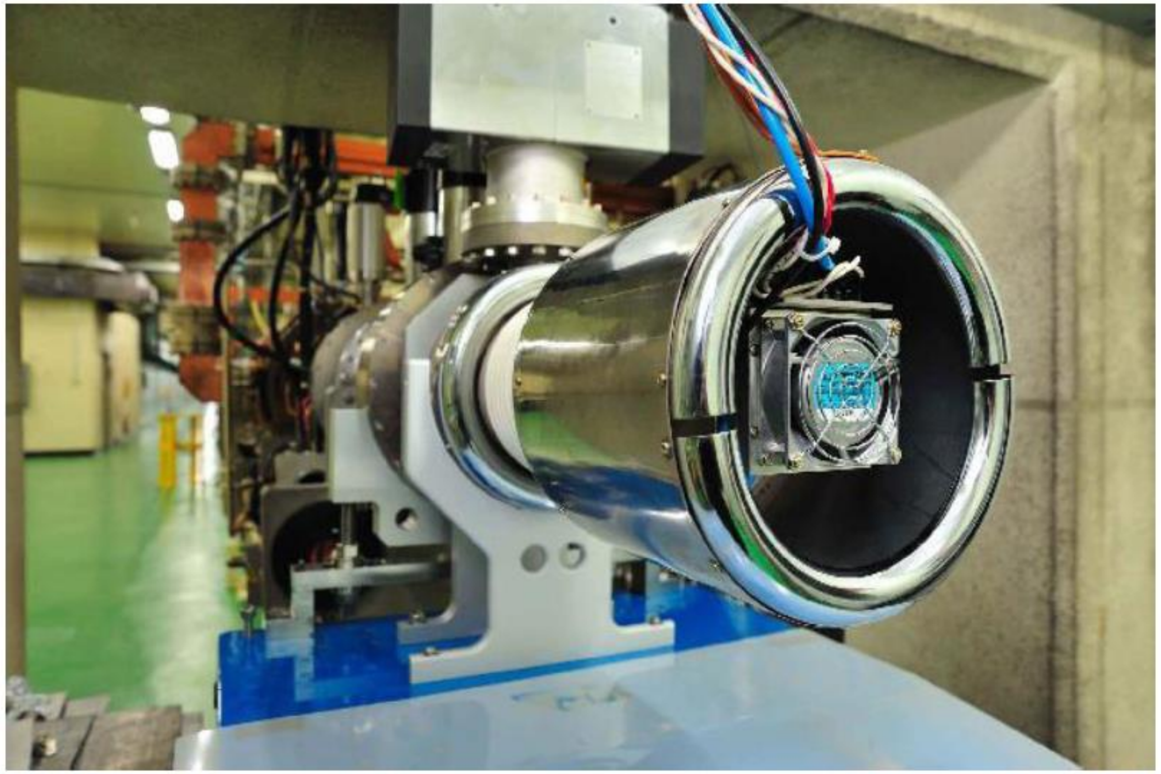




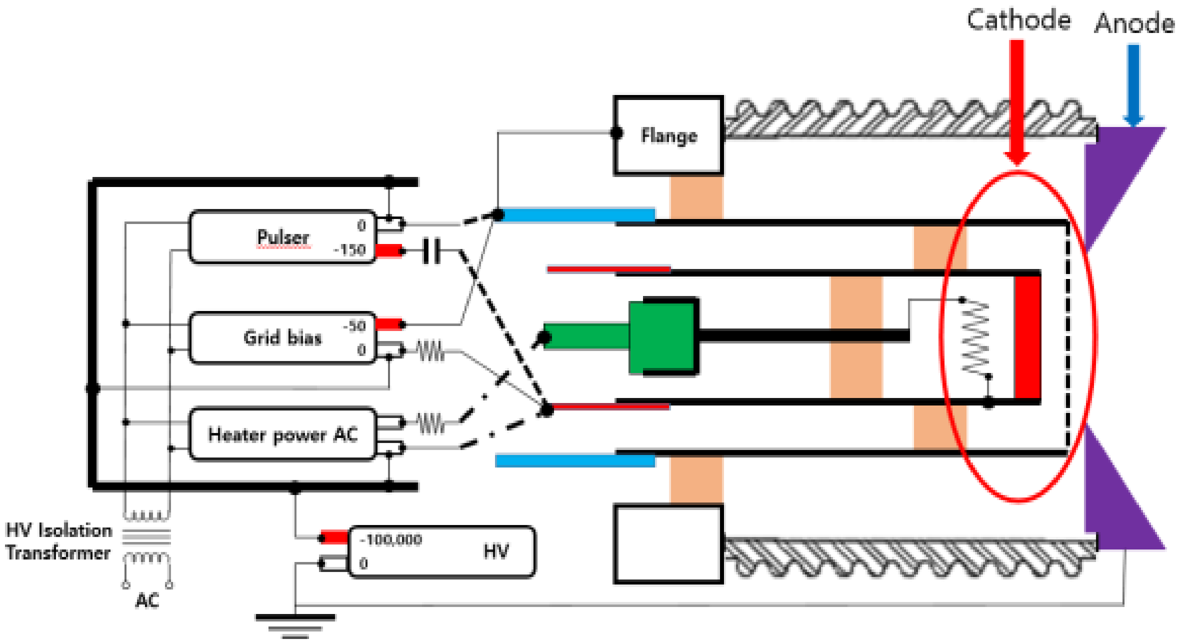
Linac Bunch Length Measurement



PLS-II Electron Gun

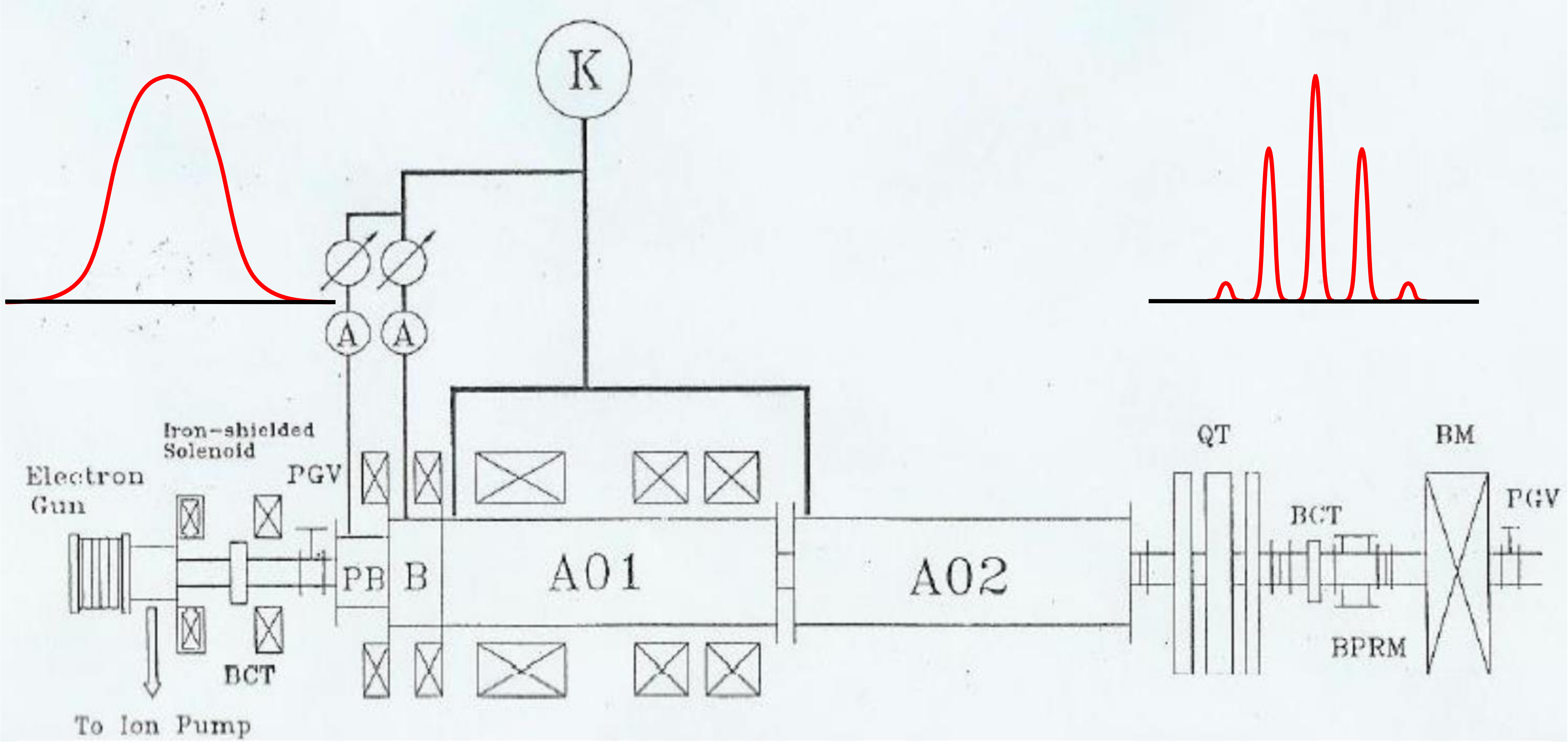


PLS-II Thermionic Electron Gun

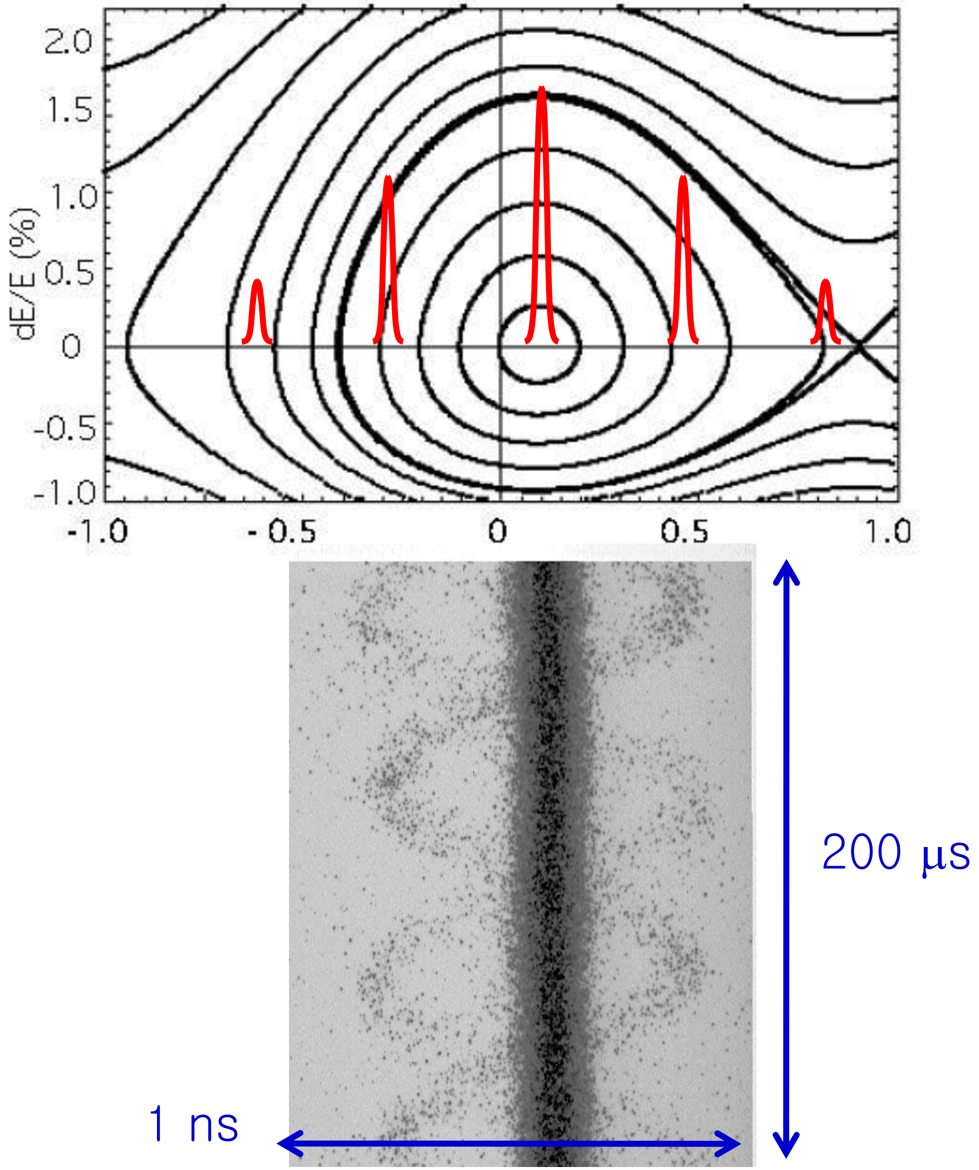


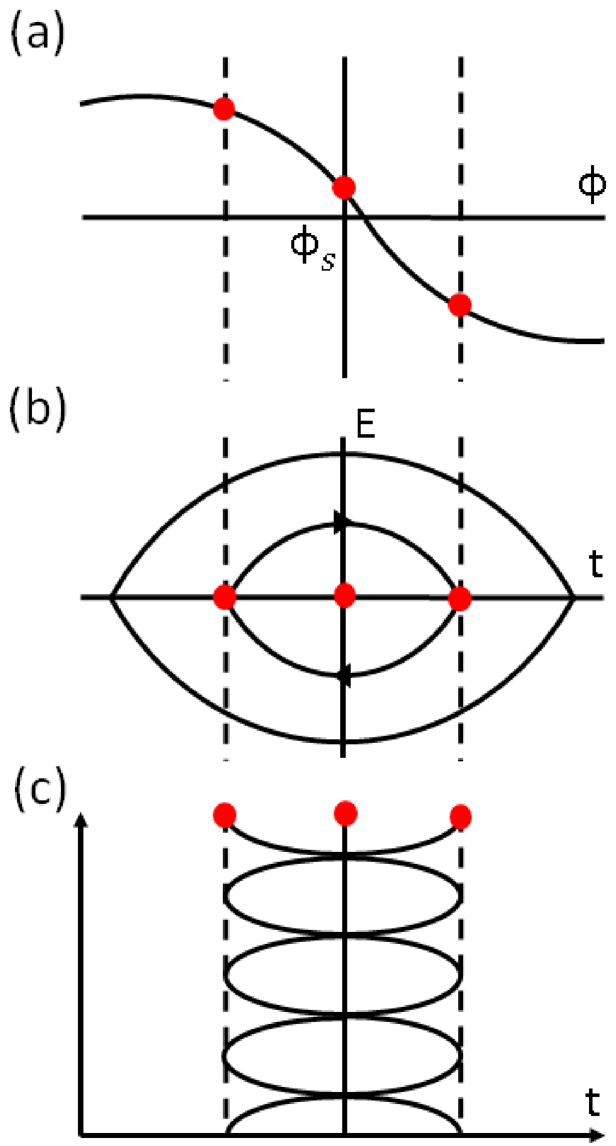
Circuit Diagram of Electron Gun

