HZB Helmholtz Zentrum Berlin
BESSY VSR

Bunch resolved beam size monitor for BESSY-VSR

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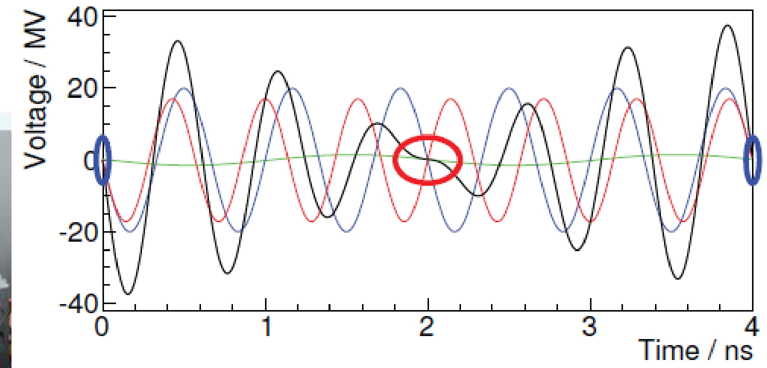
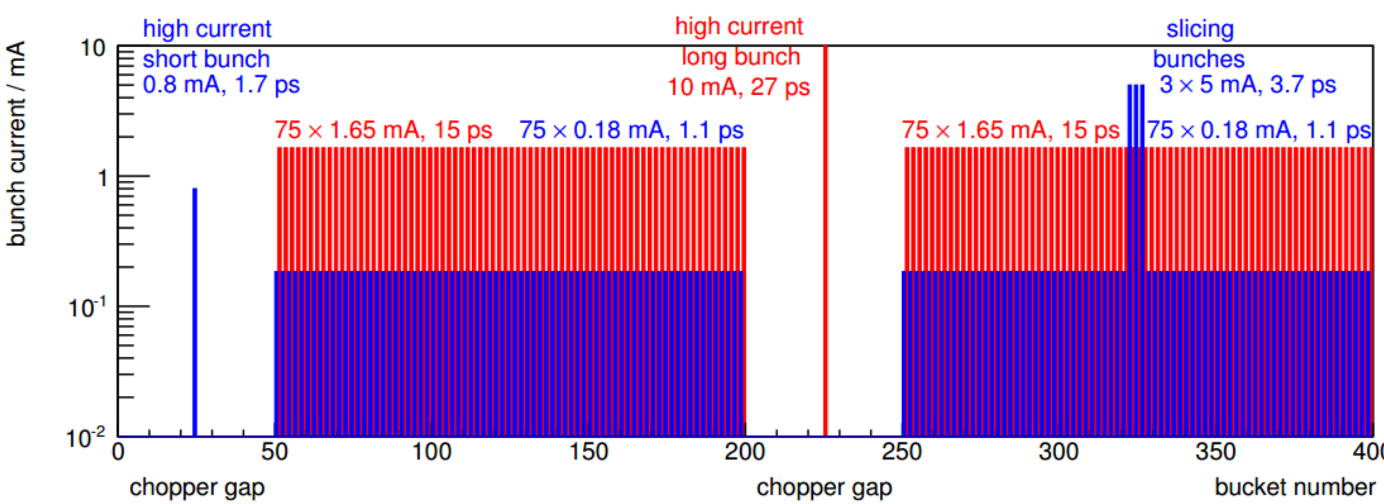
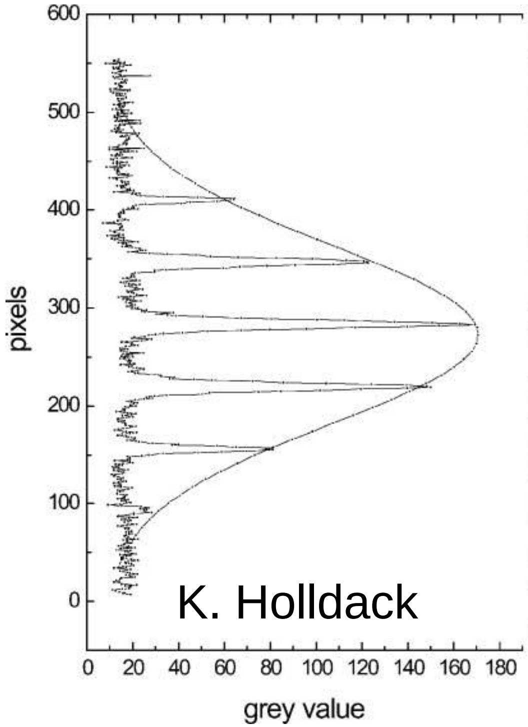
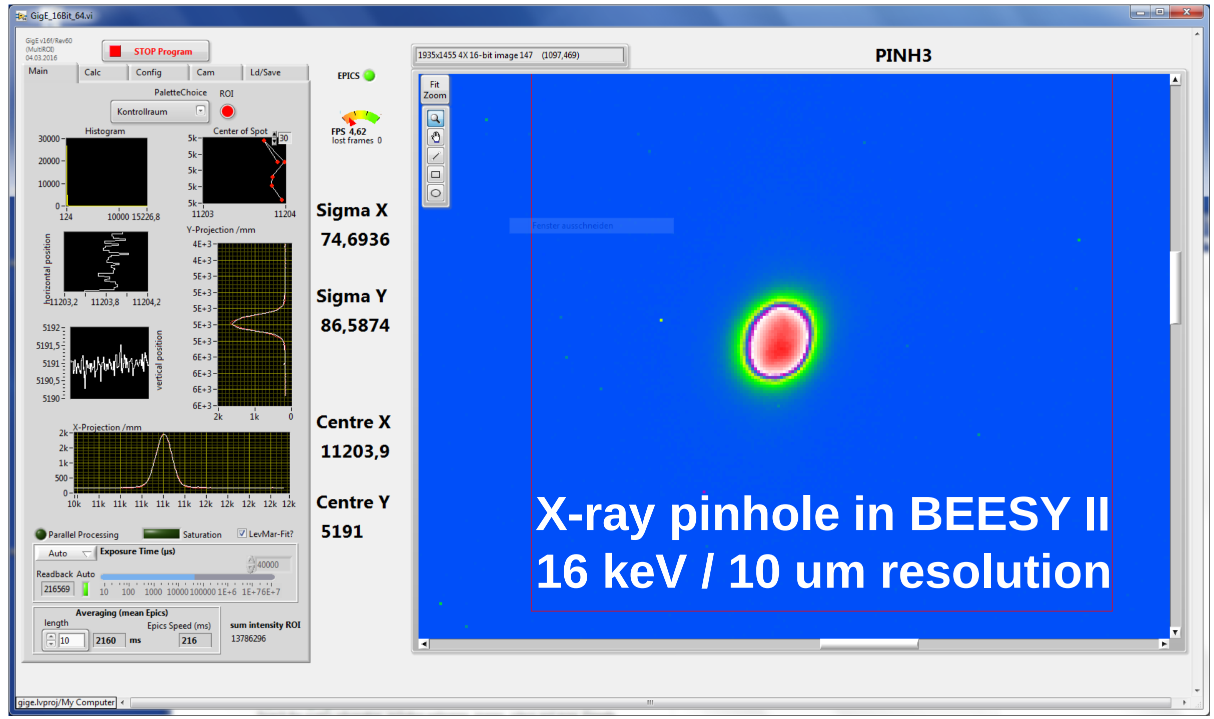


The Helmholtz-Zentrum Berlin (HZB) is proposing an innovative, challenging upgrade scheme for the storage ring BESSY II to generate simultaneously 15 ps and 1.7 ps (rms) long electron bunches.



