Measurement of the beam profiles with the improved Fresnel Zone Plate (FZP) monitor -- X-ray SR monitor --

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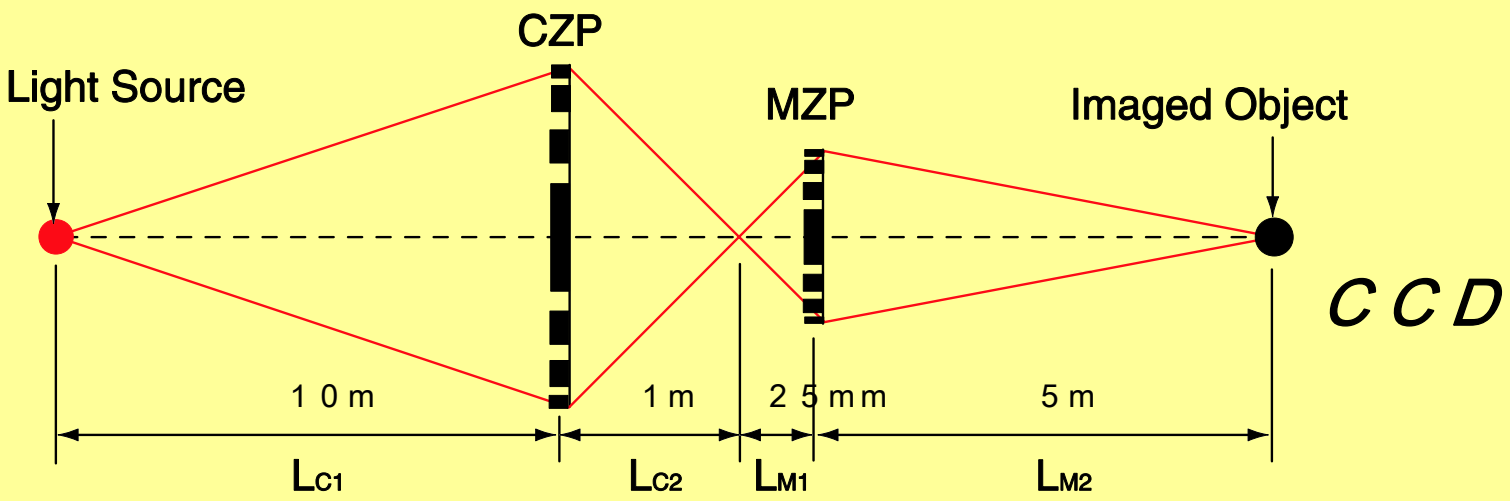
1. Principle of FZP monitor
2. Setup of FZP monitor
3. Measurement results
4. Summary

Apparatus of Fresnel Zone Plate (FZP) 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)
  - Non-destructive measurement
  - 2-dimentional (x,y) beam profiling
  - Real time beam profile mesurement (<1ms)

Principle of FZP monitor

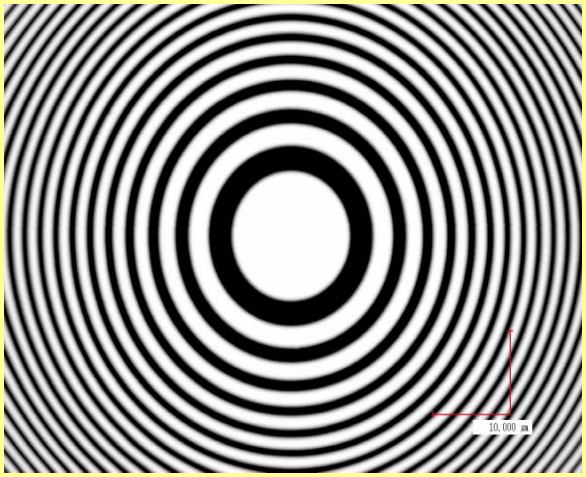


$M_{CZP}=1/10$, $M_{MZP}=200$

$M = M_{CZP} \times M_{MZP} = 20$

- 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

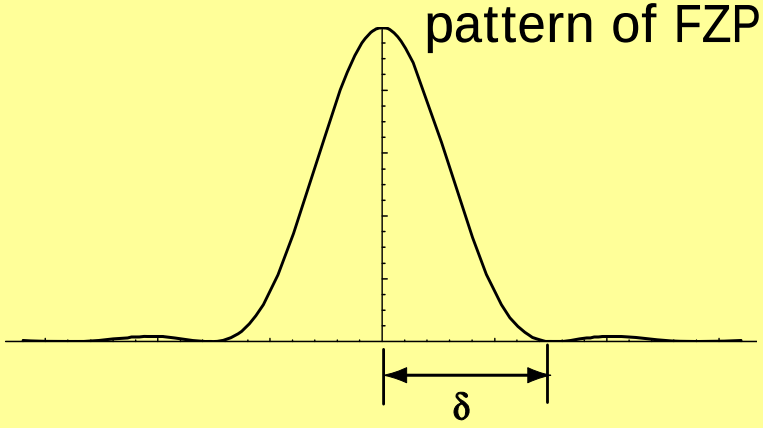
$$\delta = 1.22\,\Delta r_N \approx 3\sigma$$

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

Δr_N: Most outer zone width

Airy pattern

Diffraction pattern of FZP



Parameters	CZP	MZP
Number of zone: N	6444	146
Radius of FZP	1500 μm	37.3 μm
Most outer zone width : Δr_N	116nm	128nm
Focal length: f	909mm	24.9mm

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

Total spatial resolution of FZP 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]

$M_{CZP} = 1/10$, $M_{MZP} = 200$, $M_{CZP} \times M_{MZP} = 20$

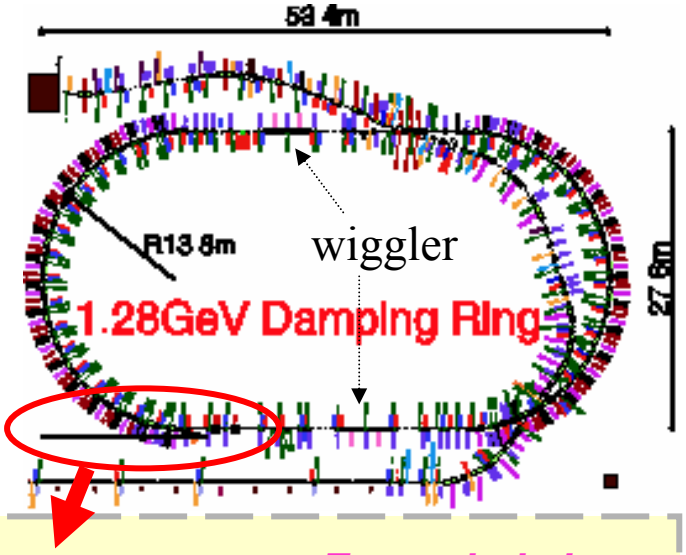
The total estimated spatial resolution is 0.7μm in R.M.S .

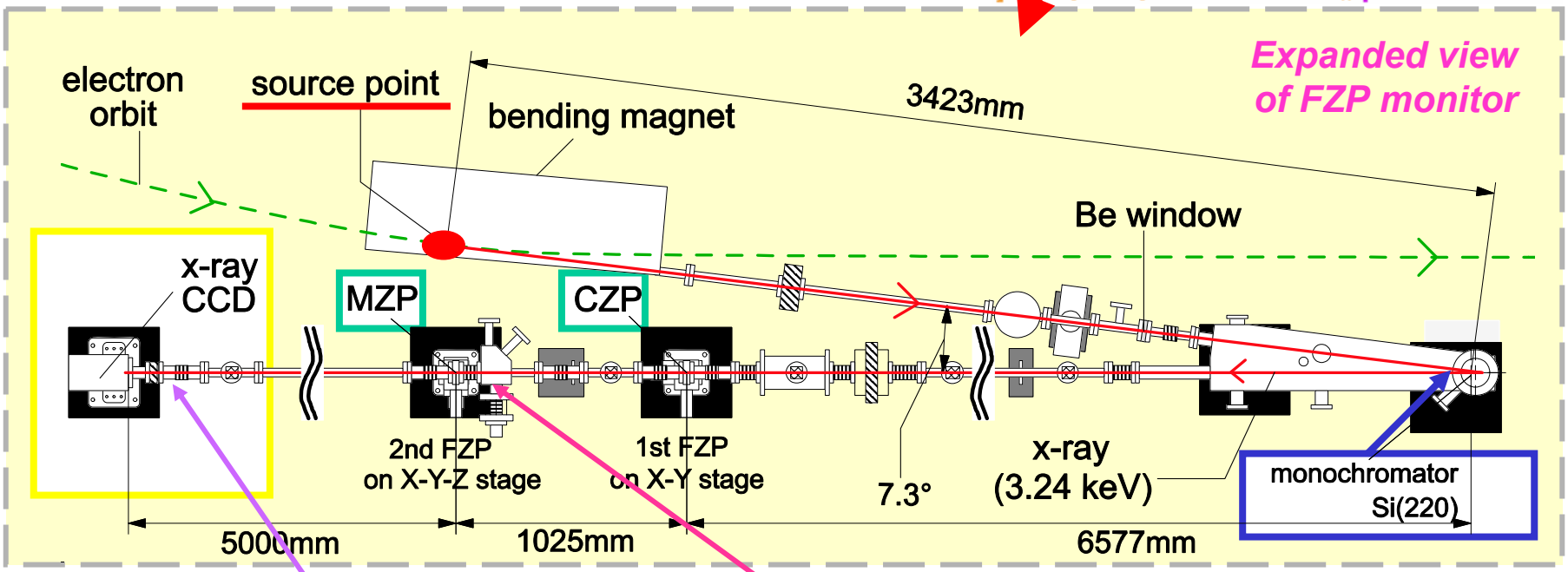
↓

Submicron spatial resolution will be expected on this FZP monitor.

