X-ray SR monitor
(Fresnel Zone Pate (FZP) monitor)

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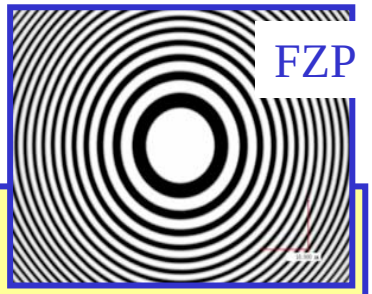
1. Principle of FZP monitor
2. Setup of FZP monitor
3. Measurement results
4. Summary

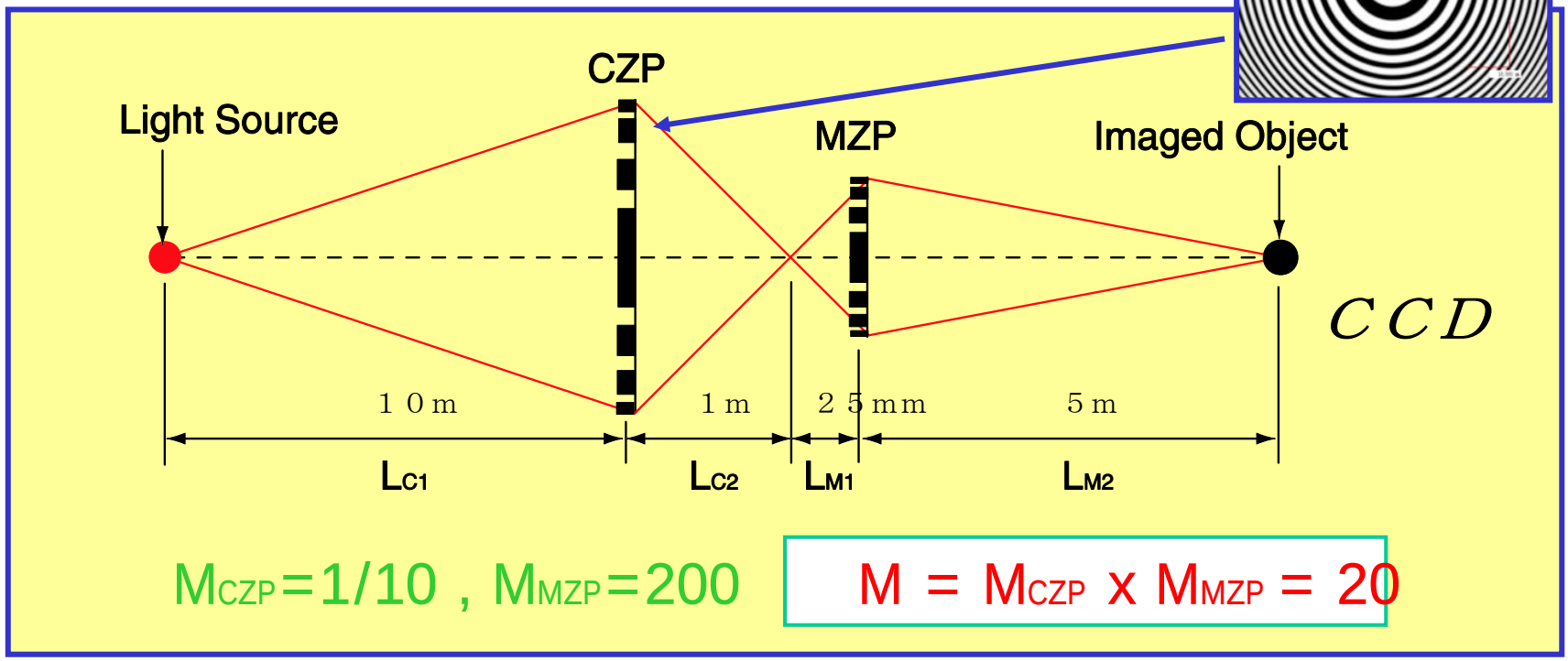
- Laser-wire mini workshop 2006 , Oxford, England ,3rd July -

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)

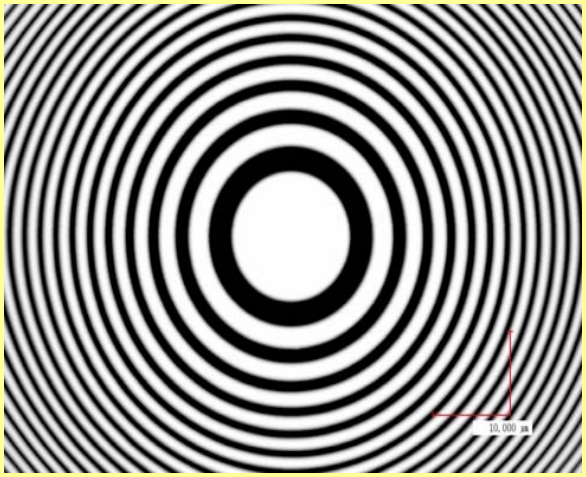
Principle of FZP monitor





- 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

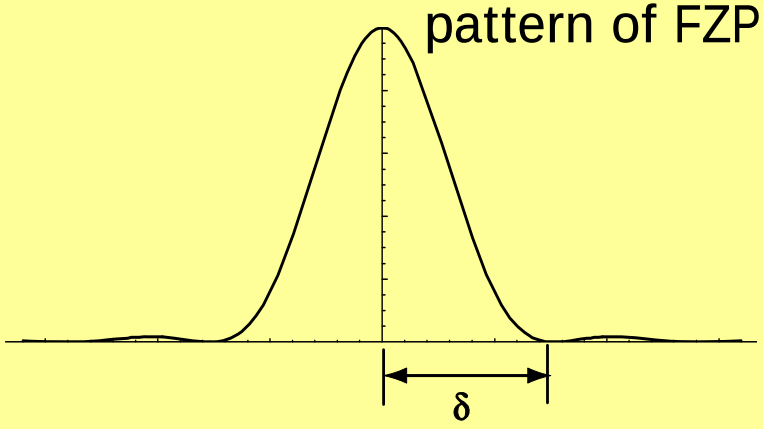
$$\delta = 1.22\,\Delta r_N \approx 3\sigma$$

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

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} x M_{MZP} = 20

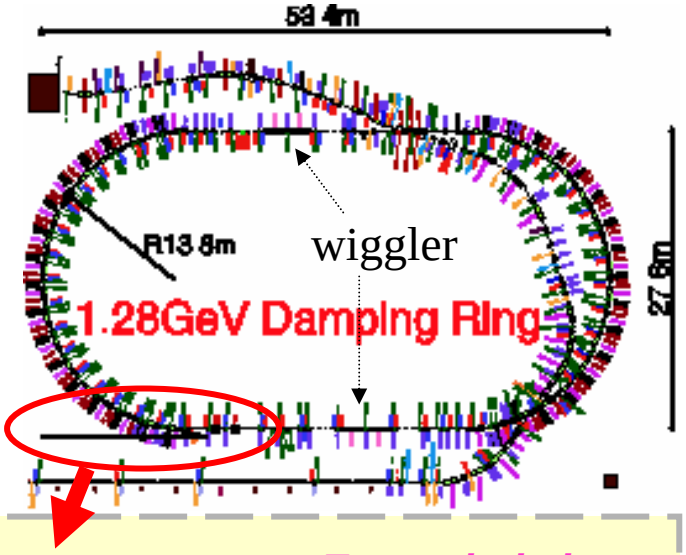
The total spatial resolution is 0.7μm in R.M.S .

↓

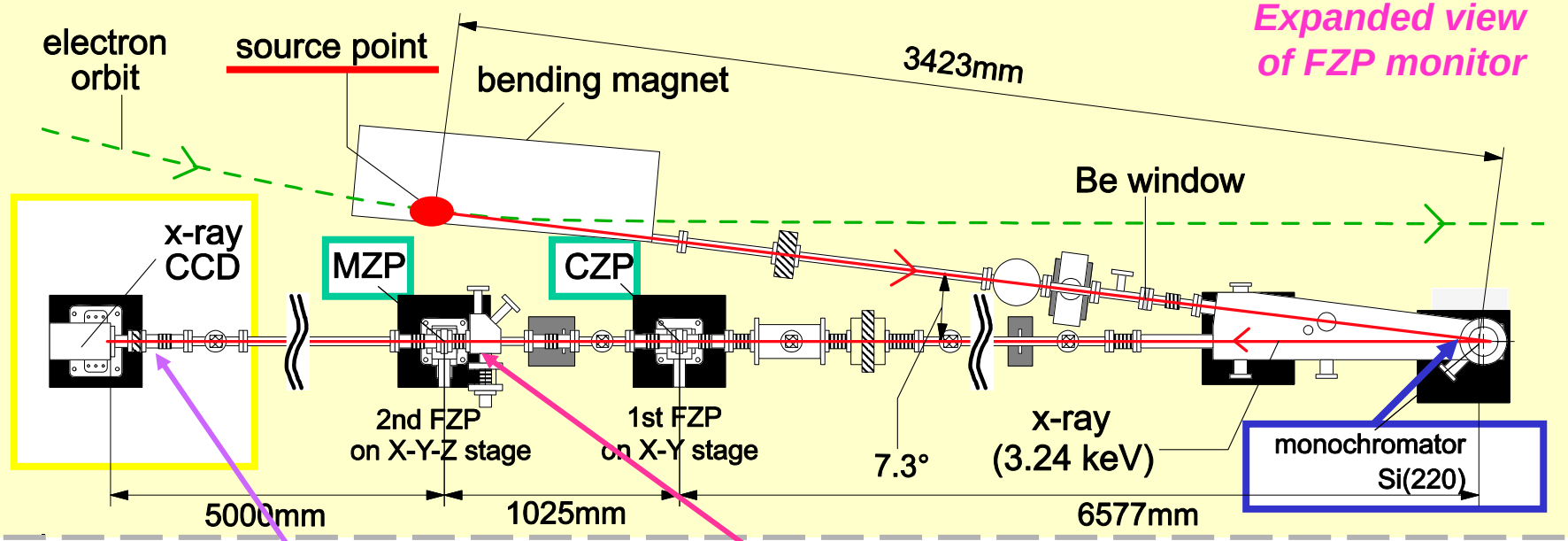
Submicron spatial resolution will be expected on this FZP monitor.

Setup of FZP monitor

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



Expanded view of FZP monitor

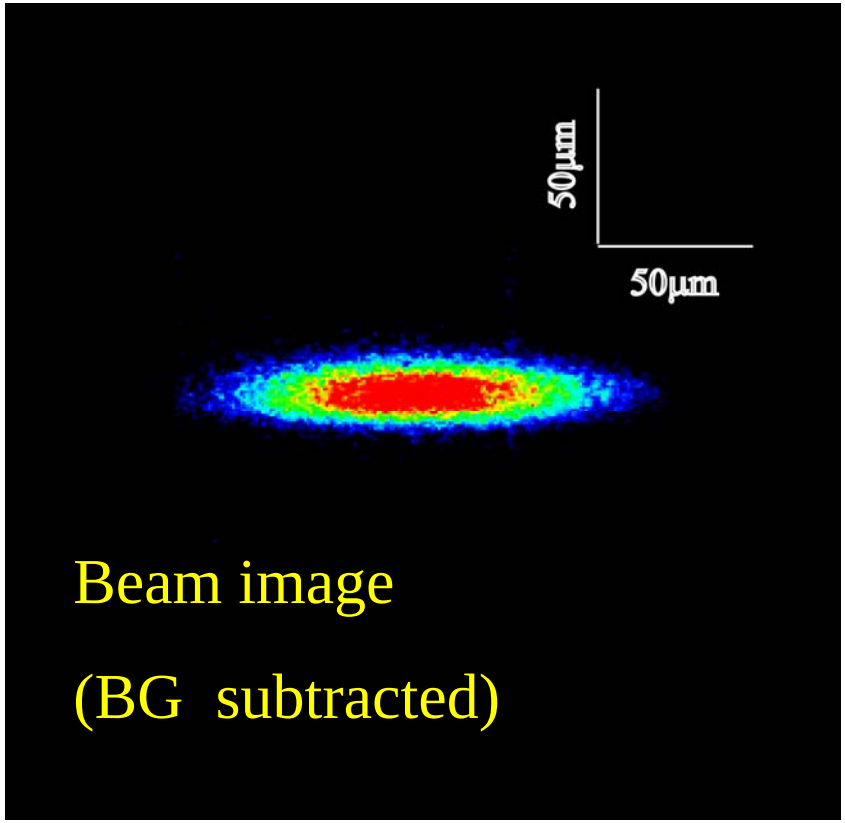


Previous shutter was set in front of CCD camera [shutter time >20ms]

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

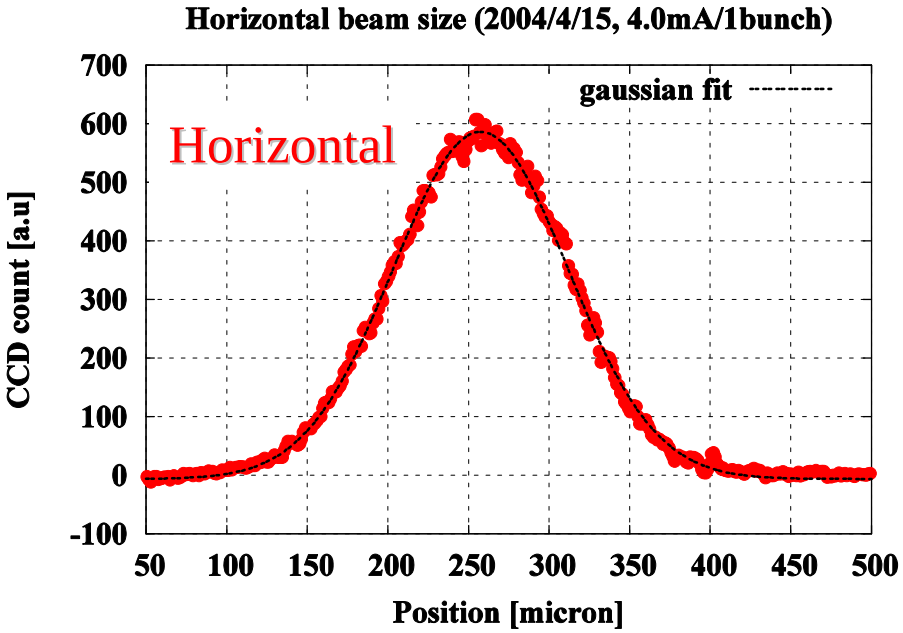
Monitor Beam Line (picture)

