X-ray SR (XSR) monitor at KEK-ATF damping ring

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-Hiroshima Univ. [C] -

- Apparatus of XSR monitor
- Performance of XSR monitor
- Comments of XSR monitor

See details in ref: H.Sakai et al., Phys Rev. ST Accel. Beams 10,041801 (2007)

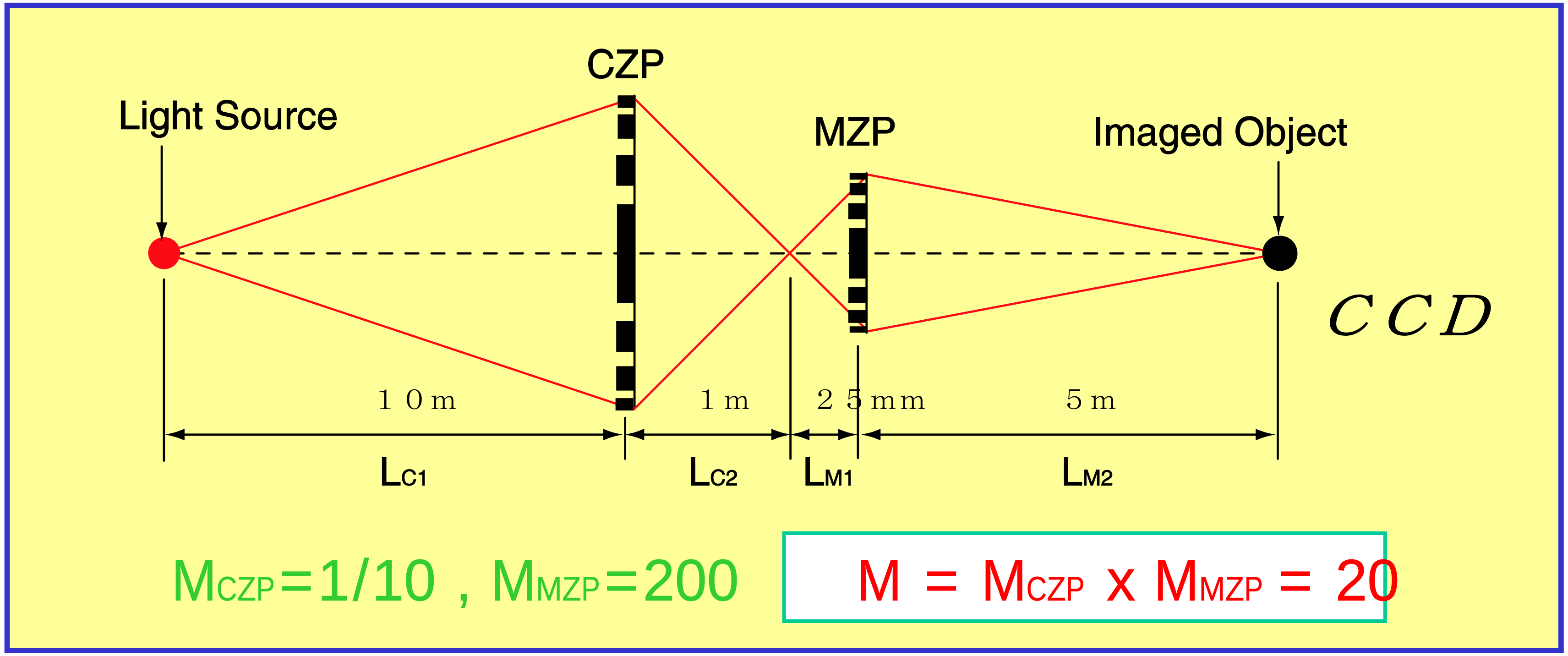
- ILCDR 08 , Cornell Univ. -

Apparatus of XSR monitor

Introduction of X-ray SR (XSR) monitor

- Motivation
  - The FZP monitor is aimed to measure the small electron beam size (<10μm) appeared at the ultra low emittance ring like linear-collider damping ring , 3rd generation synchrotron light source and future light sources like ERL (Energy Recovery Linac).
- Features
  - High spatial resolution (<1 μm)
    especially for 1pm vertical emittance
  - Non-destructive measurement
  - 2-dimentional (x,y) beam profiling
  - Real time beam profile mesurement (<1ms)

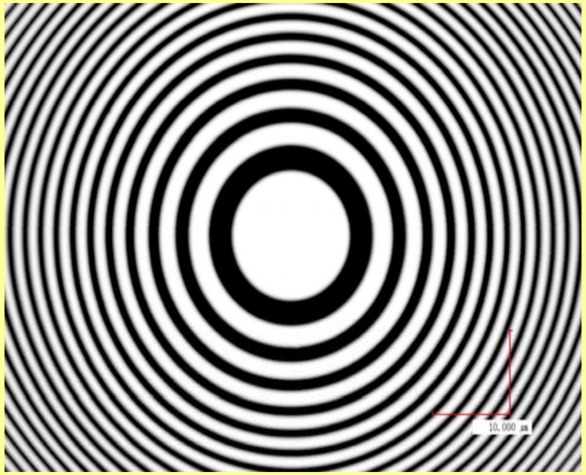
Principle of XSR monitor



•Monochromated **X-ray SR(3.235keV)** from bending magnet is used.
→ *Reduce the diffraction limit from SR-light.*

• ***Two*** **Fresnel zone plates (FZPs)** are used
→ *The 20 times magnified beam image is obtained at X-CCD.*

Fresnel Zone Plate (FZP)



$$r_n = \sqrt{n f \lambda}$$

λ: wave length

n: zone number

f: focal length

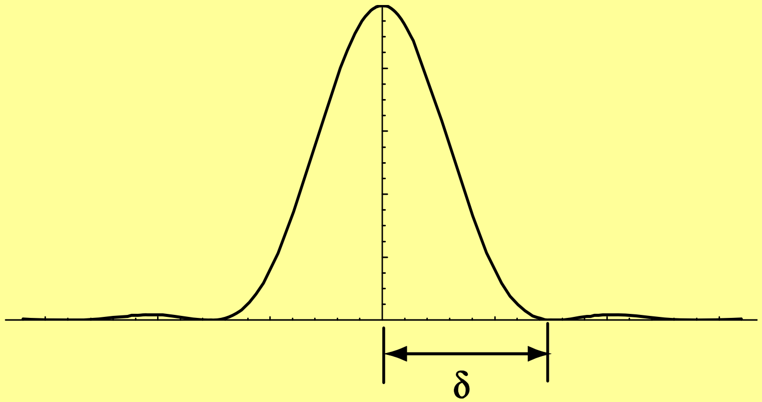
$$\delta = 1.22\,\Delta r_N \approx 3\sigma$$

$$\Delta r_N = \frac{1}{2}\sqrt{\frac{f\lambda}{N}} = \frac{f\lambda}{2 r_N}$$

Δr_N : Most outer zone width

Airy pattern

Diffraction pattern of FZP



Spatial resolution is also determined by **most outer zone width** of FZPs

Total spatial resolution of XSR monitor

Parameters	Definition	Resolution(1σ)
Diffraction limit (3.235keV)	$\lambda/4\pi\sigma_{SR}$	0.24 [μm]
CZP (Δr_N=116nm)	σ_{CZP} / M_{CZP}	0.55 [μm]
MZP (Δr_N=124nm)	σ_{MZP} / (M_{CZP} x M_{MZP})	0.002 [μm]
CCD (1 pixel=24μm×24μm)	σ_{CCD} / (M_{CZP} x M_{MZP})	0.35 [μm]
Total	--	0.7 [μm]

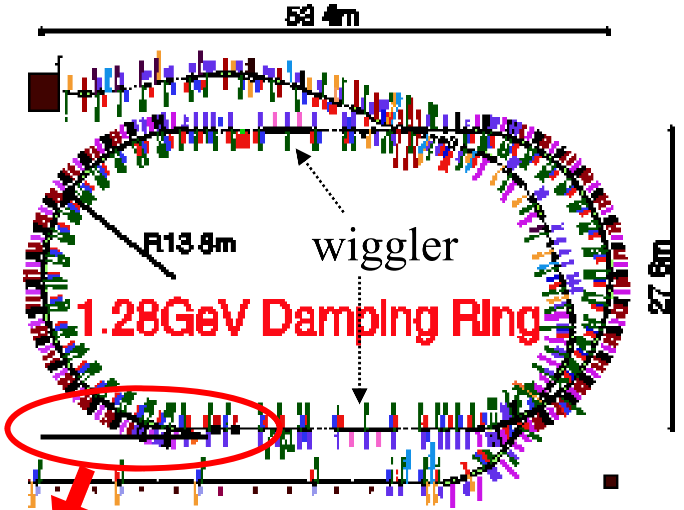
M_{CZP} = 1/10 , M_{MZP} = 200, M_{CZP} x M_{MZP} = 20

The total spatial resolution is 0.7μm in R.M.S .

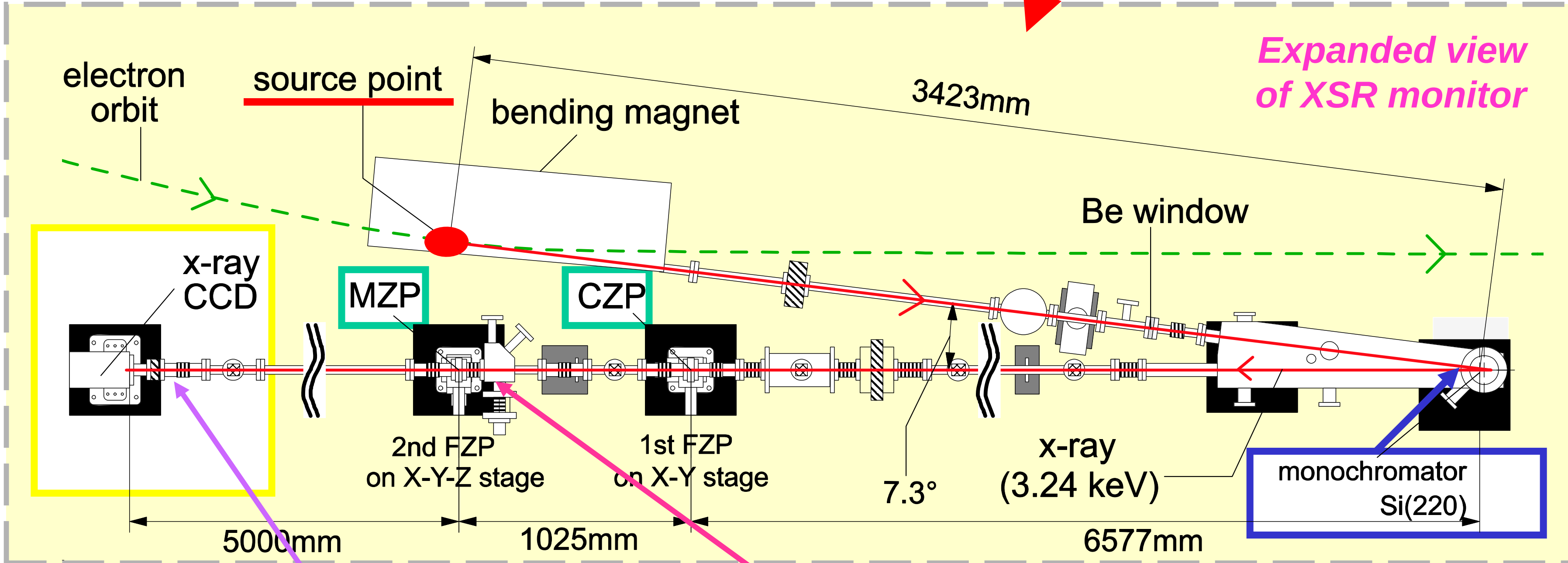
↓

Submicron spatial resolution will be expected on this XSR monitor.