Setup of FZP monitor

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

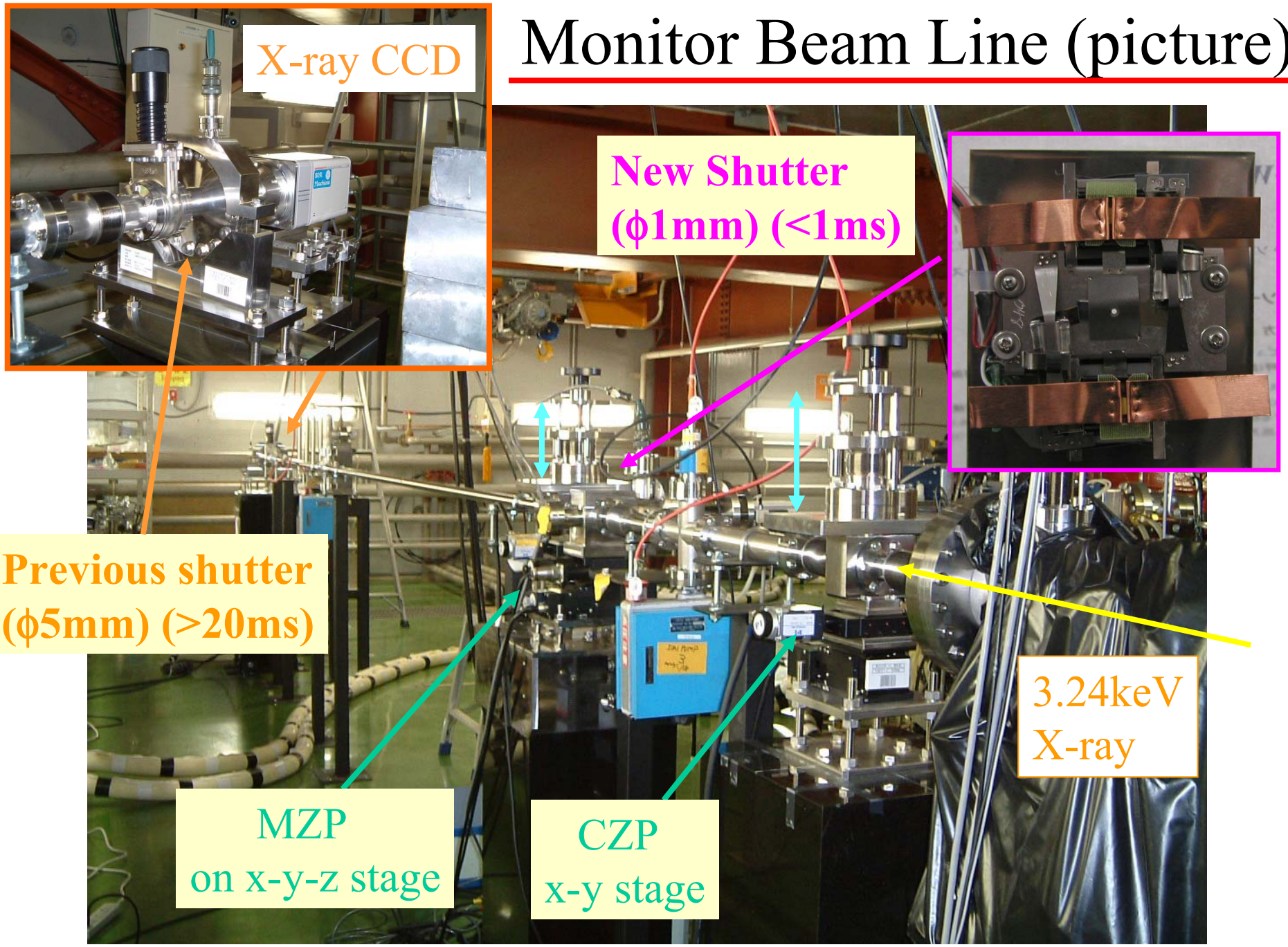




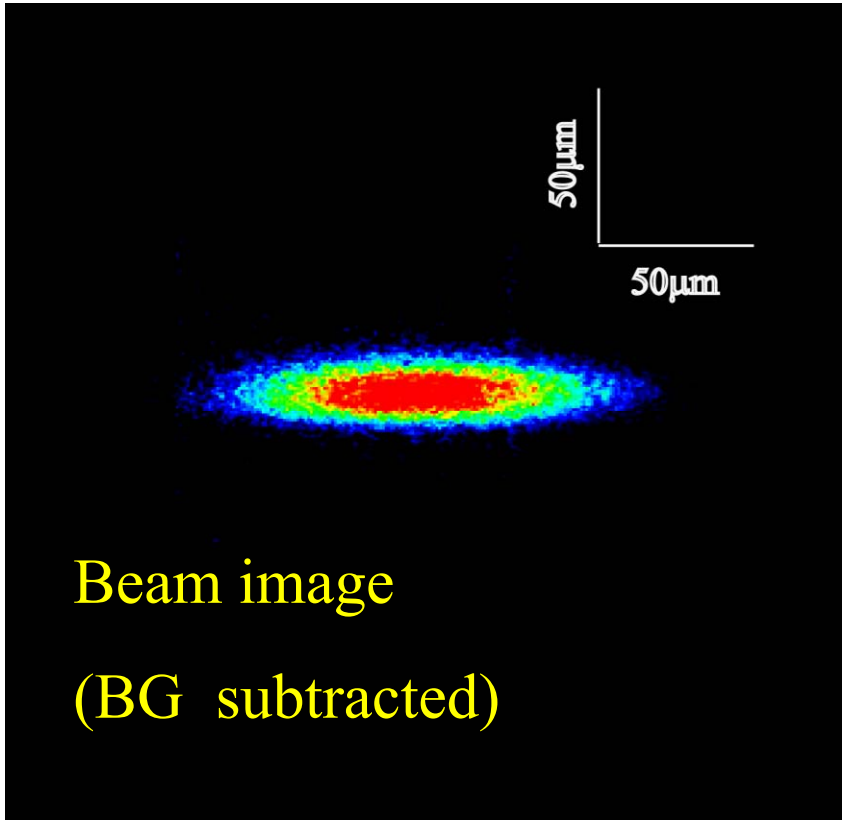
Previous shutter was set in front of CCD camera [shutter time >20ms]

New mechanical shutter installed on April 2005 (opening shutter time <1ms)

Monitor Beam Line (picture)



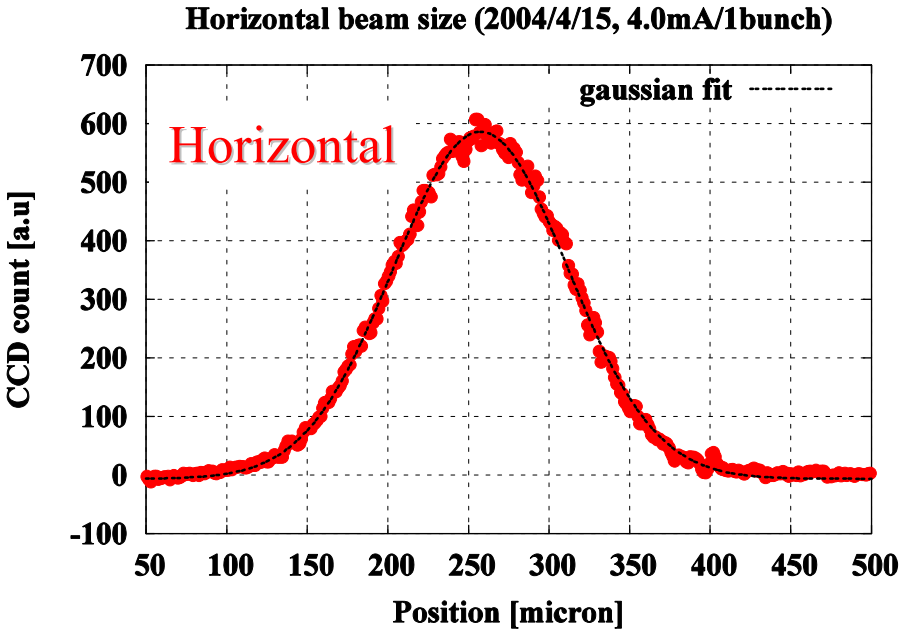
Example of beam image (shutter with 100ms)

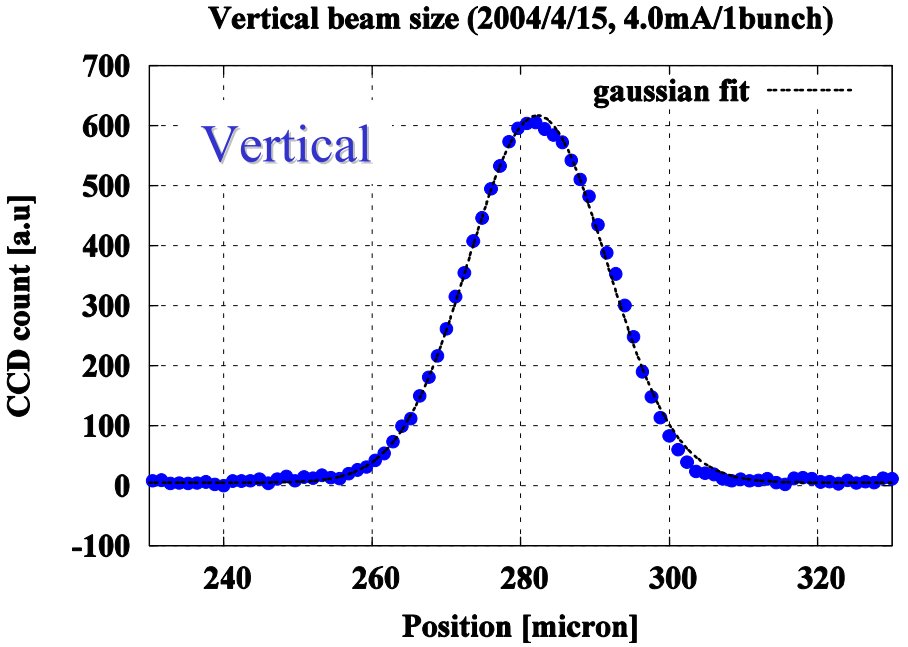


I=4.0mA, Shutter time = 100ms
(2004/4/15)