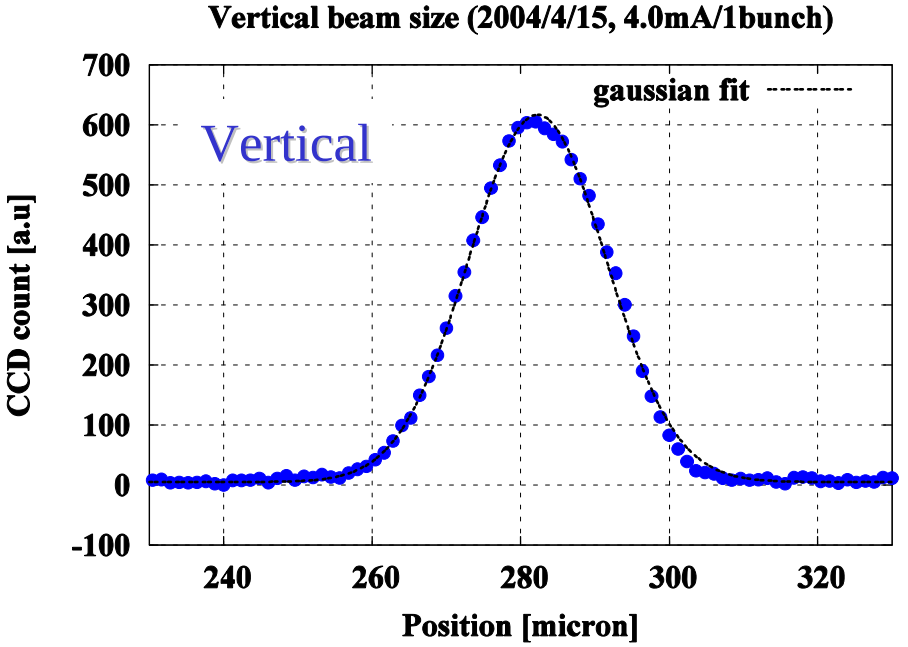
Example of beam image (shutter with 100ms)



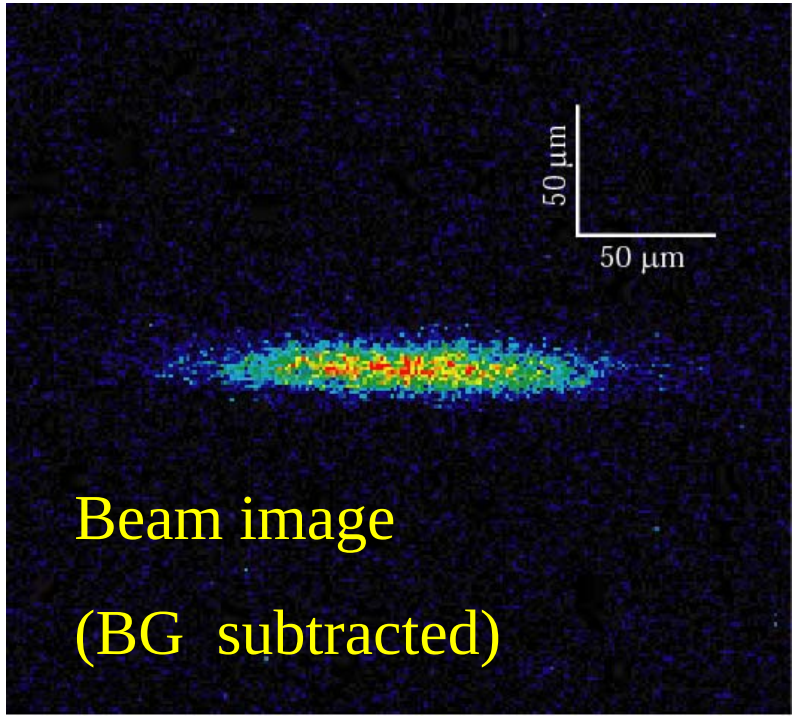
I=4.0mA, Shutter time = 100ms
(2004/4/15)

$$\sigma_x = 54.2 \pm 0.2 \quad [\mu m]$$
$$\sigma_y = 9.2 \pm 0.1 \quad [\mu m]$$





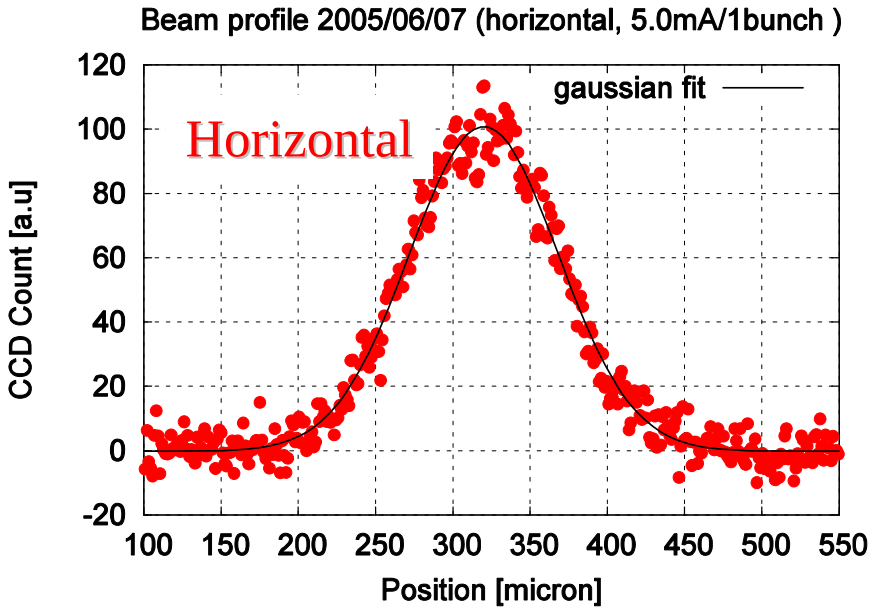
Example of beam image (new shutter with 1ms)

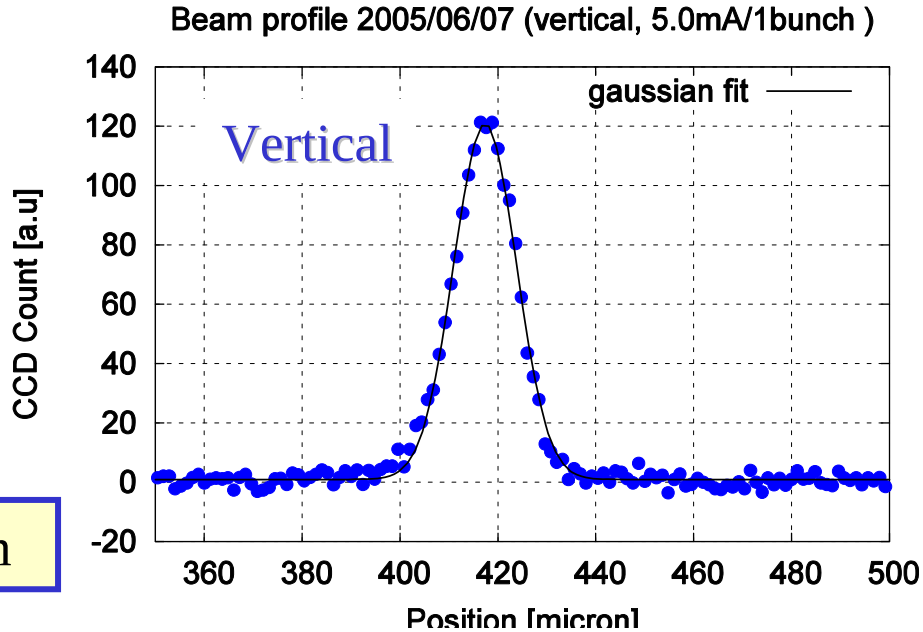


I=5.0mA, Shutter time = 1ms
(2005/06/07)

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

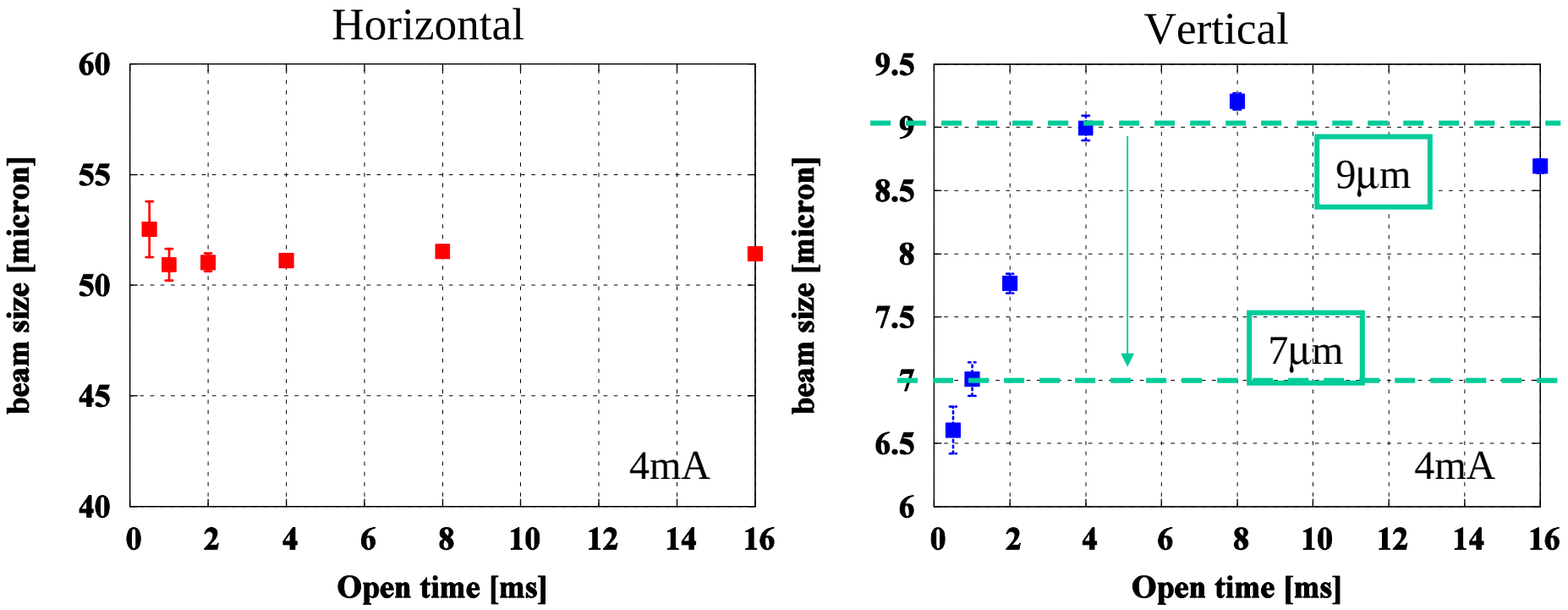
Reduce vertical beam size : 9.2μm → 6.4μm





Shutter opening time dependence

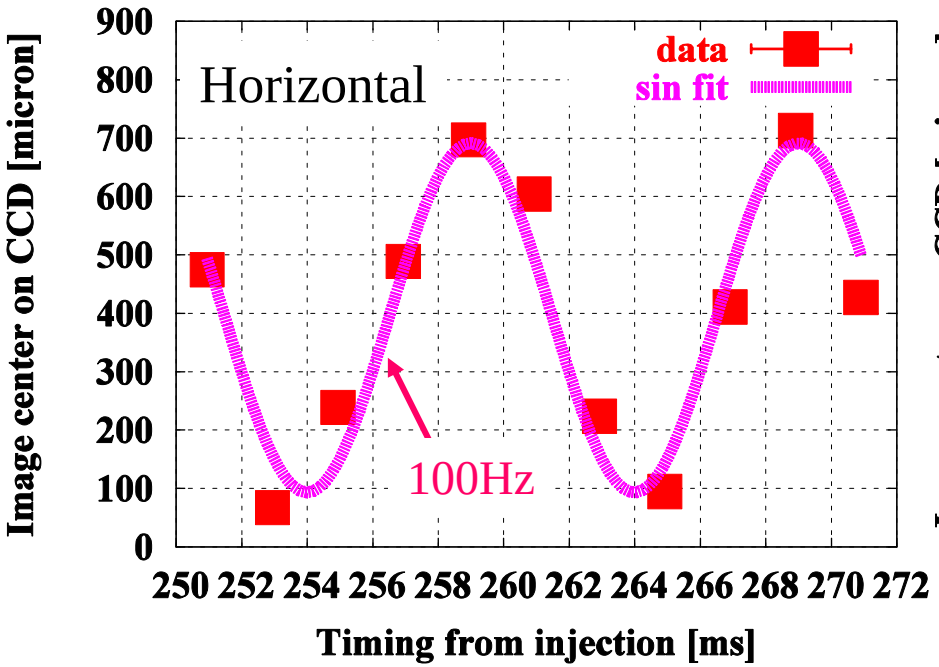
Measure the beam size by changing shutter opening time.