Setup of XSR monitor



XSR monitor was installed at KEK-ATF damping ring.
Expected beam sizes are
Horizontal: 50µm, Vertical: <10µm

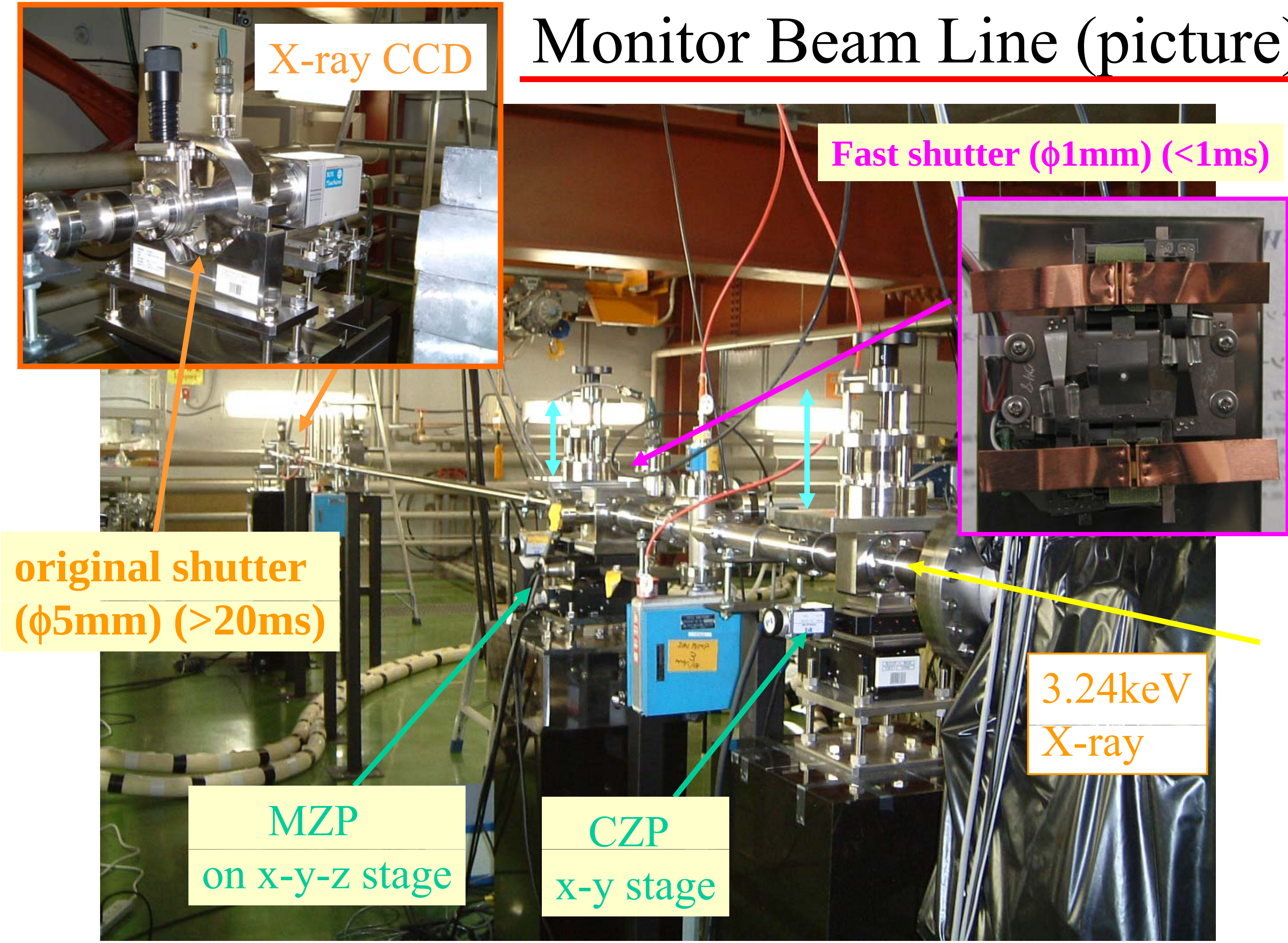


Original shutter was set in front of CCD camera [shutter time >20ms]

fast mechanical shutter (opening shutter time <1ms)

→ Avoid 50 Or 100Hz AC line noise

Monitor Beam Line (picture)



Photon Flux

Energy E=1.28 [GeV]

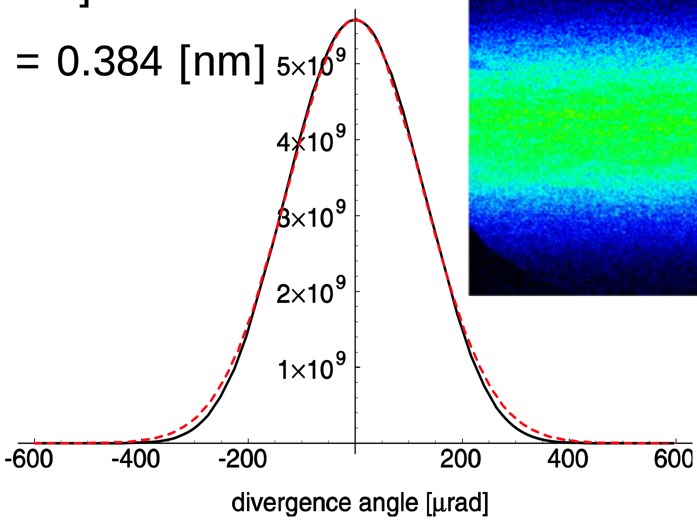
Bending field B=0.748 [T]

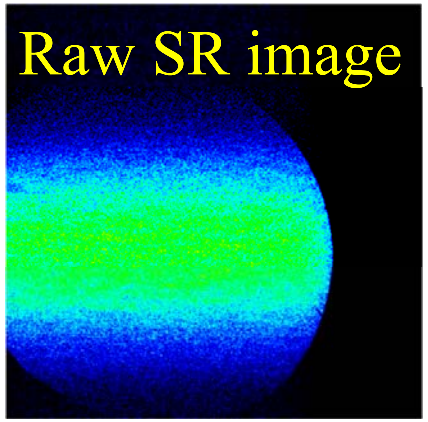
Critical length λ_C =1.52 [nm]

$$\sigma_{SR}[\text{mrad}] = 0.289\left(\frac{\lambda}{\lambda_C}\right)^{0.425} \Big/ E\,[\text{GeV}]$$

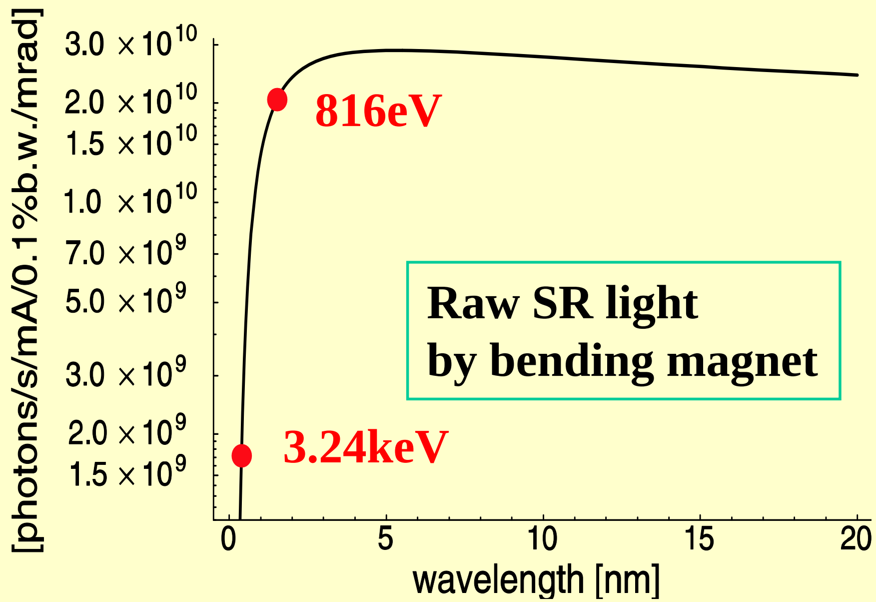
σSR =126 [μrad]

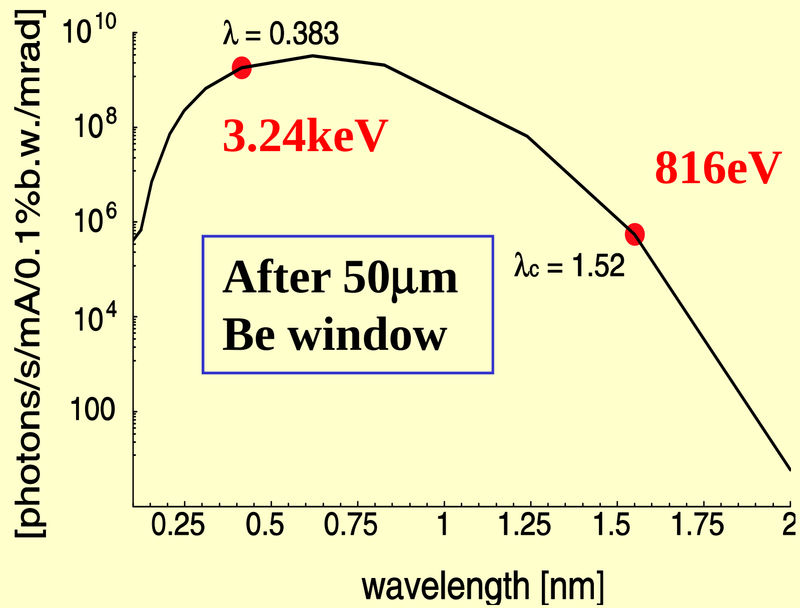
λ = 0.384 [nm]





Photon flux by XSR source point

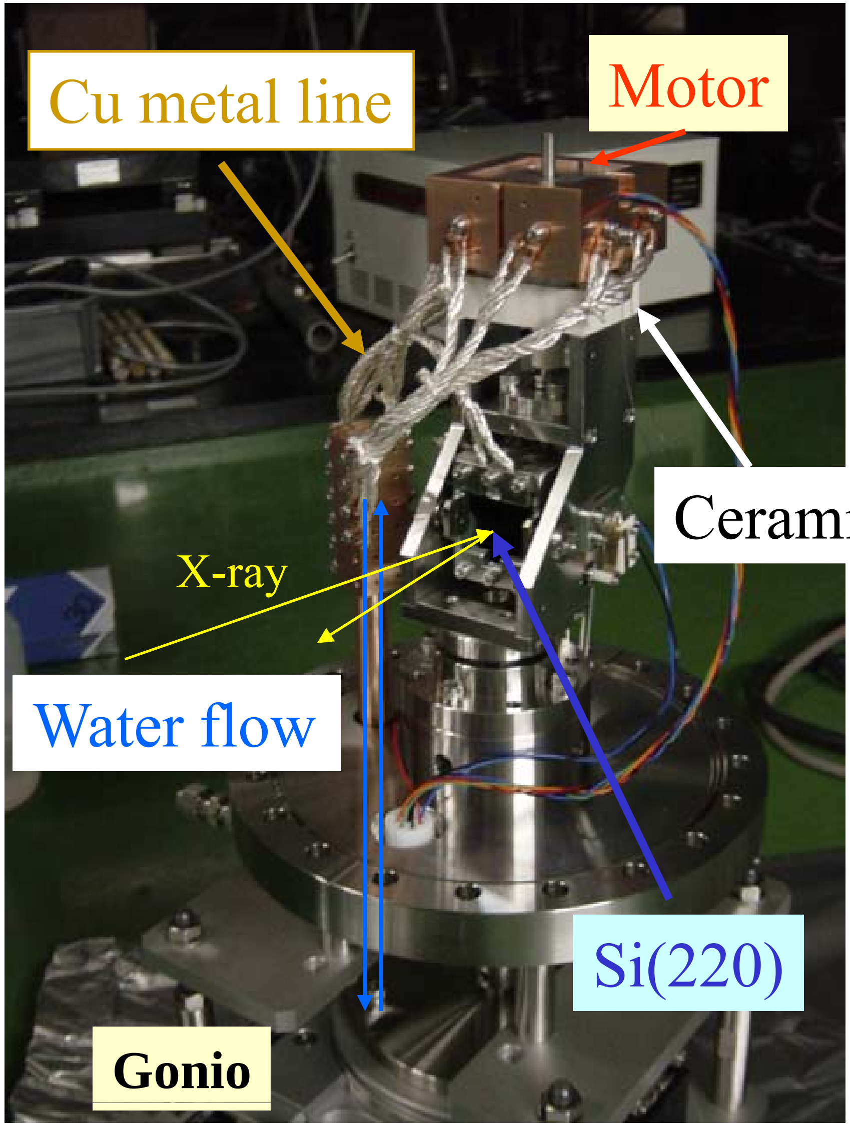




Monochromator

Crystal	Si (220)
Grid interval	d = 0.192 [nm]
Bragg angle	θ_B = 86.35 deg
Wave length	$\lambda = d \sin\theta_B$ = 0.383 [nm] (3.235keV)
Energy resolution	$\frac{\Delta\lambda}{\lambda} = 5.6\times10^{-5}$

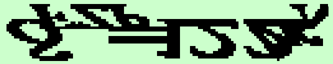
Enough energy resolution for avoiding chromatic abberation of FZP (1.3 x 10^{-4} (1μm beam size case))



Mirror angle drift is reduced less than a few μrad by adding the water cooling

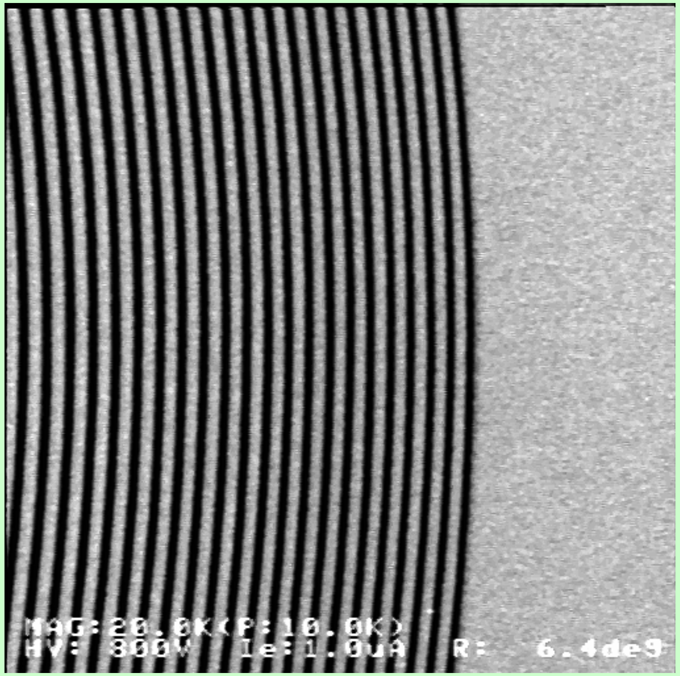
Fresnel Zone Plates

Parameters of two FZP (λ = 0.383 nm)

FZP resolution defined by 

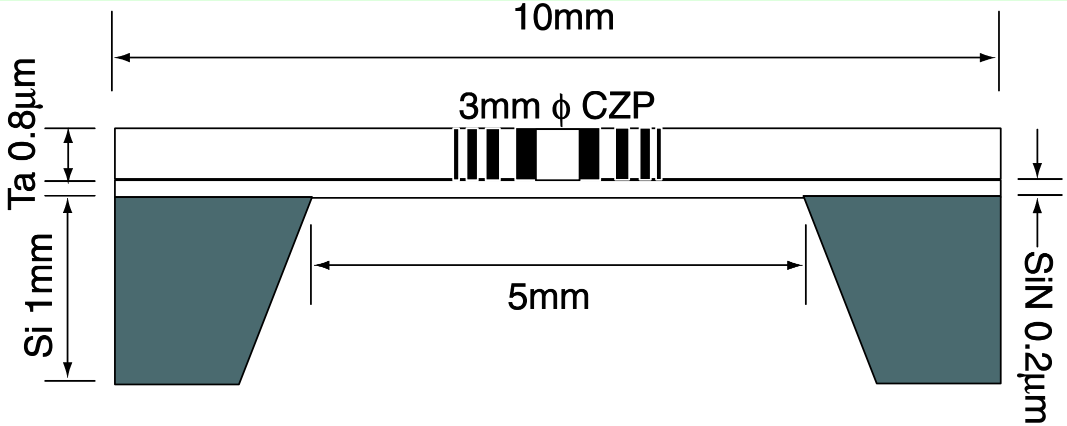
	CZP	MZP
Number of Zone	6444	146
Radius	1500 μm	37.3 μm
Most outer zone width Δr_N (δ_{FZP})	116nm (142nm)	128nm (156nm)
Focal length f	909mm	24.9mm
Magnification	1/10	200

Outer zone of MZP by SEM



Cross Section of FZP

Produced by
NTT-AT corp.