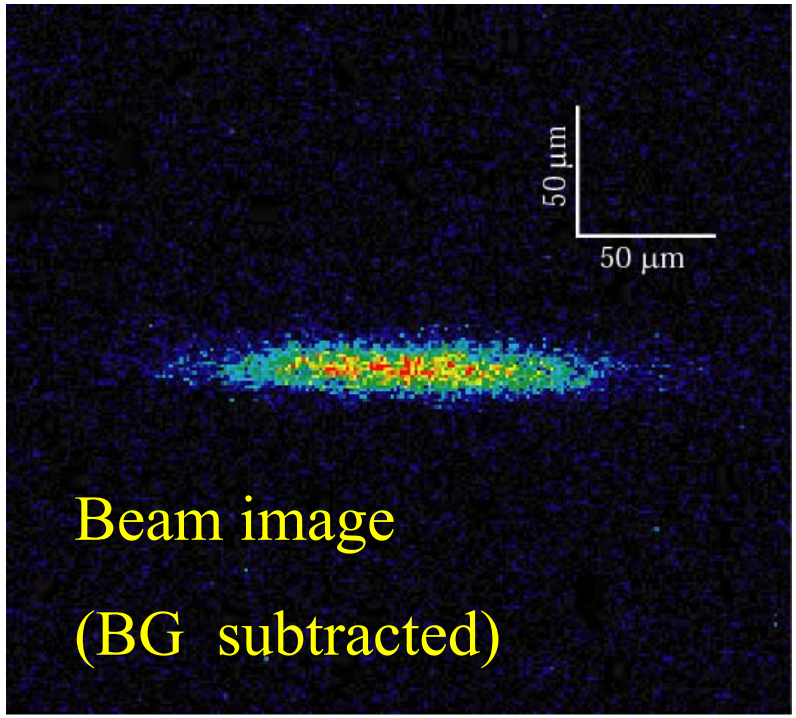
$\sigma_x = 54.2 \pm 0.2$ [μm]

$\sigma_y = 9.2 \pm 0.1$ [μm]





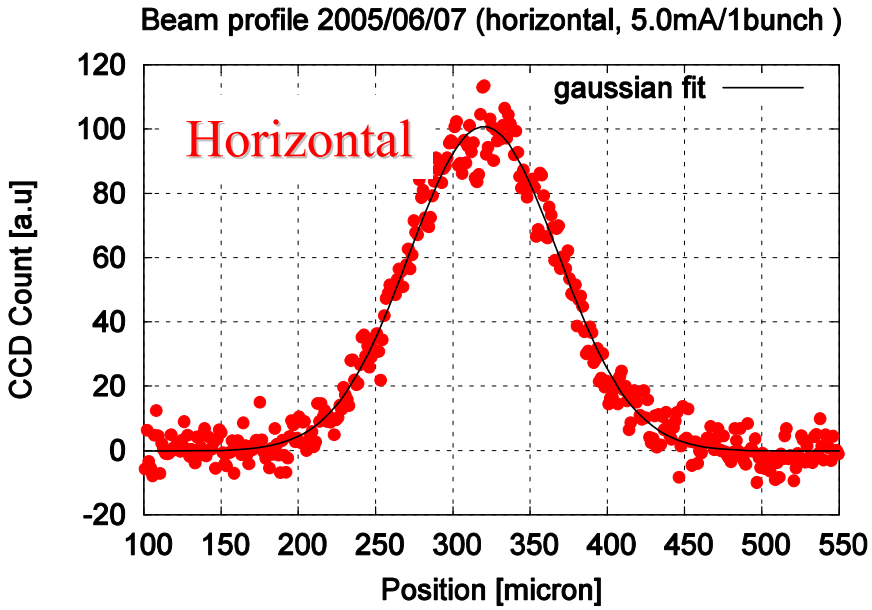
Example of beam image (new shutter with 1ms)

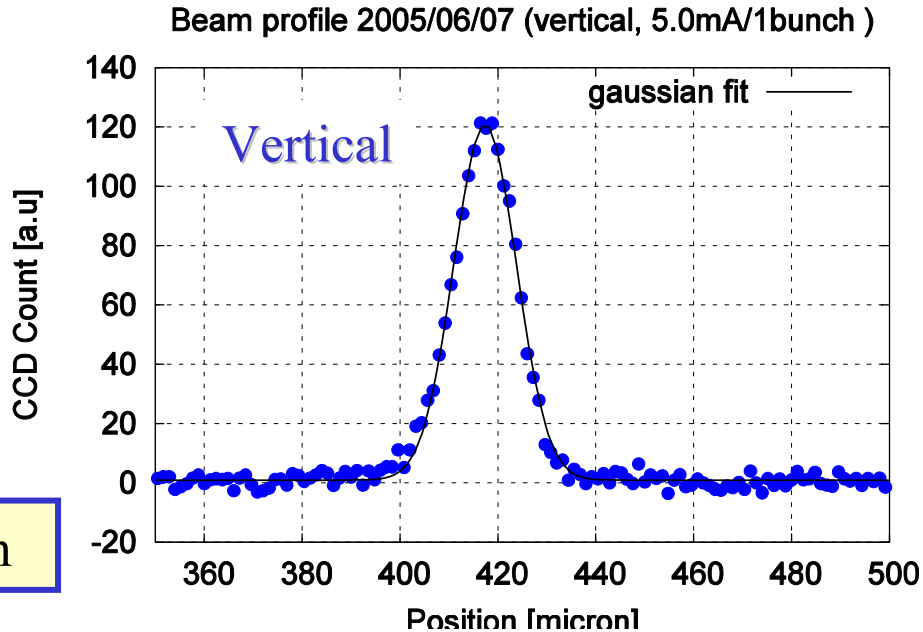


I=5.0mA, Shutter time = 1ms
(2005/06/07)

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

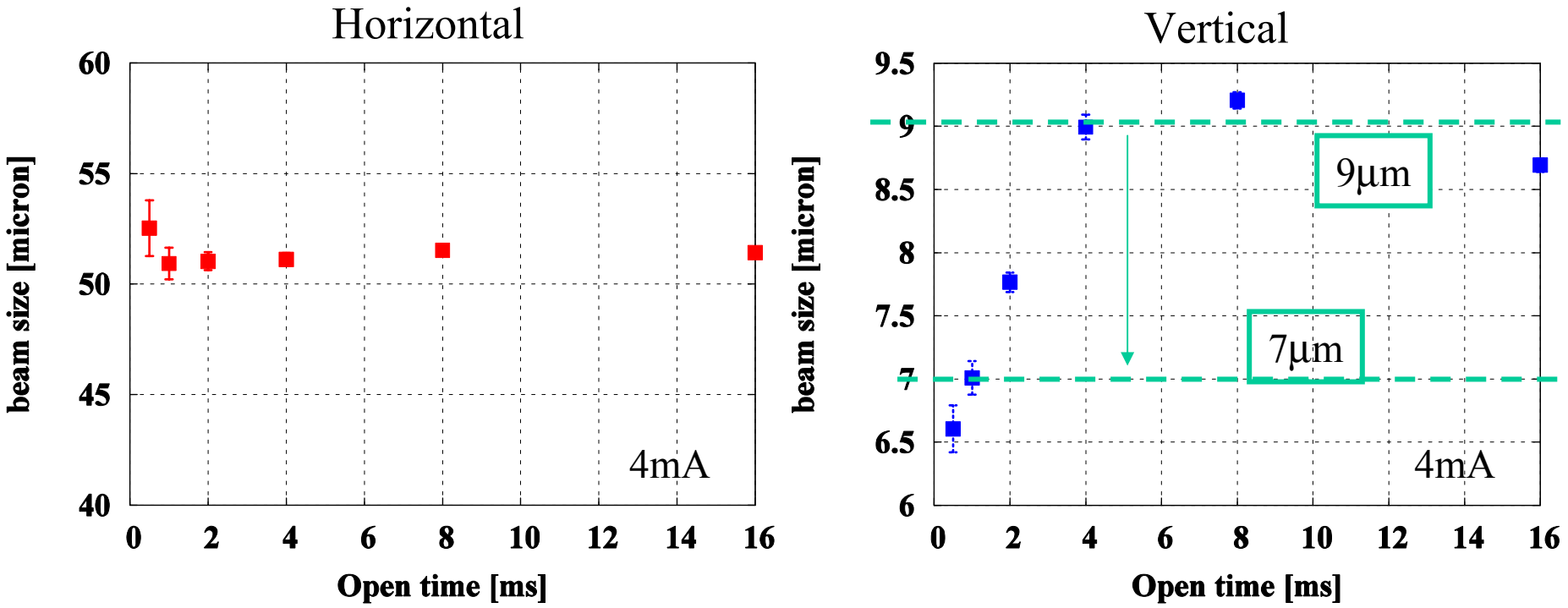
Reduce vertical beam size : 9.2μm → 6.4μm





Shutter opening time dependence

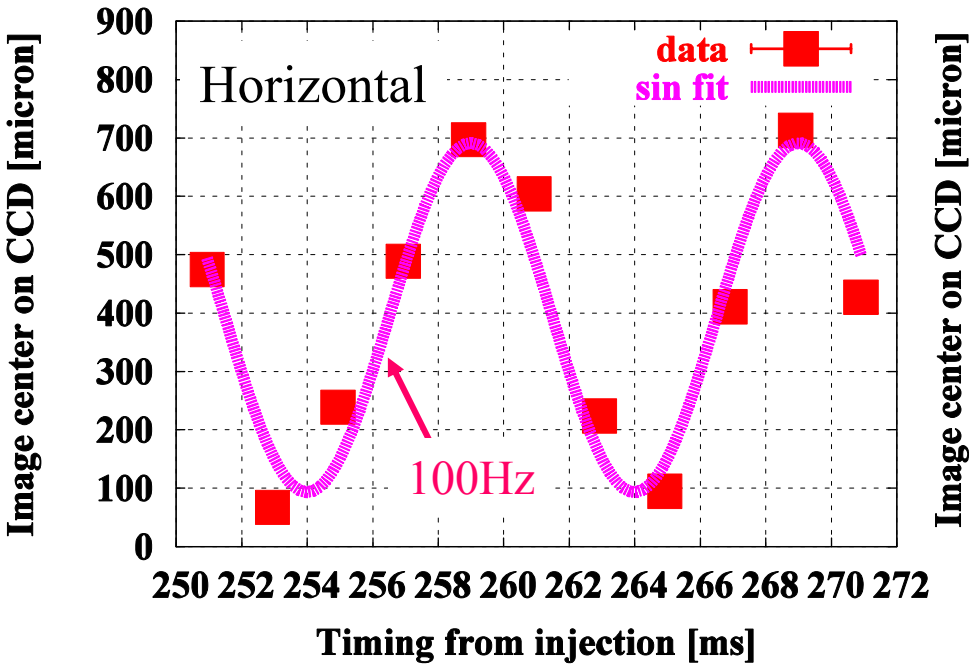
Measure the beam size by changing shutter opening time.