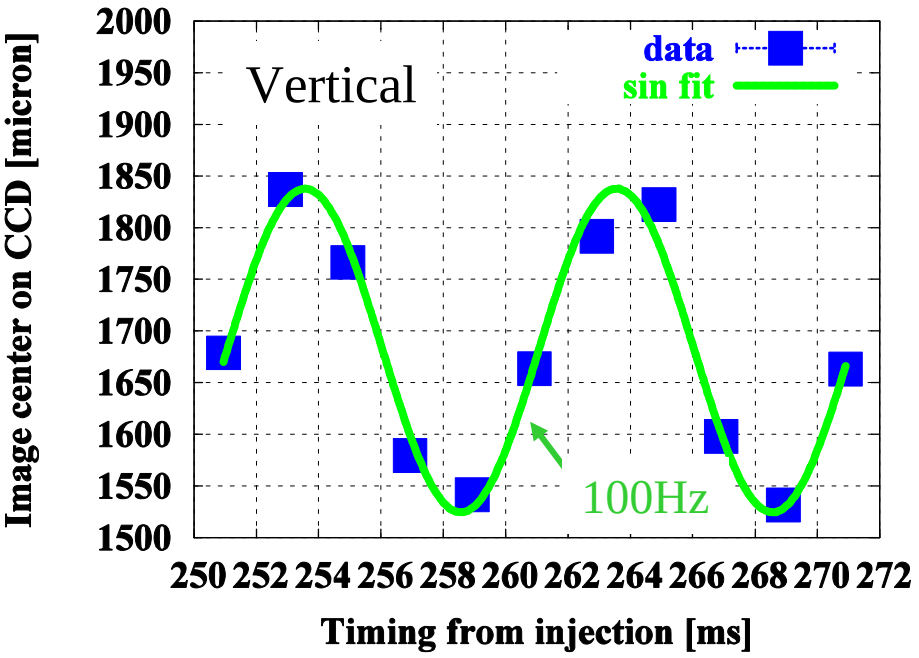


The measured horizontal beam size was almost 50μm and was independent of the shutter opening time. On the other hand, the measured vertical beam size was changed from 9μm to 7μm by changing the shutter opening time from 4ms shorter.

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.）



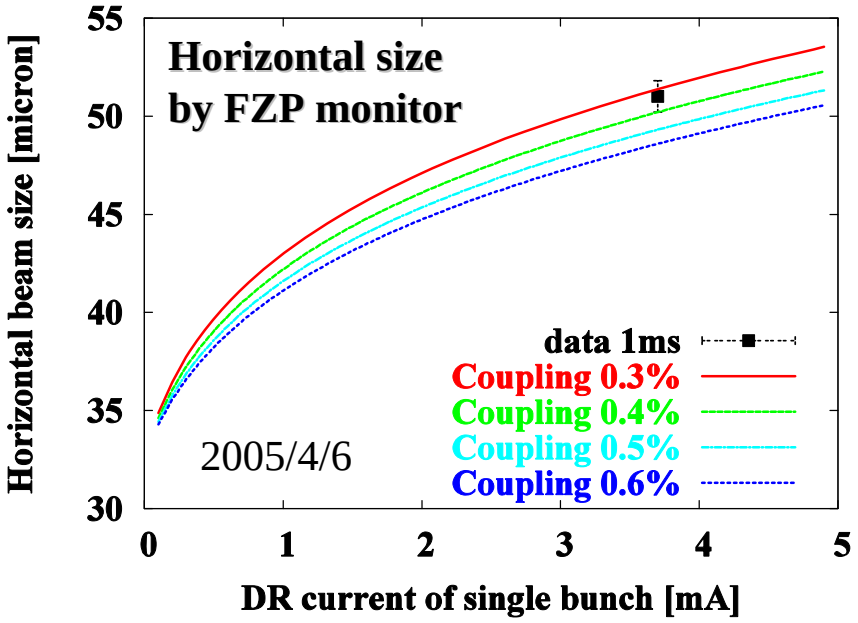


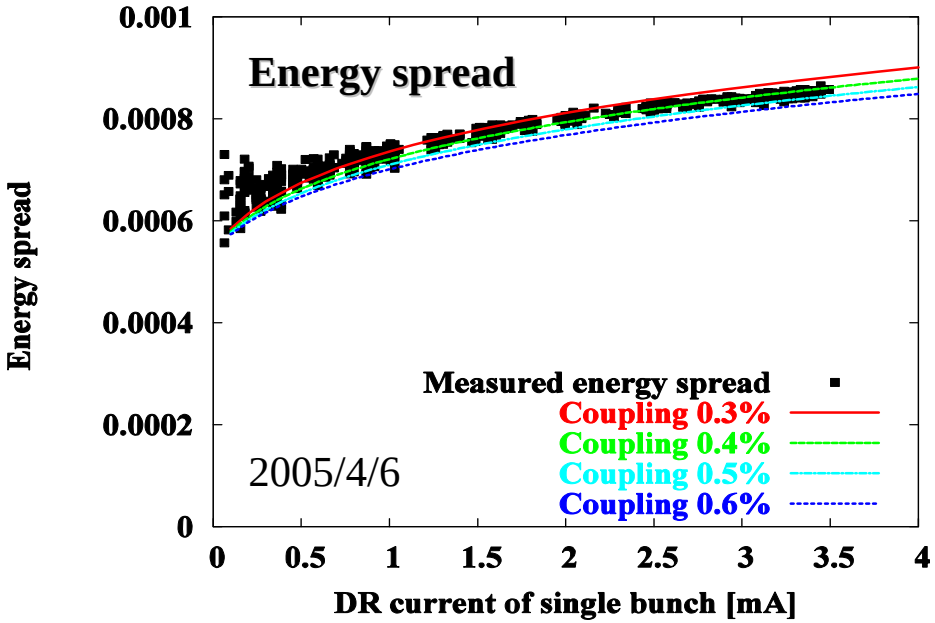
Horizontal amplitude ： 14.9μm

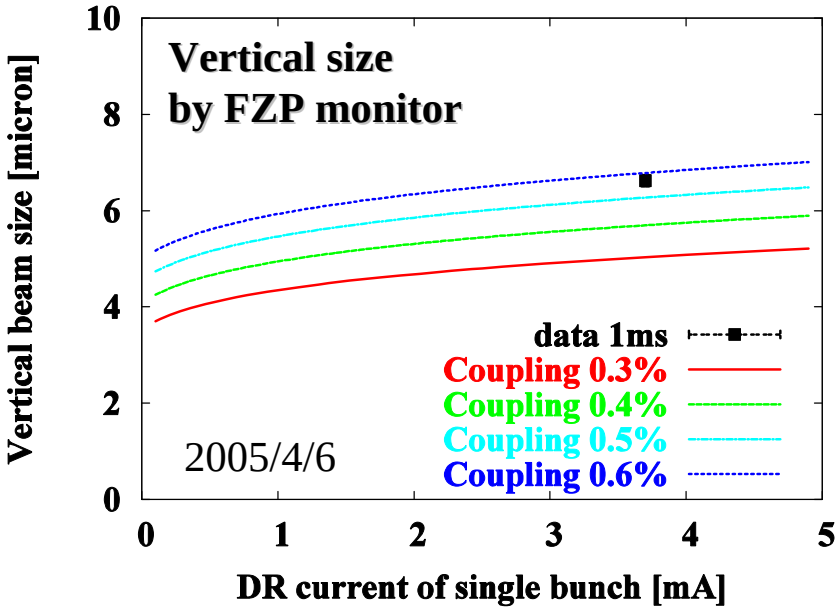
Vertical amplitude ： 7.8μm

100Hz beam oscillation made the vertical beam size enhancement

Measured sizes by FZP monitor vs calculation

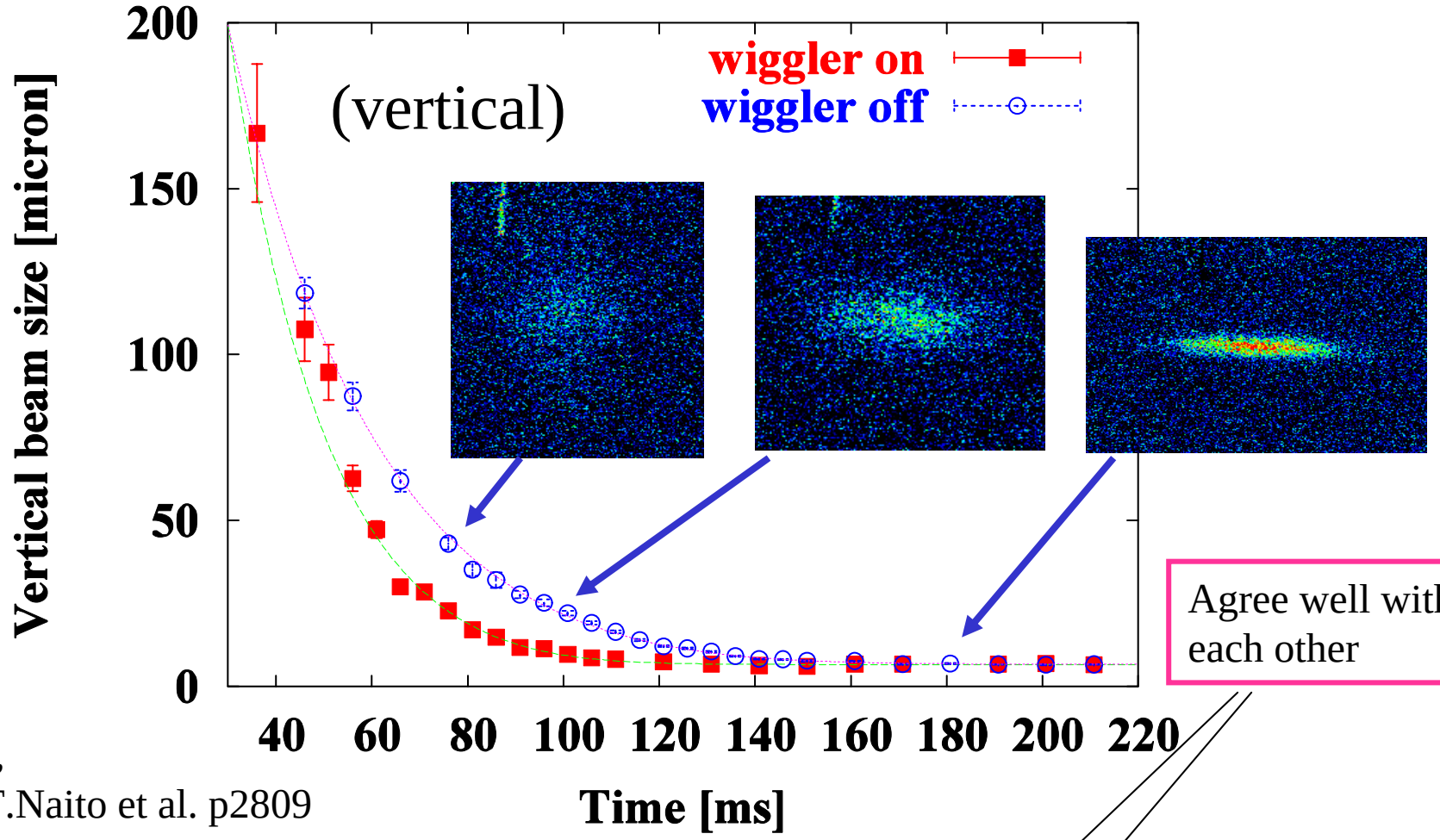






Three measurements (horizontal and vertical beam size by FZP monitor and energy spread by screen monitor at the extraction line plotted by black squares) agree well with the calculation results by assuming the betatron coupling of 0.3～0.6 % (solid and dotted lines)