X-ray pinhole monitor in BESSY II

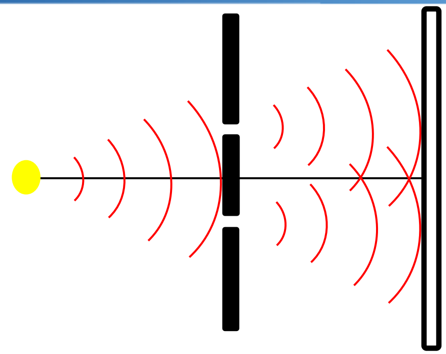




Commissioning and operation of BESSY VSR requires an upgrade of machine diagnostics. There will be new beam parameters used as a figure of merit as well as existing parameters **in new ranges**. In particular, this involves understanding the injection process as well as combining BESSY VSR and low-α to generate short pulses in the sub-ps range.

Fast gated (< 2 ns) technique with X-ray regime is expensive.
→ Bunch resolved profile monitor with visible light

Interferometry beam size monitor



An interference pattern produced by double slit with a “**point-like**” source is given by

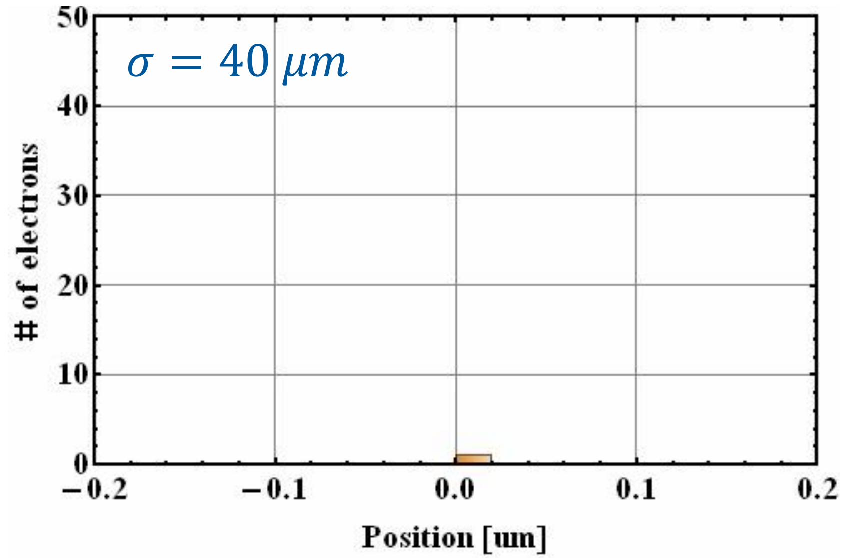
$$I(x) = I_0 sinc^2\left(\frac{\pi a}{\lambda R}x\right) cos^2\left(\frac{\pi d}{\lambda R}\,x + \phi\right)\,,$$

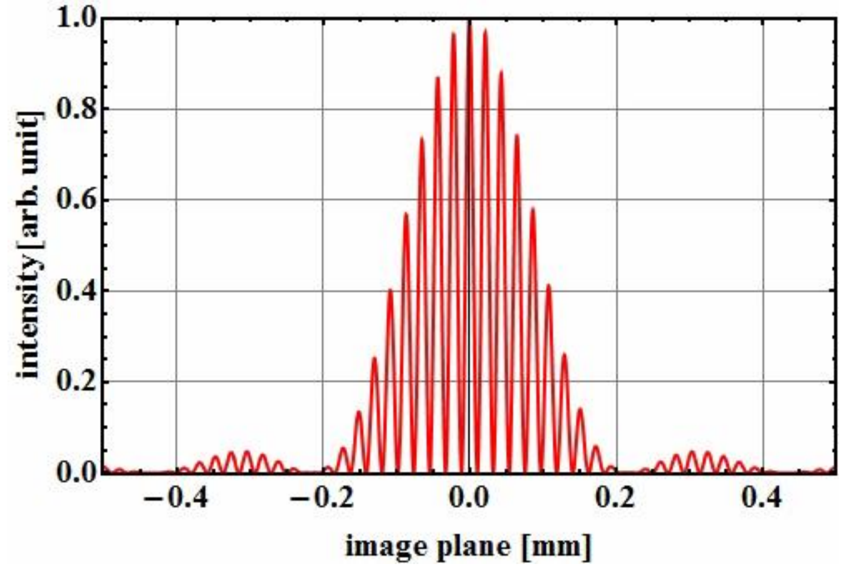
where λ is wavelength, R is distance between slit and screen, d is slit separation, a is slit width, ϕ is phase difference.

For a Gaussian distributed light source, the interference pattern is

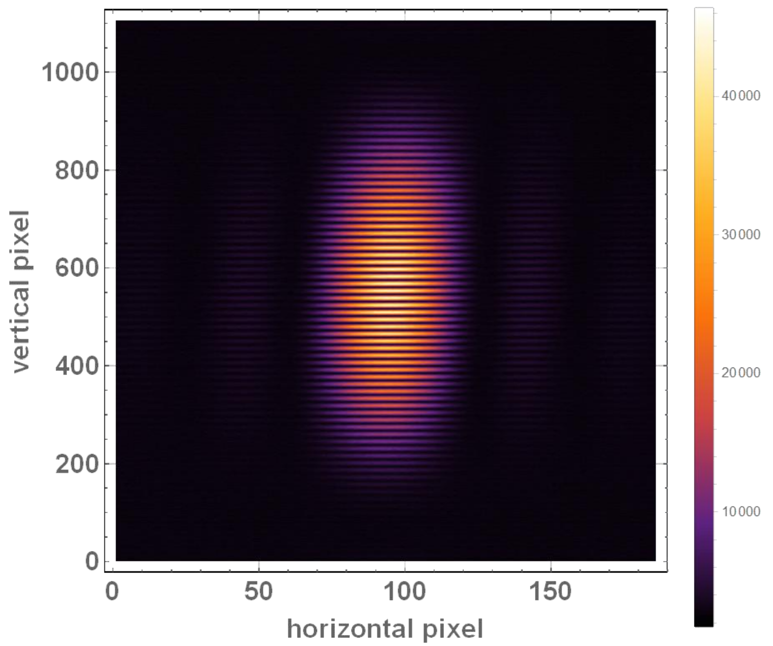
$$I(x) = I_0 sinc^2\left(\frac{\pi a}{\lambda R}x\right)\left(1 + \gamma cos\left(\frac{2\pi d}{\lambda R}\,x + \phi\right)\right),$$