Layout of PLS-II Injector

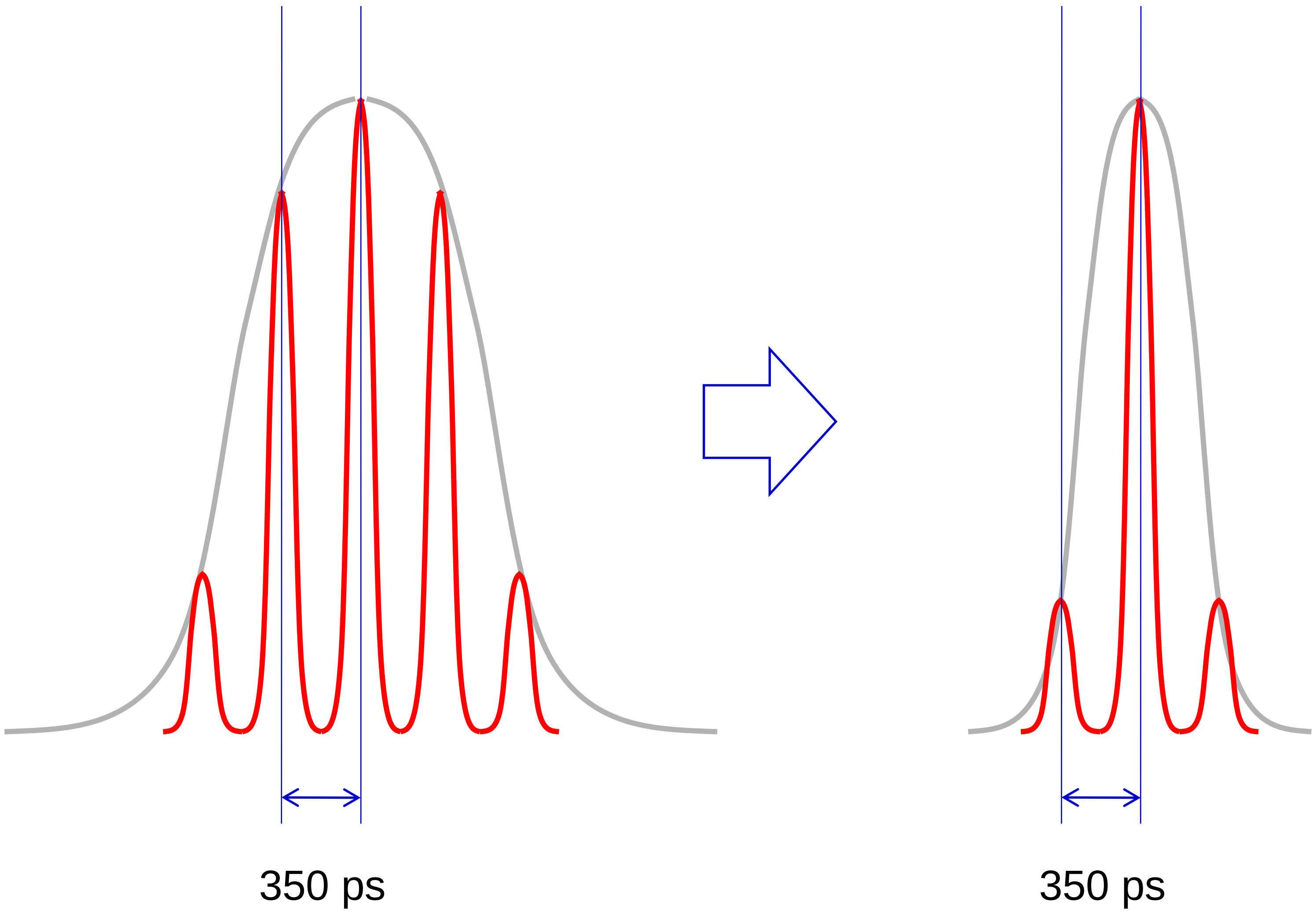


Longitudinal Oscillation of Injected Beam



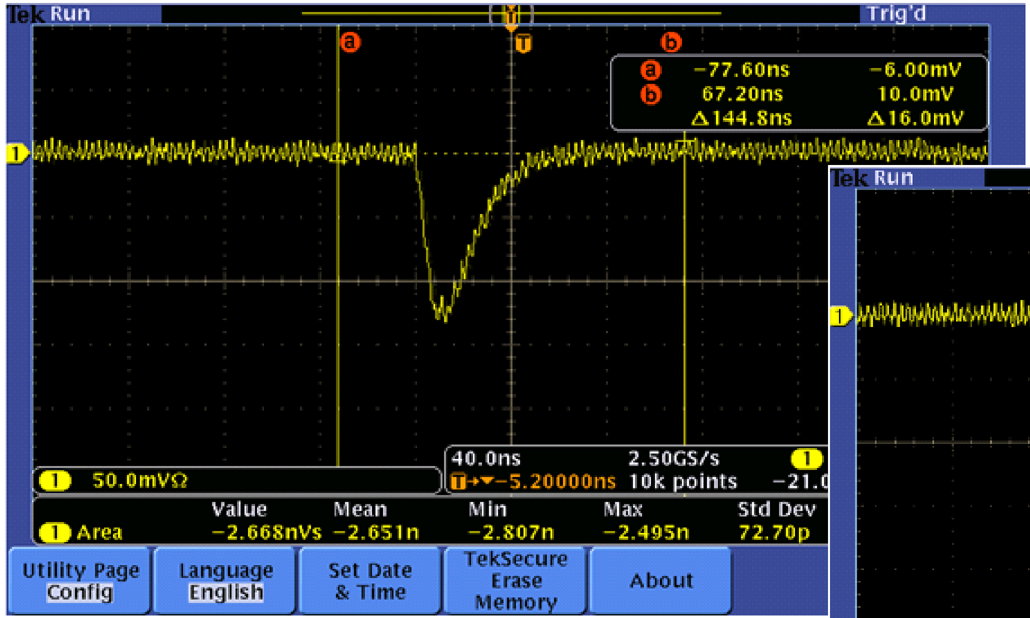


Long Pulse vs. Short Pulse

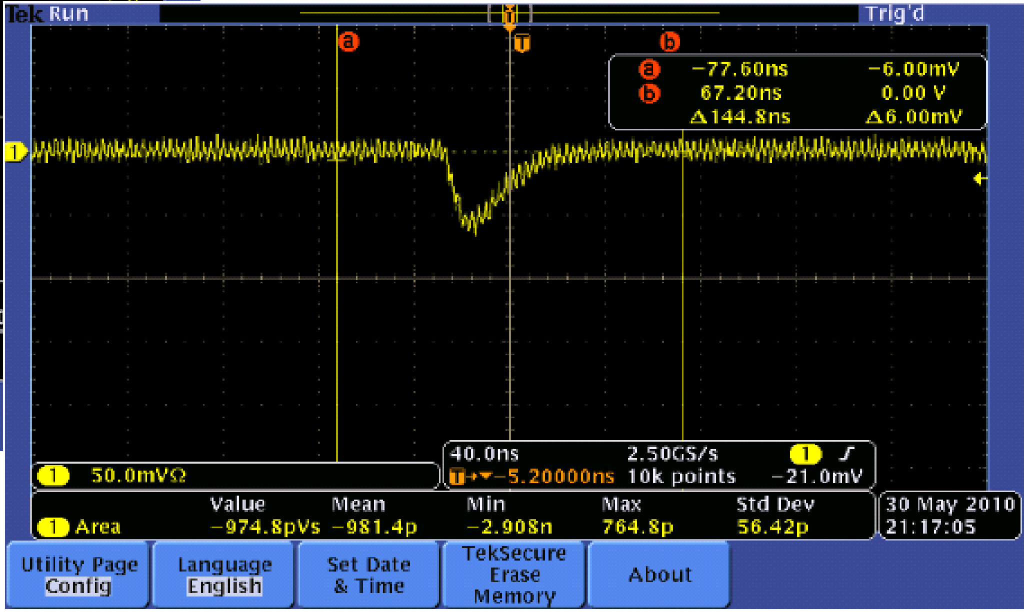


Injection Efficiency of Short Pulse Beam

ICT signal @ BTL



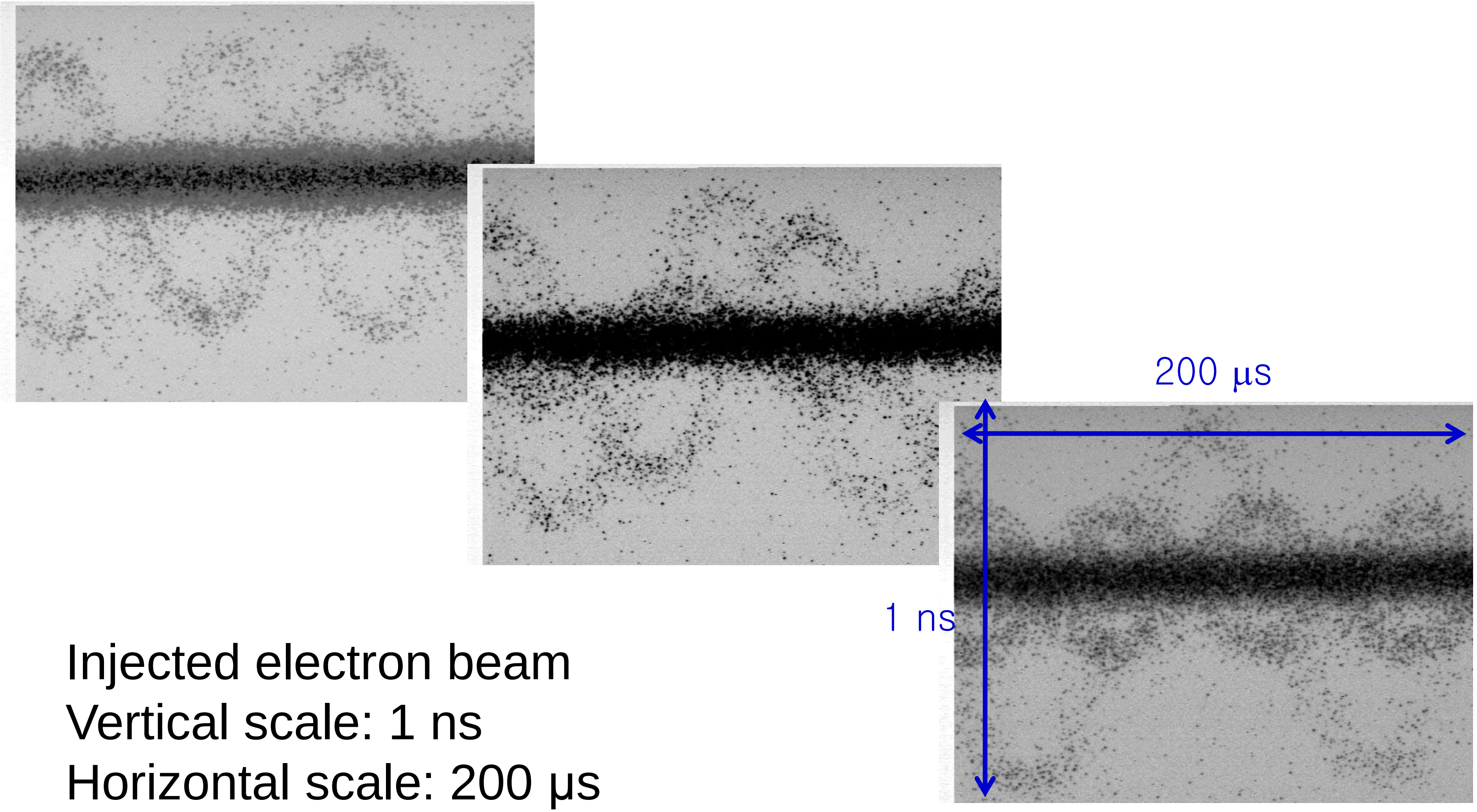
Long pulse case