(Application) 1. Measurement of damping time

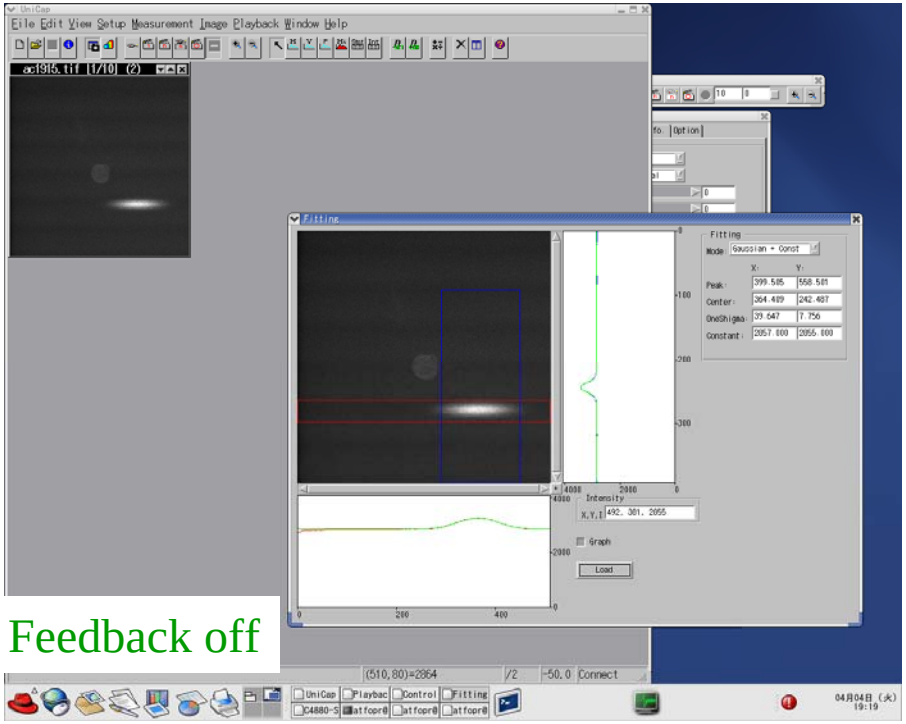


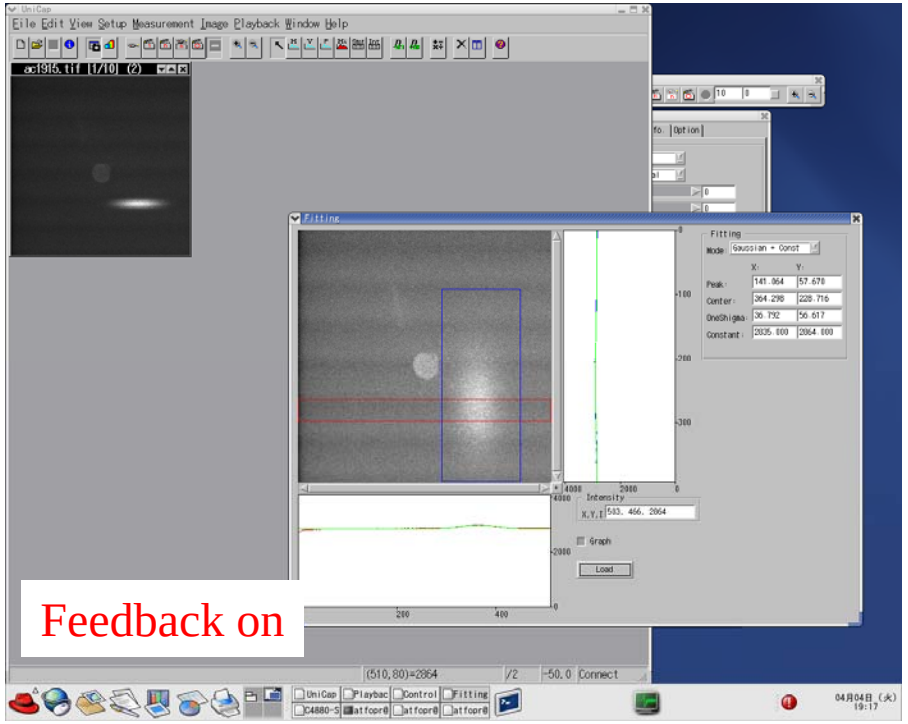
Agree well with each other

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

(Application) 2. Difference between Longitudinal feedback on and off (2006/4/4)





Horizontal : 47.6μm
Vertical : 9.3μm

$$\sigma_x = \sqrt{\beta_x \varepsilon_x + \left(\eta_x \frac{\sigma_p}{p}\right)^2}$$

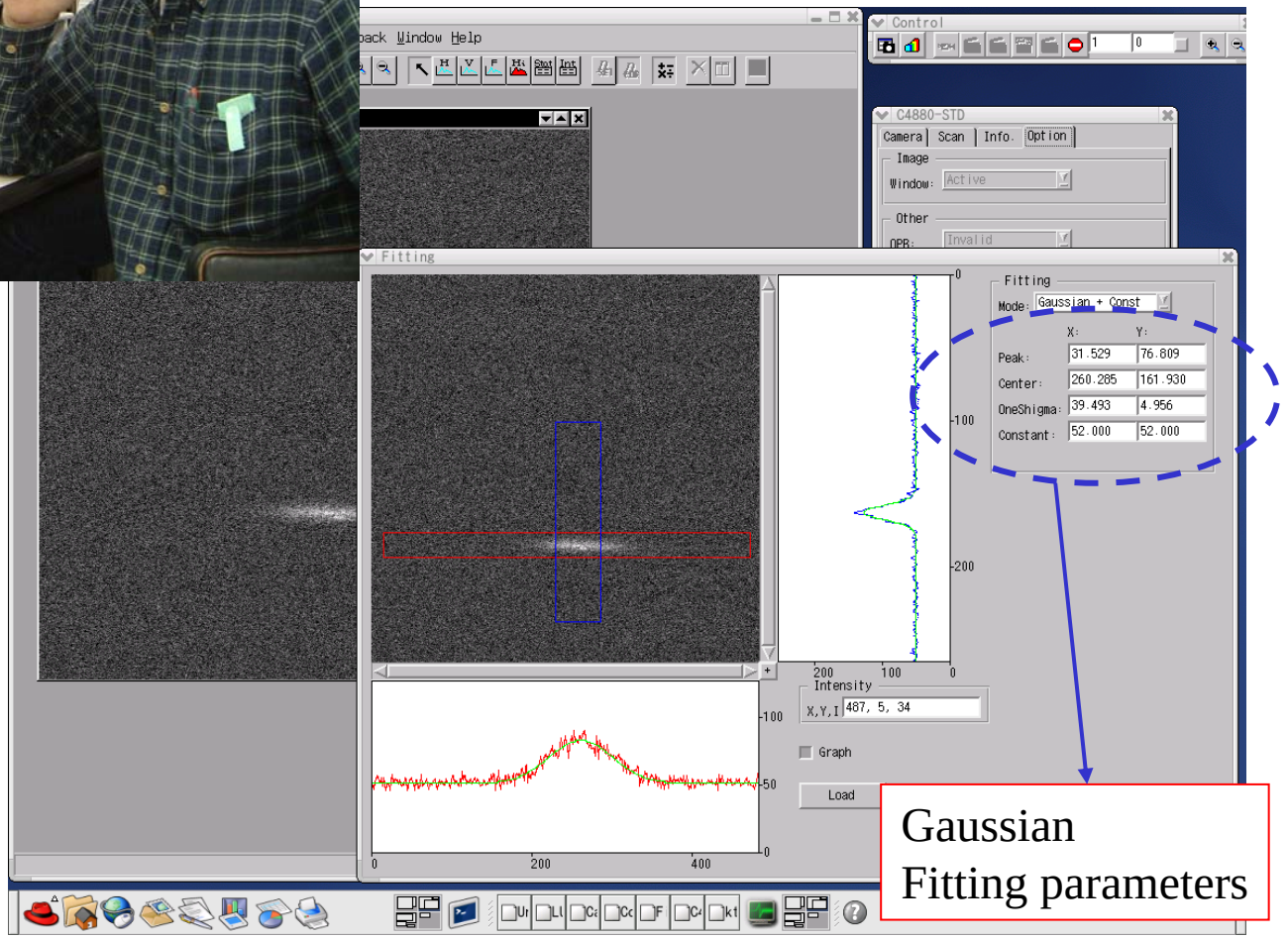
Horizontal : 44.2μm
Vertical : 67.9μm

Live mode: no BG subtract TTL pulse 20ms (※ Don't remove the effect of 100Hz oscillation)

The large vertical beam profile enhancement was observed by adding longitudinal feedback on. This data is consistent with the measurment of wire scanner at extaction line. (The reason was not understood. Please ask Naito-san)

Remote data taking of FZP monitor

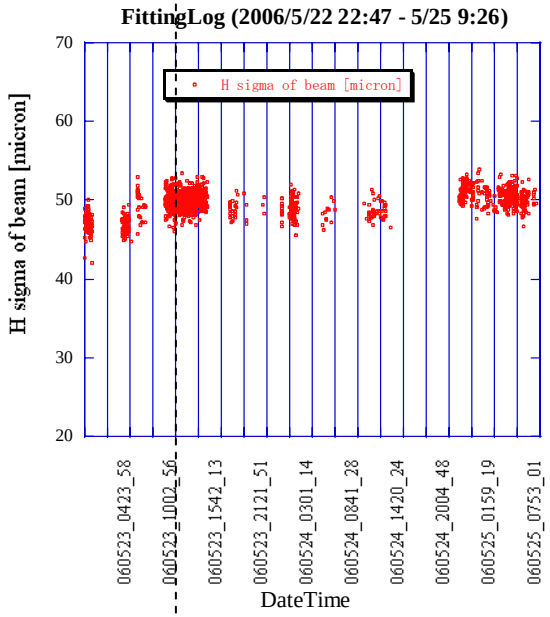
Monitor panel was set on the ATF 1st container.



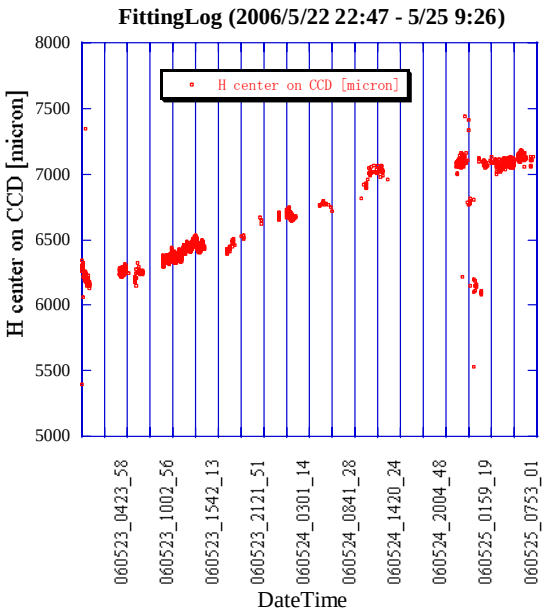
Now we can continuously take data of FZP monitor on ATF 1st container from April 2006.

Longterm position & size (2006/5/22 – 5/25)