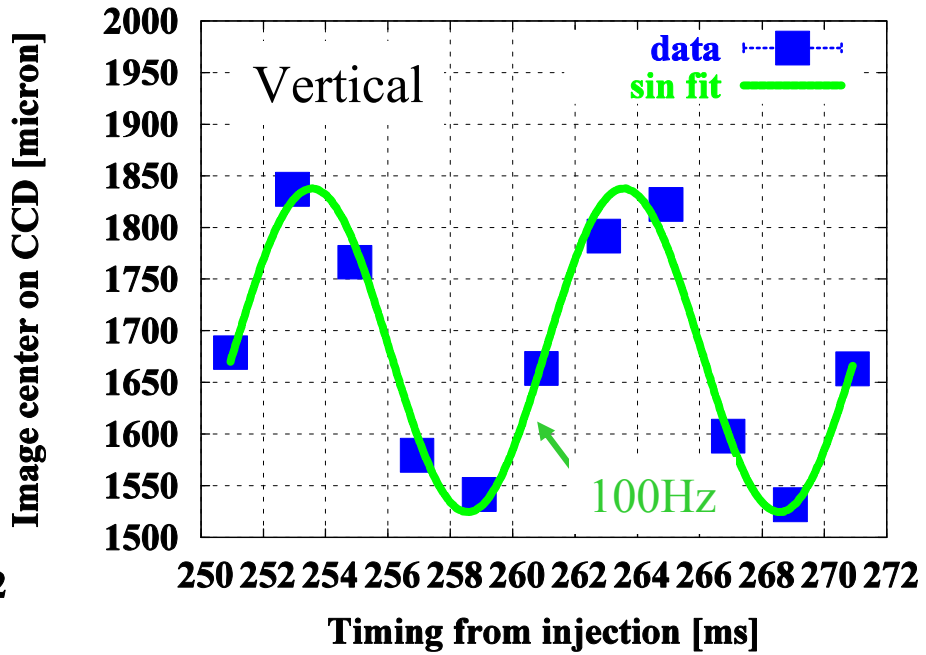


The measured horizontal beam size was almost 50μm and was independent of the shutter opening time. On the other hand, the measured vertical beam size was changed from 9μm to 7μm by changing the shutter opening time from 4ms shorter.

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.)