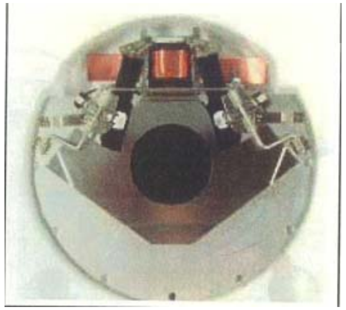
X-ray CCD

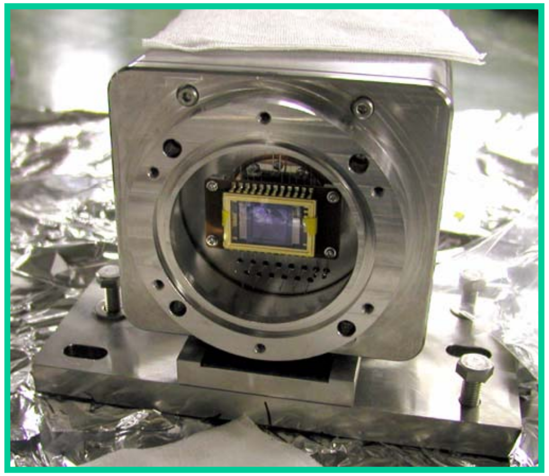
CCD	Backward full frame transfer type
Area	12.29 mm x 12.29 mm
Pixel size	24 µm x 24 µm
Quantum effeciency	< 90 % (3.24 keV)
Cooling	Peltier **(-50 C^o)**
Dark current	2 electrons/pixels/sec
Scanning speed	7 frame/sec (Live) 0.5 frame/sec (Acquire)
Shutter speed	Less than 20ms

C4880-21-24-WD

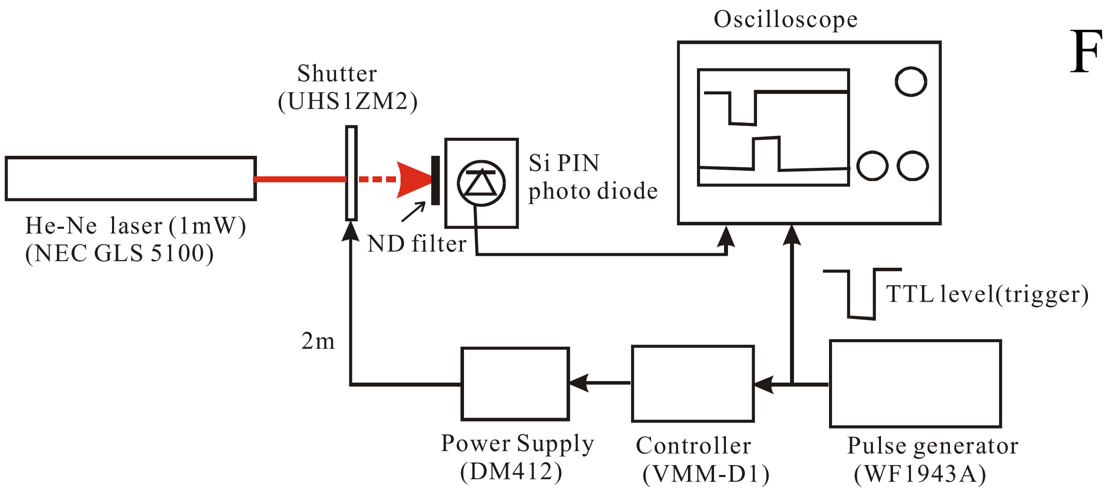
(made by Hamamatsu K.K)

X-ray shutter

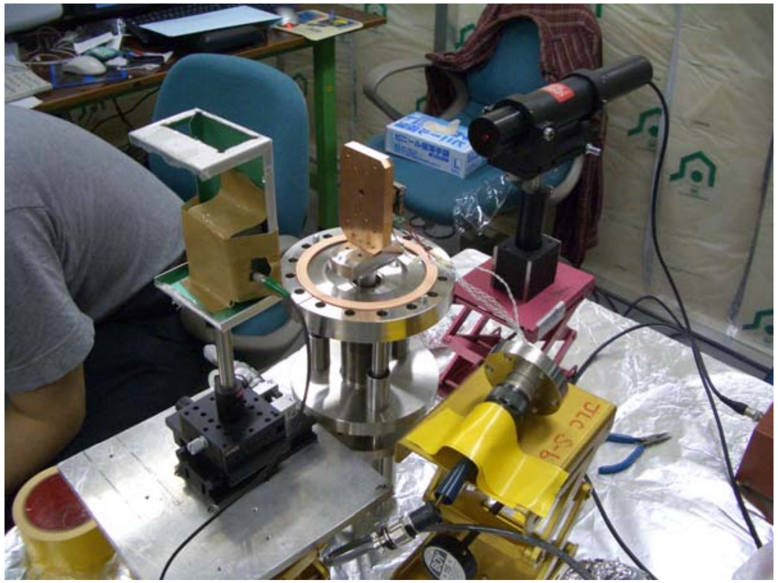


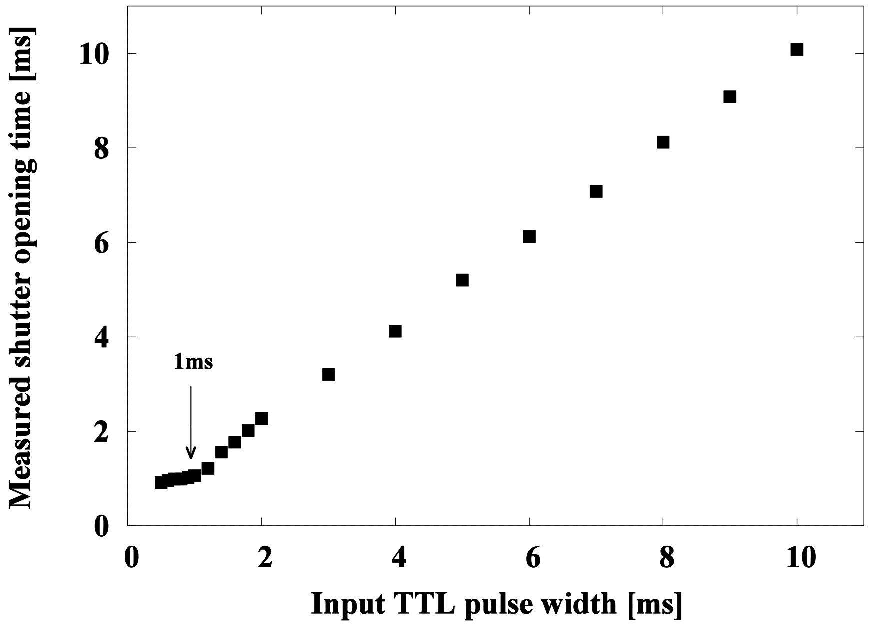


Fast shutter performance at test bench



Horizontal : width of input TTL pulse
Vertical : measured shutter width by using laser and PIN photo diode