Measured Charge: 500 pC



Short pulse case
Measured Charge: 200 pC

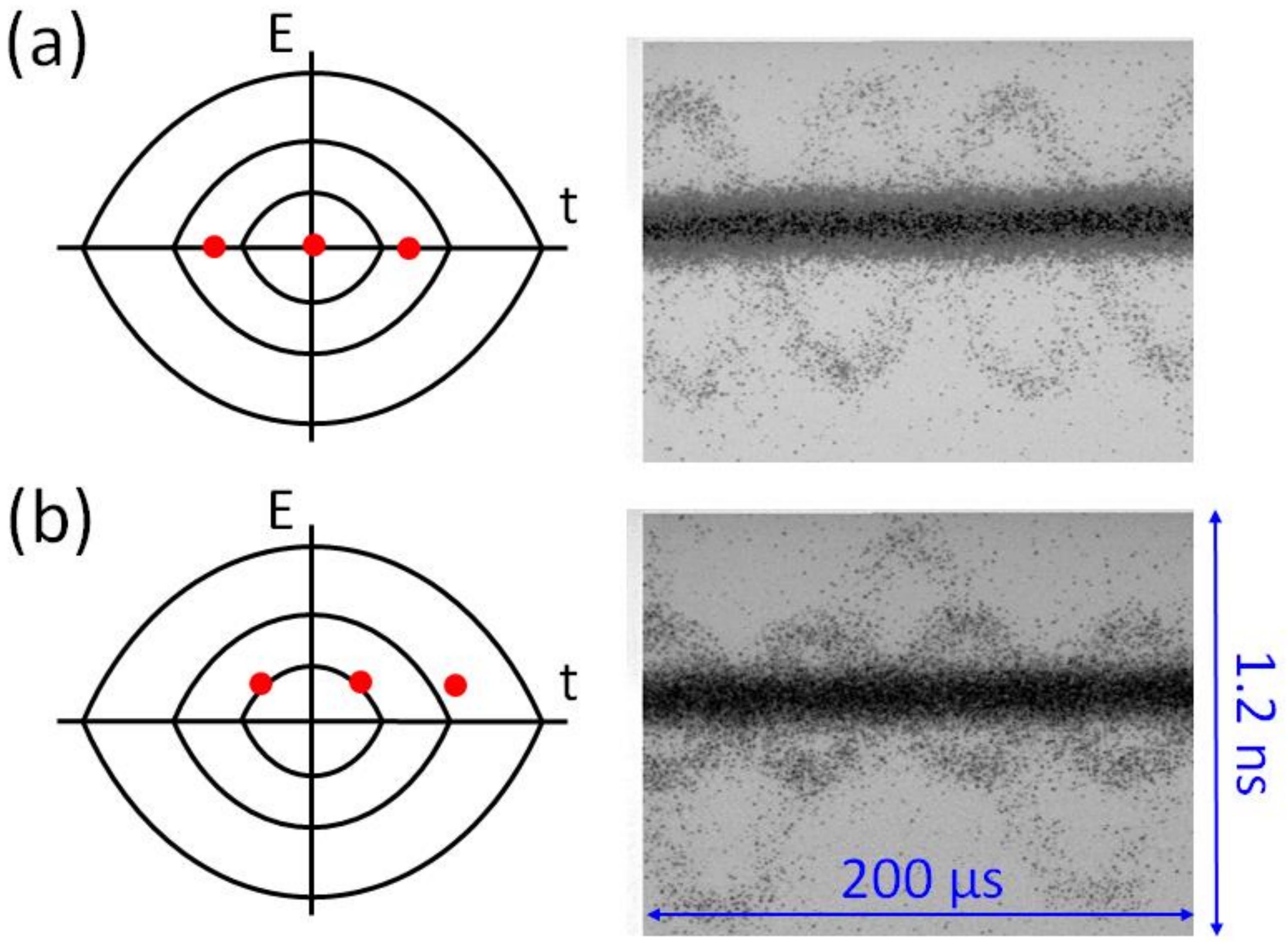
Two times improvement of injection efficiency

Streak Camera Image of Injected Beam

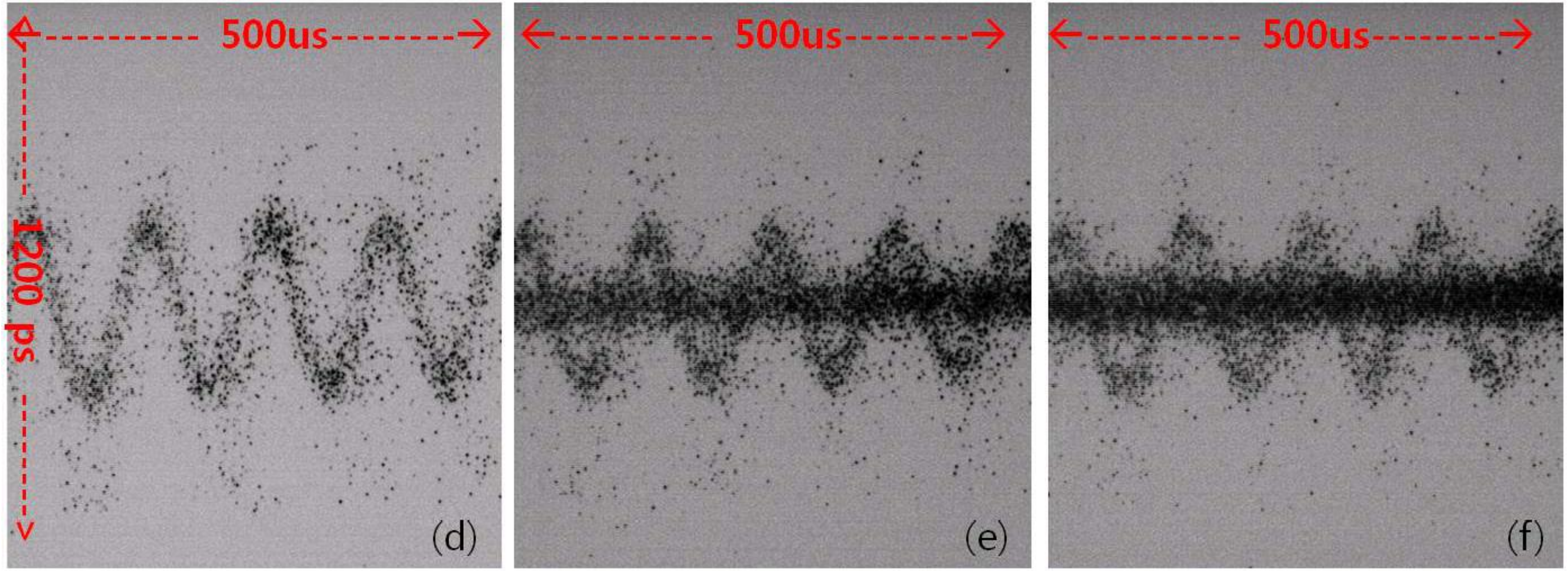


Injected electron beam
Vertical scale: 1 ns
Horizontal scale: 200 μs
Streak camera delay: 0