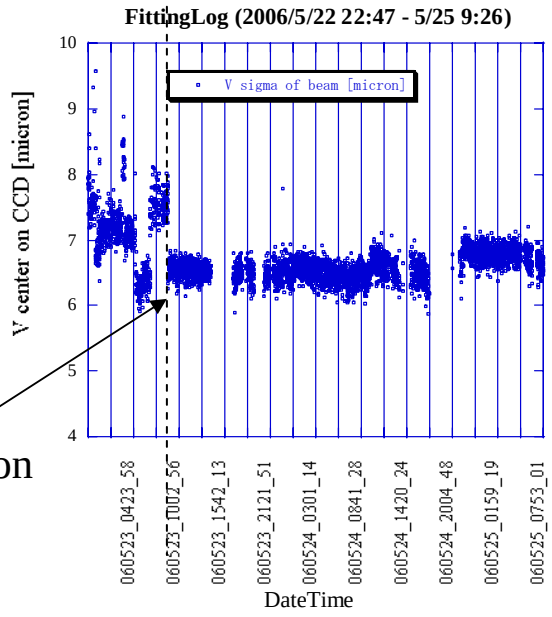
Horizontal size



Horizontal position

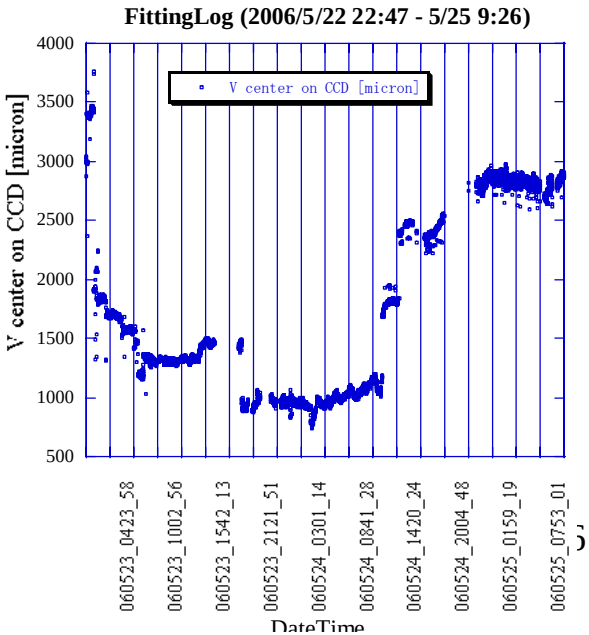


Vertical size



Skew correction was done

Vertical position



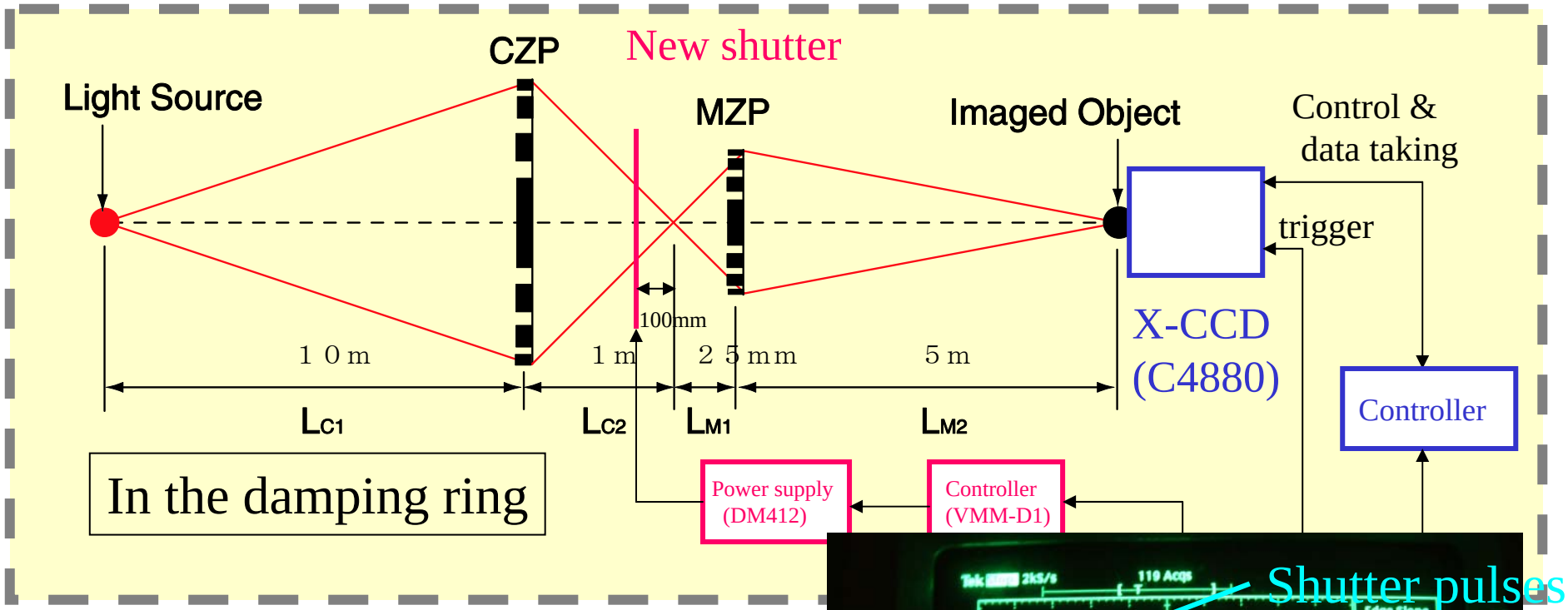
Summary & Future

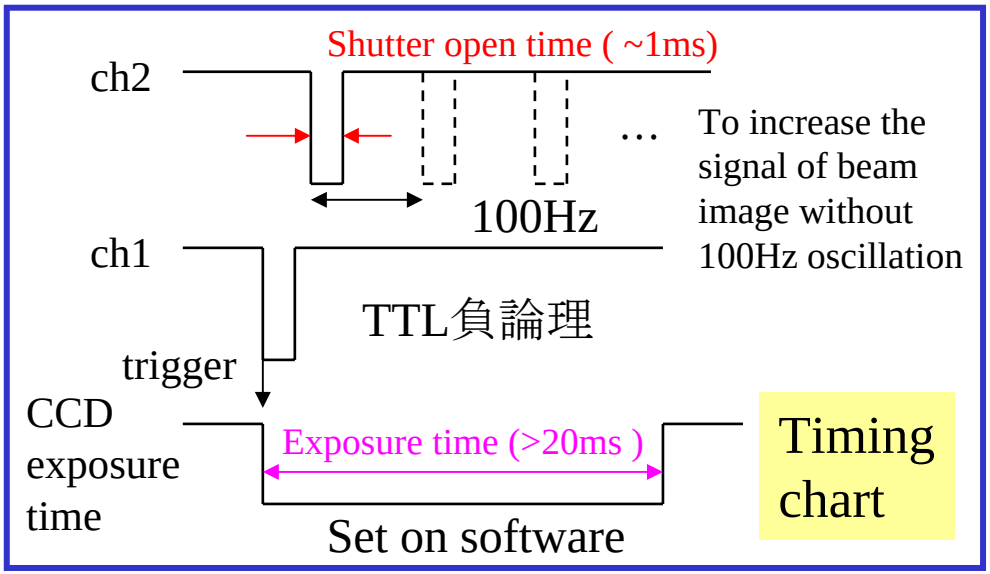
- We measure the beam size by using FZP monitor at KEK-ATF damping ring. The effect of the unknown 100Hz oscillation was removed on the measurement by using new mechanical shutter with 1ms shutter opening time. After that, the measured vertical beam size of this monitor was less than 7μm.
- The measured 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.
- We can use the FZP monitor as online monitor.

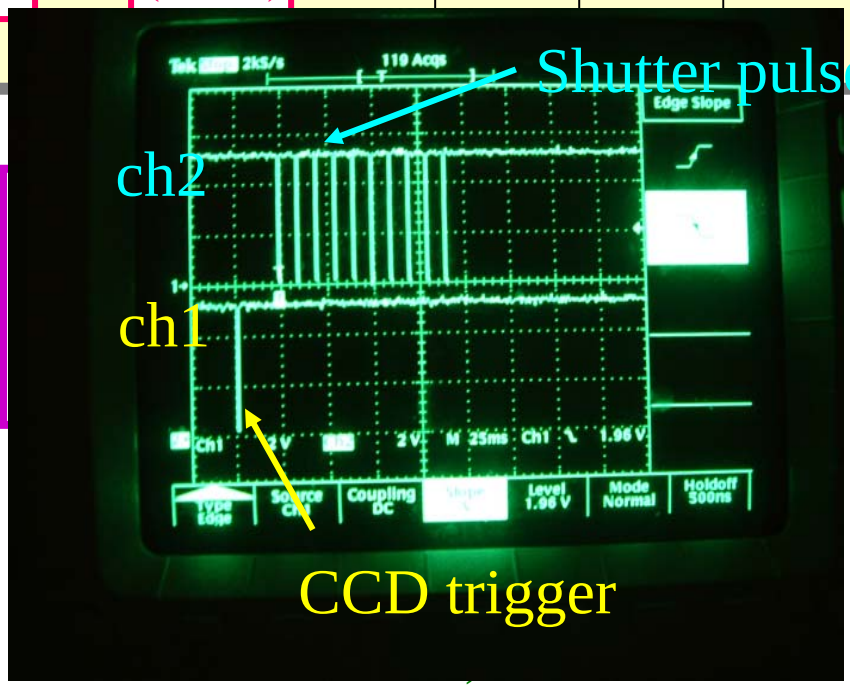
Future plan

- Search the 100Hz vibration source
  - Measure the correlation with B,Q,S power supply data and/or temperature.
  - Plan to add new digital BPM system (Libera) less than 1μm resolution near FZP monitor
- Increase the S/N ratio.
  - apply multi pulses operation (now under going)
- Longterm stability
  - We need to data taking correlated with DCCT ,BPM and other monitor on same data

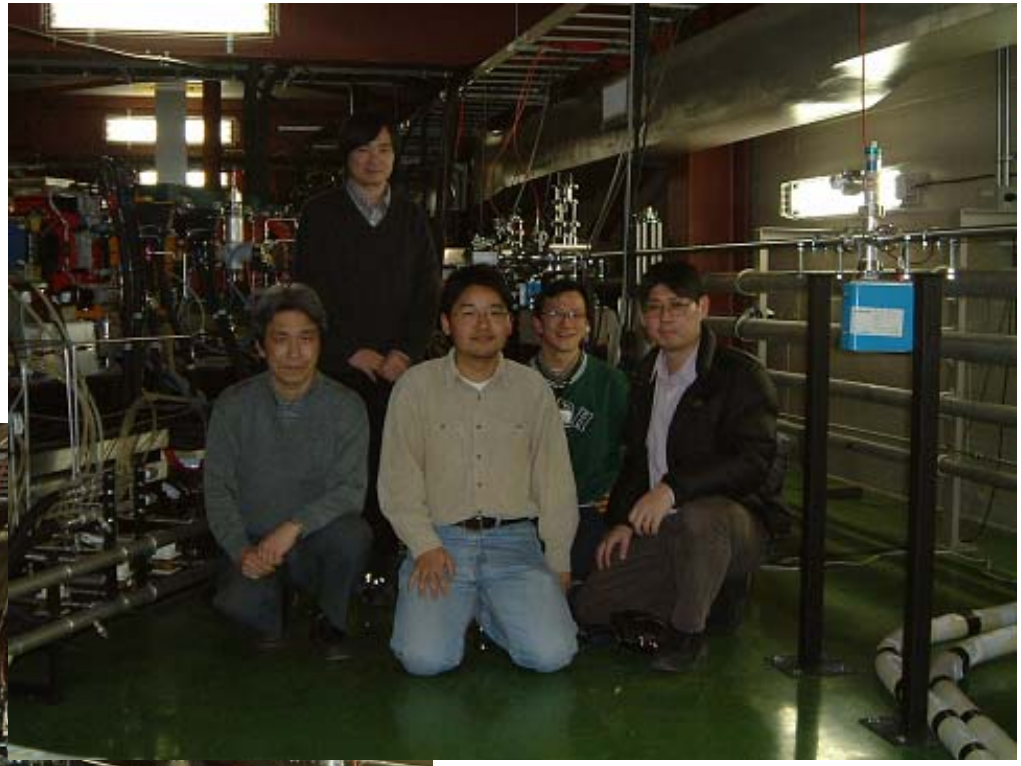
Multi pulses operation

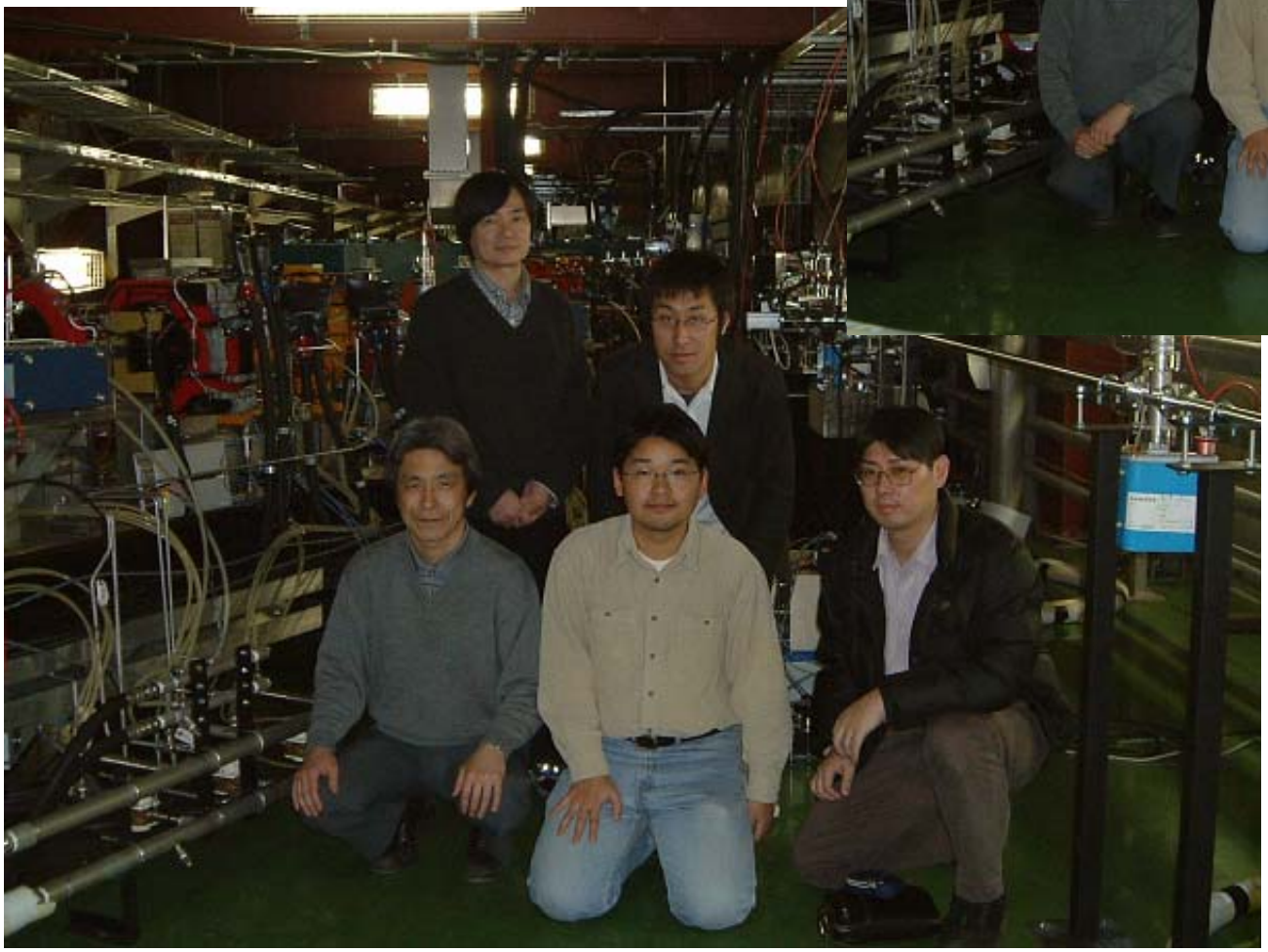






Thank you





Welcome Kuriki-san (KEK) and Itoh-san (ISSP U-tokyo) to new FZPmonitor group from April 2006.