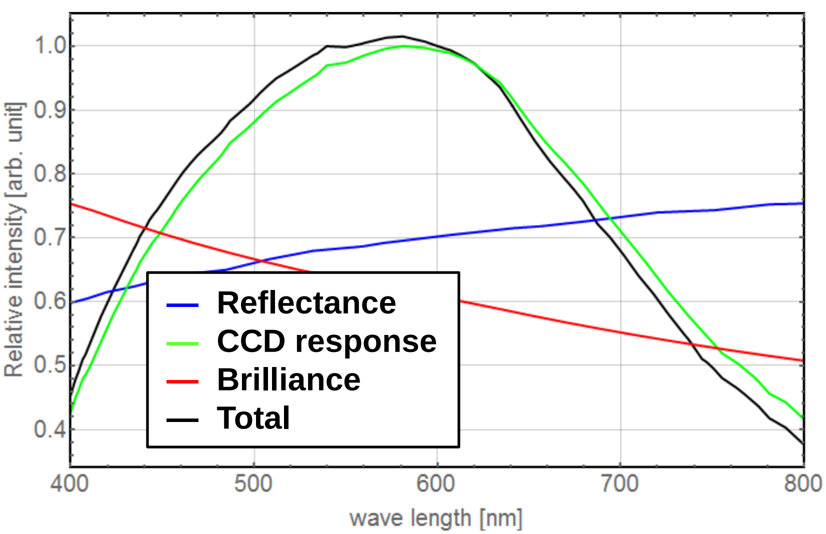
where γ denotes the visibility.





Interferometry beam size monitor





From the visibility (complex degree of coherence) given by the van Cittert-Zernike theorem, the beam size is

$$\sigma_{x,y} = \frac{\lambda L}{\pi d}\sqrt{\frac{1}{2}\ln\frac{1}{|\gamma_{eff}|}},$$

Where L is distance between source and slit, and

$$\gamma_{eff} = \frac{2\sqrt{I_1 \cdot I_2}}{I_1 + I_2}|\gamma|$$

when I_1 and I_2 are not equal, the visibility is given as a function unbalance ratio of the incident light.

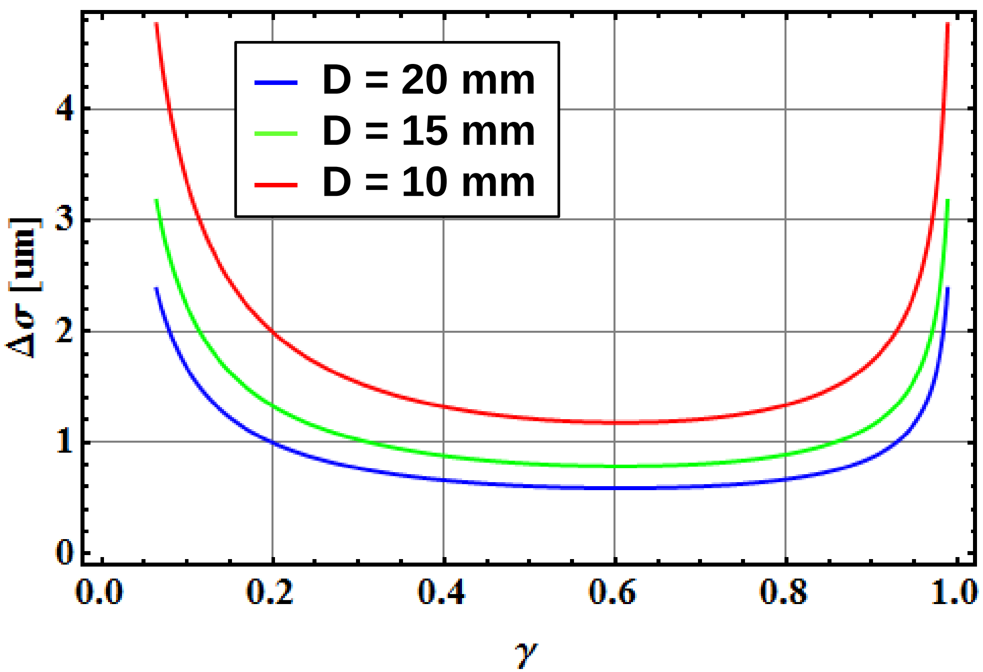
The wavelength of the light is limited by the photon flux at the beam line.

Minimization of systematic errors

1. Statistical error of the measurement due to the CCD noise is given by

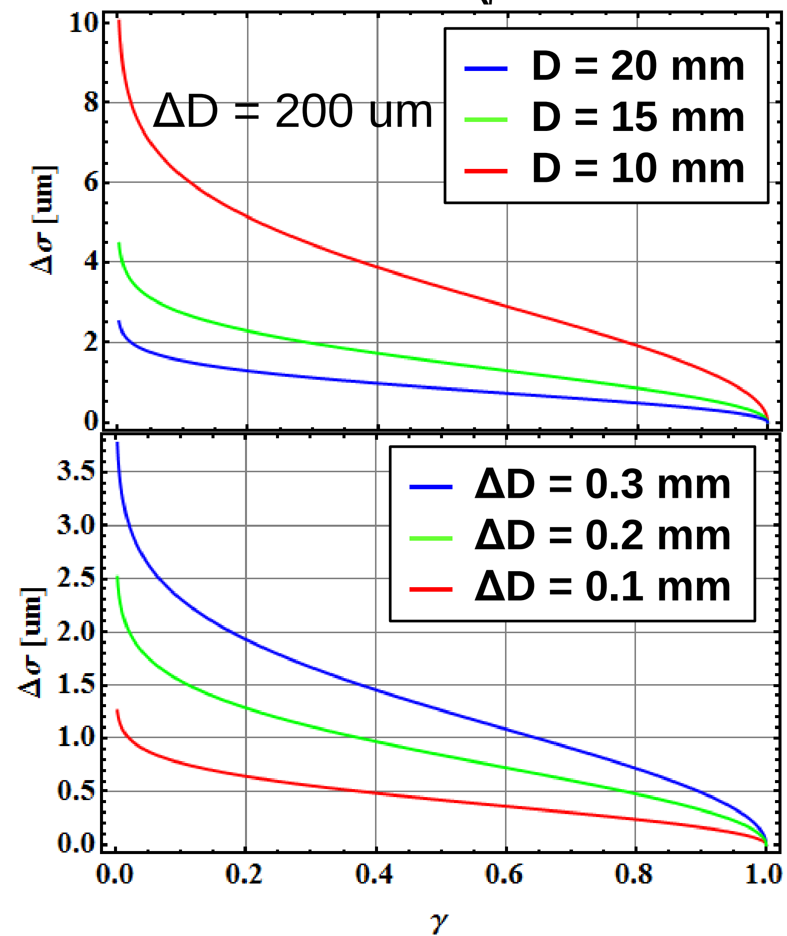
$$\Delta\sigma_{\Delta\gamma} = \frac{\lambda L}{\pi D}\frac{\Delta\gamma}{2\gamma\sqrt{2\ln\frac{1}{|\gamma|}}},$$