Synchronized vs. Non Synchronized Injection



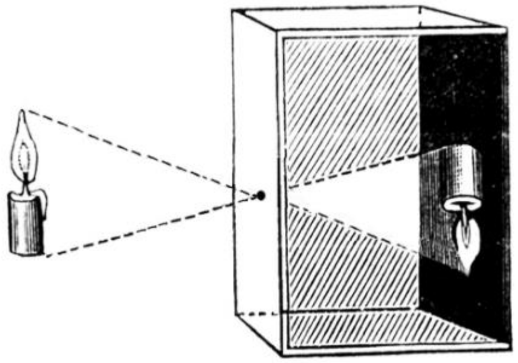
Streak Camera Image

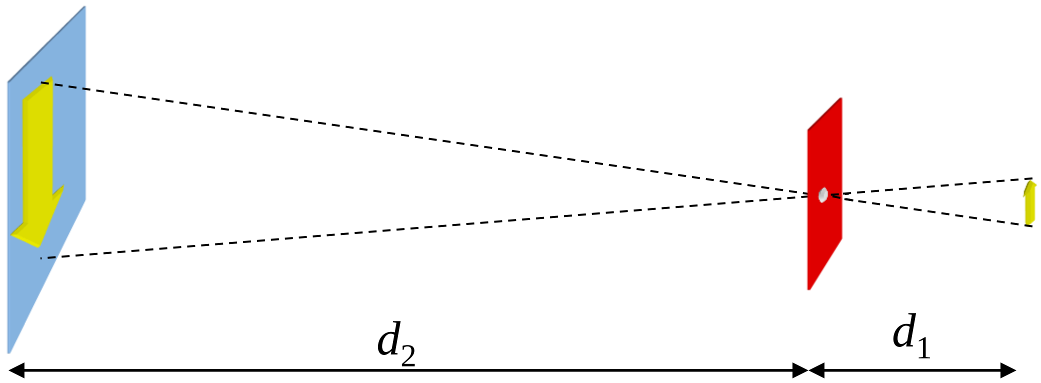


After synchronization and pulse width reduction

Beam Size Monitor

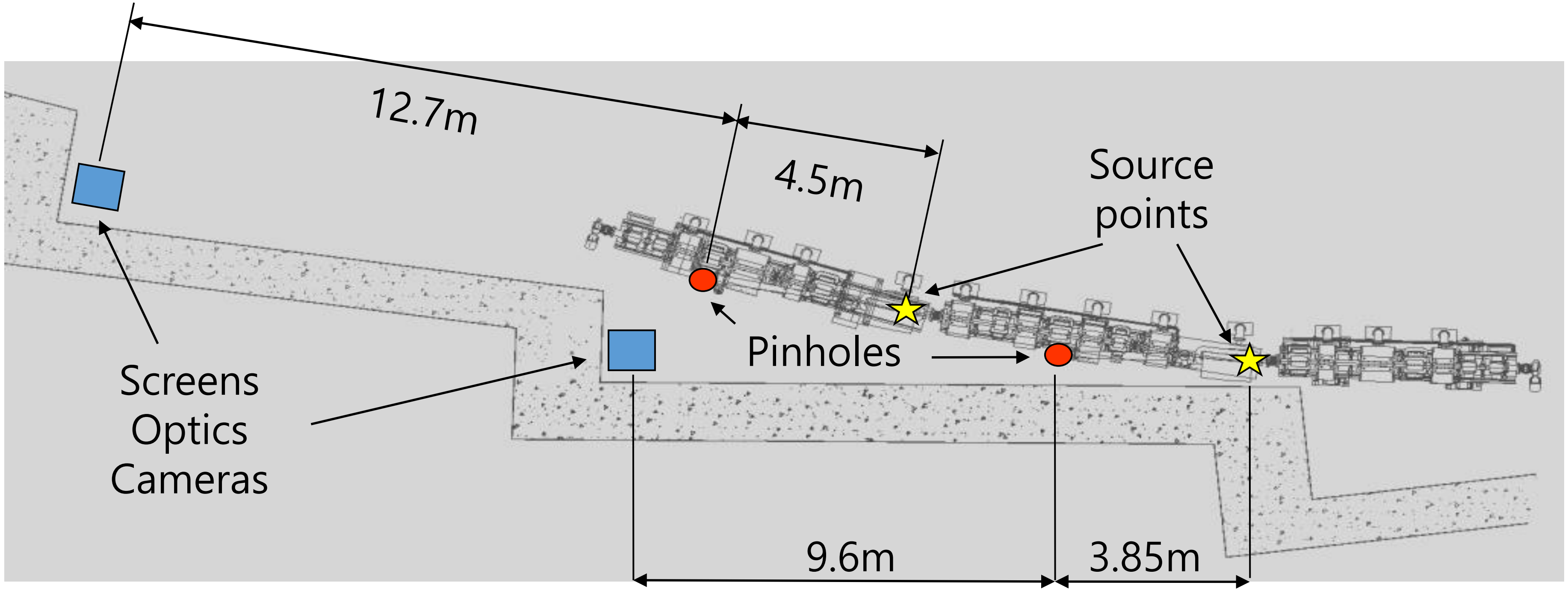
X-ray Pinhole Camera



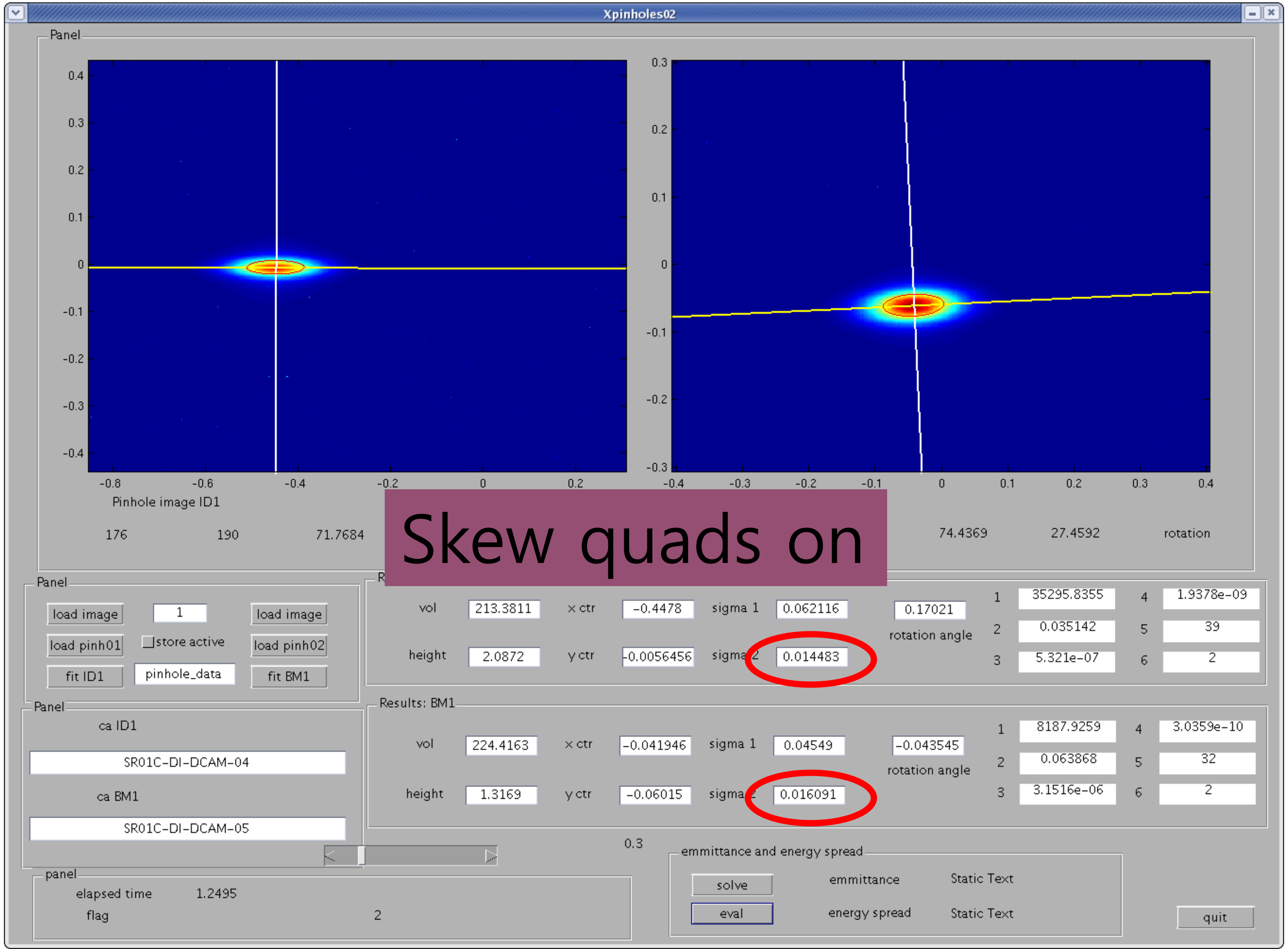


Magnification

$$m = \frac{d_2}{d_1}$$



X-ray Pinhole Image



Skew quads on

Interference with partially coherent light

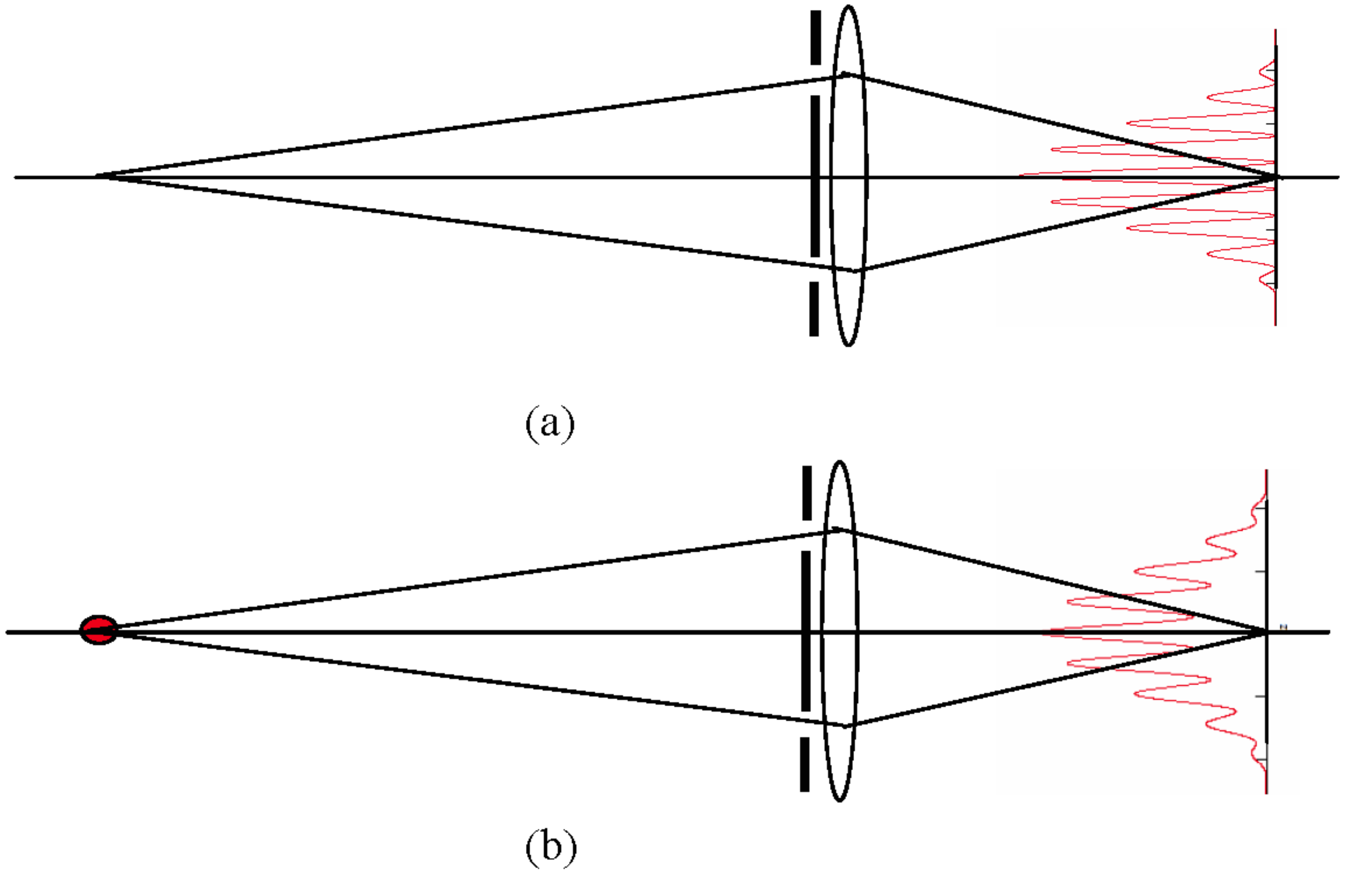


FIGURE 1. A simple representation of the visibility of an interferogram and light source size. (a) A point source yields an interferogram with a visibility of 1; (b) an ensemble of point source yields a reduced visibility.

Source Size and Interference

$$I = I_0 \left\{ \frac{\sin(u)}{u} \right\}^2 \left\{ 1 + \left| \frac{2J_1(\upsilon)}{\upsilon} \right| \cos(\delta) \right\}$$

$$u = \frac{kax}{R}, v = \frac{k\xi d}{L}, \delta = \frac{kdx}{R}$$

k: wavelength of the light
a: aperture size of slit
ξ: source size
d: distance between slit and screen

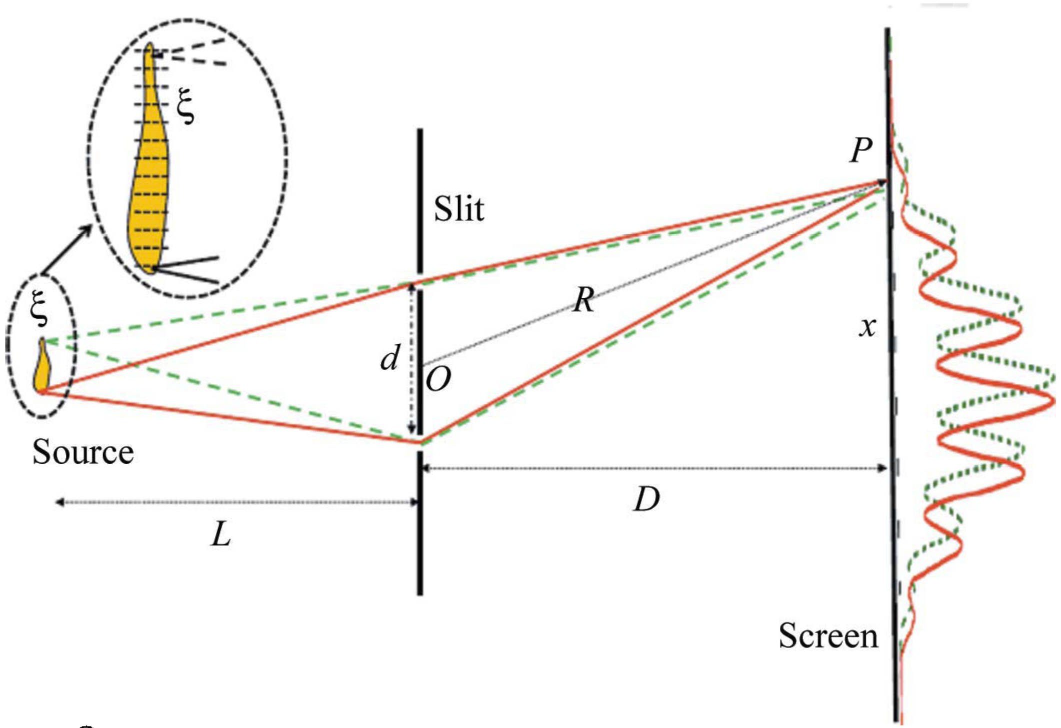
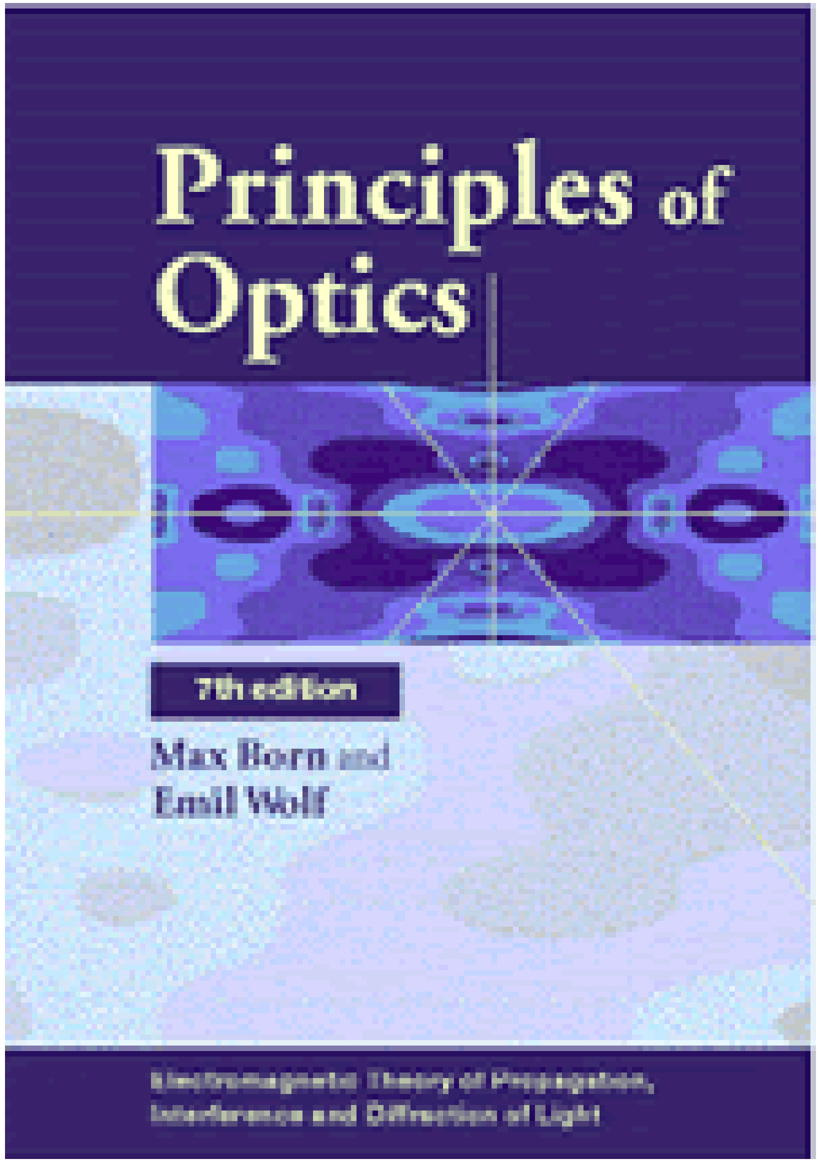