References

Photon Flux

Energy E=1.28 [GeV]

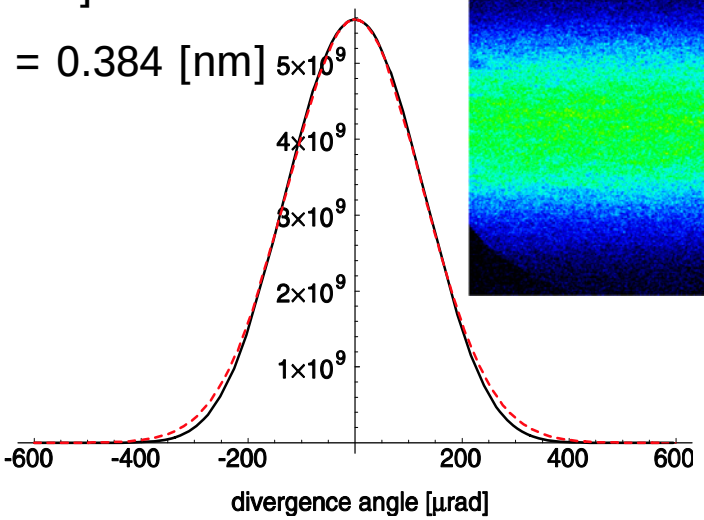
Bending field B=0.748 [T]

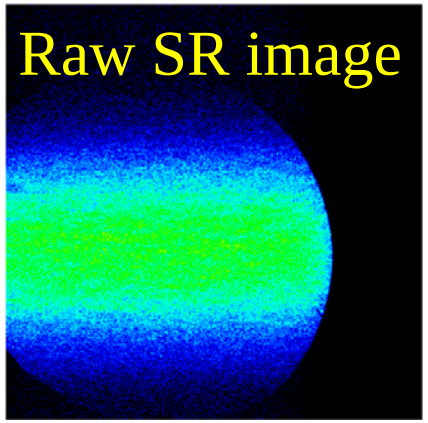
Critical length λ_C =1.52 [nm]

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

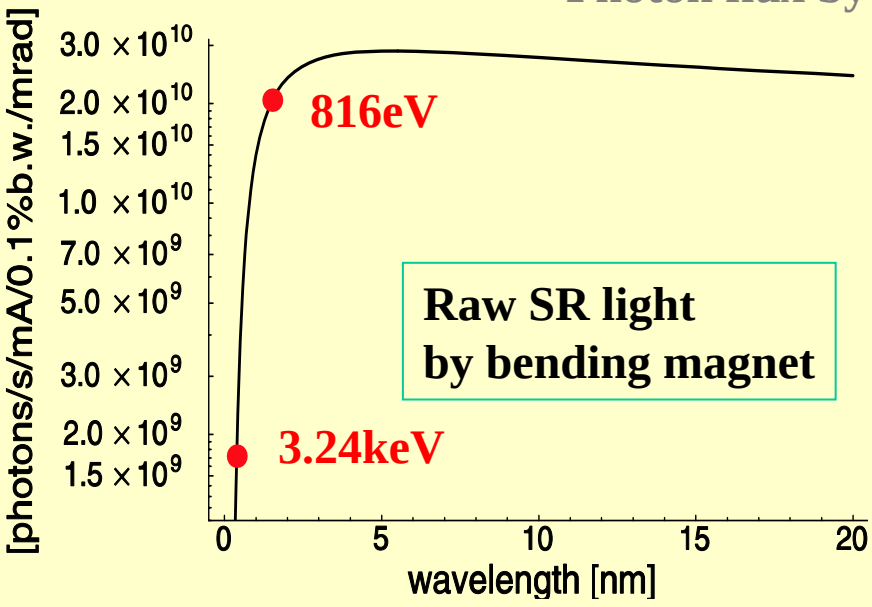
σSR =126 [μrad]

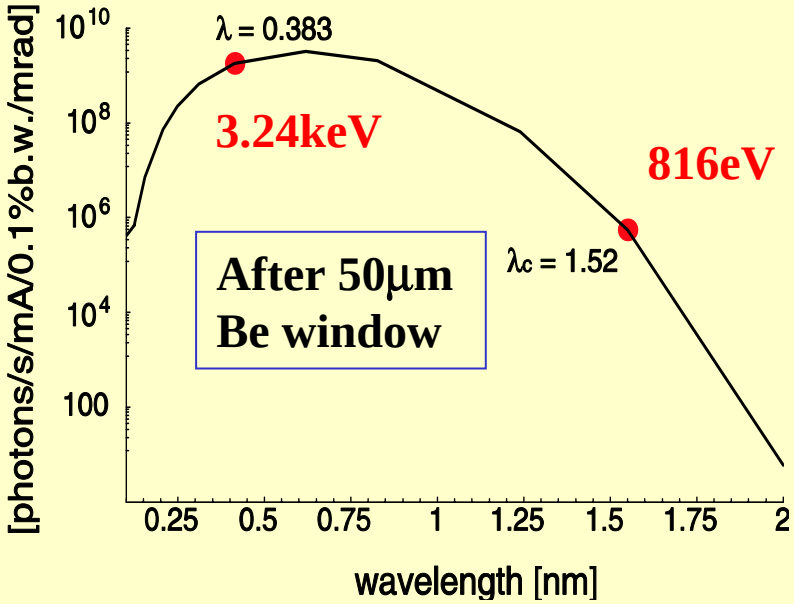
λ = 0.384 [nm]





Photon flux by SR source point



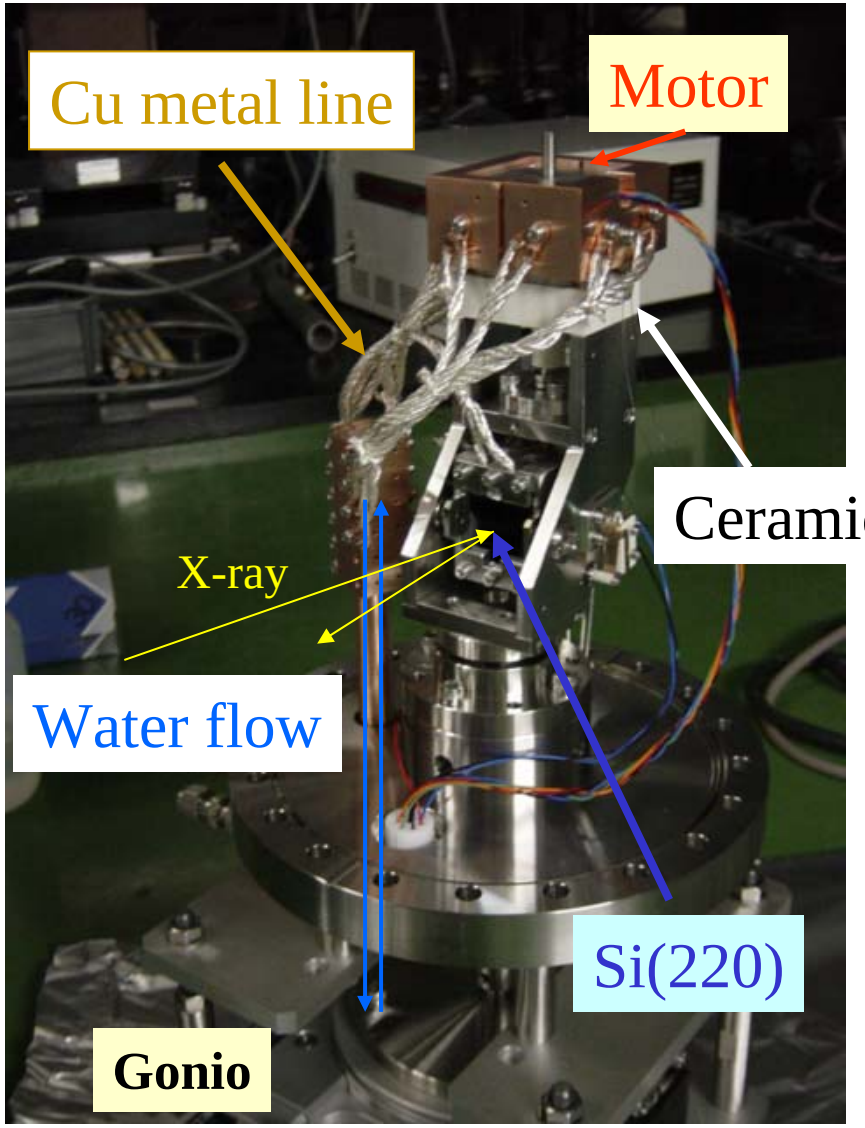


Monochromator

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



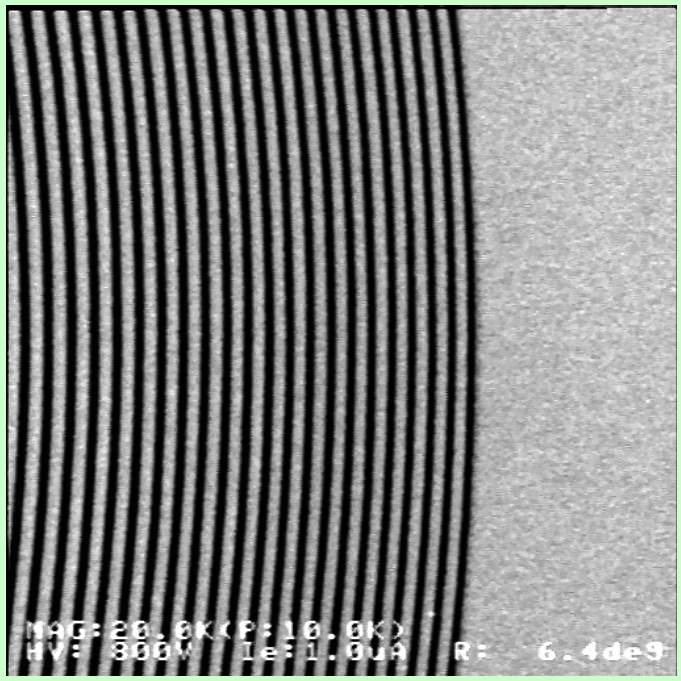
Fresnel Zone Plates

Parameters of two FZP (λ = 0.383 nm)

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

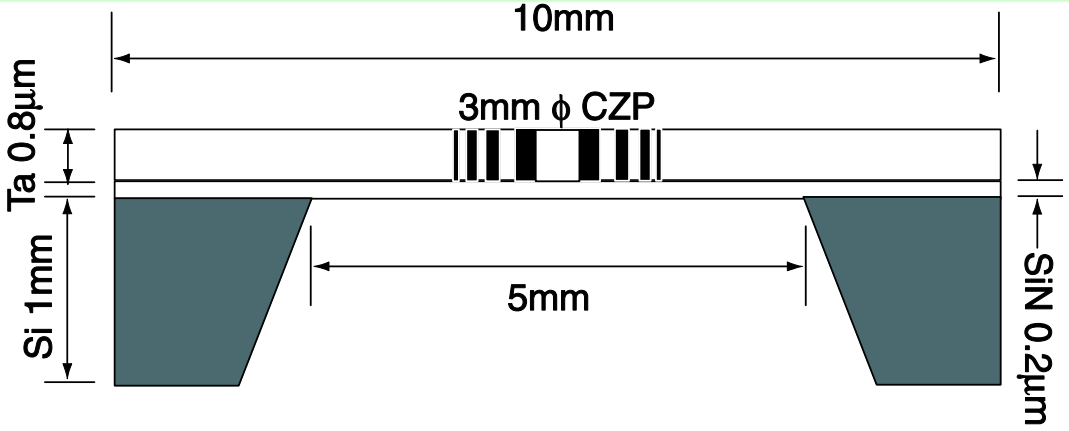
	CZP	MZP
Number of Zone	6444	146
Radius	1500 μm	37.3 μm
Most outer zone width Δr_N (δ_{FZP})	116nm (142nm)	128nm (156nm)
Focal length f	909mm	24.9mm
Magnification	1/10	200

Outer zone of MZP by SEM



Cross Section of FZP

Produced by
NTT-AT corp.



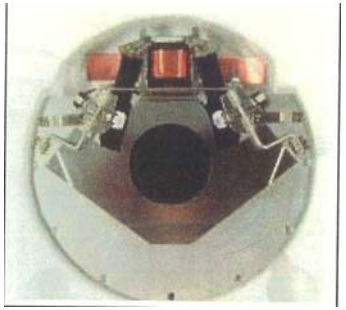
X-ray CCD

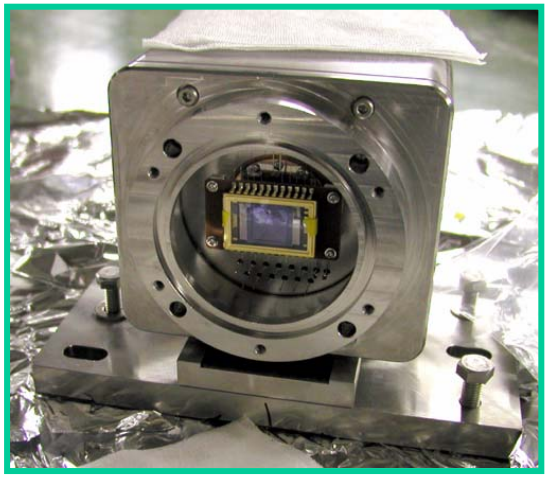
CCD	Backward full frame transfer type
Area	12.29 mm x 12.29 mm
Pixel size	24 μm x 24 μm
Quantum effeciency	< 90 % (3.24 keV)
Cooling	Peltier **(-50 C°)**
Dark current	2 electrons/pixels/sec
Scanning speed	7 frame/sec (Live) 0.5 frame/sec (Acquire)
Shutter speed	Less than 20ms

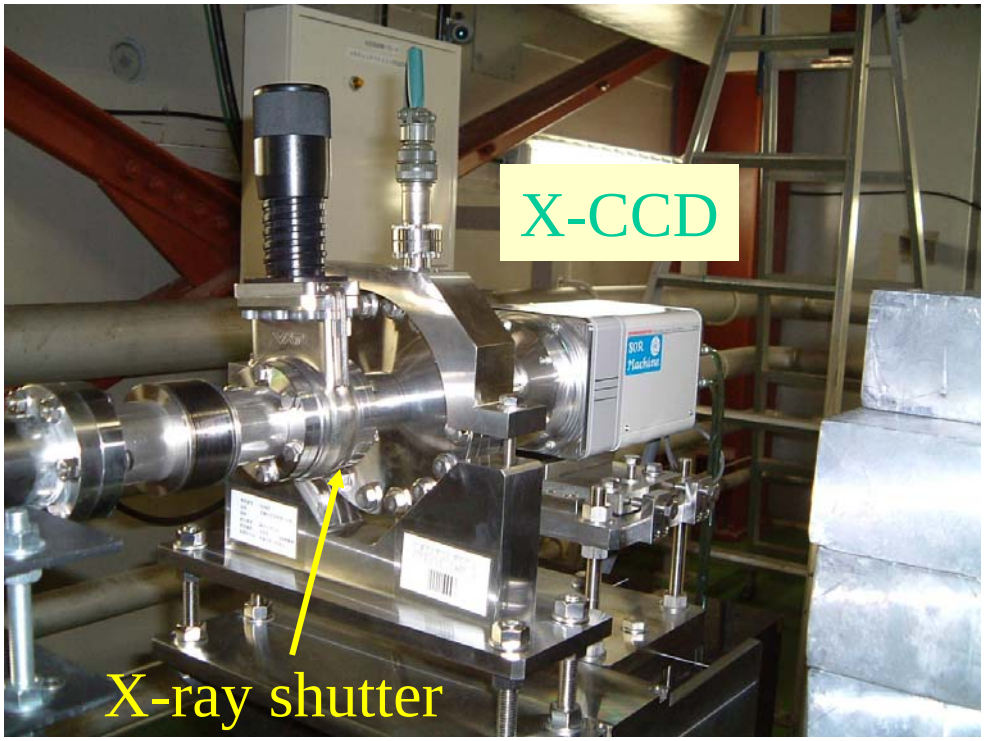
C4880-21-24-WD

(made by Hamamatsu K.K)