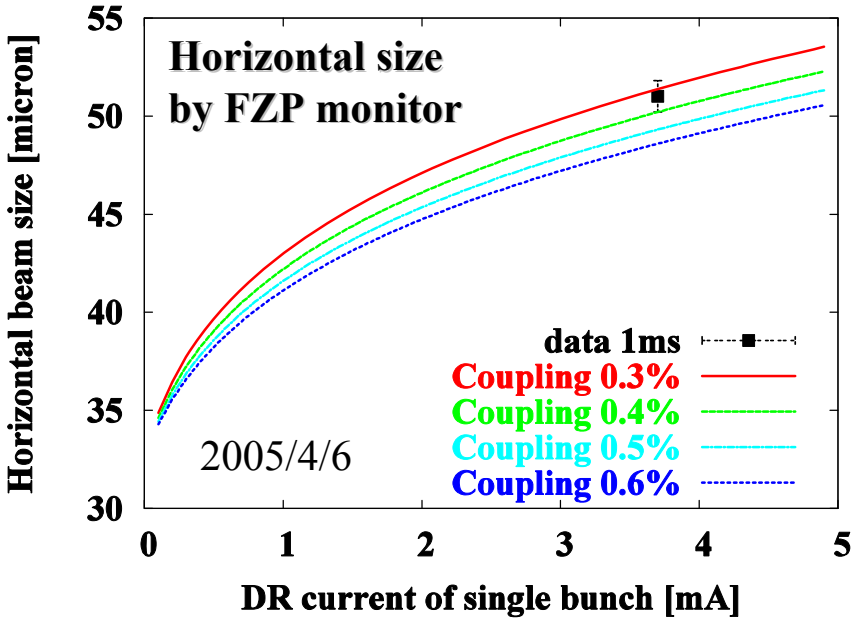


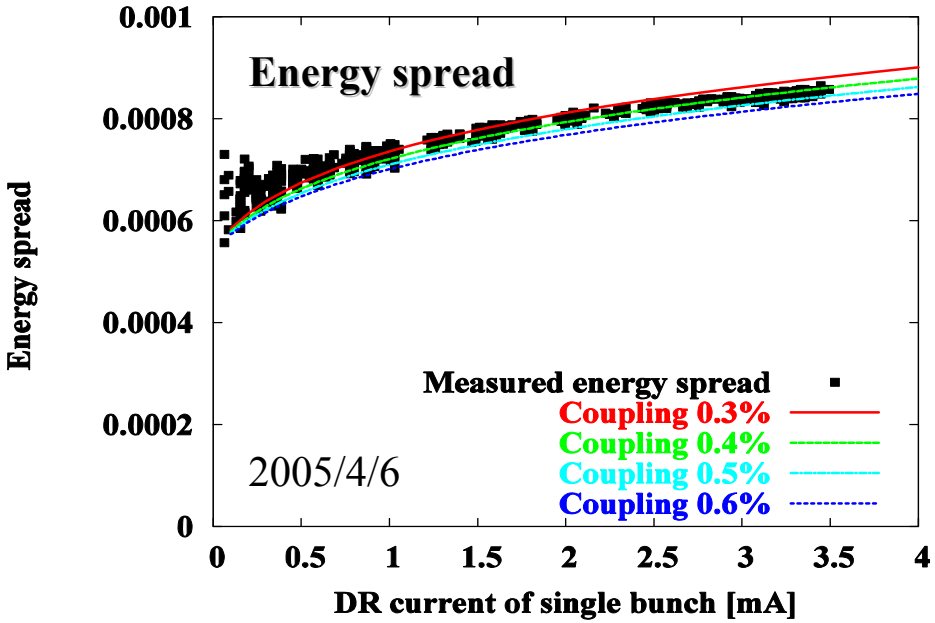
Horizontal amplitude ： 14.9μm

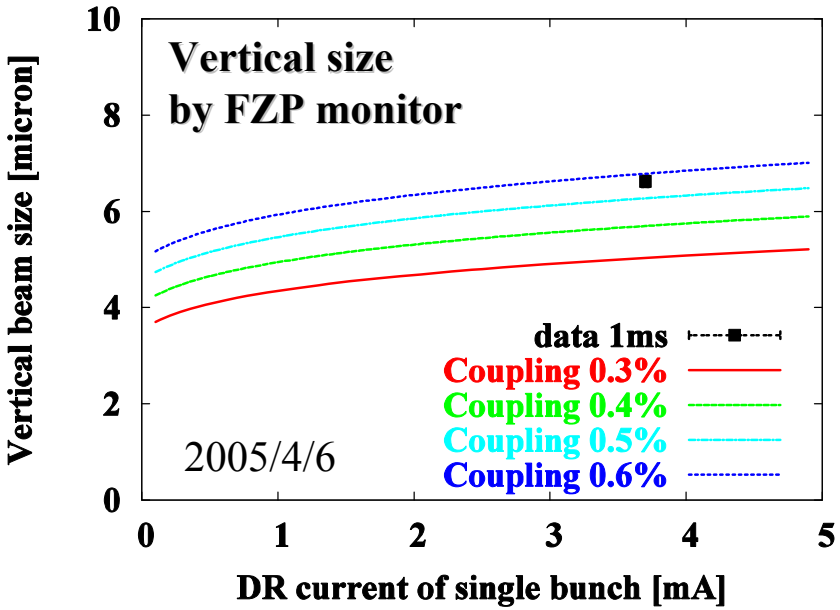
Vertical amplitude ： 7.8μm

100Hz beam oscillation made the vertical beam size enhancement

Measured sizes by FZP monitor vs calculation

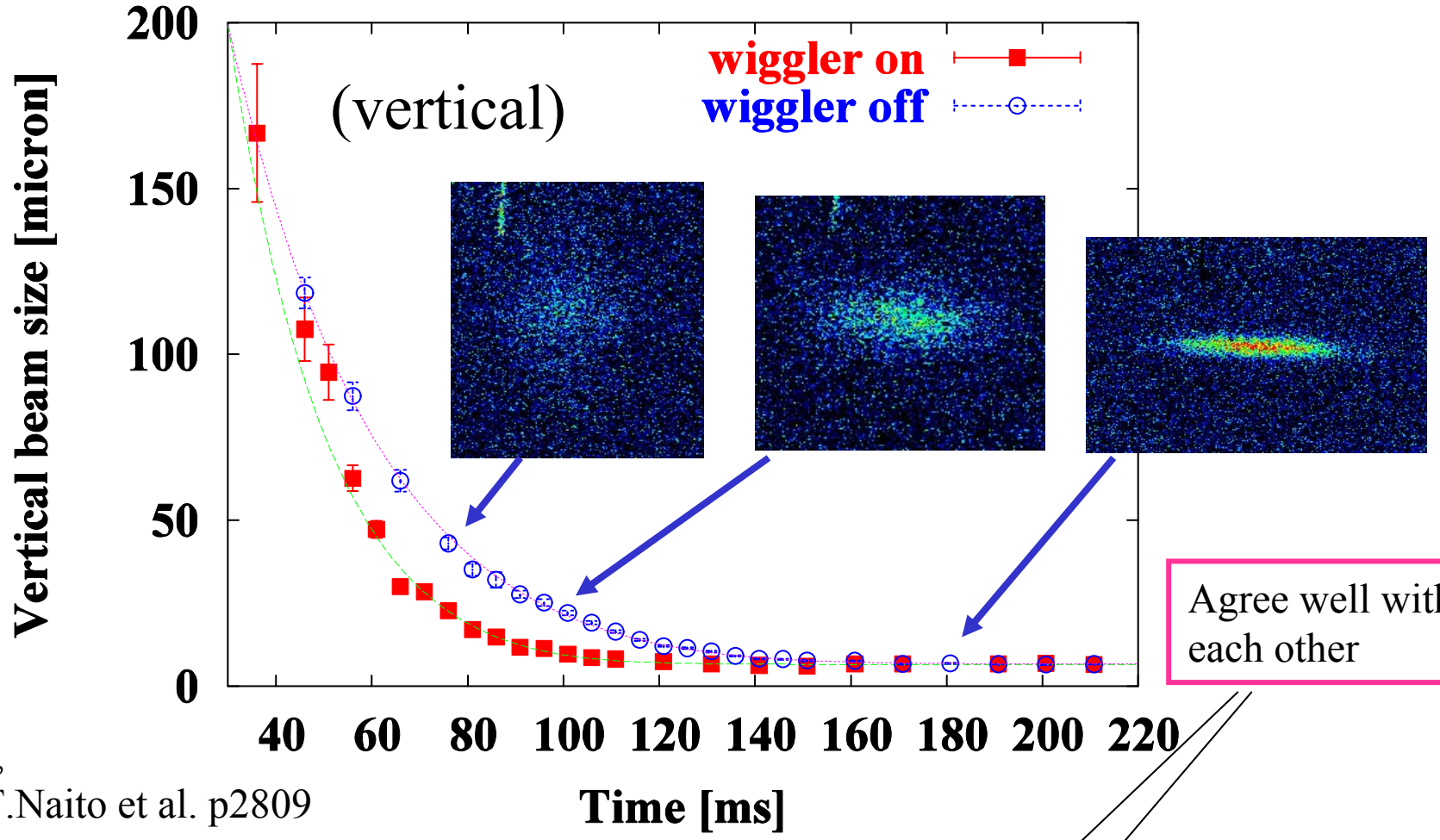






Three measurements (horizontal and vertical beam size by FZP monitor and energy spread by screen monitor at the extraction line plotted by black squares) agree well with the calculation results by assuming the betatron coupling of 0.3 ~ 0.6 % (solid and dotted lines)

(Application) Measurement of damping time



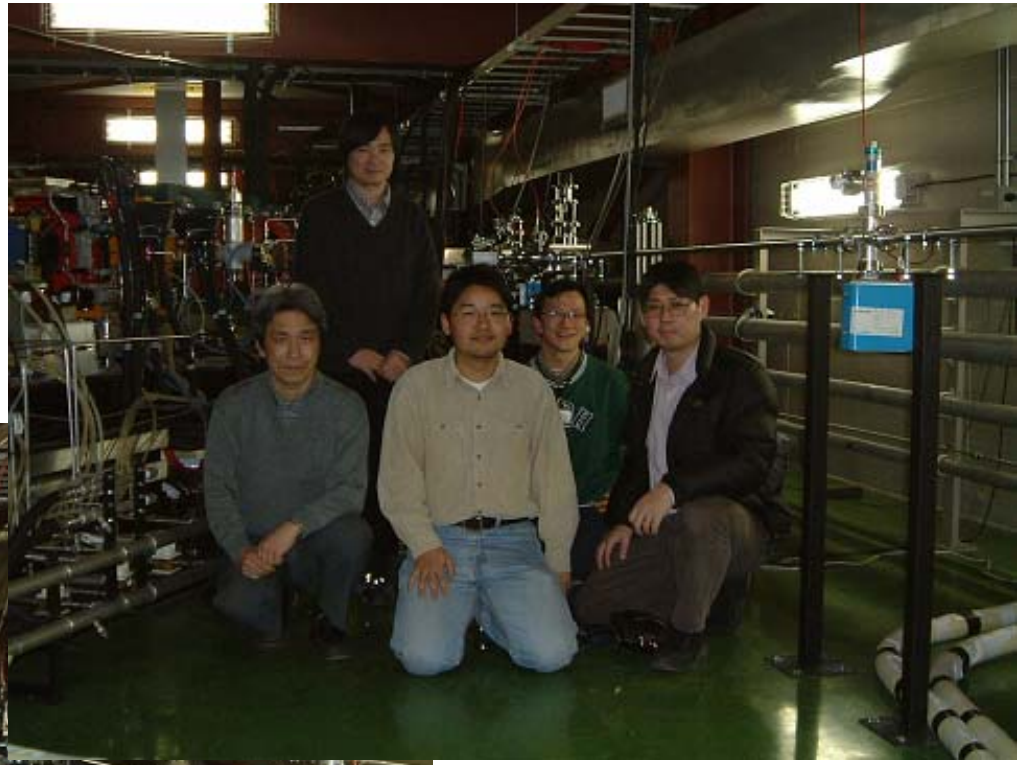
Agree well with each other

In detail ,
PAC05 T.Naito et al. p2809

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

Summary

- We measure the beam size by using FZP monitor at KEK-ATF damping ring. The effect of the unknown 100Hz oscillation was removed on the measurement by using new mechanical shutter with 1ms shutter opening time. After that, the measured vertical beam size of this monitor was less than 7μm.
- The measured horizontal and vertical beam sizes by FZP monitor and the measured energy spread agreed well with the calculation by assuming the coupling ratio with 0.3 ~ 0.6 % with including intra beam scattering .
- The damping time of ATF damping ring with/wihout wiggler were clearly measured by using FZP monitor. The measured damping time agrees well with calculation with each other.



Thank you for the invitation

References

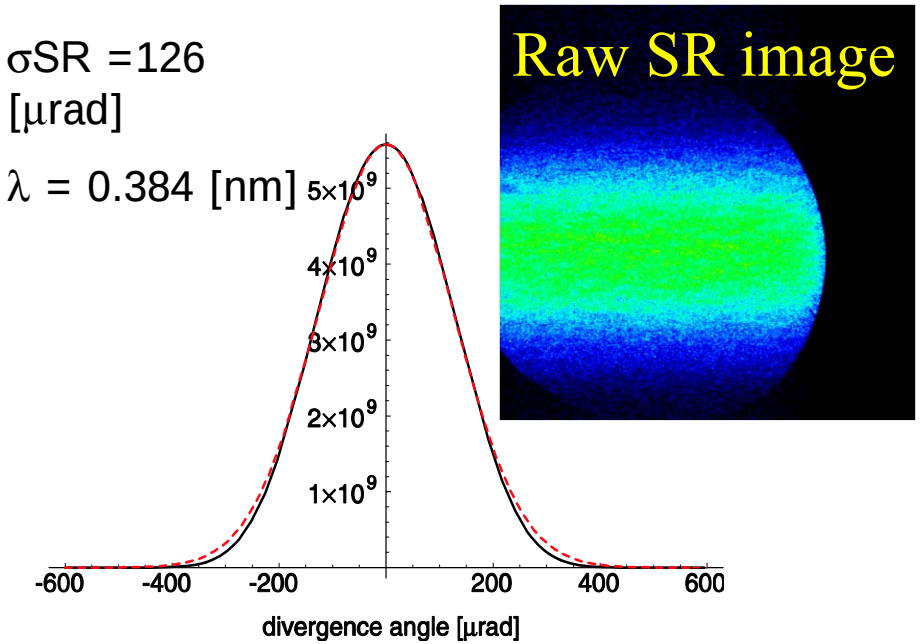
Photon Flux

Energy E=1.28 [GeV]

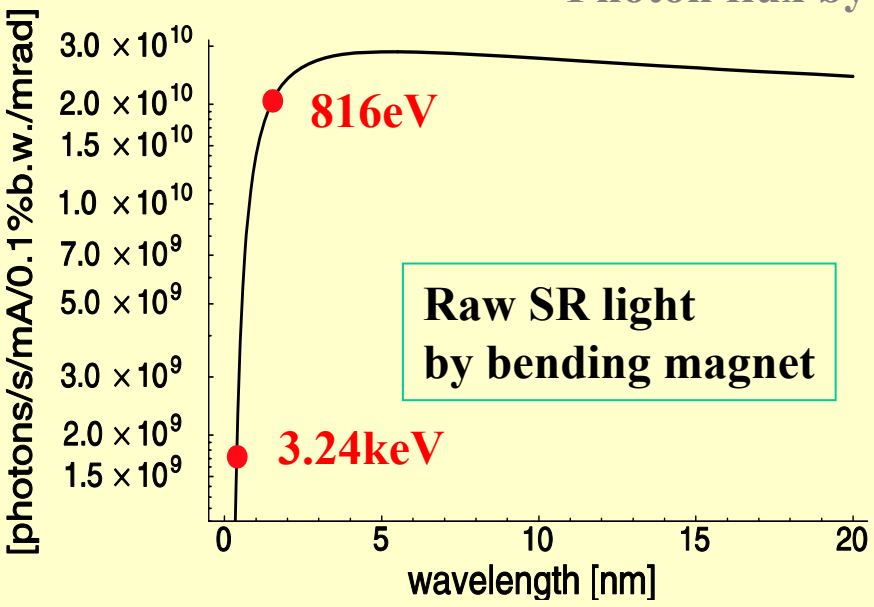
Bending field B=0.748 [T]