Figure 2
Configuration of the interference with a finite light source. The point O is defined as the centre of the slits. d is the distance between the two square apertures. R is the distance between points O and P on the screen. L is the distance between the source and the diffracting mask. D is the distance from the diffracting mask to the detection screen.

Reference



Principles of Optics

Electromagnetic Theory of Propagation, Interference and Diffraction of Light

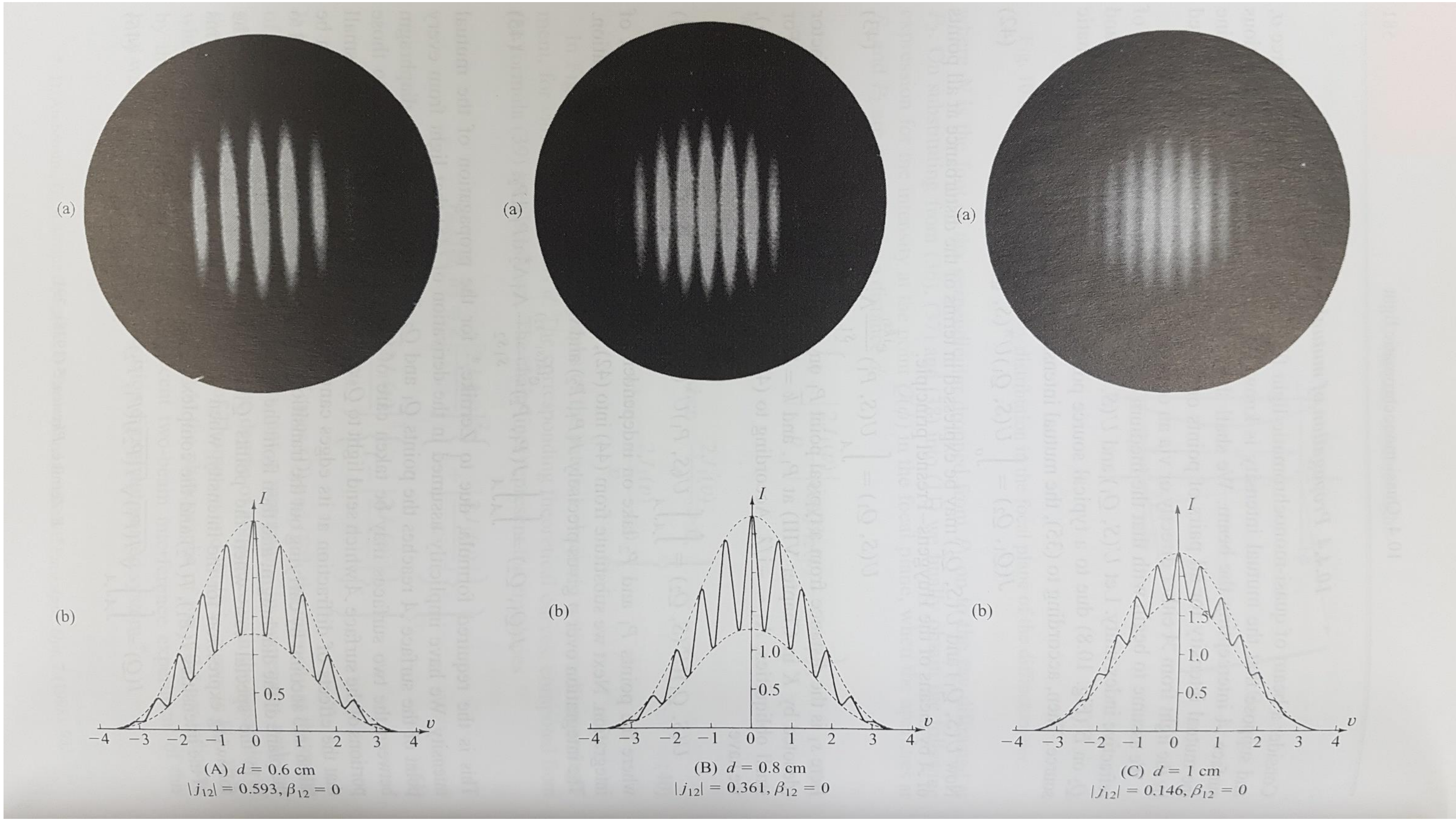
- Max Born and Emil Wolf

Chapter X

Interference and diffraction with partially coherent light

(p. 554 ~ 632)