X-ray shutter



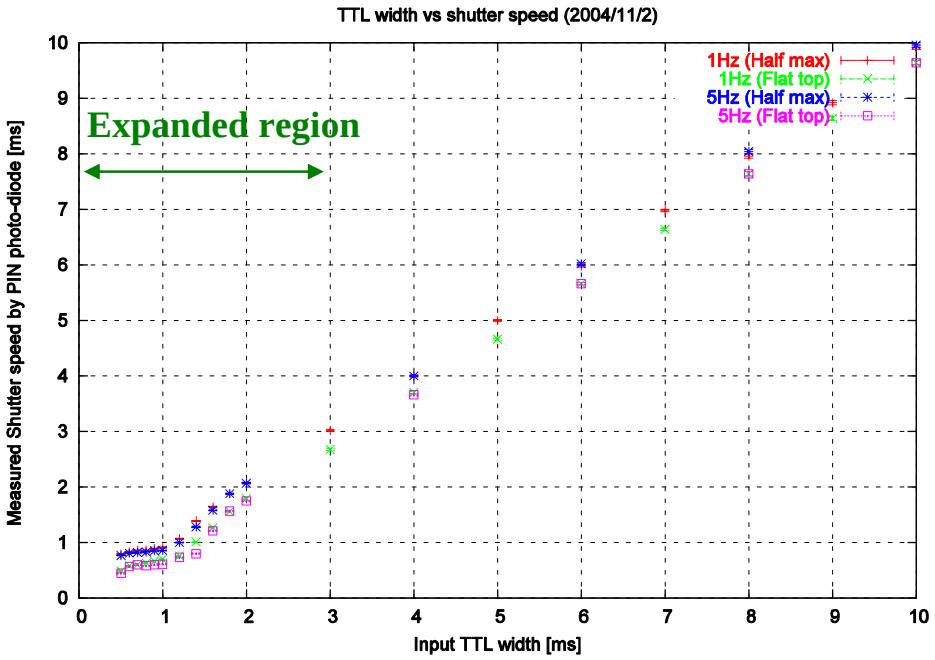




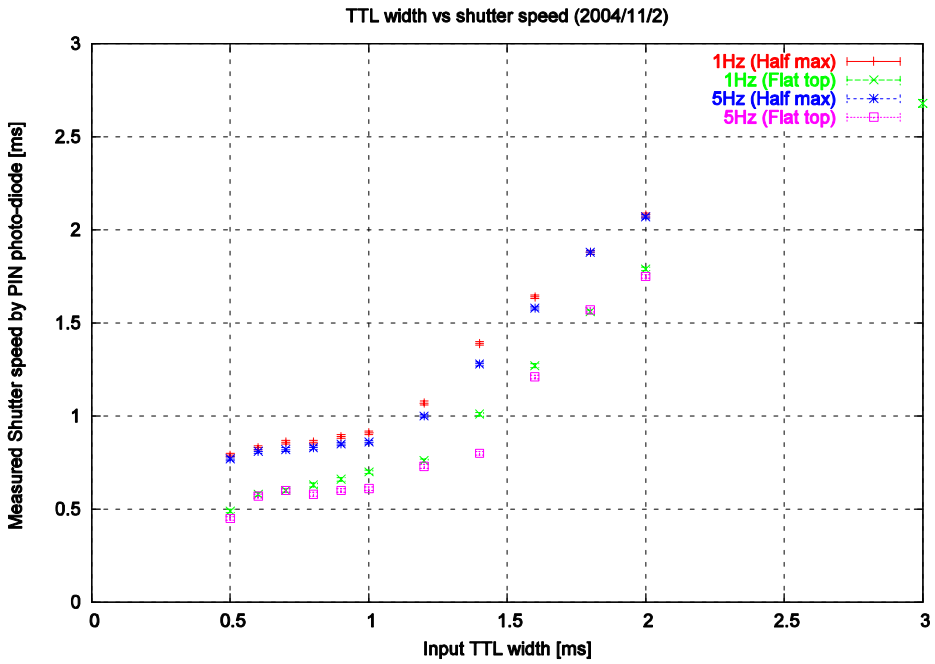
Performance （Normal mode） at test bench

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

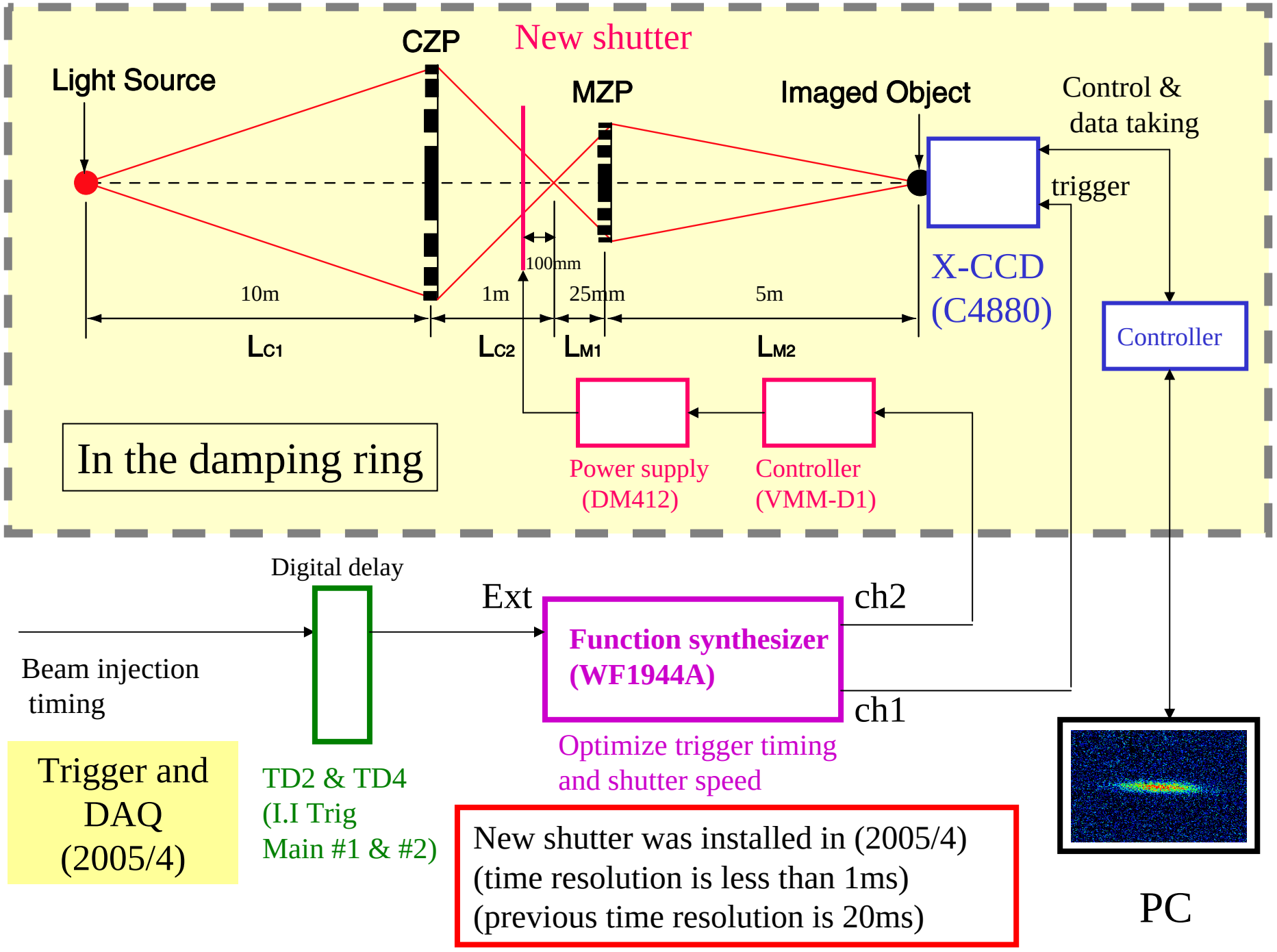
All view



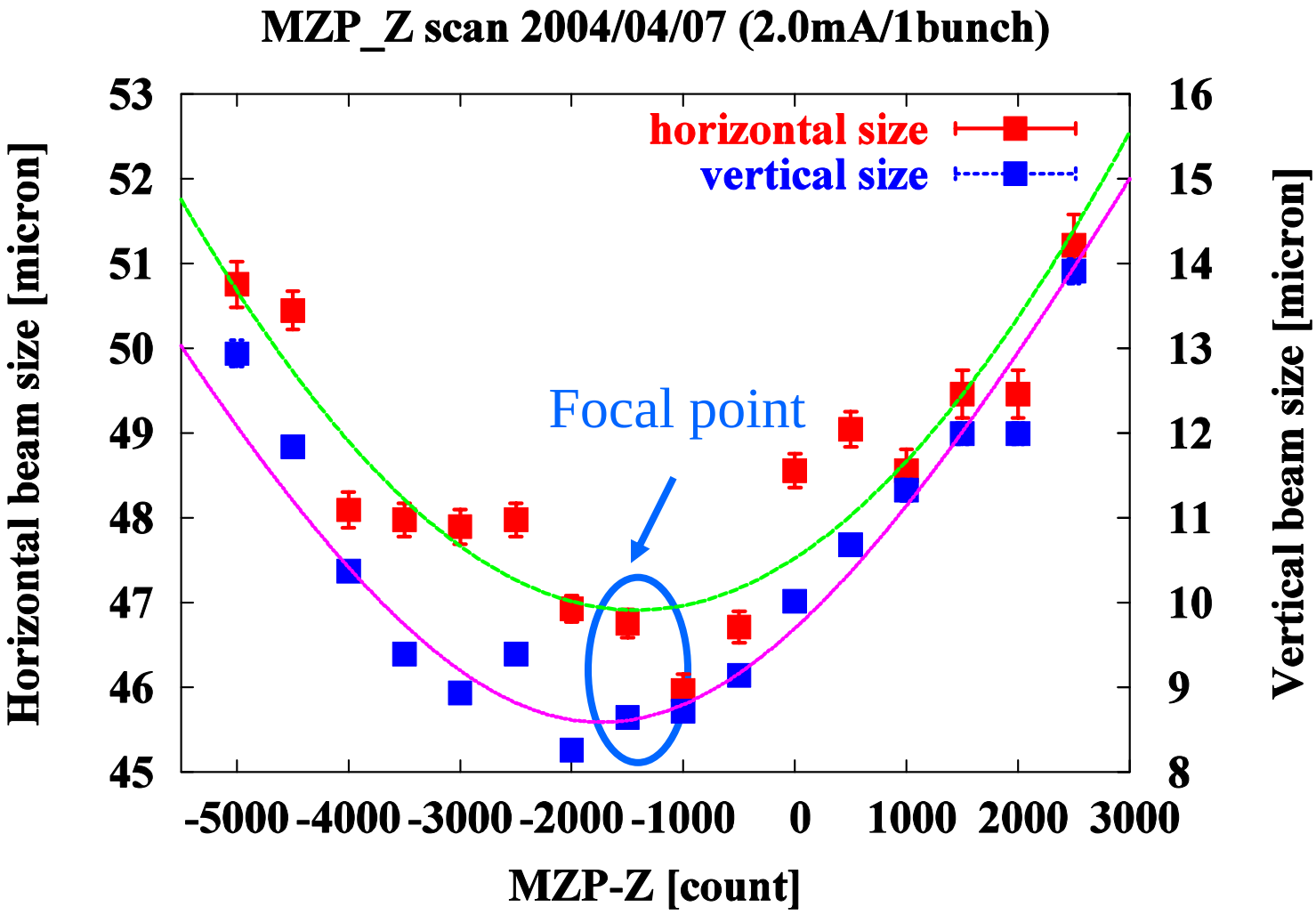
Expanded view



Minimum width of shutter opening time is less than 1ms


CZP
New shutter
Light Source
MZP
Imaged Object
Control &
data taking
trigger
X-CCD
(C4880)
Controller
100mm
10m
1m
25mm
5m
Lc1
Lc2
LM1
LM2
In the damping ring
Power supply
(DM412)
Controller
(VMM-D1)
Digital delay
Ext
ch2
Function synthesizer
(WF1944A)
ch1
Beam injection
timing
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