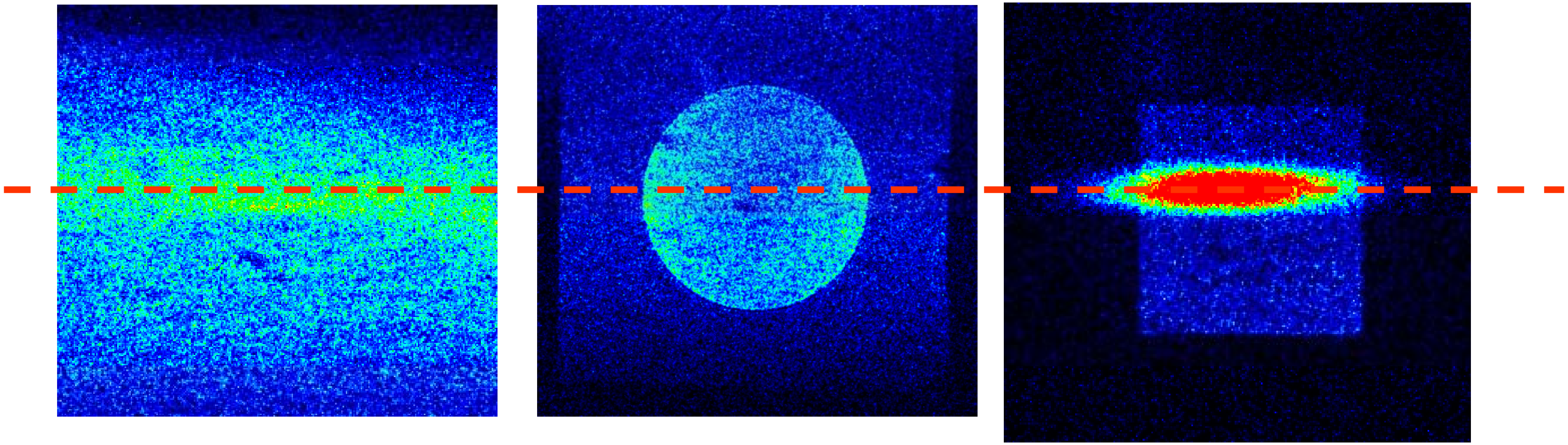


Minimum width of shutter opening time is less than 1ms

Performance of XSR monitor

Alignment strategy

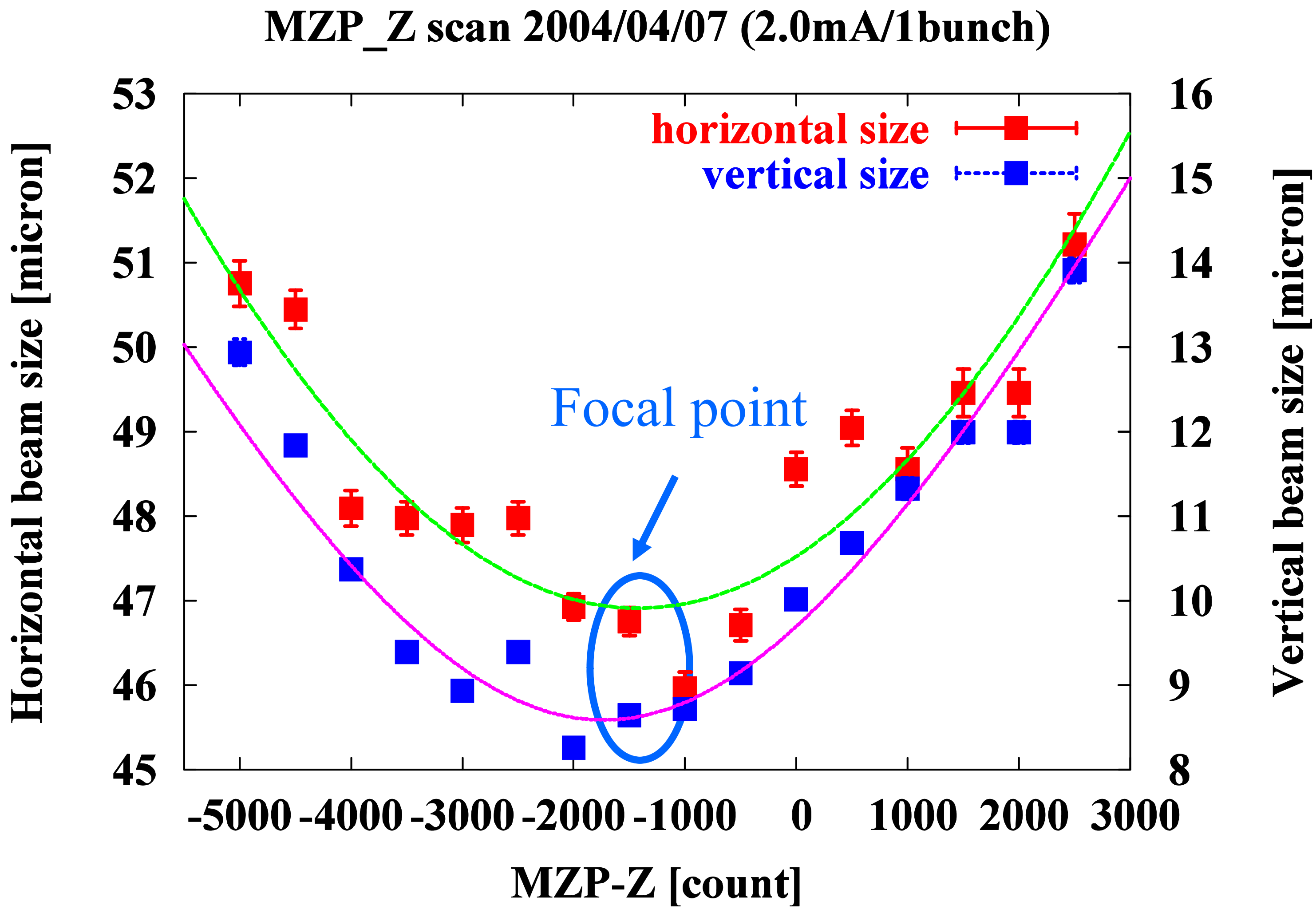
1 2 3



See direct SR light / Enter the CZP / Enter the MZP

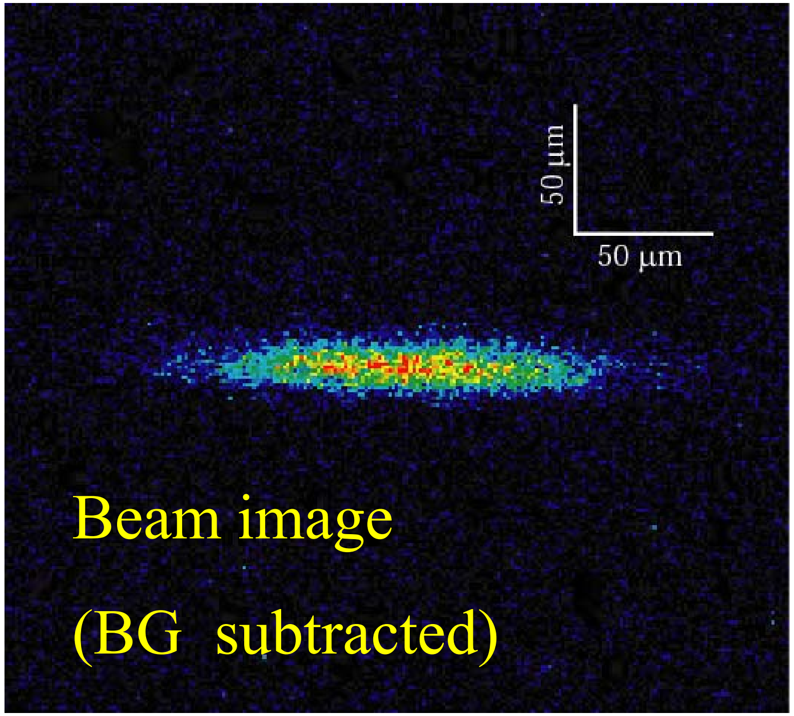
All of the image centers were adjusted on SR light center.

MZP z-scan



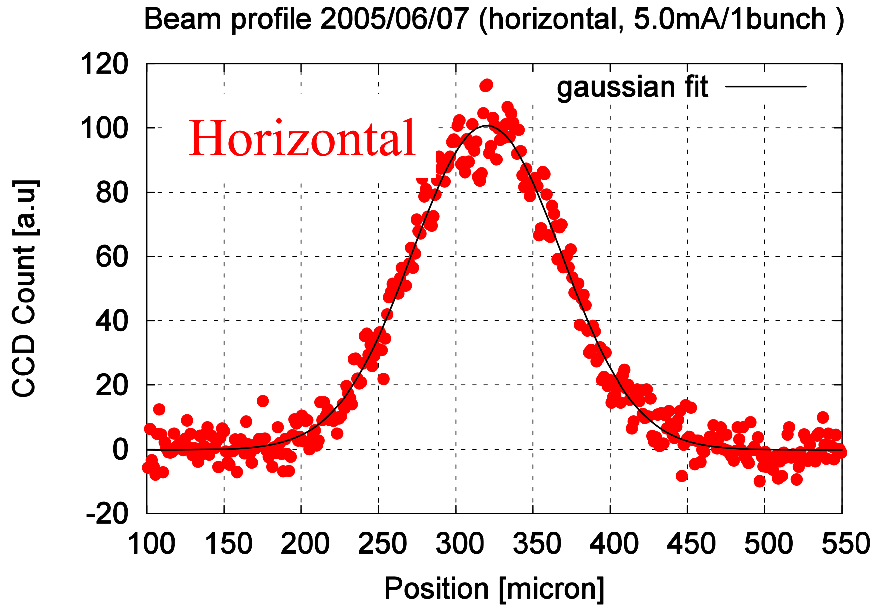
Find the focal point on X-CCD by moving MZP longitudinally.

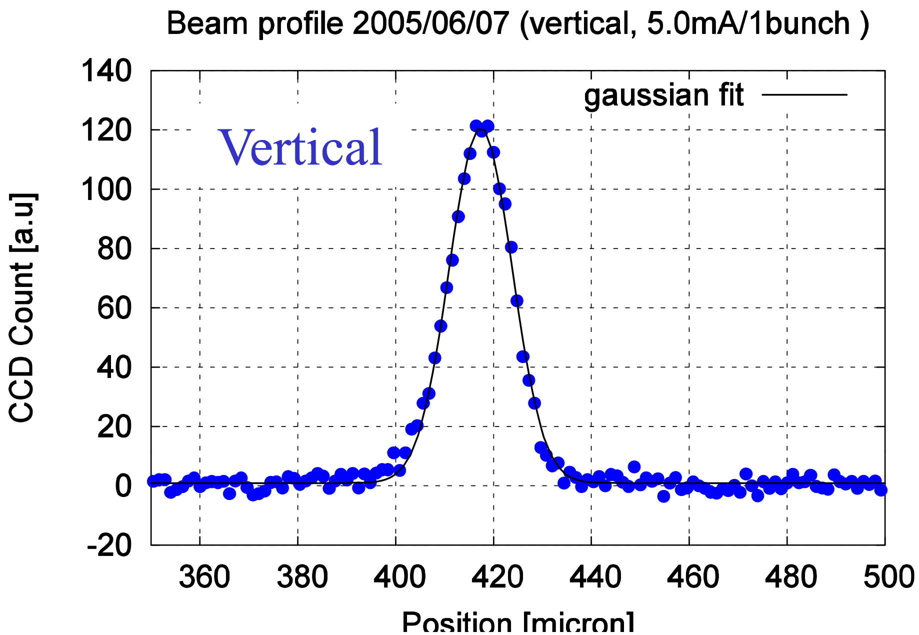
Example of beam image (fast shutter with 1ms)



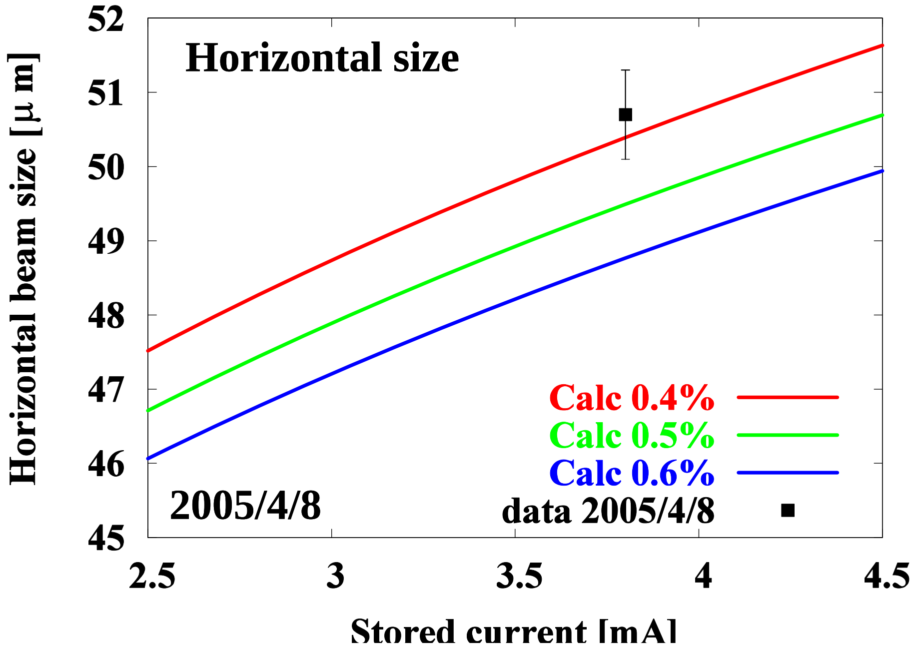
I=5.0mA, Shutter time = 1ms
(2005/06/07)

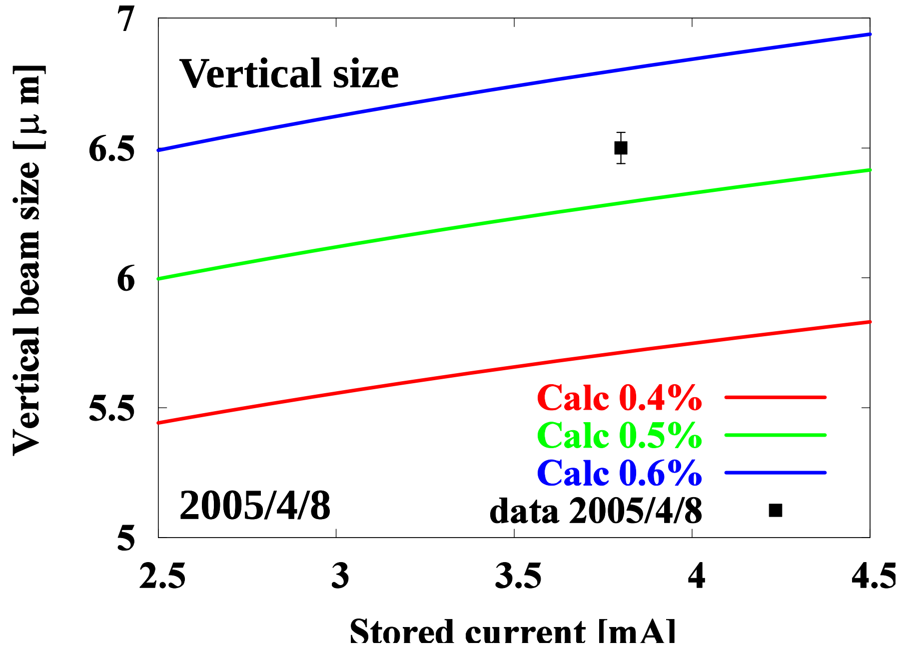
$\sigma_x = 48.2 \pm 0.5$ [μm]
$\sigma_y = 6.4 \pm 0.1$ [μm]