The statistical error of the visibility measurement due to the CCD noise is measured to be 0.6 % from the experiment.



2. Beam size measurement error due to the fabrication tolerance of the slit is given by

$$\Delta\sigma_{\Delta D} = \Delta D\,\frac{\lambda L}{\pi D^2}\sqrt{\frac{1}{2}\ln\frac{1}{|\gamma|}},$$

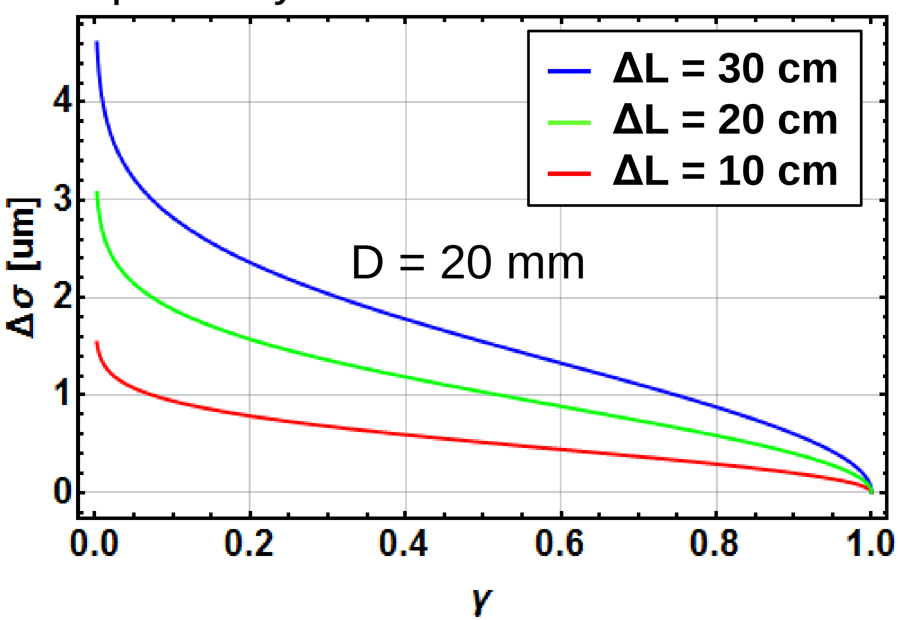


Minimization of systematic errors

3. Beam size measurement error due to the distance error between source point and slit is given by

$$\Delta\sigma_{\Delta L} = \frac{\lambda\, \Delta L}{\pi D}\sqrt{\frac{1}{2} ln \frac{1}{|\gamma|}}\ ,$$

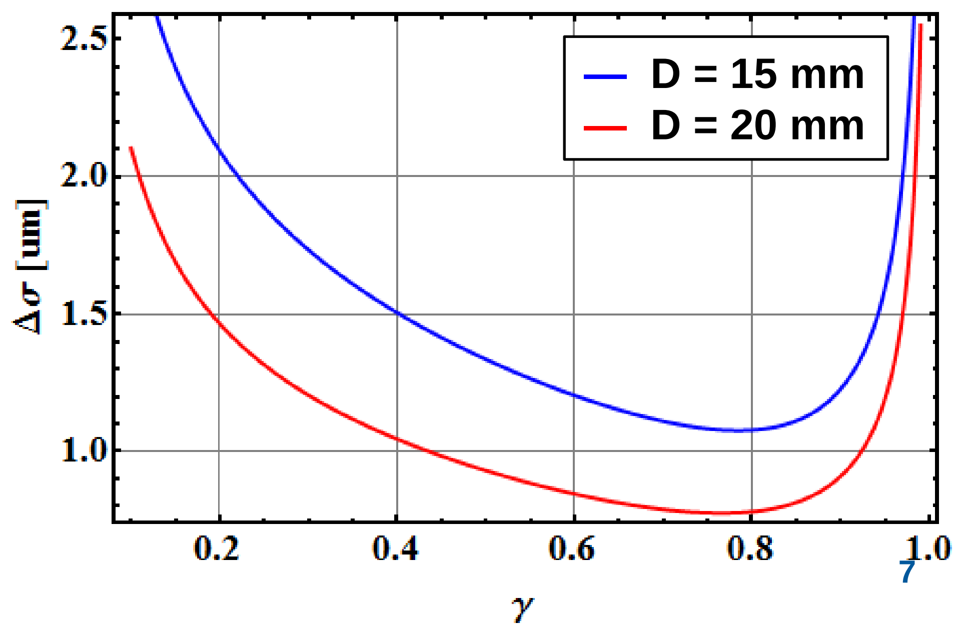
The measurement error with the slit separation of 20 mm is less than the 1 um when the visibility and distance error are over 0.5 and less than 0.2 m, respectively.