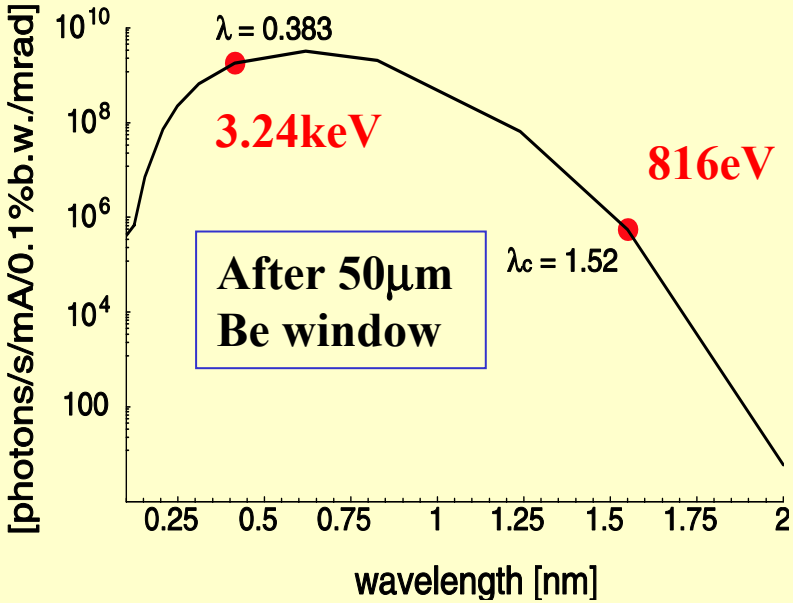
Critical length λ_C =1.52 [nm]

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



Photon flux by SR source point



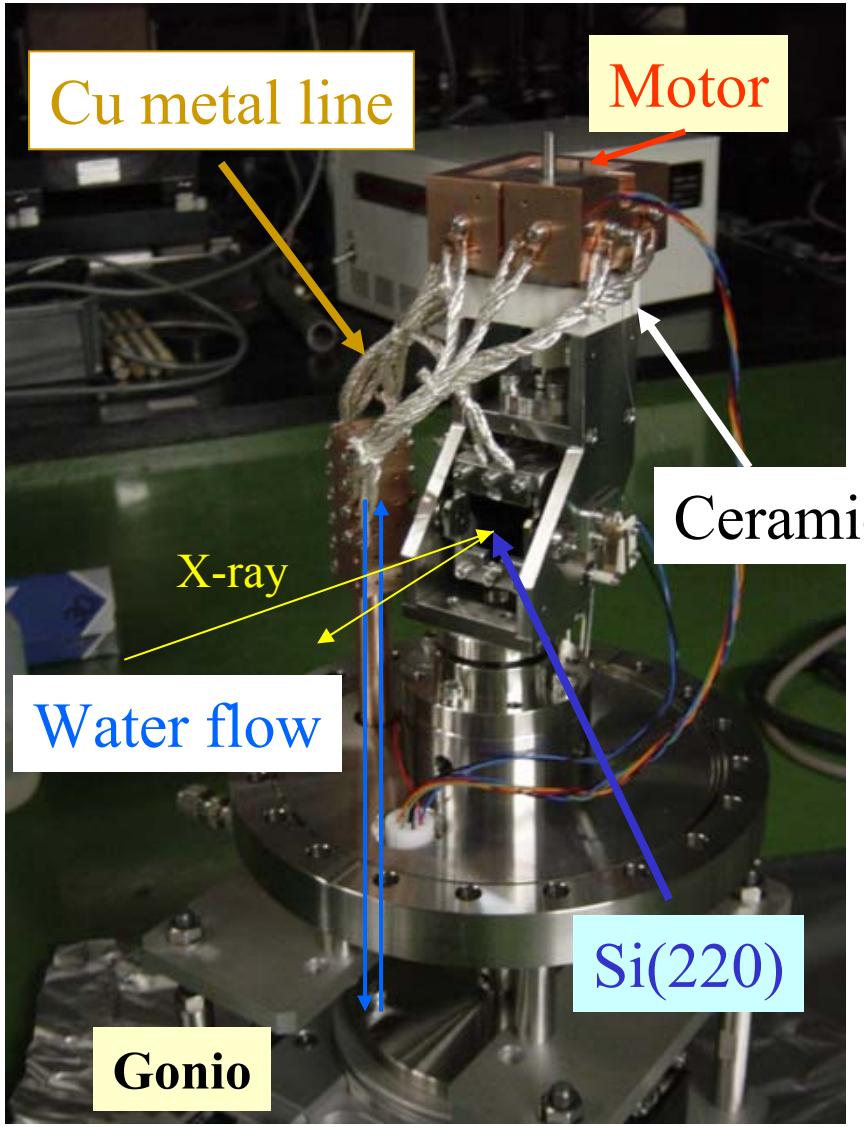


Monochromator

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]
Energy resolution	$\frac{\Delta\lambda}{\lambda} = 5.6\times10^{-5}$

Enough energy resolution for avoiding chromatic abberation of FZP (8 x 10^{-4})

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



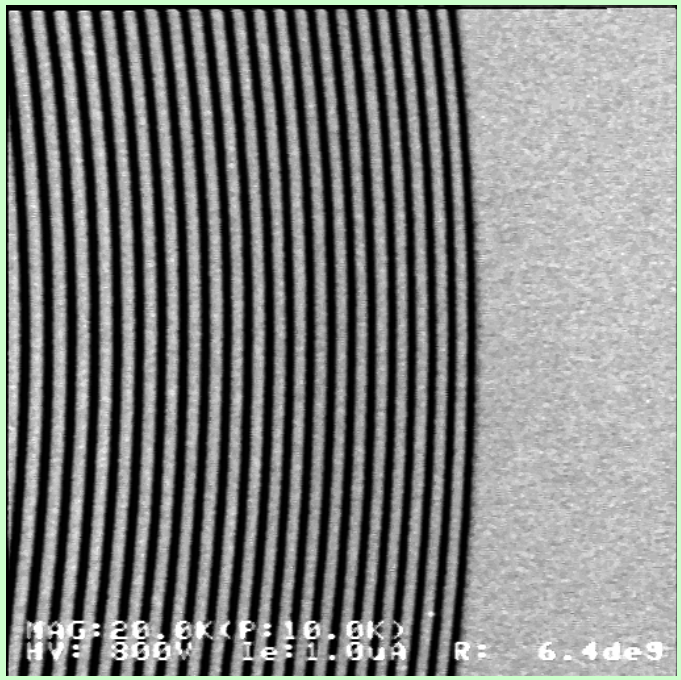
Fresnel Zone Plates

Parameters of two FZP (λ = 0.383 nm)

FZP resolution defined by $\delta_{FZP} = 1.22\Delta r_N$

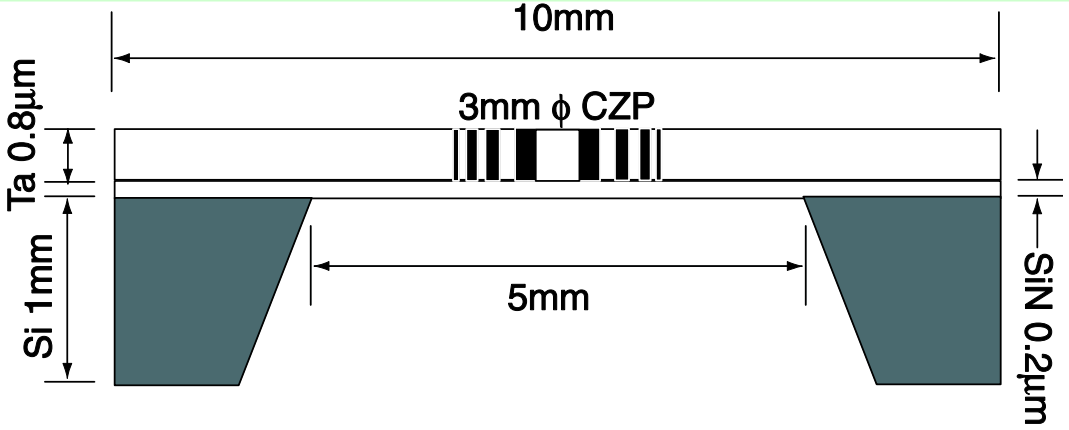
	CZP	MZP
Number of Zone	6444	146
Radius	1500 μm	37.3 μm
Most outer zone width Δr_N (δ_{FZP})	116nm (142nm)	128nm (156nm)
Focal length f	909mm	24.9mm
Magnification	1/10	200

Outer zone of MZP by SEM



Cross Section of FZP

Produced by
NTT-AT corp.



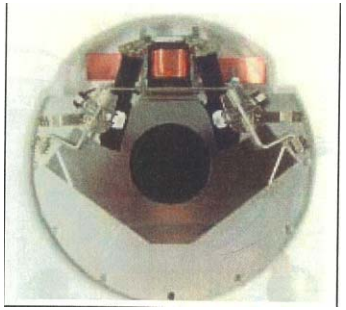
X-ray CCD

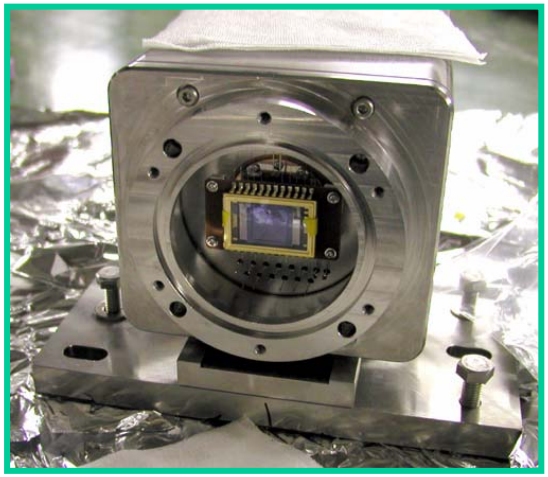
CCD	Backward full frame transfer type
Area	12.29 mm x 12.29 mm
Pixel size	24 μm x 24 μm
Quantum effeciency	< 90 % (3.24 keV)
Cooling	Peltier **(-50 C°)**
Dark current	2 electrons/pixels/sec
Scanning speed	7 frame/sec (Live) 0.5 frame/sec (Acquire)
Shutter speed	Less than 20ms