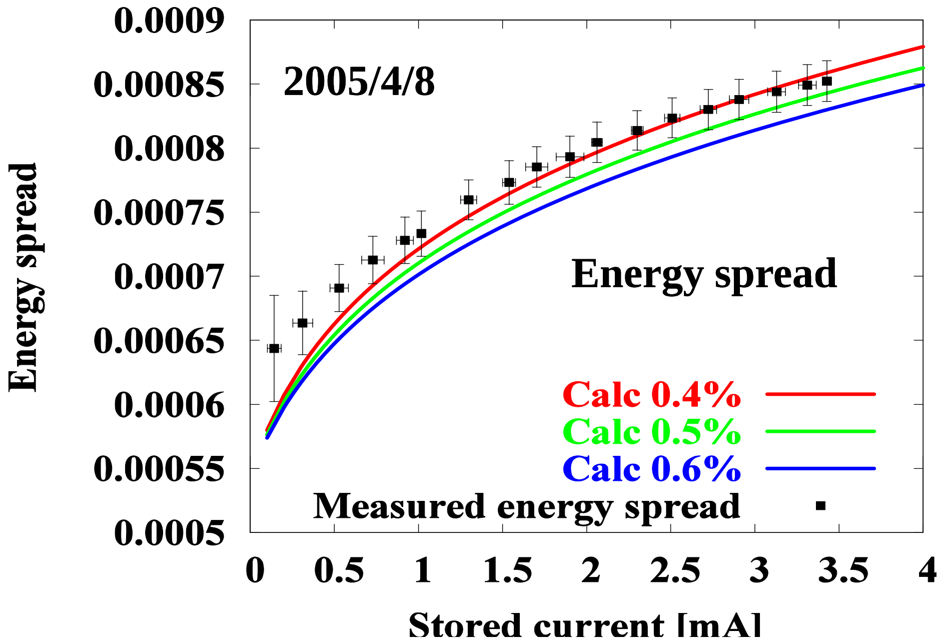




Measured sizes by XSR monitor and calculation

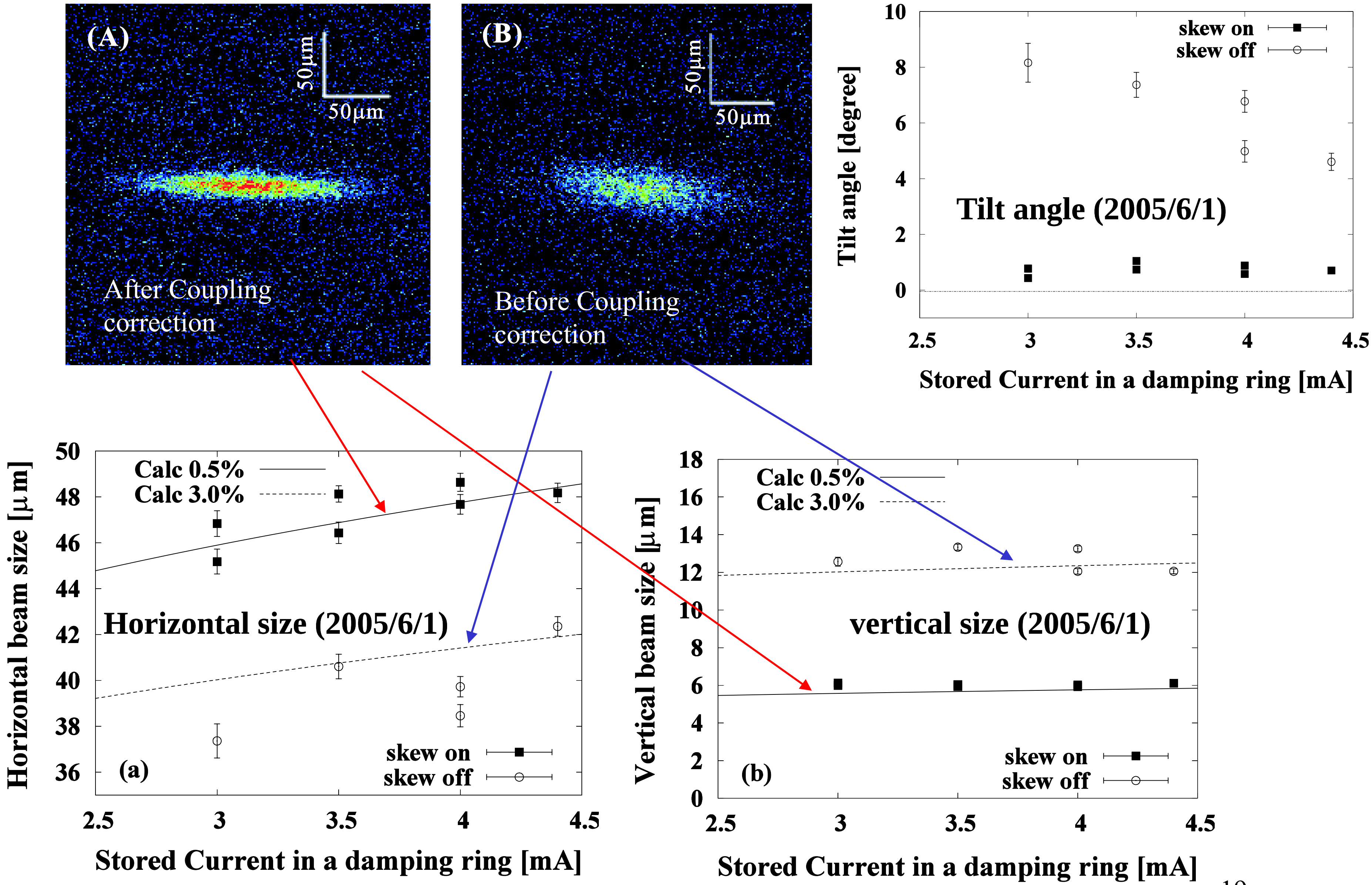






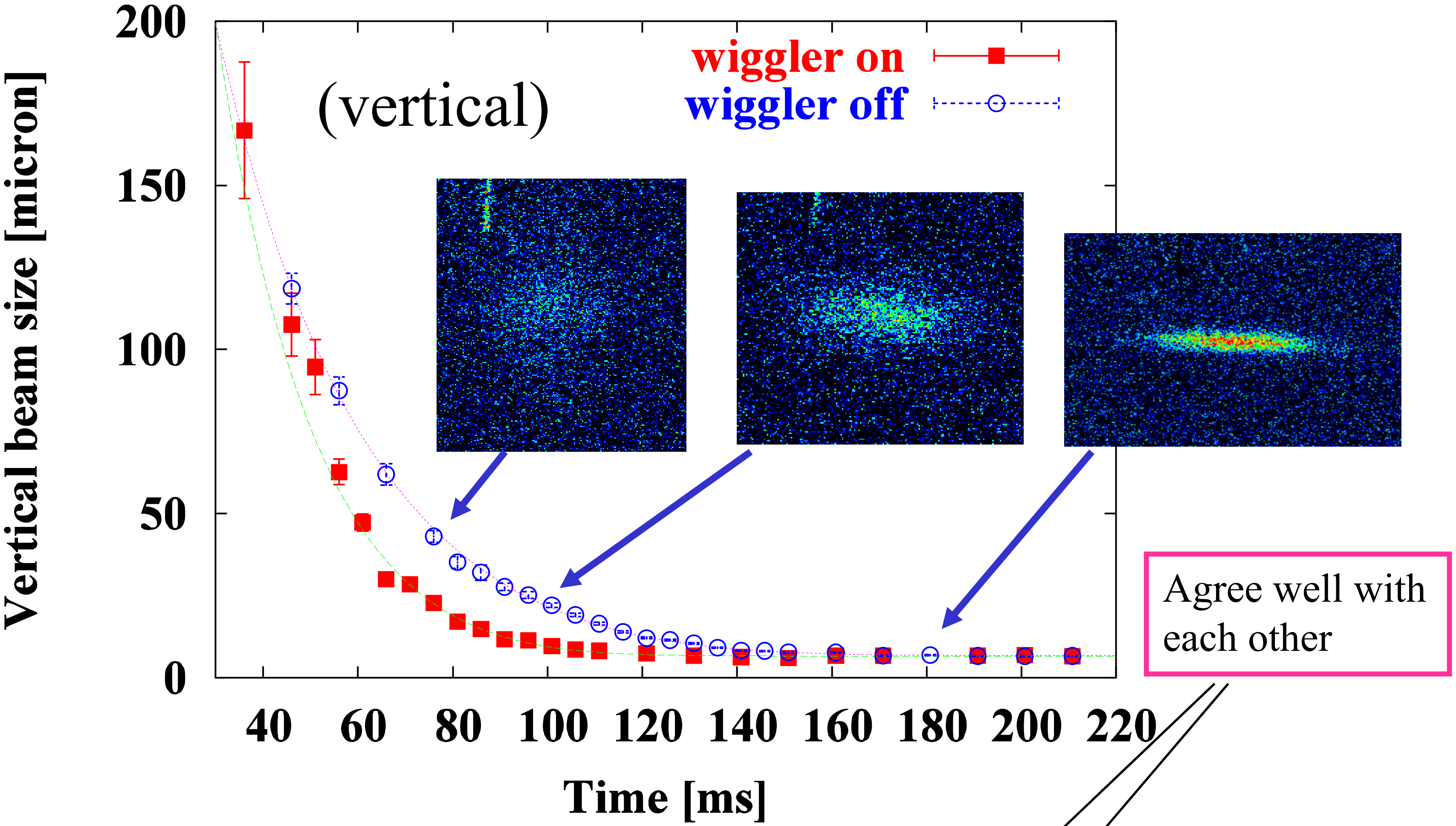
Three measurements (horizontal and vertical beam size by XSR monitor and energy spread by screen monitor at the extraction line plotted by black squares) agree well with the calculation (SAD) results including intrabeam scattering by assuming the betatron coupling of (0.5+-0.1) % (solid and dotted lines)

Coupling correction and dependence by XSR monitor



Beam size and beam tile are also measured

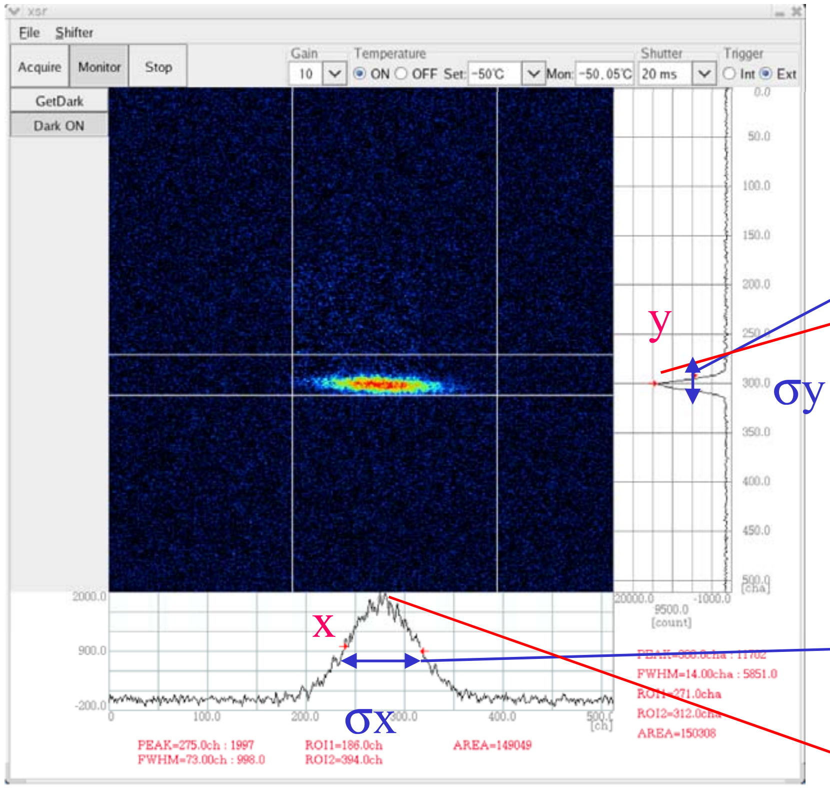
Measurement of damping time by XSR monitor

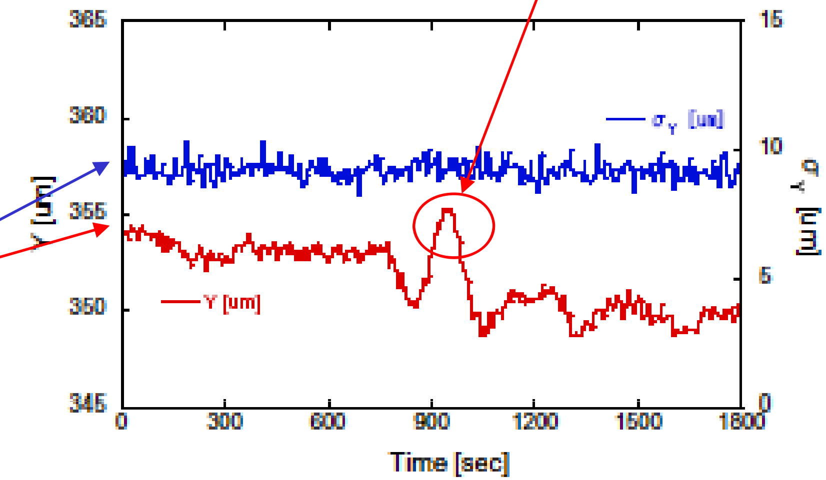


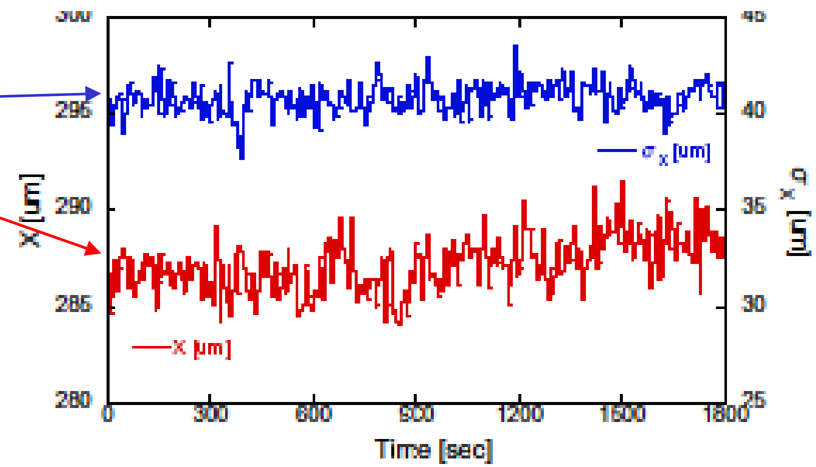
	Measurement of FZP monitor	Calculation (SAD)
Wiggler off	(30.9±0.6) ms	28.5ms
Wiggler on	(20.7±0.8) ms	21.1ms

Measurement of long term stability by XSR monitor

We can see the beam orbit drift correlated with BPM data (Libera)







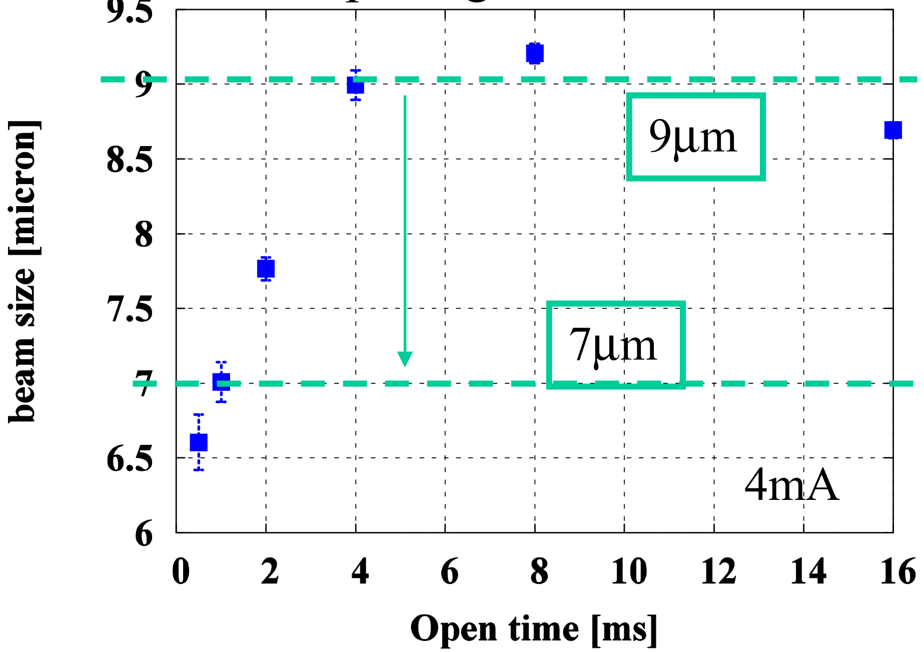
Not only the beam sizes but also beam positions of XSR monitor were routinely measured on ATF controll room. Position resolution is assumed to be less than 1um (it's depended on the beam size).