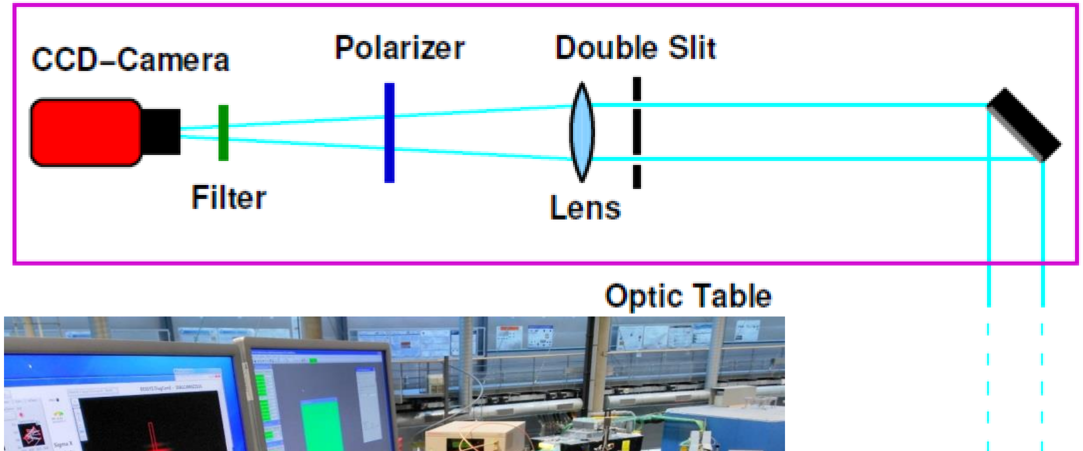
4. The total errors (combined effect), which are uncorrelated and random is given by

$$\Delta\sigma_{x,y} = \sqrt{\Delta\sigma_{\Delta\gamma}{}^{2} + \Delta\sigma_{\Delta D}{}^{2} + \Delta\sigma_{\Delta L}{}^{2}}$$

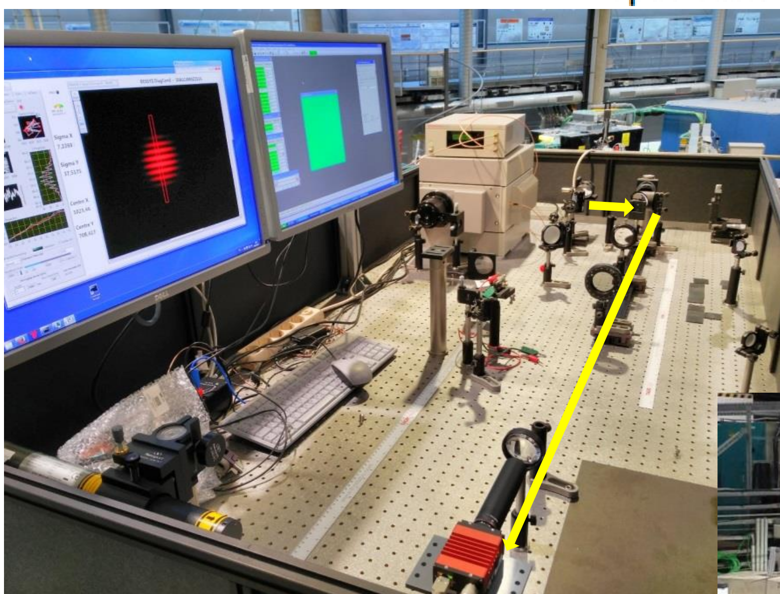
When the slit separation is 20 mm, the visibility values for horizontal and vertical beam size are 0.397 and 0.532, respectively.

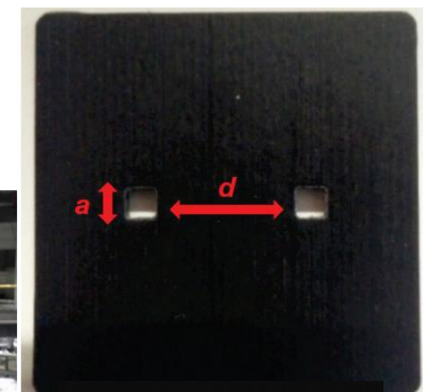


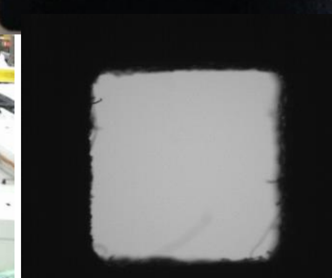
Optics diagnostics test table in BESSY II



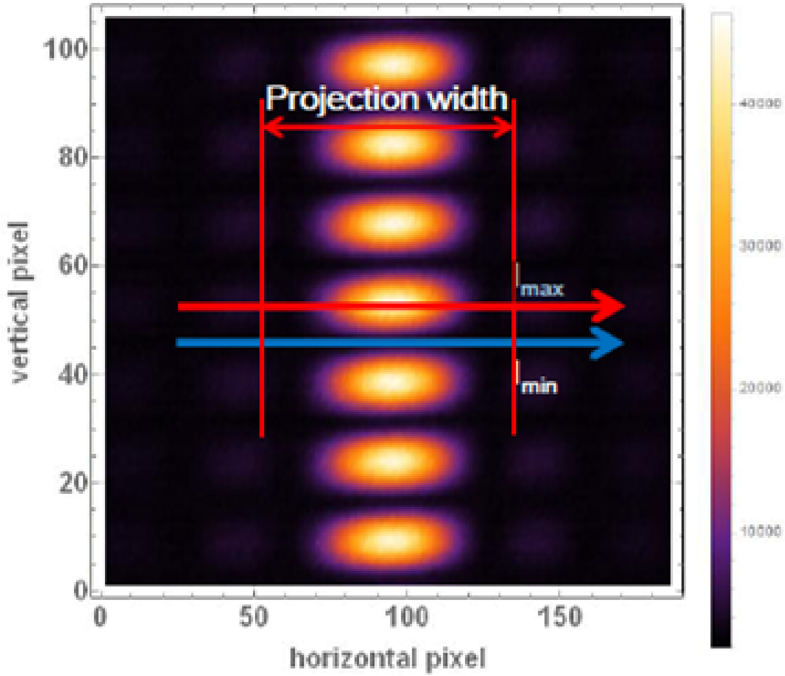
Parameter	Value
Energy	1.7 GeV
Current	300 mA
PINH3 X	97.3 um
PINH3 Y	80.5 um
L	16.1 m