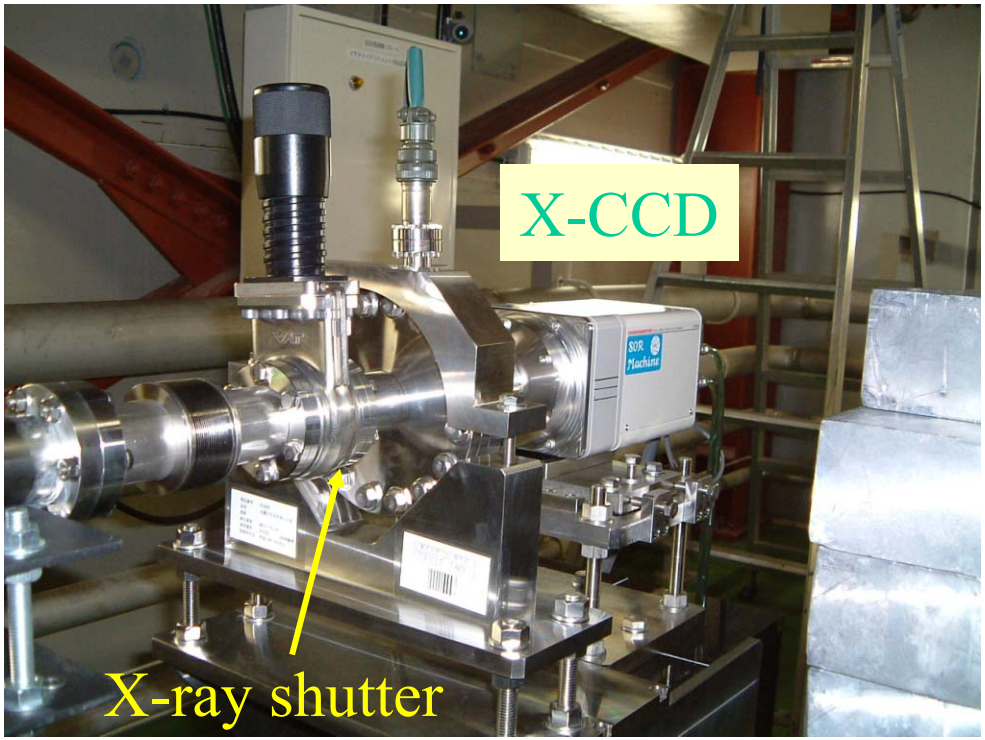
C4880-21-24-WD

(made by Hamamatsu K.K)

X-ray shutter



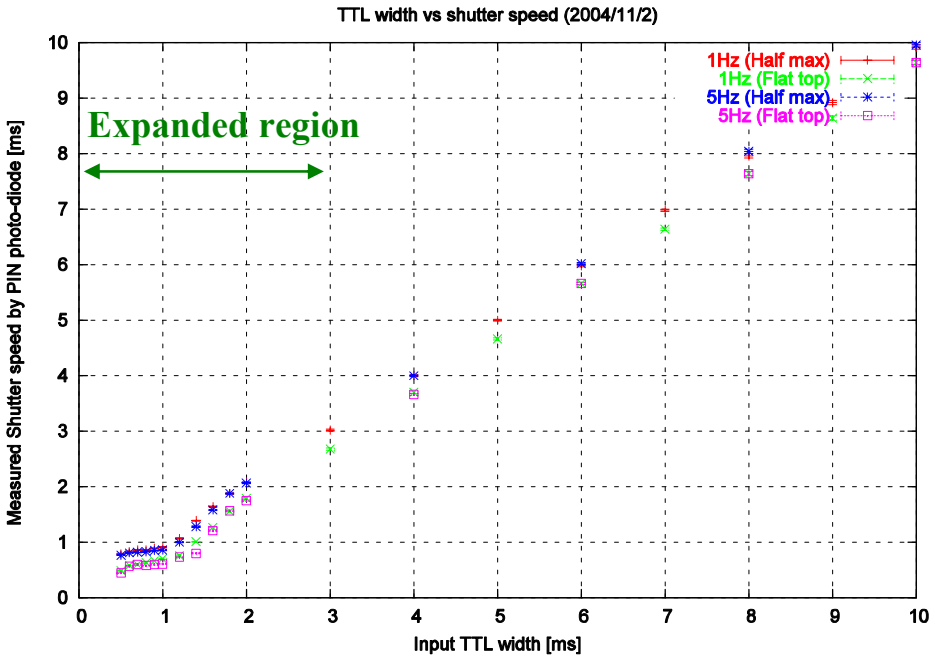




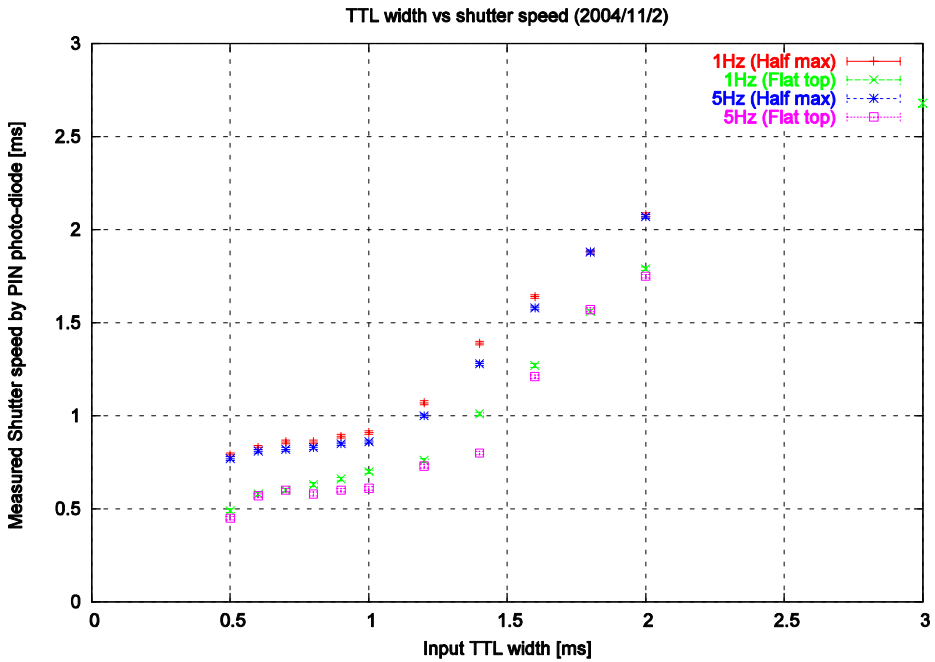
Performance （ Normal mode ） at test bench