Comments and issues of XSR monitor (mainly practical case)

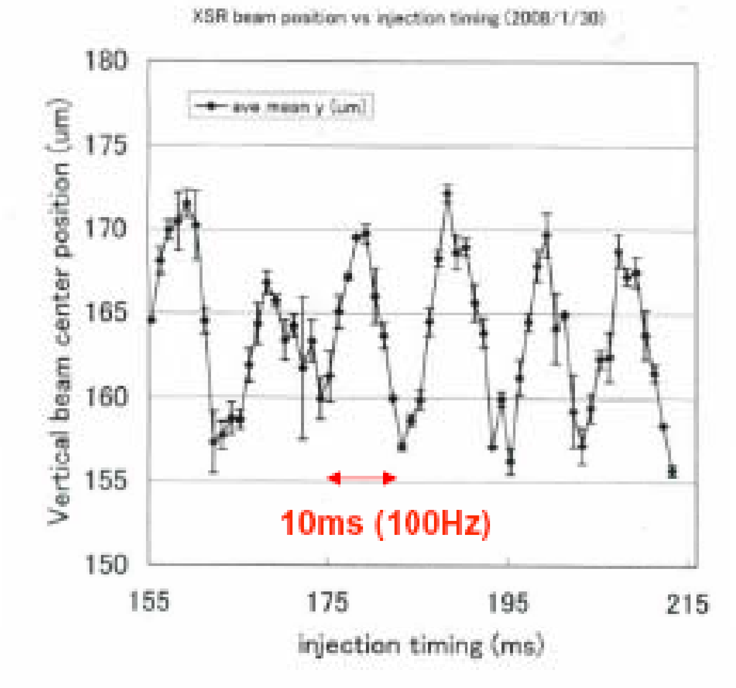
- 100Hz oscillation problem
- Vegnitting effect of MZP aperture
- Durability of mechanical shutter

100Hz oscillation problem

Vertical beam profile vs Shutter opening time

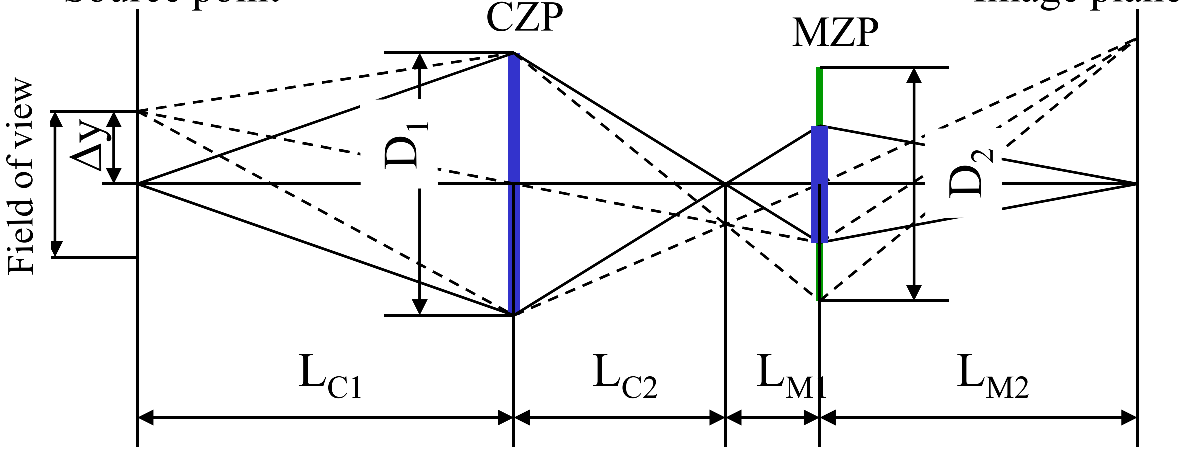


Vertical beam position vs injection timing



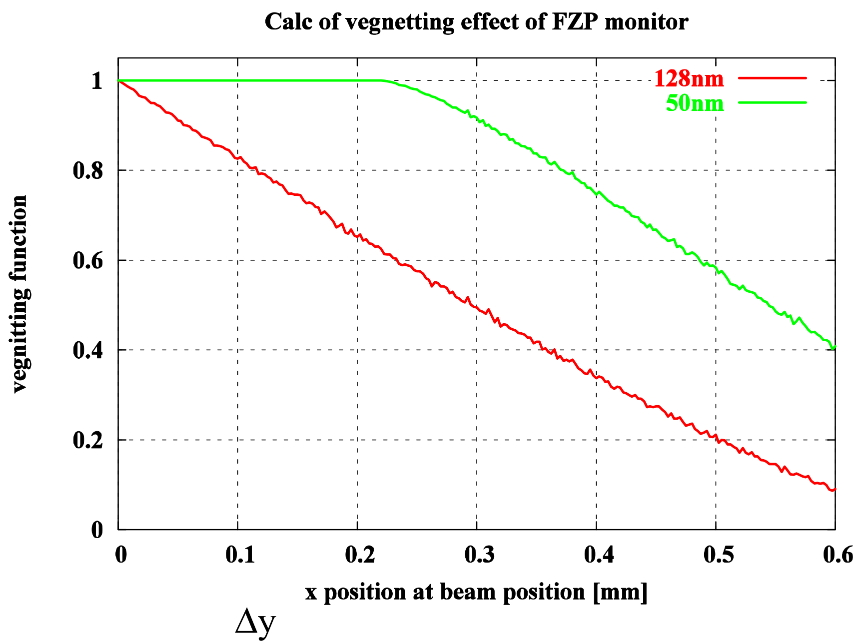
The measured vertical beam size was changed from 9μm to 7μm by changing the shutter opening time from 4ms shorter. This caused by the 100Hz oscillation of measured beam profile by XSR monitor. This could be removed by using fast shutter with 1ms opening time now. But to increase the S/N ratio of beam profile, we need to survey the source of 100Hz oscillation. Until now, we did not find the source of oscillation on both XSR monitor itself and beam motion (by Libera).

Vegnitting effect



Vegnitting effect:
Decreasing of field of view by finite MZP aperture

$$\Delta r_N = \frac{1}{2}\sqrt{\frac{f\lambda}{N}} = \frac{f\lambda}{2r_N}$$



MZP	present	New design
Radius r_N (=D_2/2)	37.3 µm	60.0µm
Δr_N	128nm	50nm

Recently fabrication technique is improved. If we apply the large aperture MZP with 50nm most outer zone width. Field of view can be enhanced to almost 250um range as shown in left figure.

Summary

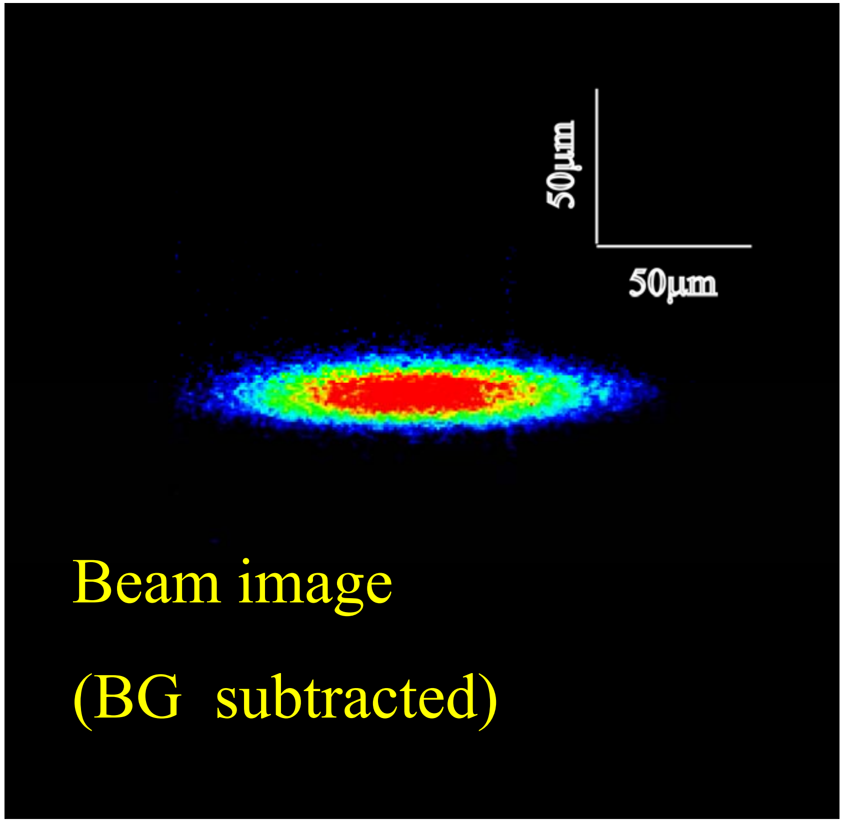
- We measure the beam size by using FZP monitor at KEK-ATF damping ring. The measured vertical beam size of this monitor was almost 6μm.

- The measured horizontal and vertical beam sizes by XSR monitor and the measured energy spread agreed well with the calculation by assuming the coupling ratio with 0.5+-0.1 % with including intra beam scattering .The damping time of ATF damping ring with/wihout wiggler and coupling dependence were clearly measured by using XSR monitor.

- Not only beam profile but also beam position and beam tilt are also measured within 1μm resolution. This monitor now routinely used as beam profile and beam position monitor with almost 1μm resolution.

References

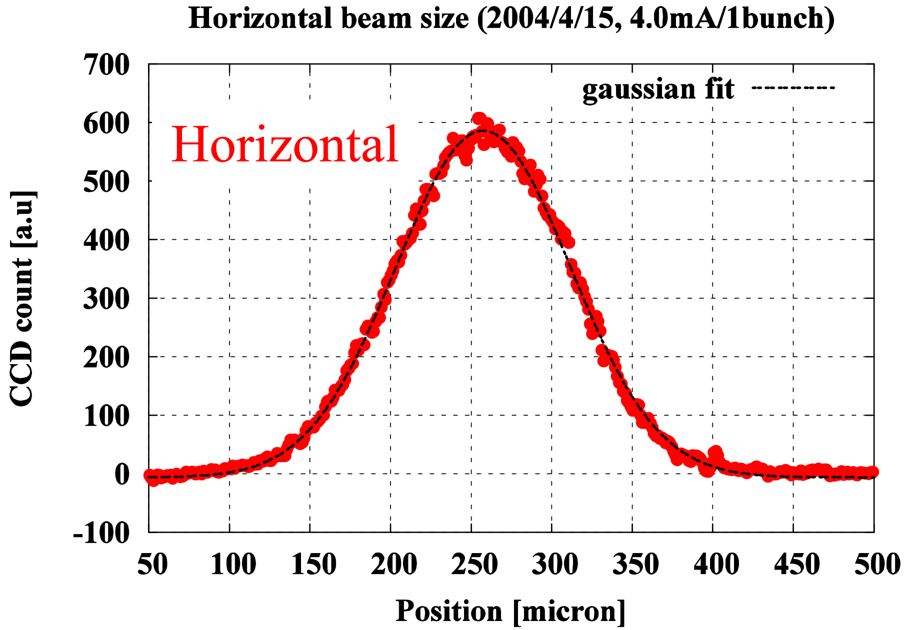
Example of beam image (shutter with 100ms)

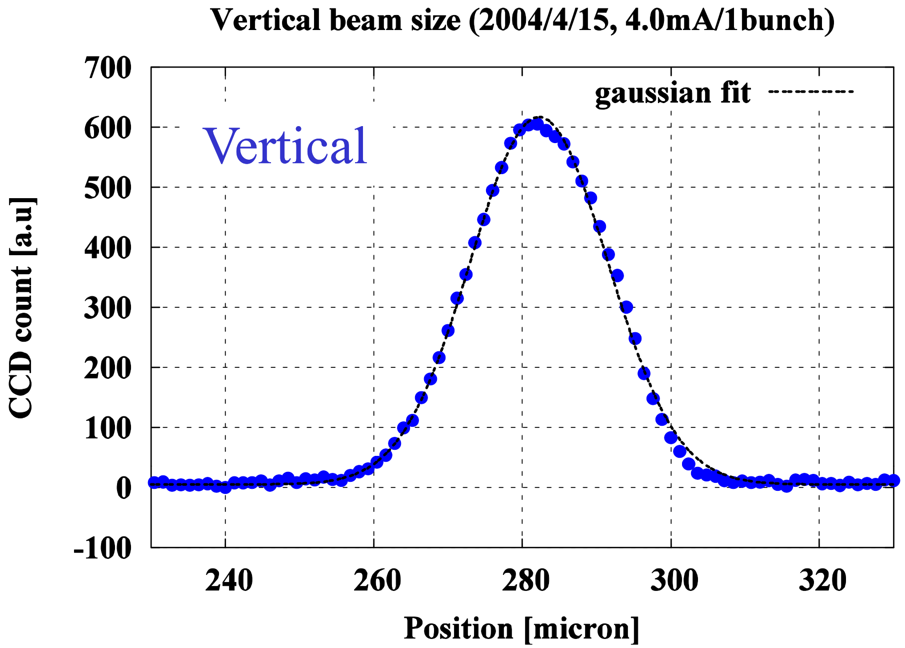


I=4.0mA, Shutter time = 100ms
(2004/4/15)

$\sigma_x = 54.2 \pm 0.2$ [μm]