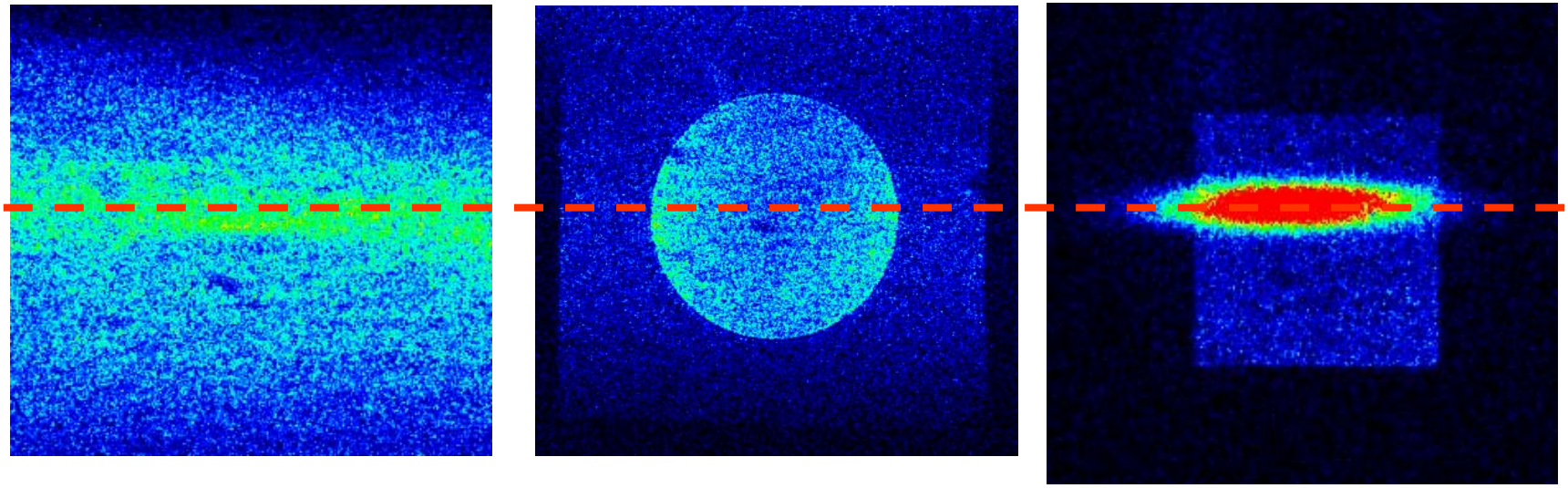
MZP z-scan



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

Alignment strategy

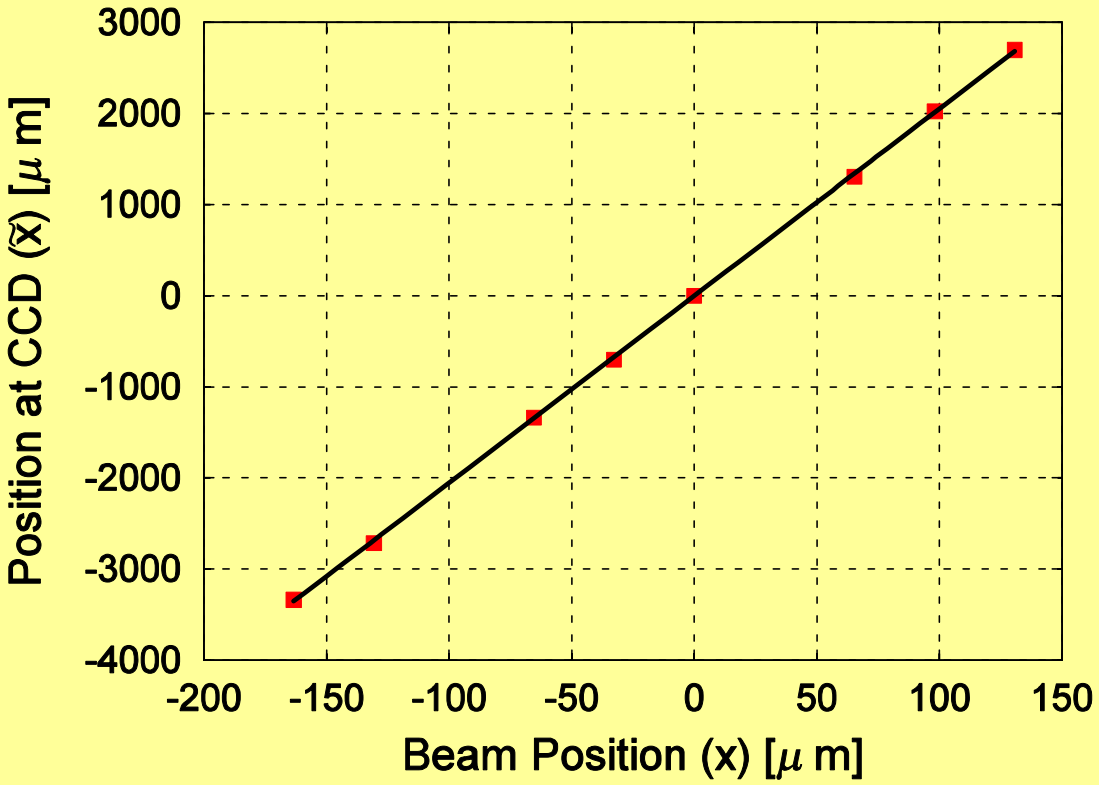
1 2 3



See direct SR light Enter the CZP Enter the MZP

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

Measurement of magnification



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

$\alpha_M = 0.002134$

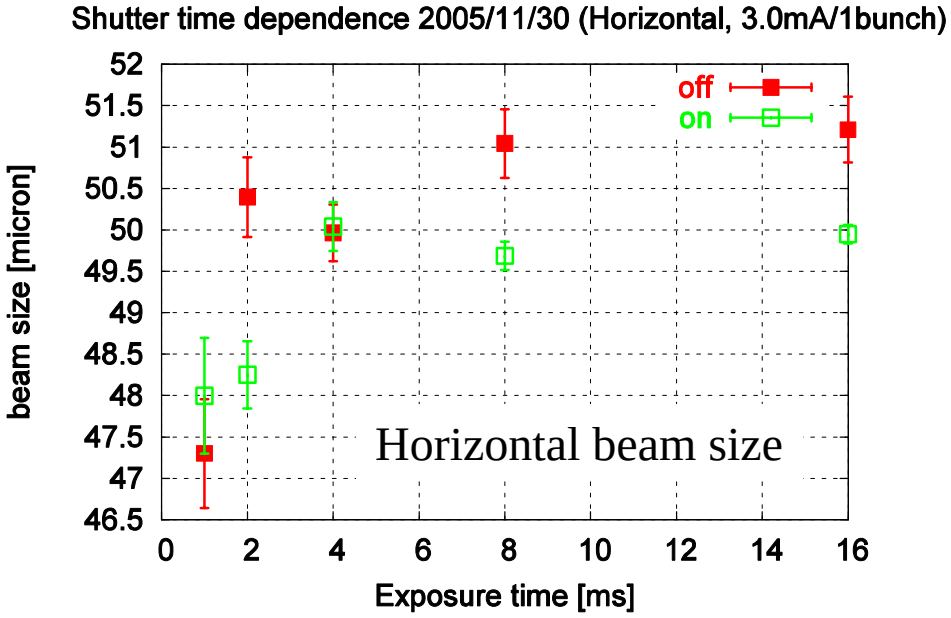
$f_{RF} = 714$ [MHz]

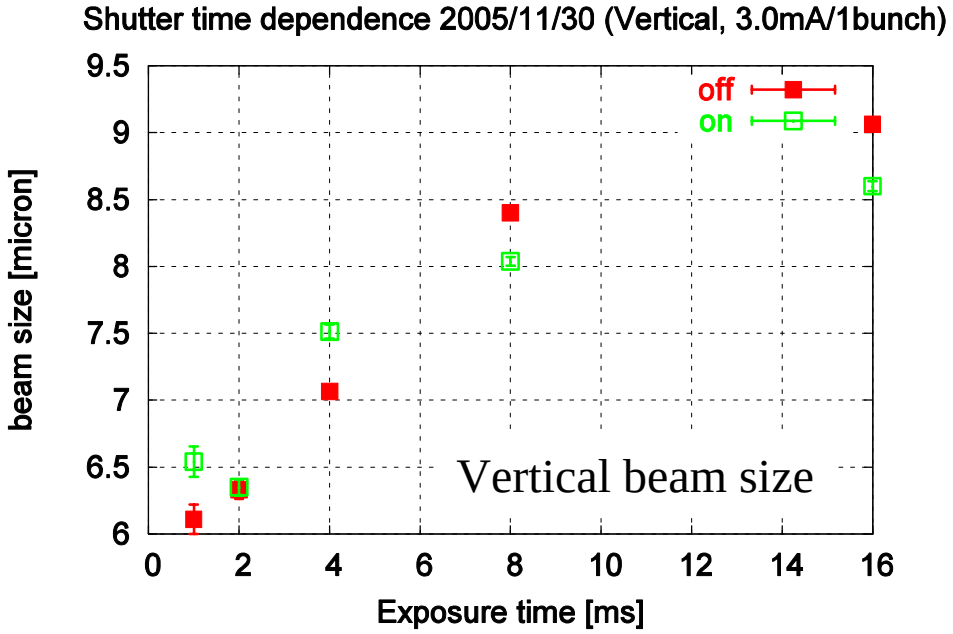
$\eta_x = 0.04980 \pm 0.0018$ [m]

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

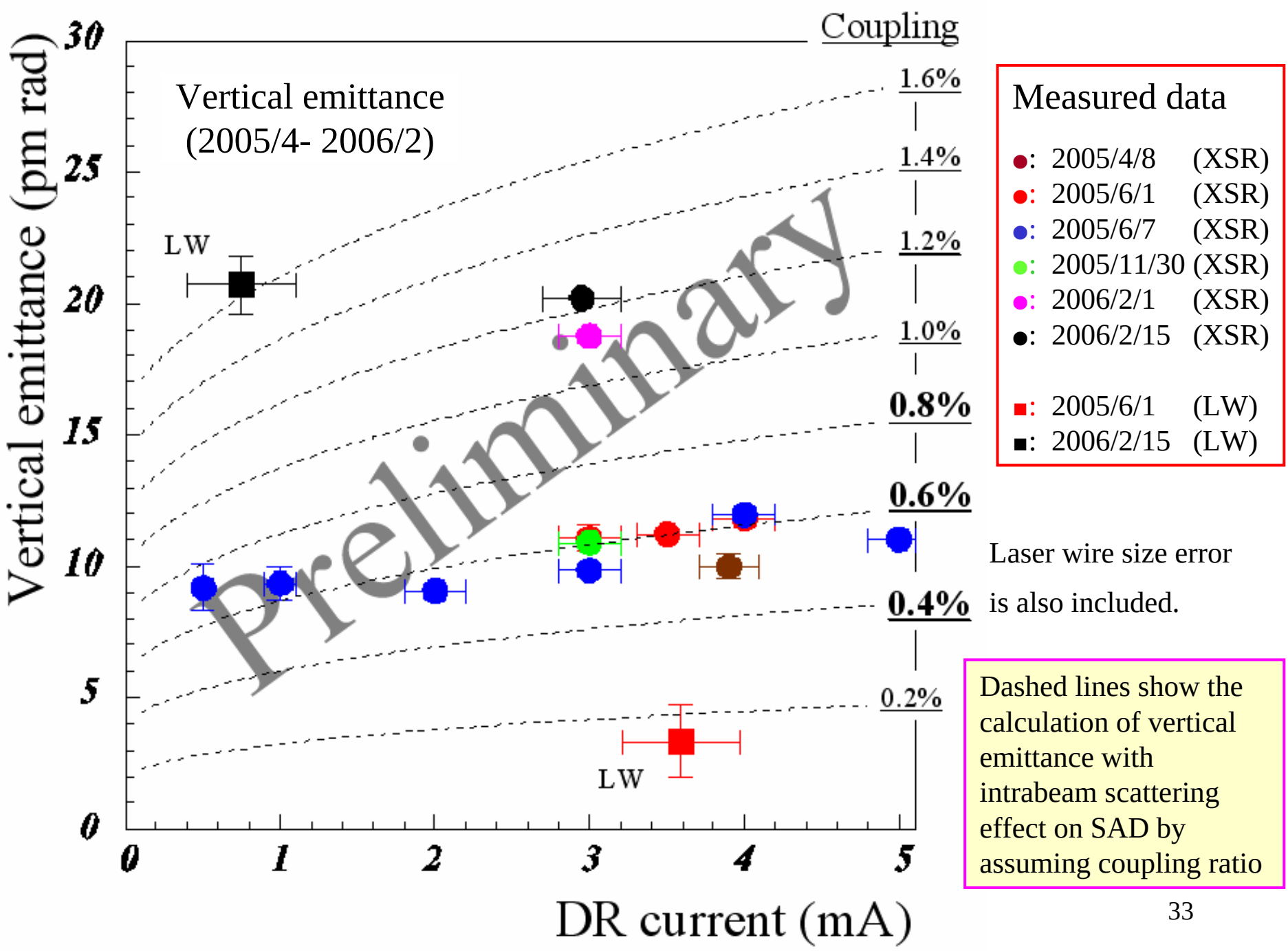
Si monochromator effect

100Hz oscillation の原因を探るべく、Si monochromatorの電源を入れた状態(on)と切った状態(off)でbeam sizeに変化があるかどうかをshutter opening time (exposure time)を変えながら測定した。





Shutter timeに応じて垂直ビームサイズは同じように変化している。但し、Si monochromatorのon/offには全く依存していないのがわかる。
→ビームサイズ増加はSi monochromatorでの振動のせいではない。これはsummer shutdown中に静電容量センサーで行った振動測定の結果と一致する。



Measured data

- ●: 2005/4/8 (XSR)
- ●: 2005/6/1 (XSR)
- ●: 2005/6/7 (XSR)
- ●: 2005/11/30 (XSR)
- ●: 2006/2/1 (XSR)
- ●: 2006/2/15 (XSR)

- ■: 2005/6/1 (LW)
- ■: 2006/2/15 (LW)

Laser wire size error is also included.

Dashed lines show the calculation of vertical emittance with intrabeam scattering effect on SAD by assuming coupling ratio