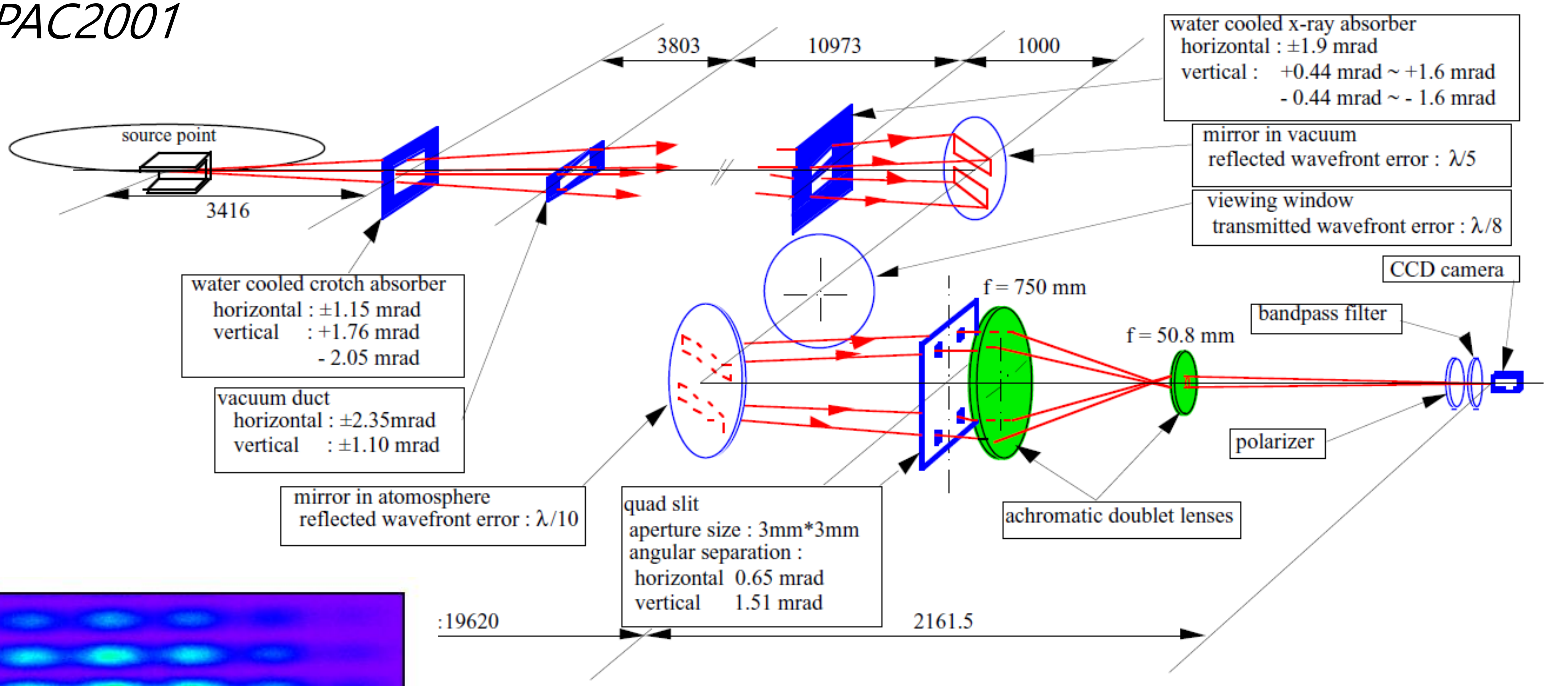
Example of Interferogram

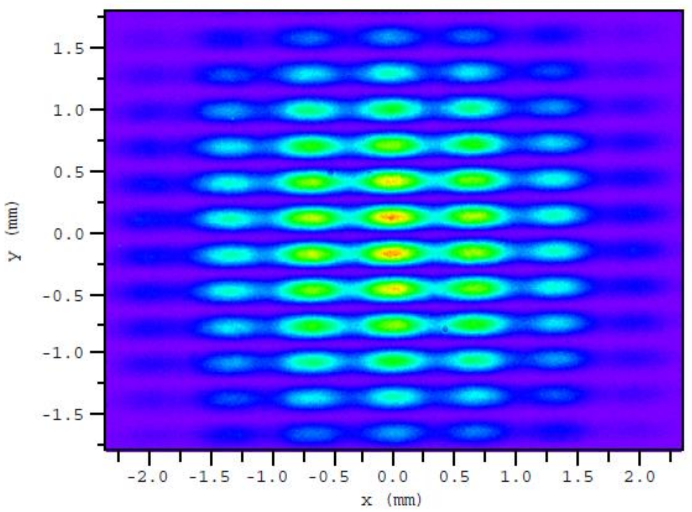


2D Visible Light Interferometry

미래기반 가속기
전문인력양성 사업단

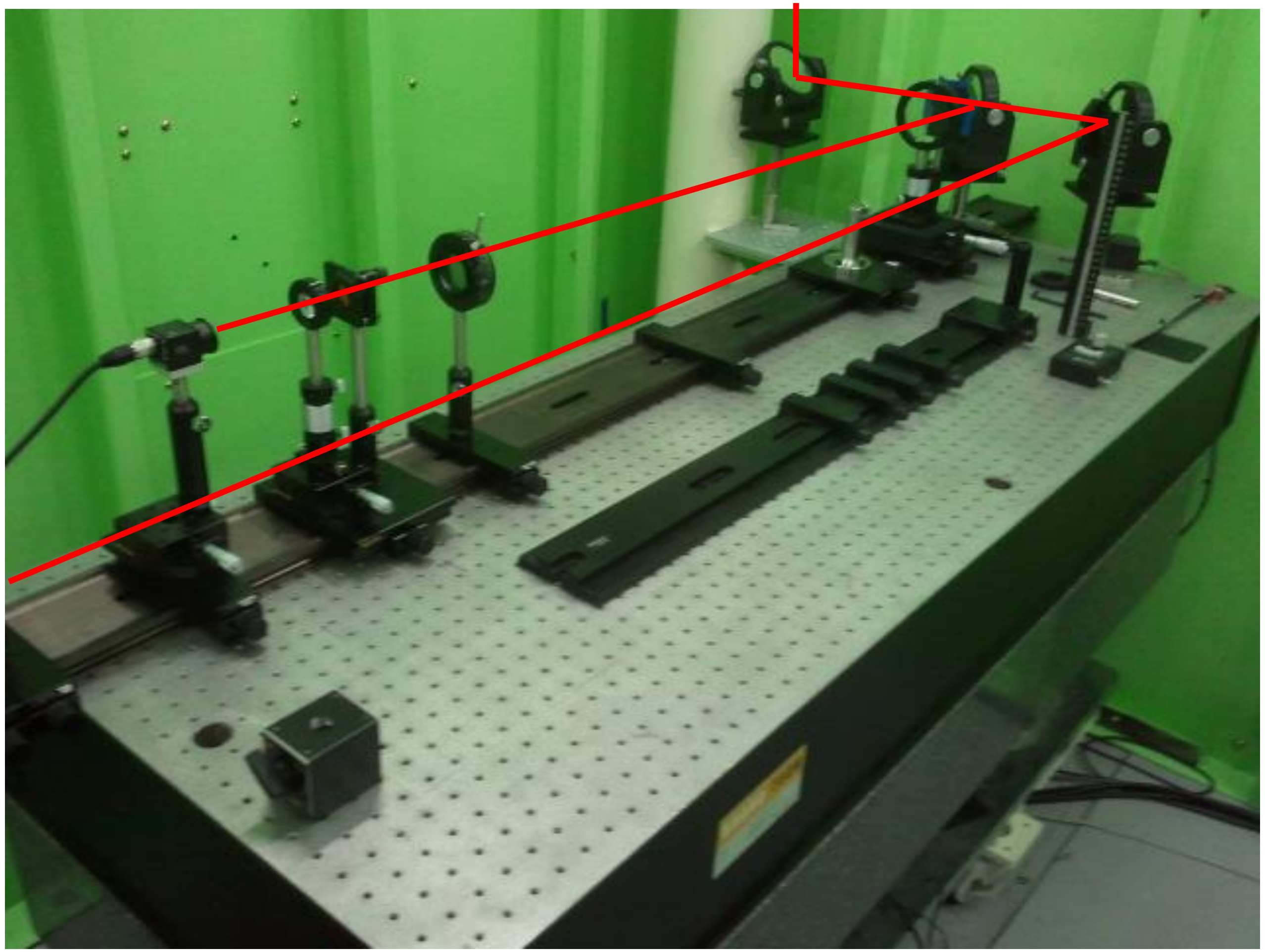
M. Masaki, DIPAC2001



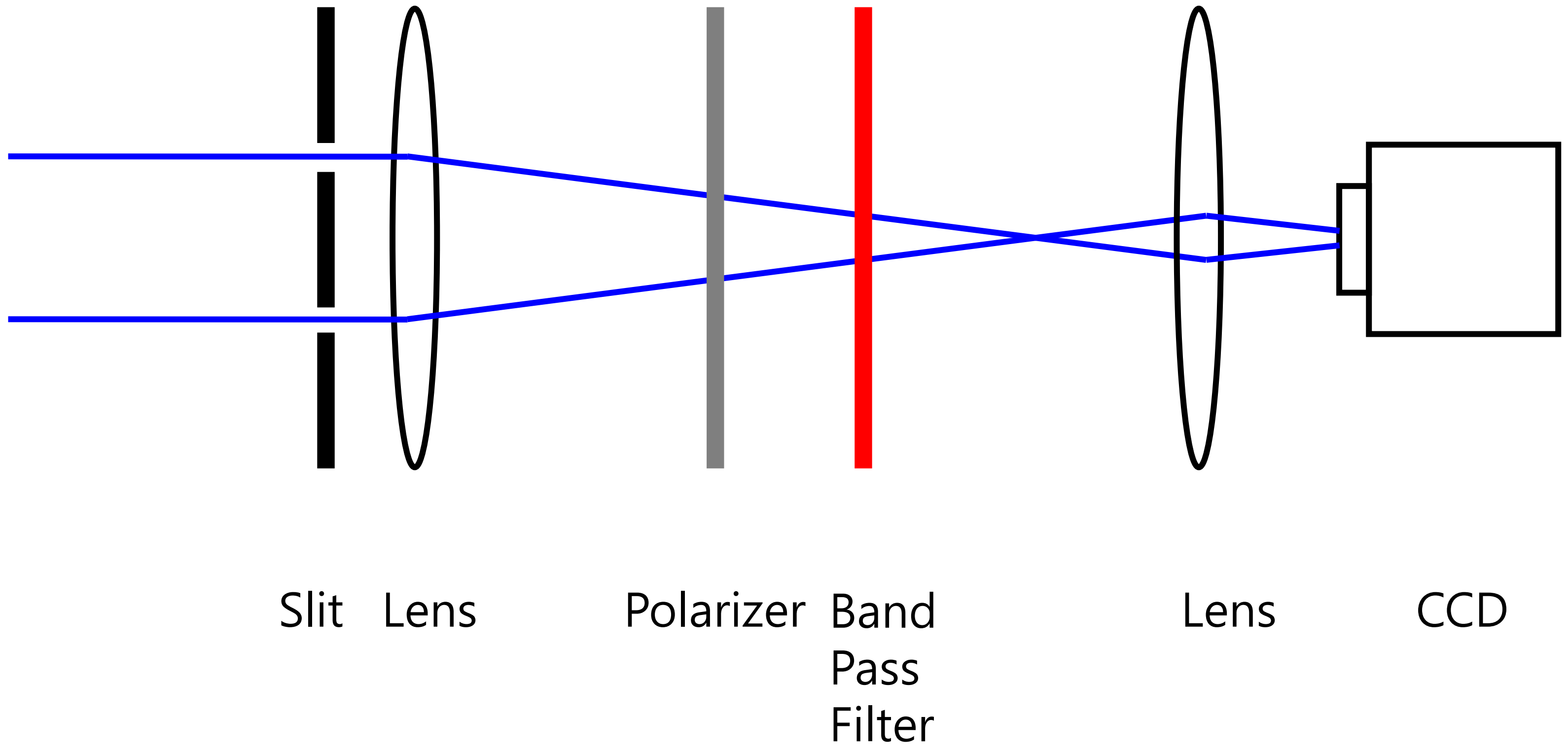


Inside of Diagnostic Beamline Hutch

SR Interferometer

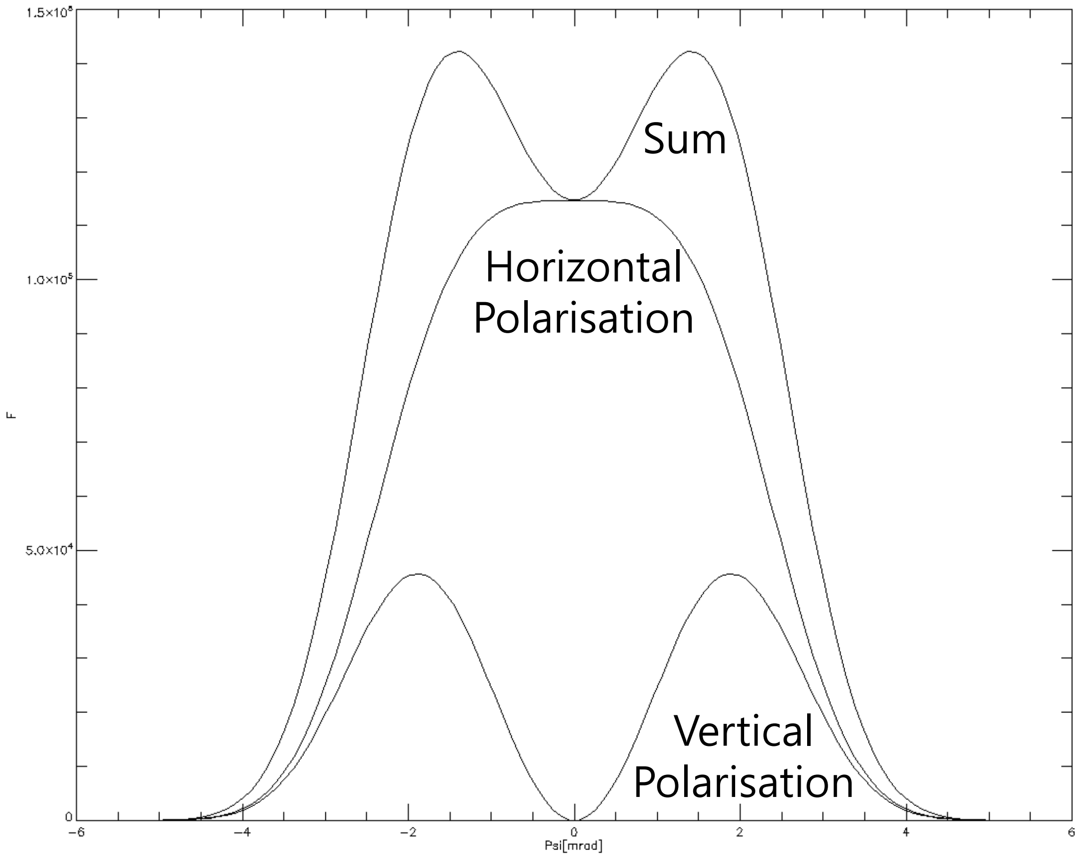


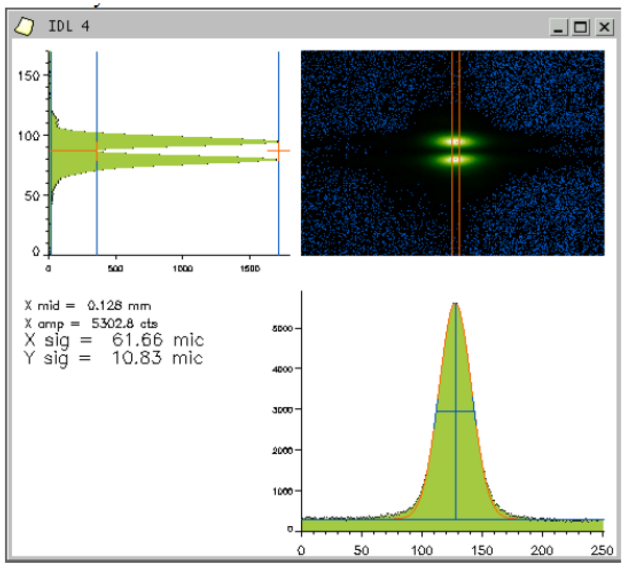
Optical Layout

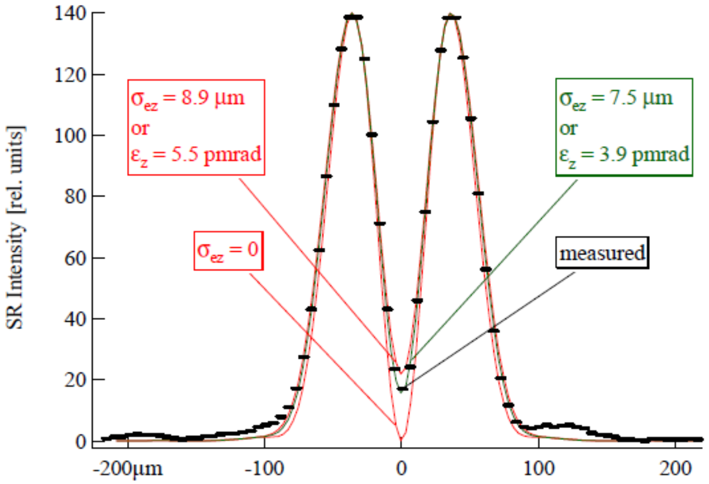


Measurement of Profile of Vertically Polarised Radiation

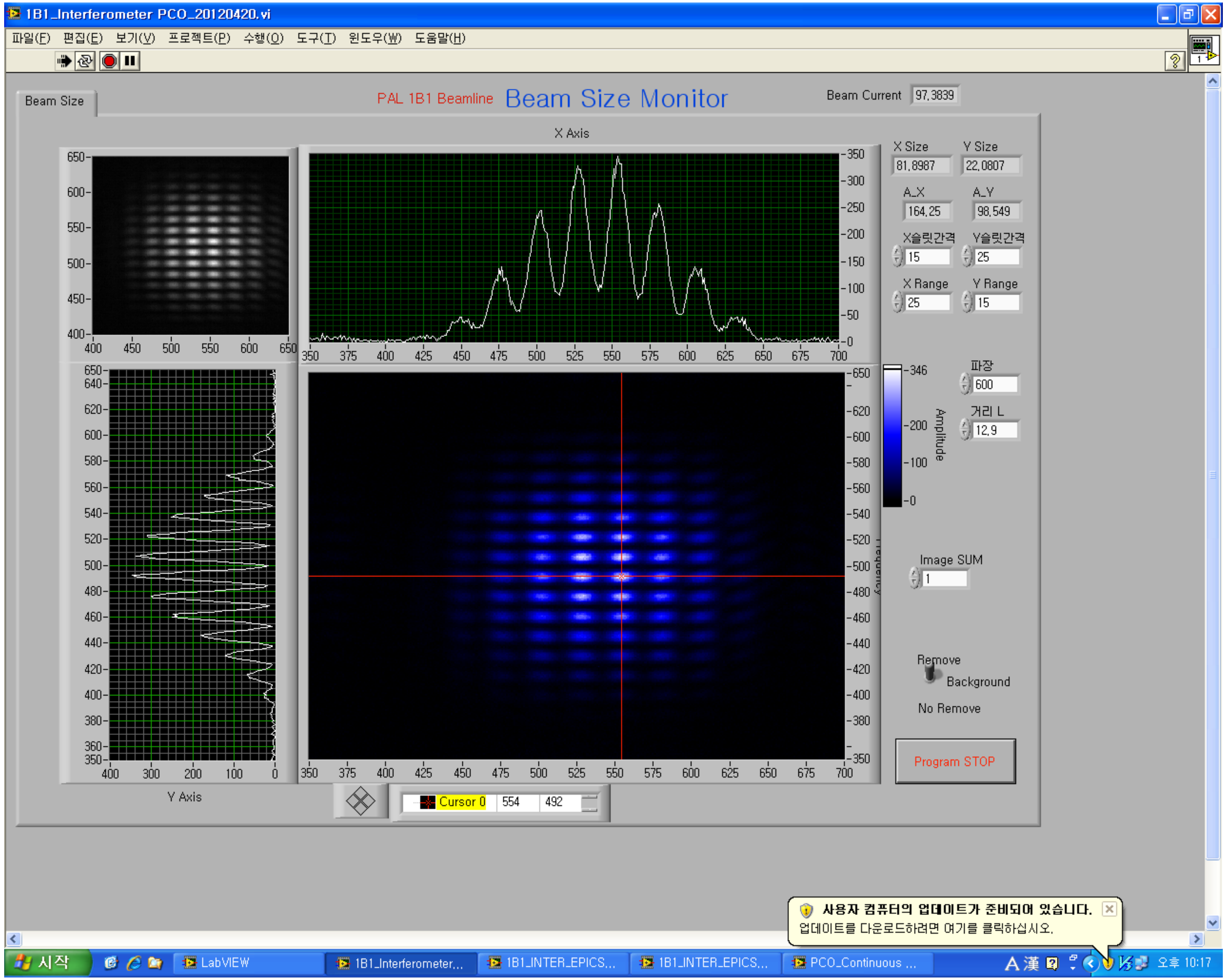
A. Andersson, DIPAC2007







Measurement Result



Matlab Simulation

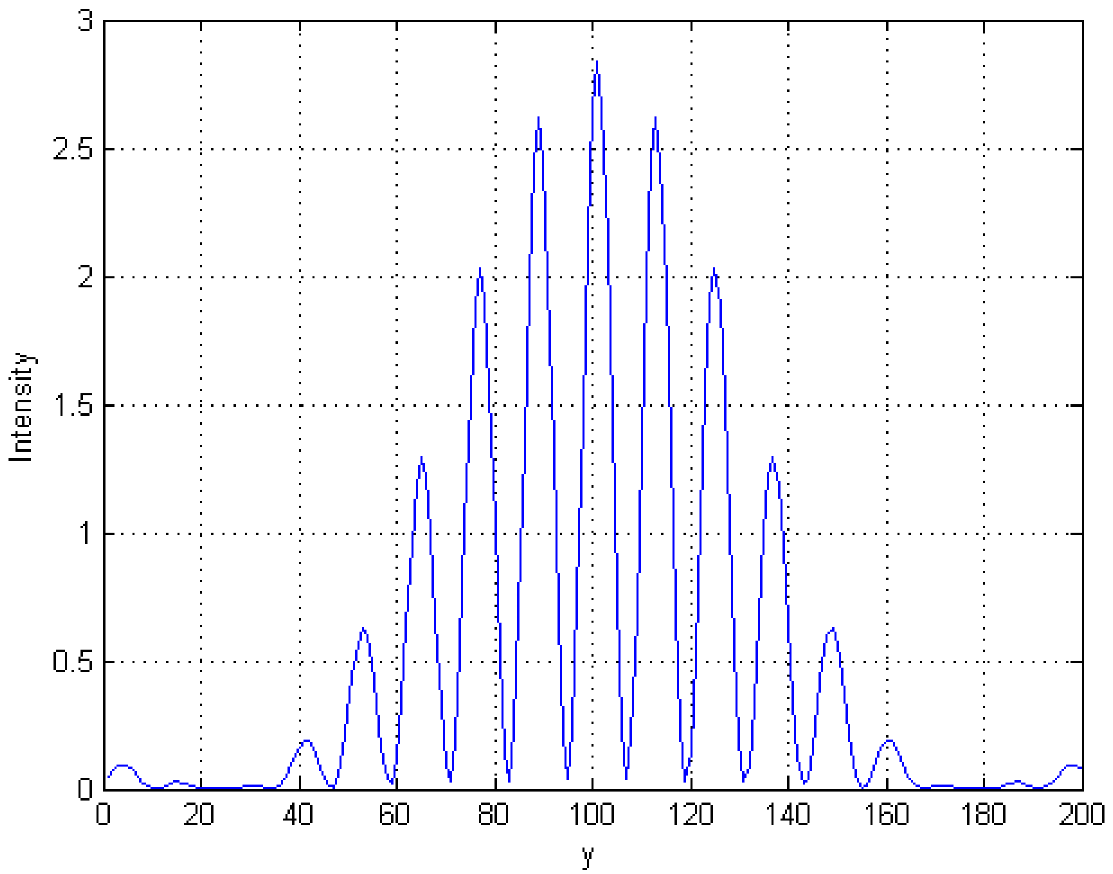