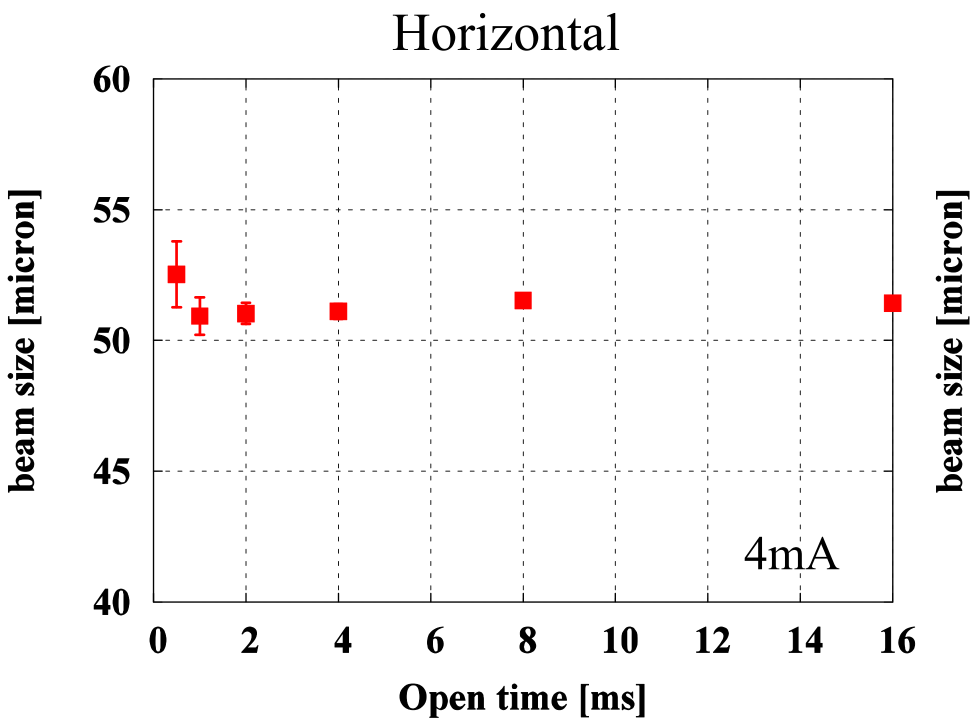
$\sigma_y = 9.2 \pm 0.1$ [μm]

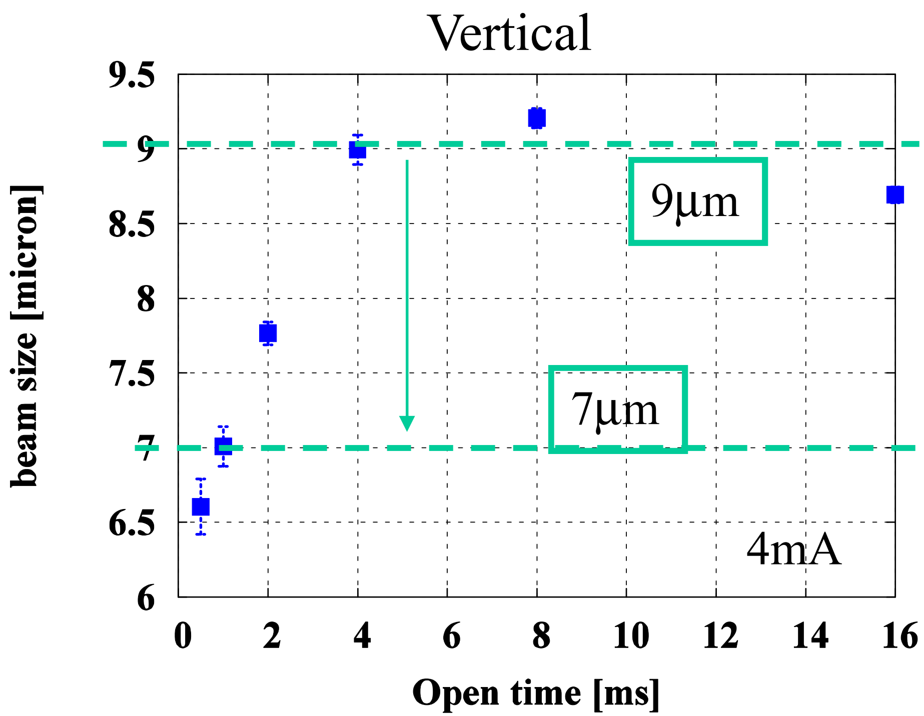




Shutter opening time dependence

Measure the beam size by changing shutter opening time.

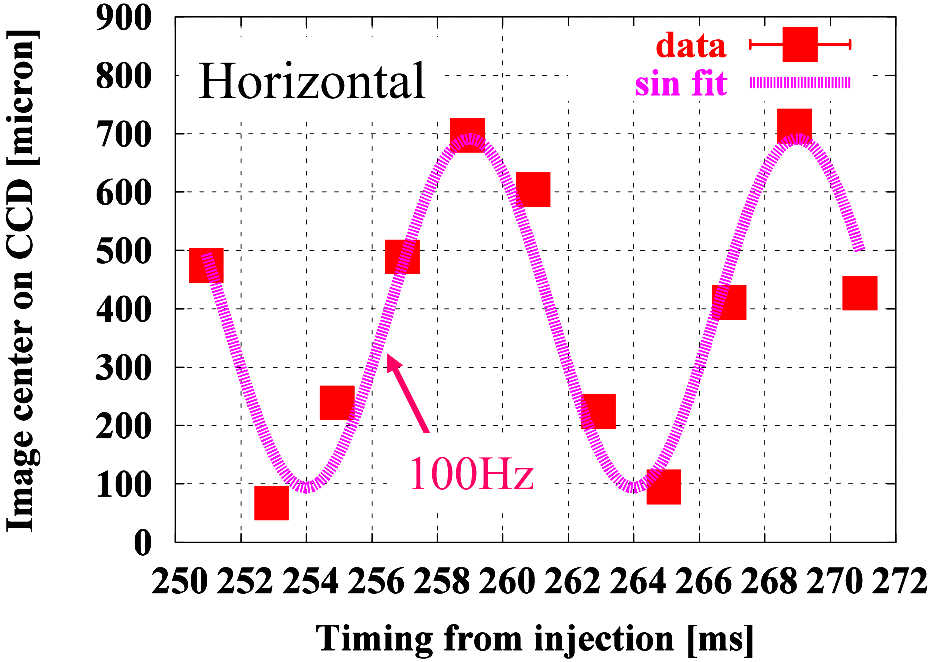


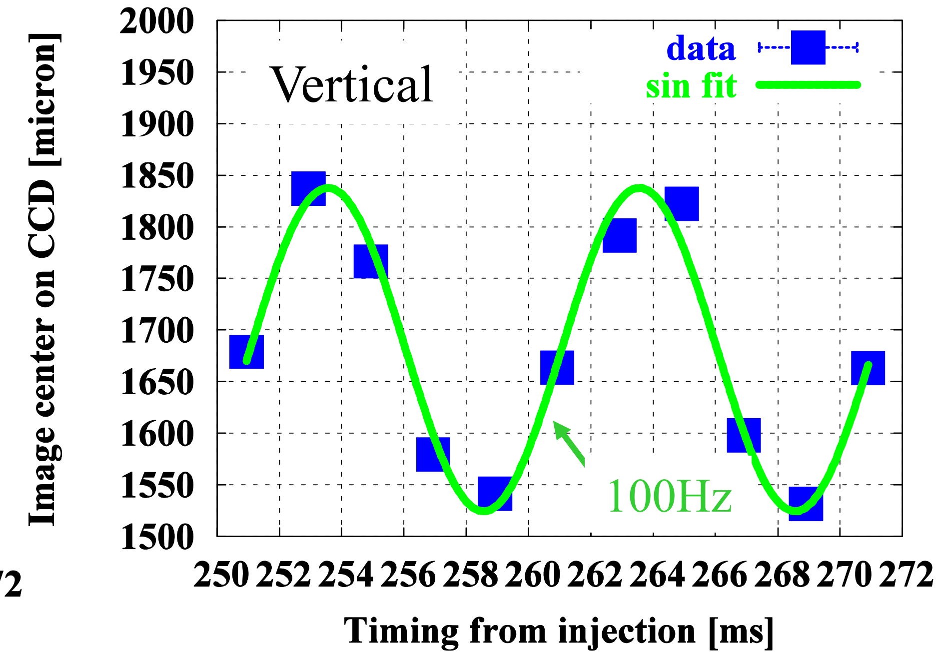


The measured horizontal beam size was almost 50µm and was independent of the shutter opening time. On the other hand, the measured vertical beam size was changed from 9µm to 7µm by changing the shutter opening time from 4ms shorter.

Measurement of beam position oscillation

In order to search the enhancement of the vertical beam size, we measure the beam position by changing the shutter trigger timing from beam injection timing (shutter opening time fixed with 1ms.)

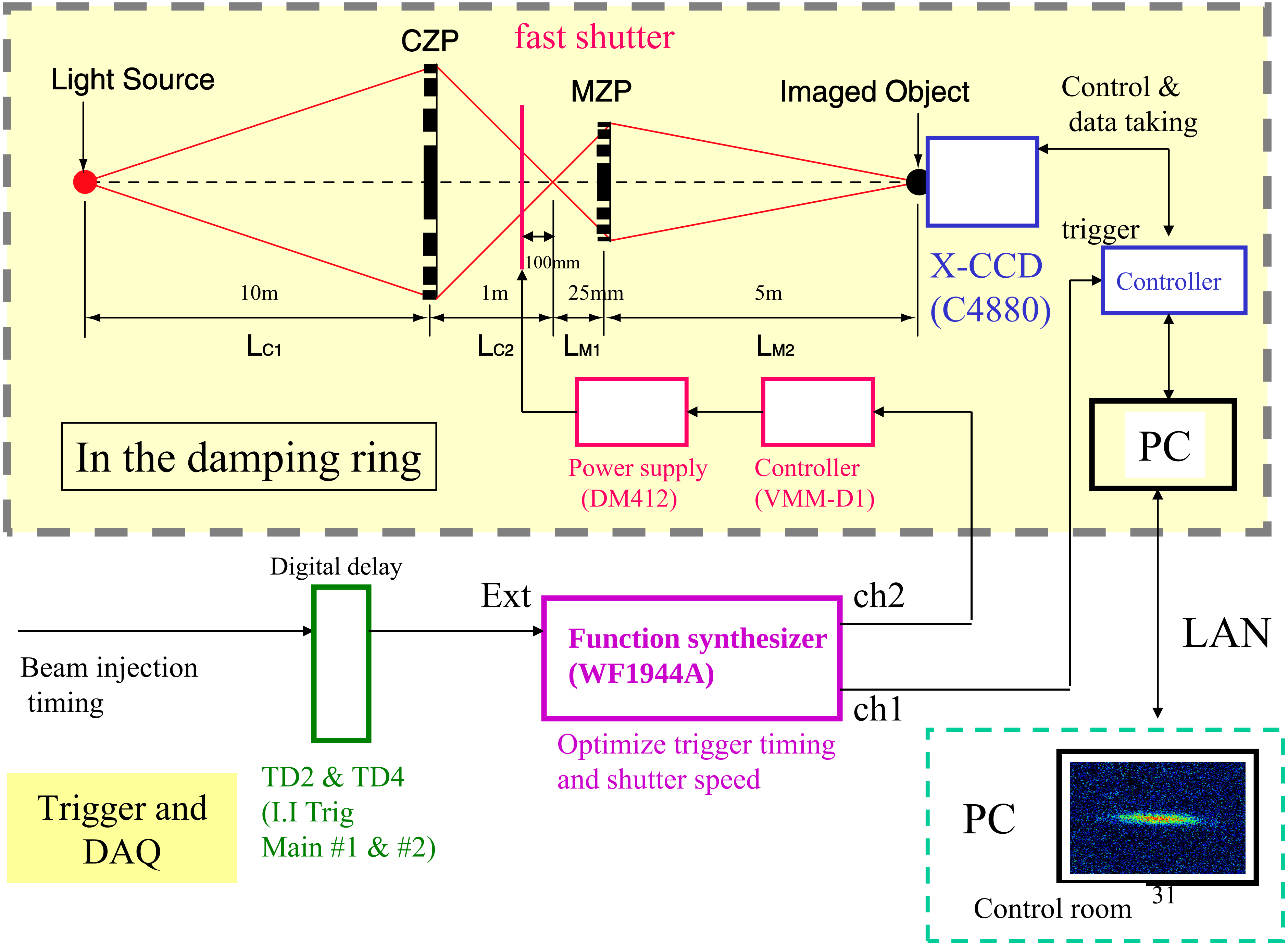




Horizontal amplitude : 14.9µm

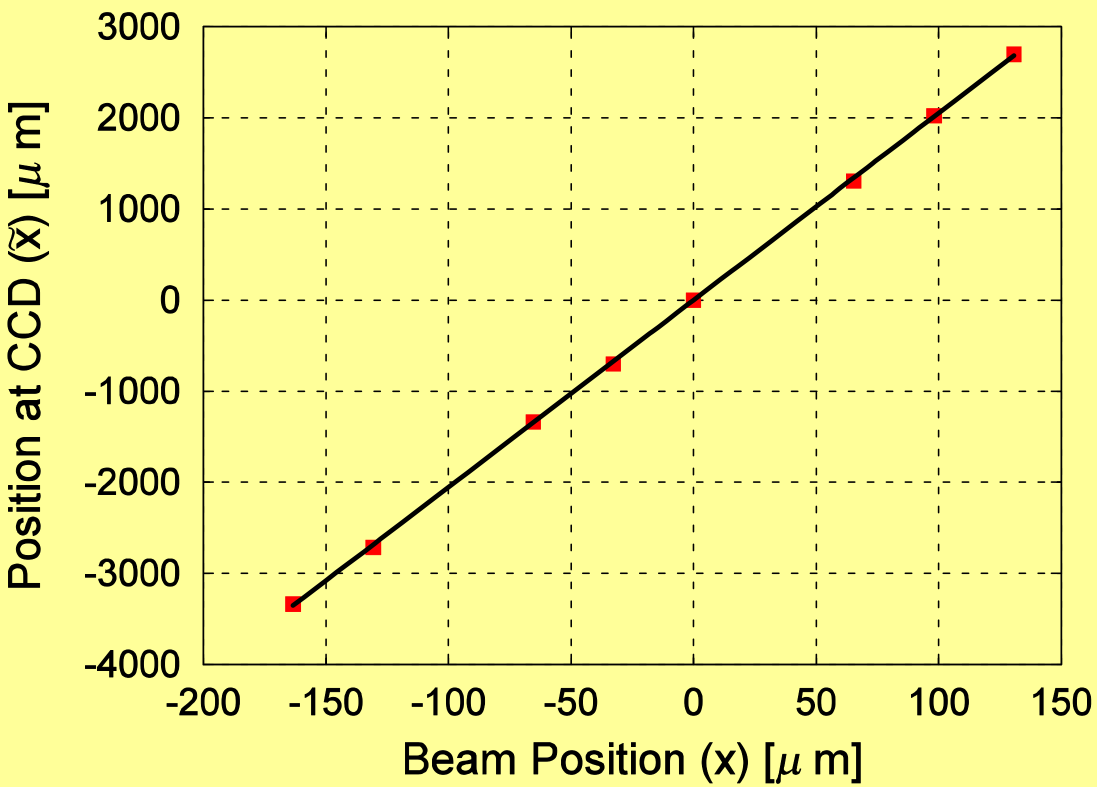
Vertical amplitude : 7.8µm

100Hz beam oscillation made the vertical beam size enhancement



CZP
fast shutter
Light Source
MZP
Imaged Object
Control &
data taking
trigger
X-CCD
(C4880)
Controller
100mm
10m
1m
25mm
5m
L_{C1}
L_{C2}
L_{M1}
L_{M2}
PC
In the damping ring
Power supply
(DM412)
Controller
(VMM-D1)
Digital delay
Ext
ch2
Function synthesizer
(WF1944A)
ch1
LAN
Beam injection
timing
TD2 & TD4
(I.I Trig
Main #1 & #2)
Optimize trigger timing
and shutter speed
Trigger and
DAQ
PC
Control room