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

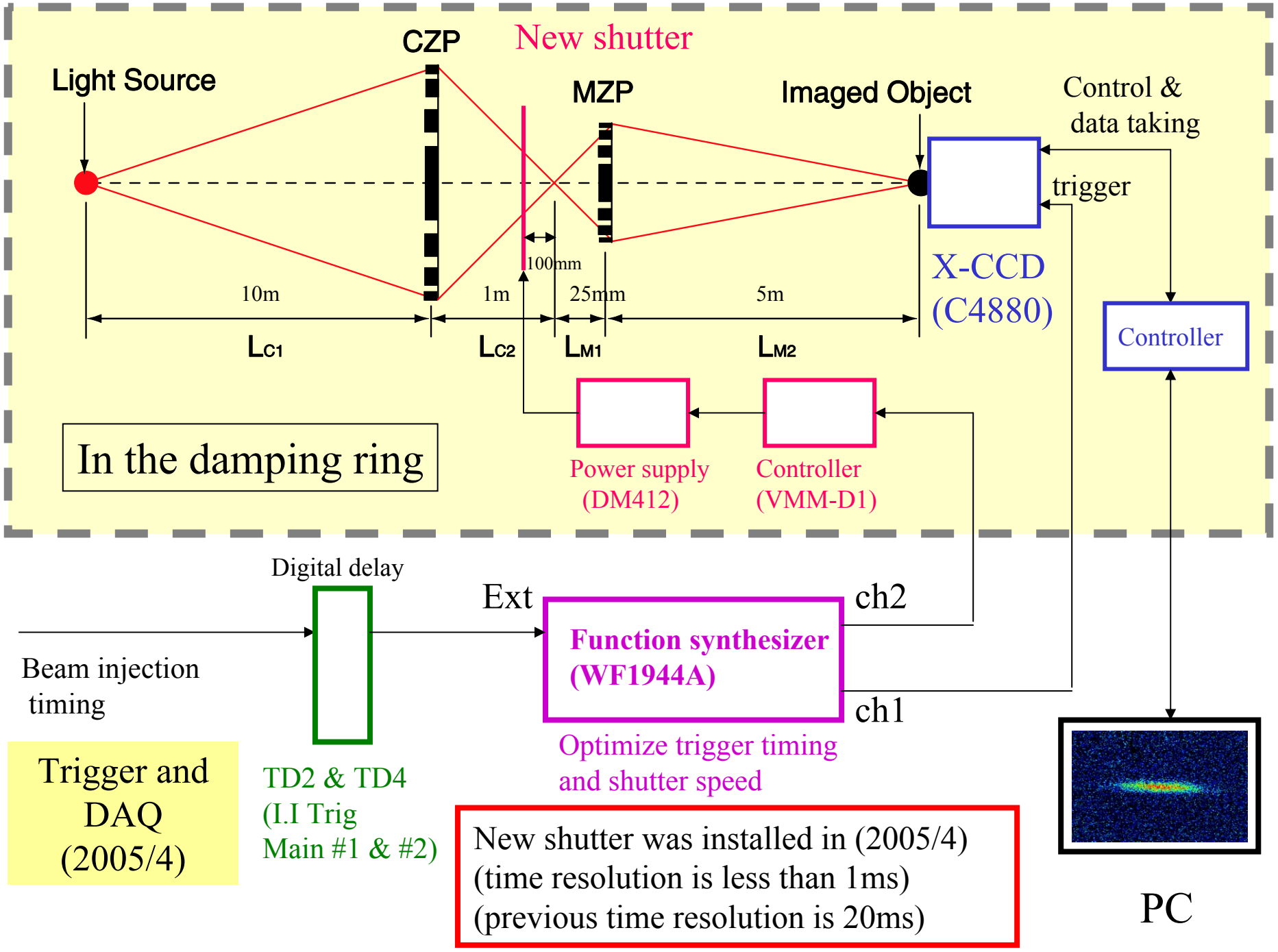
All view



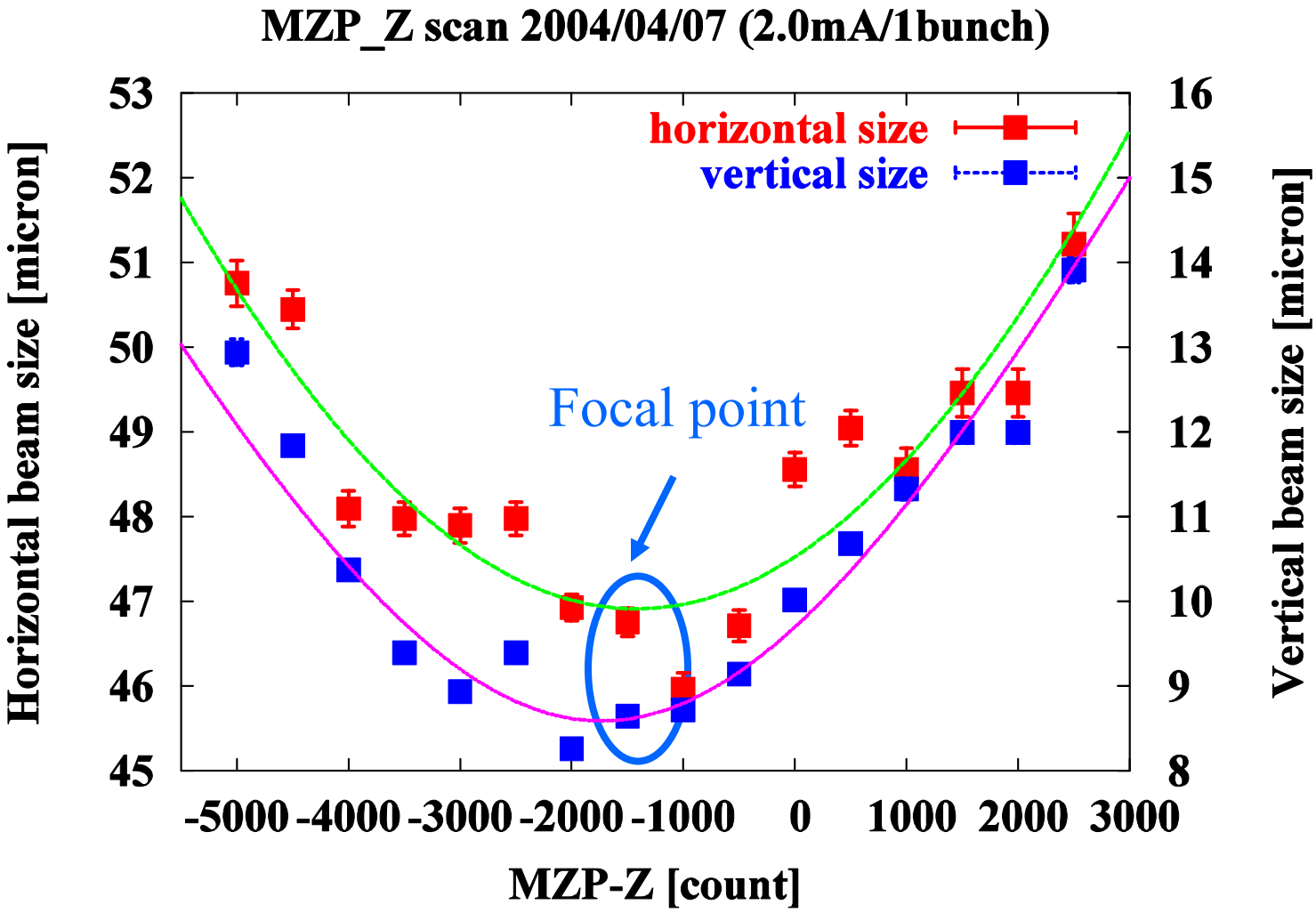
Expanded view



Minimum width of shutter opening time is less than 1ms


CZP
New shutter
Light Source
MZP
Imaged Object
Control &
data taking
trigger
100mm
X-CCD
(C4880)
10m
1m
25mm
5m
Lc1
Lc2
LM1
LM2
Controller
In the damping ring
Power supply
(DM412)
Controller
(VMM-D1)
Digital delay
Ext
ch2
Beam injection
timing
Function synthesizer
(WF1944A)
ch1
Optimize trigger timing
and shutter speed
Trigger and
DAQ
(2005/4)
TD2 & TD4
(I.I Trig
Main #1 & #2)
New shutter was installed in (2005/4)
(time resolution is less than 1ms)
(previous time resolution is 20ms)
PC

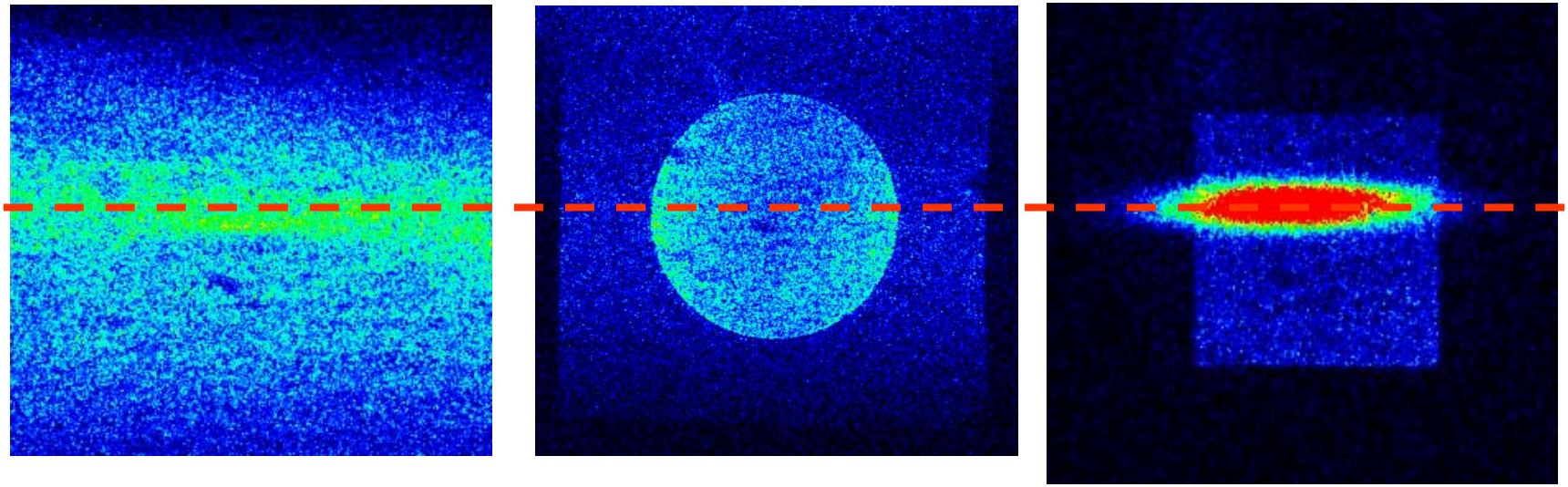
MZP z-scan



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

Alignment strategy

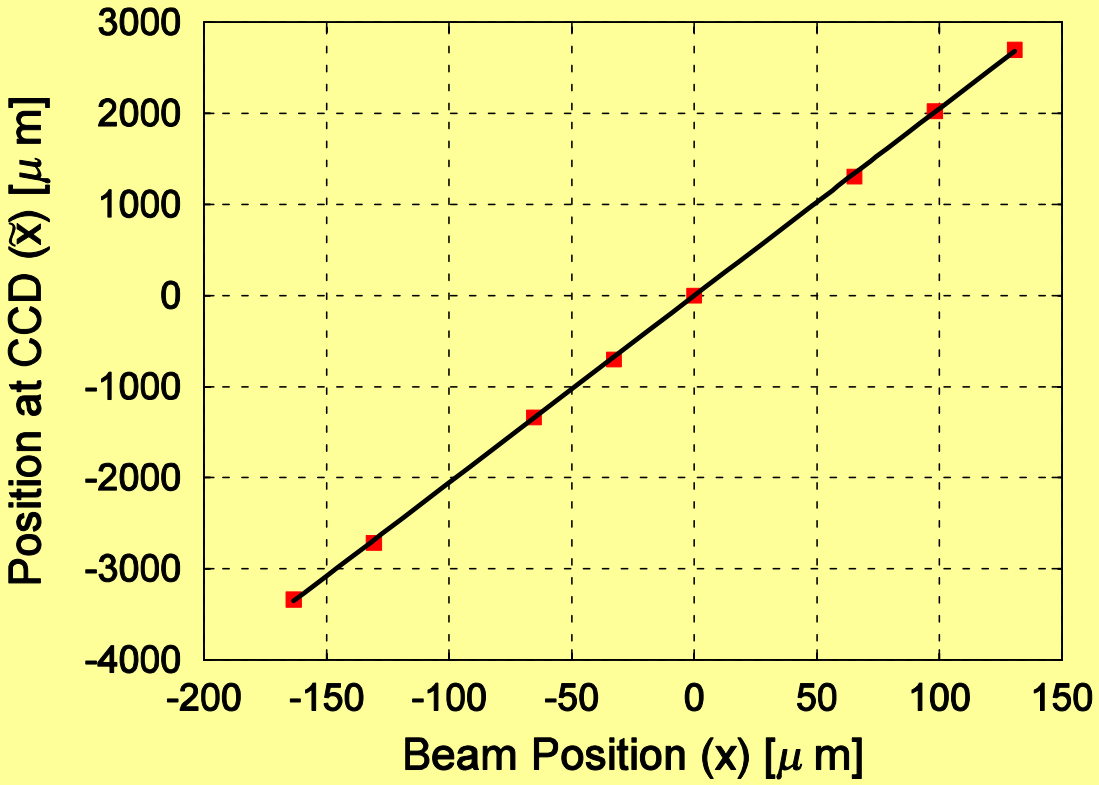
1 2 3



See direct SR light Enter the CZP Enter the MZP

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

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