- k = 0.65 % Wave length of light
- a = 0.2 % Half width of slit
- b = 0.1 % Beam size
- c = 8 % Distance between two slits

- mu = k * a * y
- nu = k * b * c
- delta = k * c * y

- I = {sinc(mu)}^2 * [1 + abs{2 * besselj(1,nu) / nu} * cos(delta)]

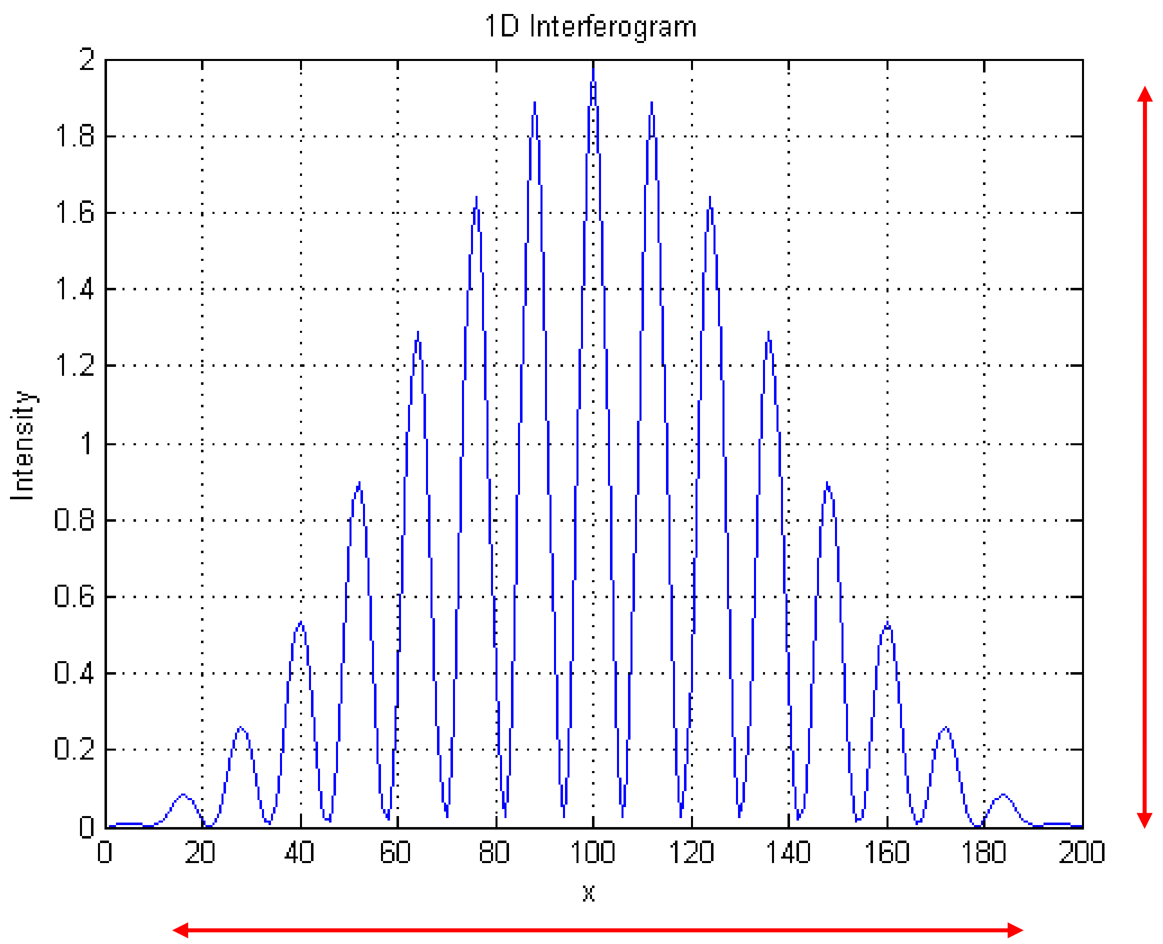
Simulation Result

- $k = 0.65$
  - Wave length of light
- $a = 0.2$
  - Half width of slit
- $b = 0.1$
  - Source size
- $c = 8$
  - Distance between two slits



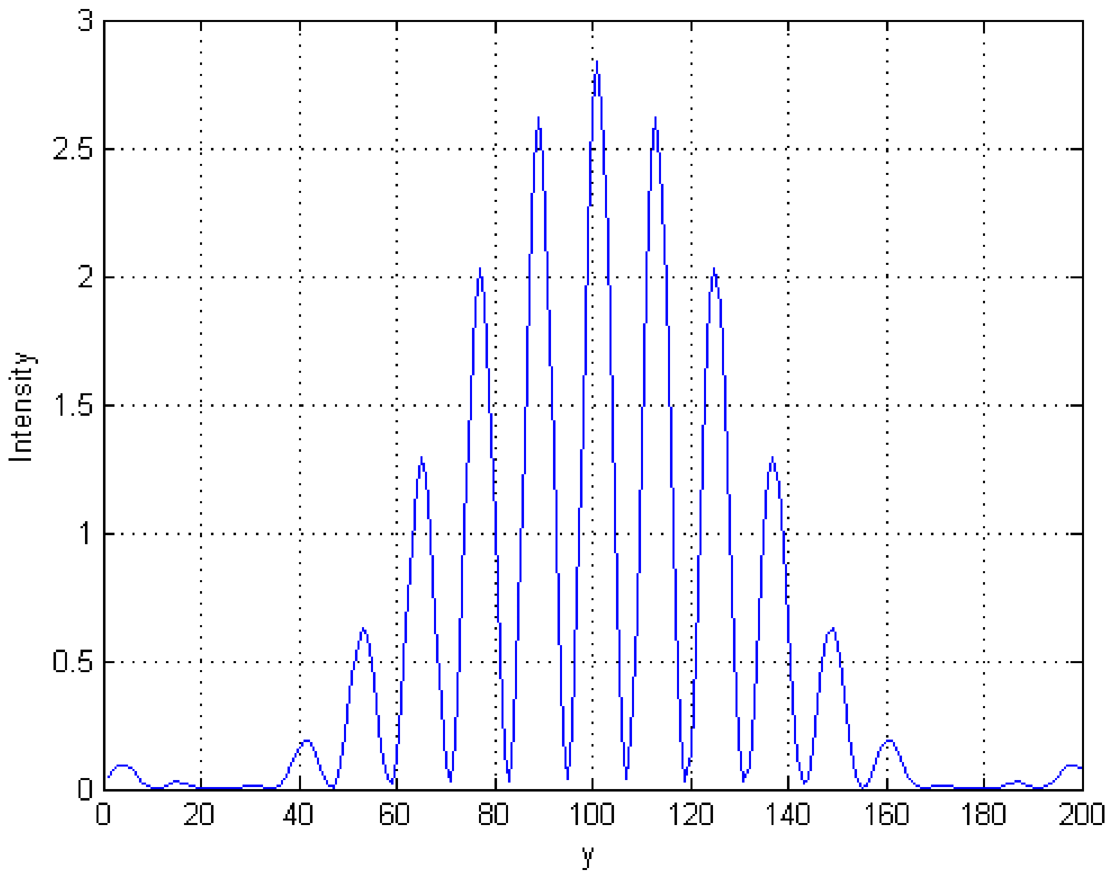
Simulation Result

- k = 0.65
  - Wave length of light
- a = 0.15
  - Half width of slit
- b = 0.1
  - Source size
- c = 8
  - Distance between two slits