Measurement of magnification



$$\Delta\tilde{x} = M\Delta x = -M\frac{\eta_x}{\alpha_M}\frac{\Delta f}{f_{RF}}$$

$\alpha_M = 0.002134$

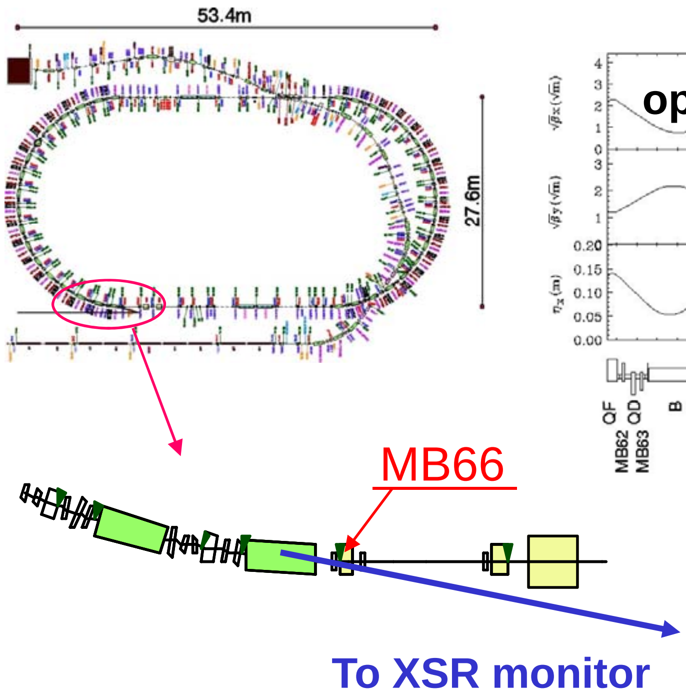
$f_{RF} = 714$ [MHz]

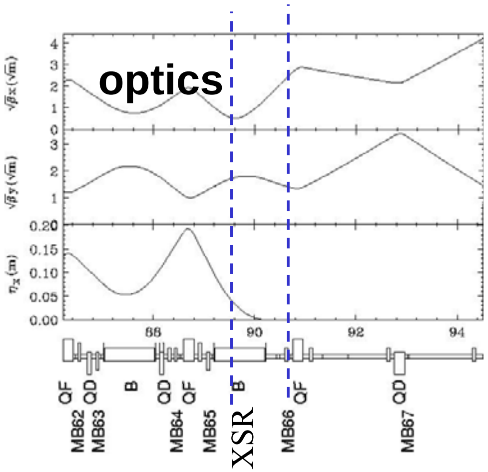
$\eta_x = 0.04980$

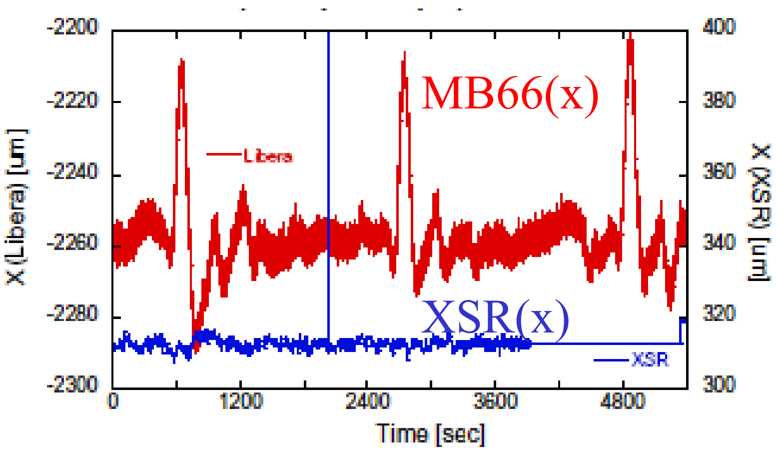
$\pm$ 0.0018 [m]

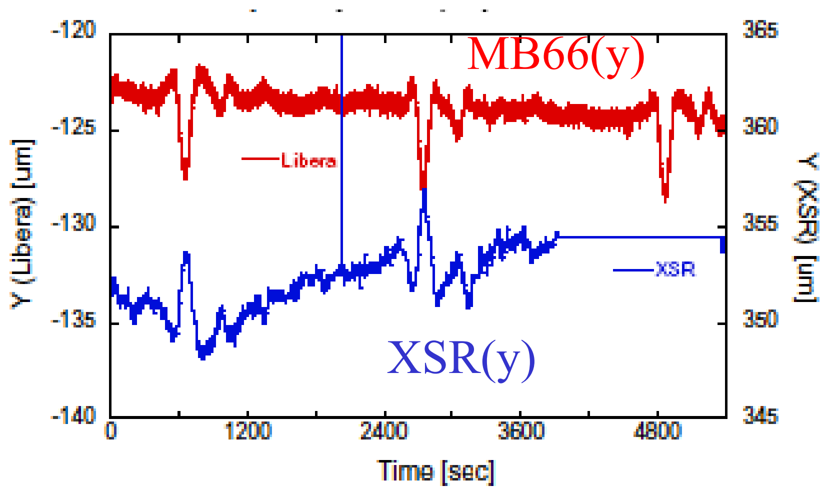
$M = 20.53 \pm 0.76$ → Consistent with design value

Long term stability with BPM (Libera) (cont)

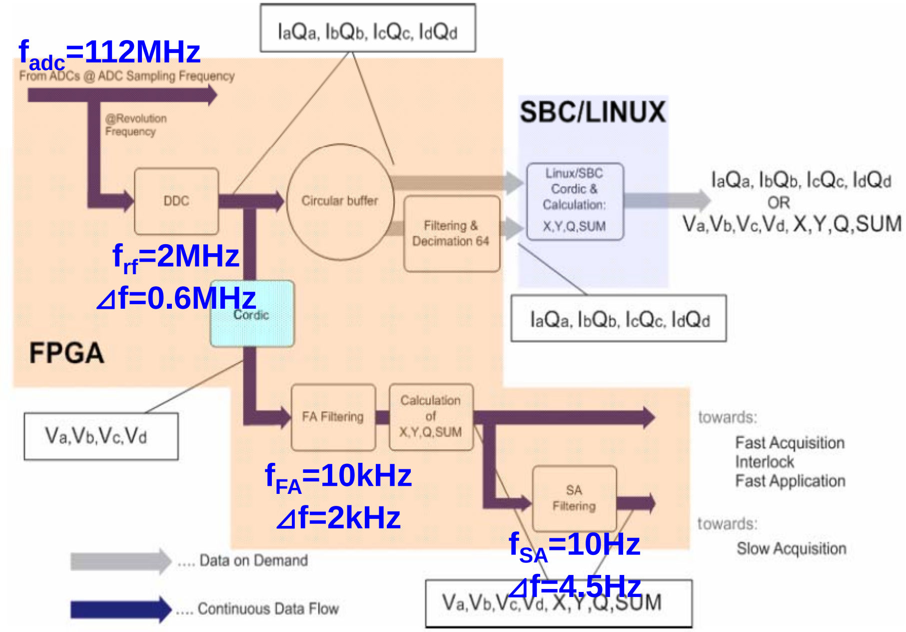


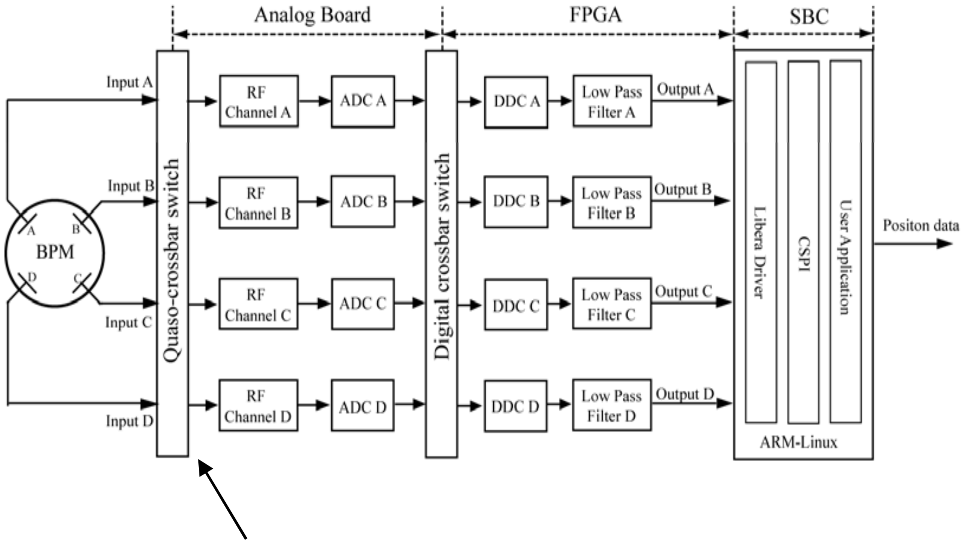






Libera





Cross bar switch

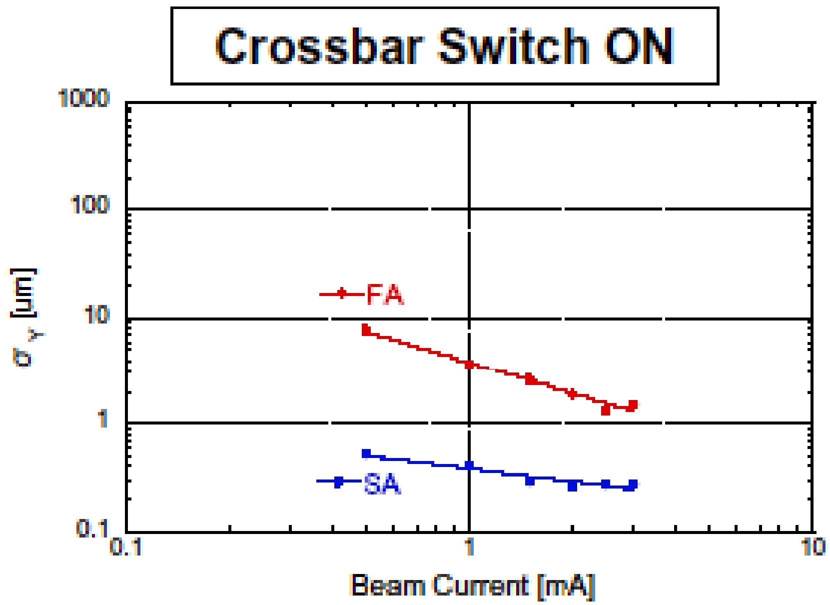
Data sampling mode

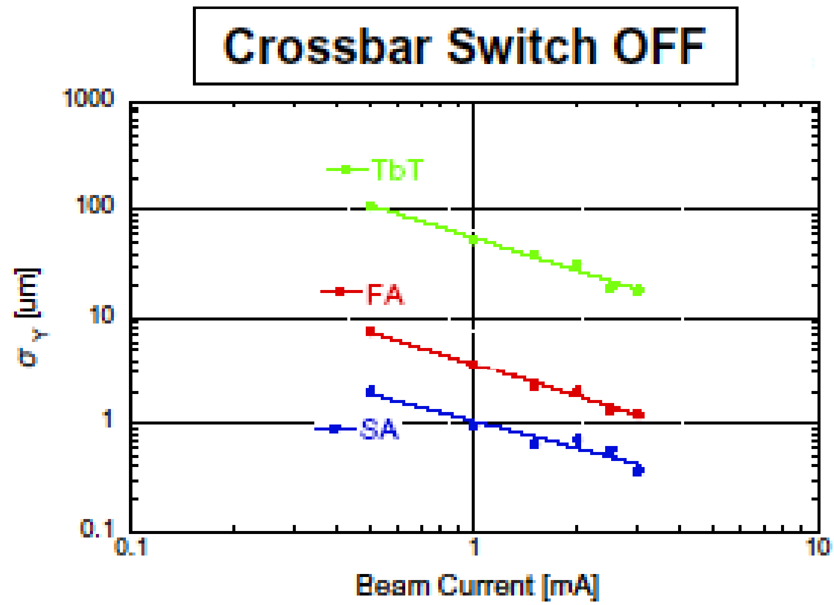
Turn-by-Turn mode (TbT) : 2.16MHz sampling

Slow Acquisition mode (SA) : 10Hz sampling

Fast Acquisition mode (FA) : 10kHz sampling

LIBERA performance at ATF damping ring





@2.5mA
FA mode: 1.3 mm
SA mode: 0.3 mm

@2.5mA
TBT mode: 19.3mm
FA mode: 1.3 mm
SA mode: 0.6 mm