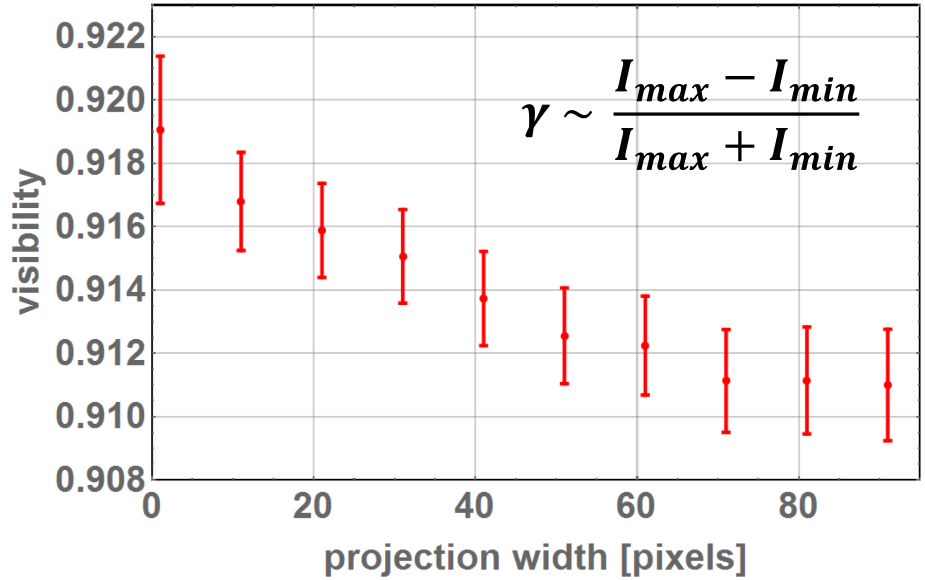


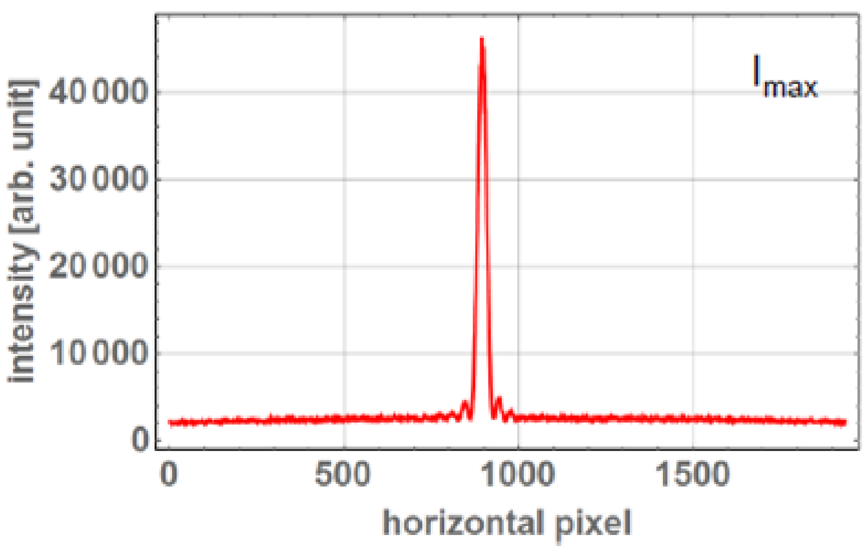


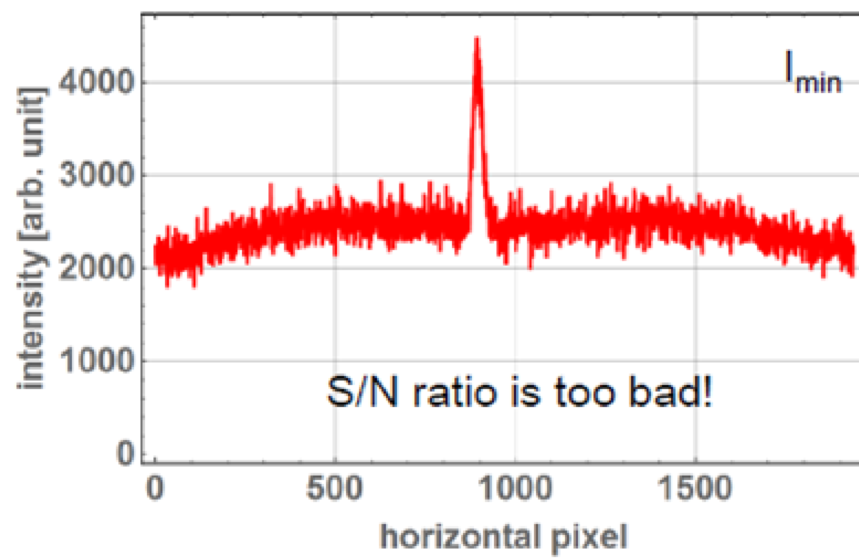


Effect of profile projection

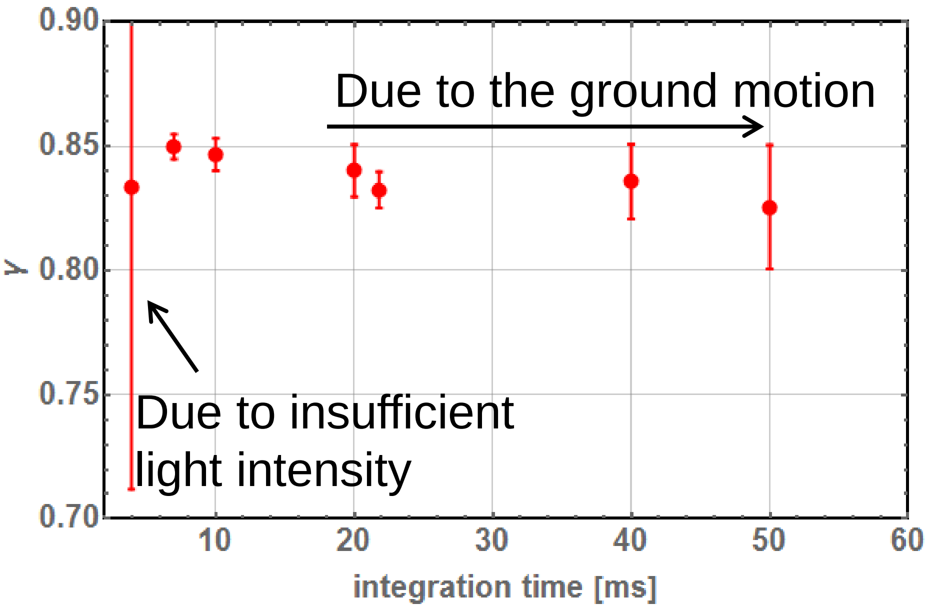


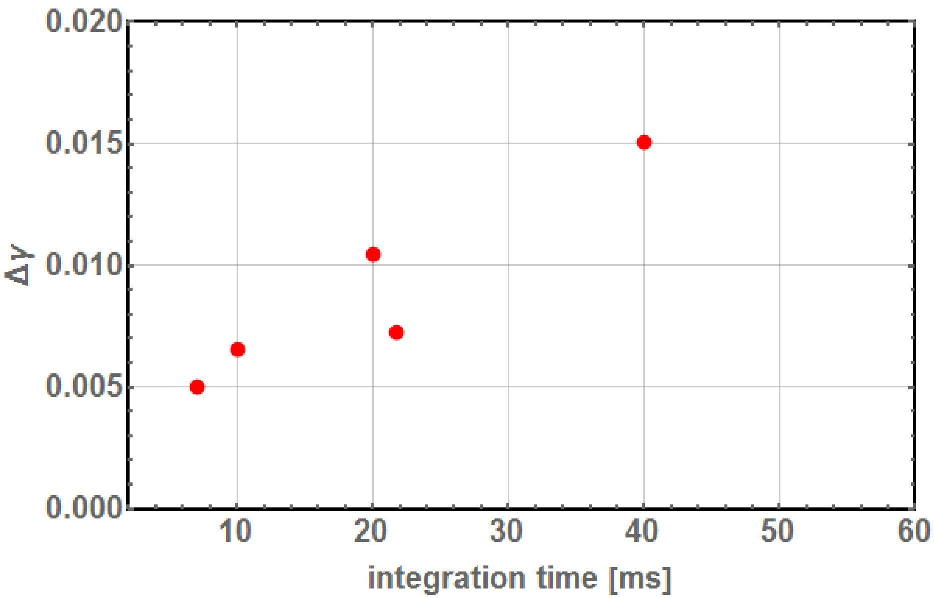






In order to confirm the visibility measurement error due to a statistical noise (dark current) of CCD sensor and observe the effect of ground motion, the visibility is