Simulation Result

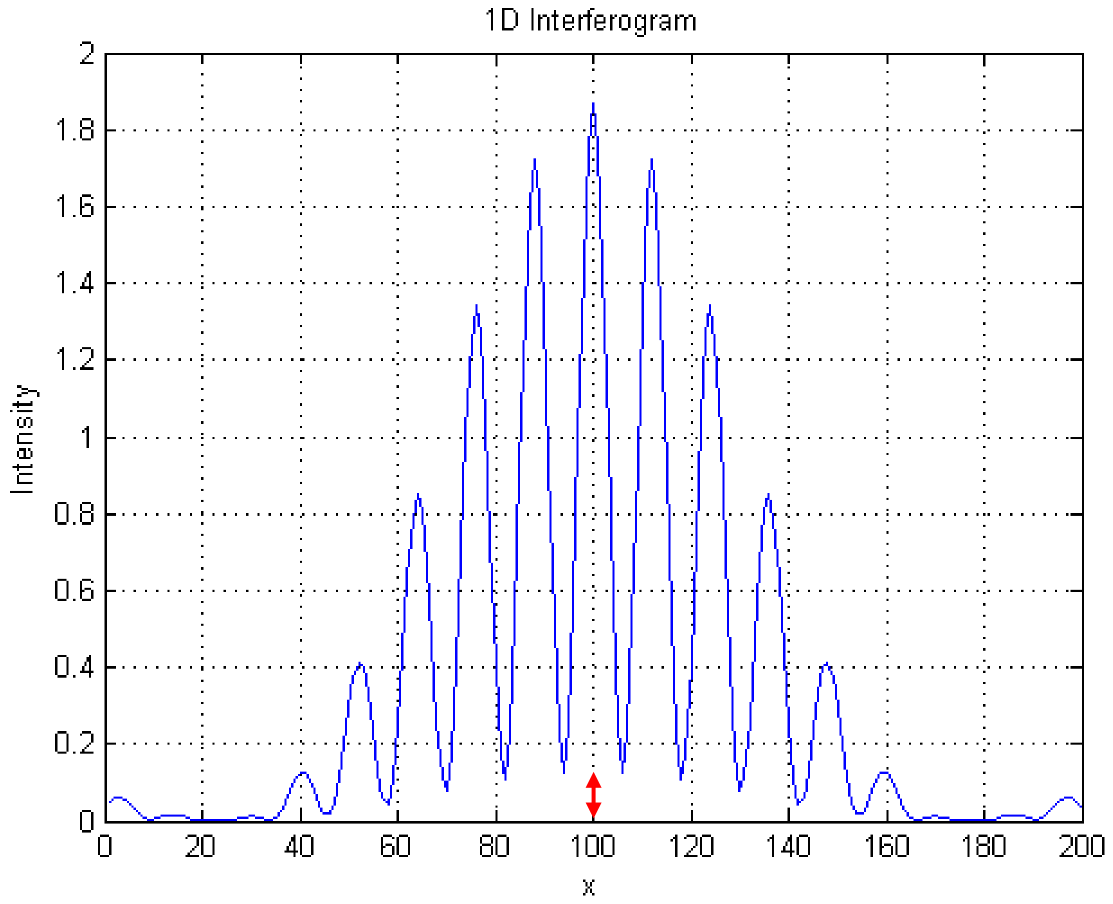
- k = 0.65
  - Wave length of light
- a = 0.2
  - Half width of slit
- b = 0.1
  - Source size
- c = 8
  - Distance between two slits



미래기반 가속기 전문인력양성 사업단

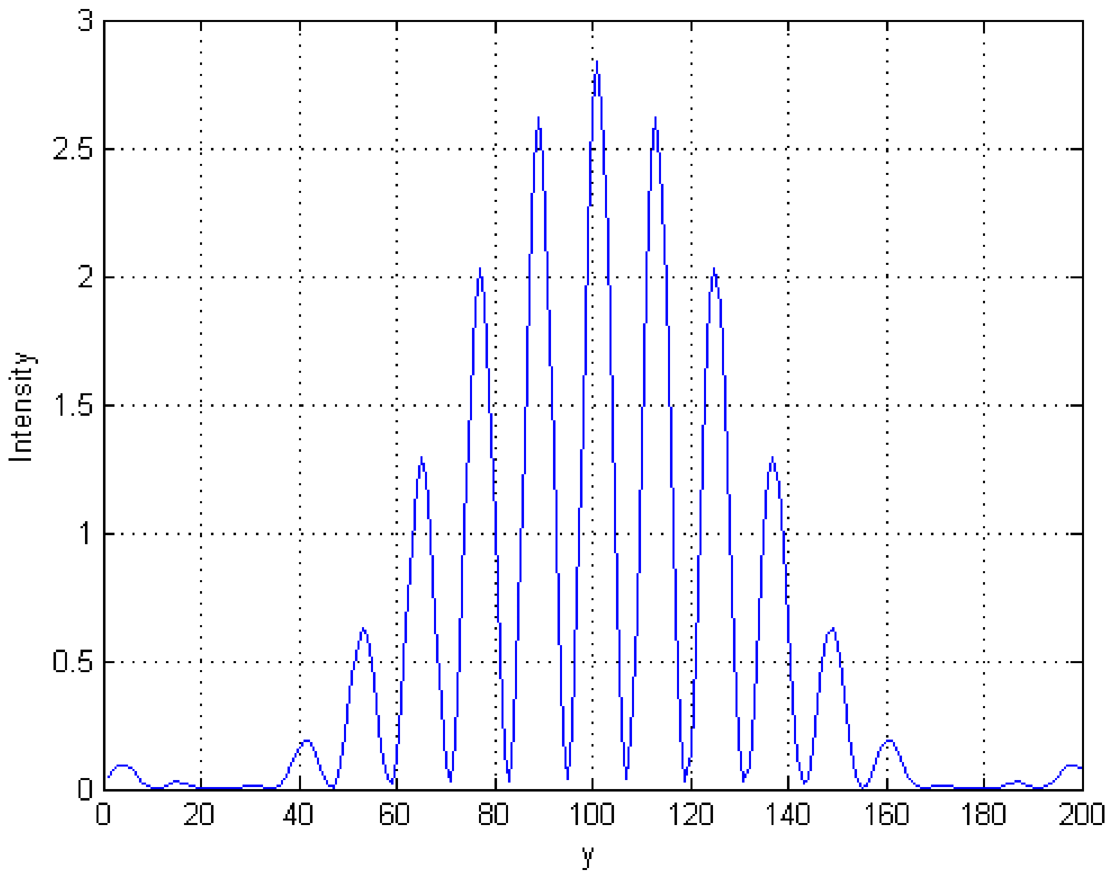
Simulation Result

- $k = 0.65$
  - Wave length of light
- $a = 0.2$
  - Half width of slit
- $b = 0.2$
  - Source size
- $c = 8$
  - Distance between two slits



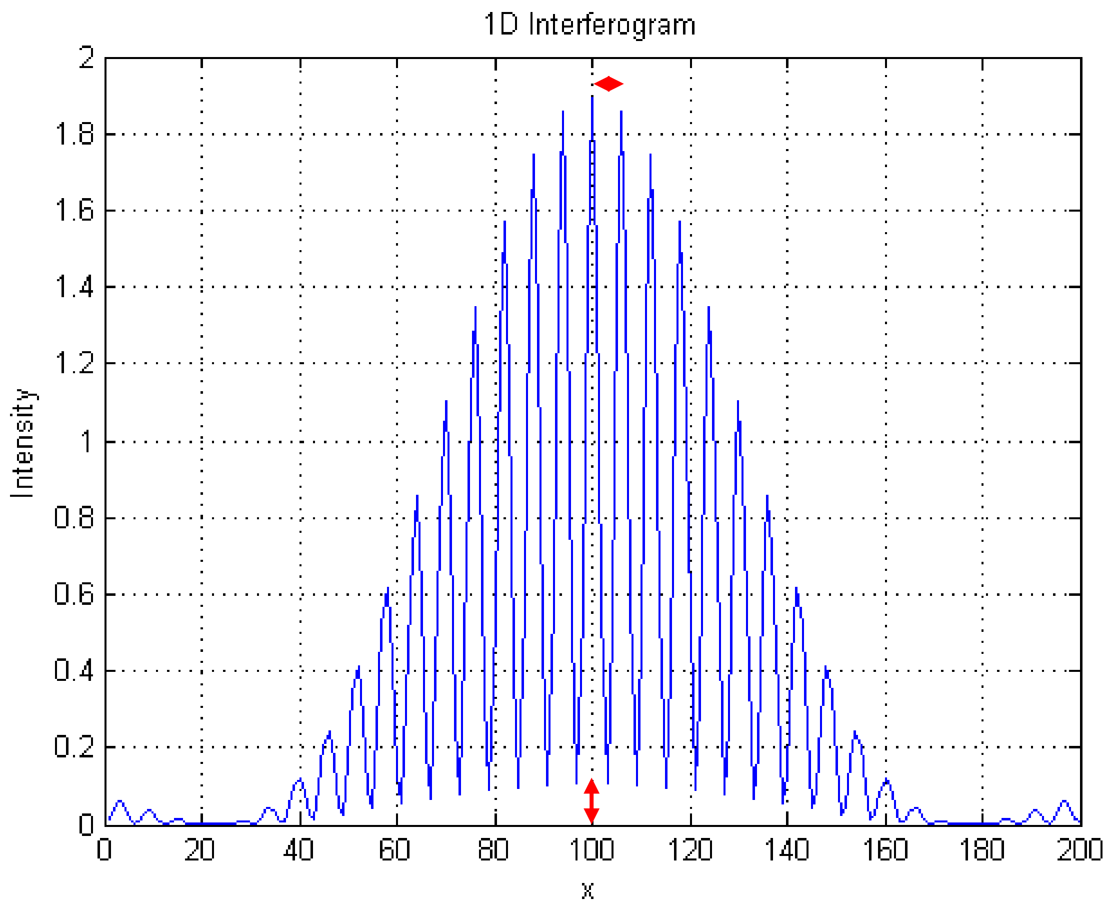
Simulation Result

- $k = 0.65$
  - Wave length of light
- $a = 0.2$
  - Half width of slit
- $b = 0.1$
  - Source size
- $c = 8$
  - Distance between two slits



Simulation Result

- $k = 0.65$
  - Wave length of light
- $a = 0.2$
  - Half width of slit
- $b = 0.1$
  - Source size
- $c = 16$
  - Distance between two slits



Slit Optimization of SR Interferometer

- Variable parameters
  - Width of slit, Distance between two slits
- Width of slit
  - Related to image size and intensity
- Distance between two slits
  - Related to local minimum and peak distance
    - Beam size can not be measured if local minimum is close to zero
    - Error can be increased if peak distance is too small

실험 방법

- 1B 진단 빔라인의 구조를 이해한다.
- SR Interferometer 구조를 알아보고 빔 크기 측정 원리를 이해한다.
- Slit 간격을 변화시킬 때 간섭무늬의 변화를 관찰한다.
- 빔 크기를 측정하는 최적 조건을 생각해본다.