measured with various integration time (shutter speed) of the camera.





The measurement error is less than 0.6 % with the integration time of about 0.8 ms.

Field of depth

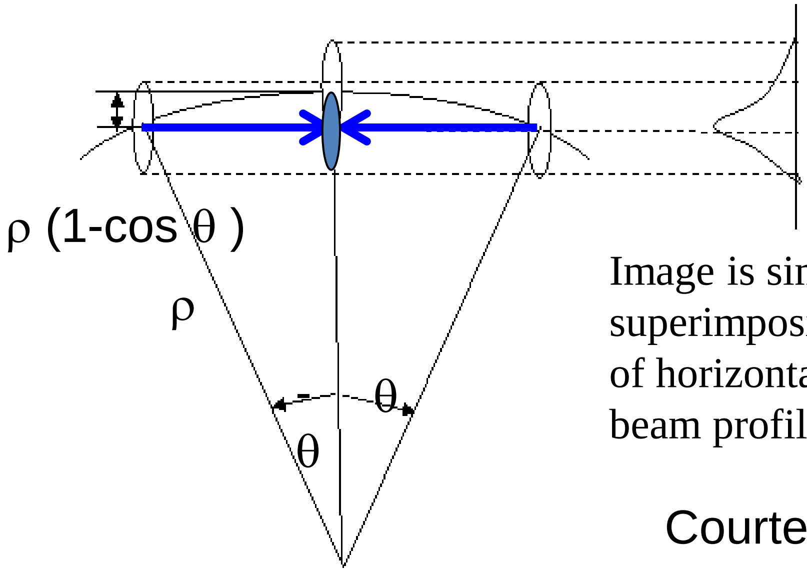
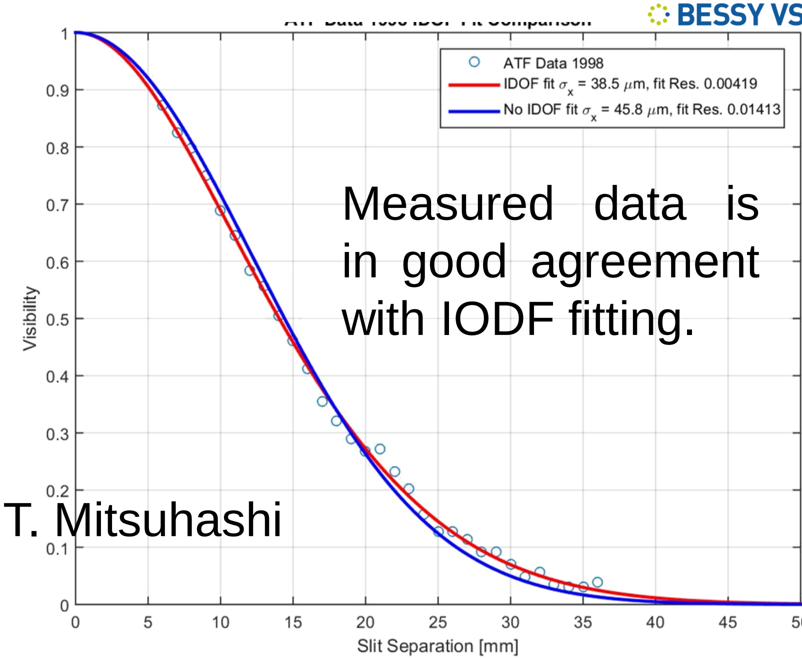
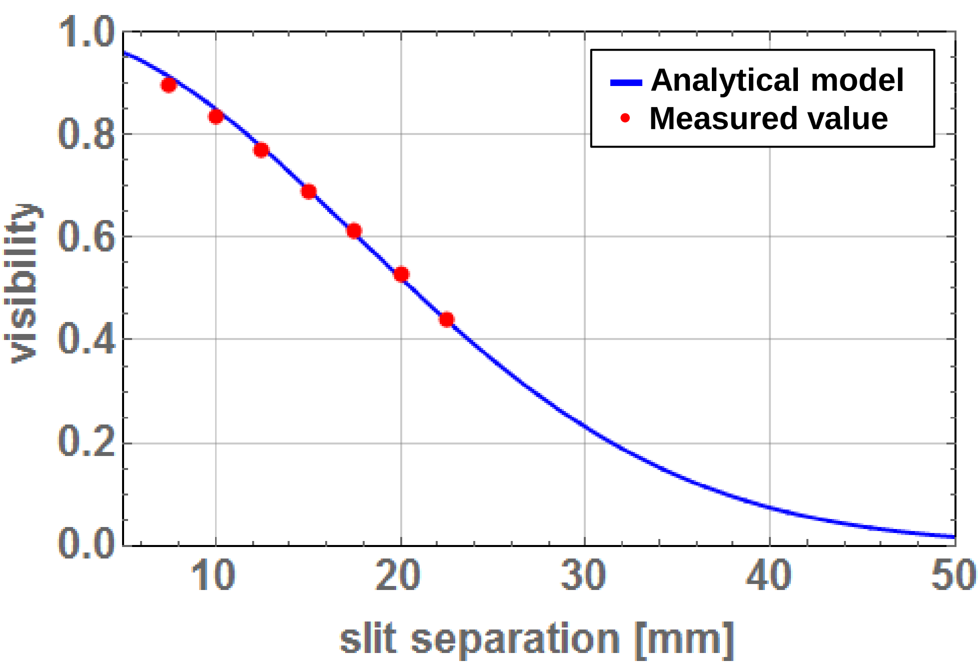


Image is simply superimposition of horizontal beam profiles



Measured data is in good agreement with IODF fitting.

Courtesy of T. Mitsuhashi



The measured result is agreed well without consideration to the effect of field of depth because the curvature of dipole is small in BESSY.

The slit separation is limited by a diameter of optical system. The maximum allowable slit separation is about 25 mm.

Measurements: Hor. Beam Size II

- Compare with results from elegant model and with pinhole systems
- Twiss functions and emittance (Std. user ~7.5 nm rad, low-α ~25 nm rad)
- $\sigma_{x,y} = \sqrt{\beta_{x,y}\varepsilon_{x,y} + \eta^2\delta^2}$

	PINH3 meas.	PINH3 model	Interferometer meas.	Interferometer model	PINH9 meas.	PINH9 model
Std. User	74 µm	54.9 µm	(58.5 ± 1.4) µm	54.6 µm	60 µm	59.4 µm
low-α	177 µm	132.5 µm	(155.2 ± 3.7) µm	127.6 µm	143 µm	133.0 µm

- Resolution of pinhole monitors ~10 µm
- Good agreement in standard user mode

Comparison with pinhole monitor

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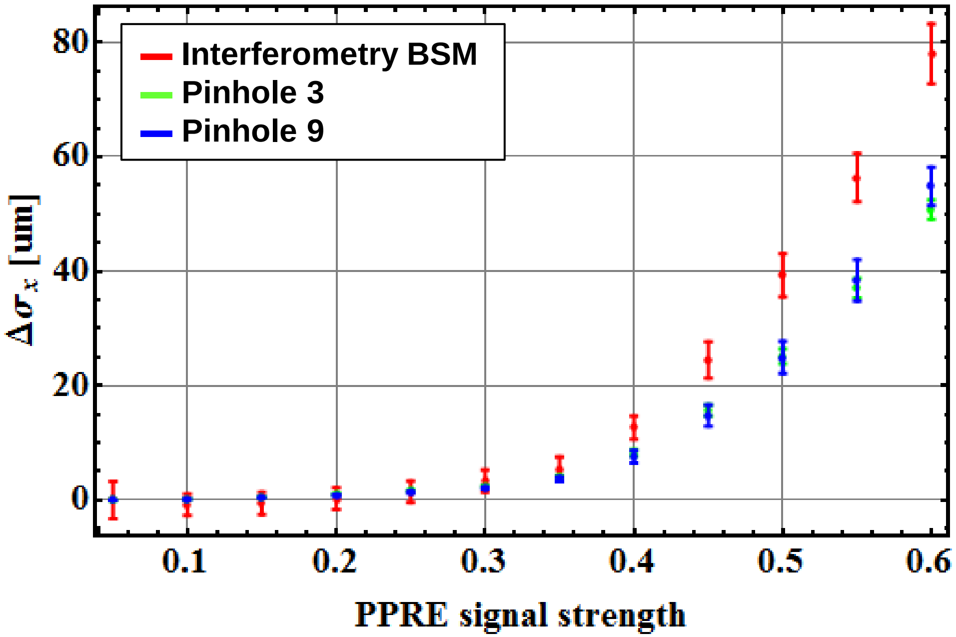
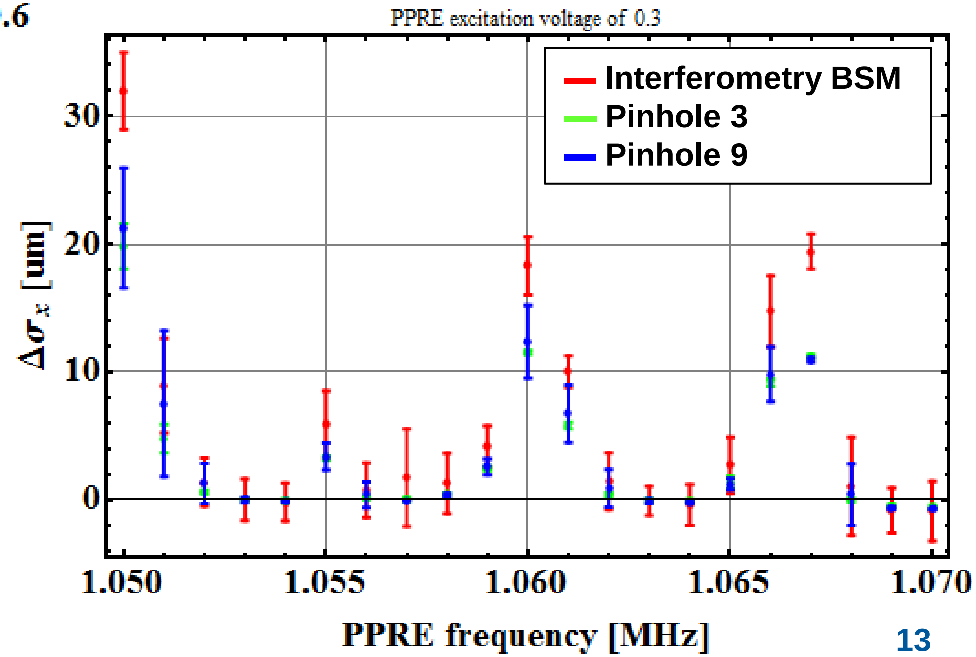


Since the absolute beam size is not suitable for a comparison with the pinhole monitor, the measurement with the Pulse Picking by Resonant Excitation (PPRE) , sort of a horizontal excitation, is performed to compare the beam size behavior.

The interferometry beam size monitor is installed near Pinhole 3 monitor.

The slope of beam size increment is to be proportional to square root of betatron function

$$\Delta\sigma \propto \sqrt{\beta}$$



For bunch resolved system design

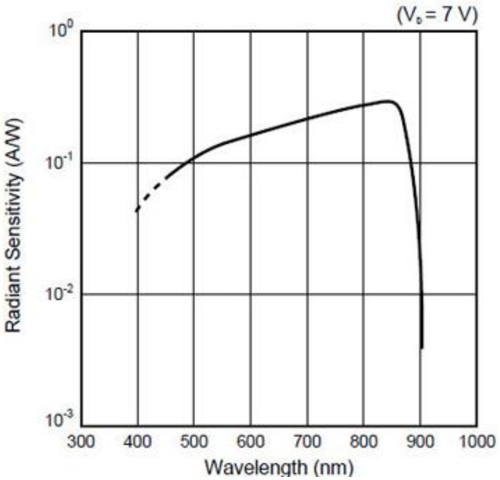
According to quantum optics, uncertainty principle concerning to phase is given by

$$\Delta\phi \cdot \Delta N \geq \frac{1}{2}$$

where ΔN is uncertainty of photon number.

The photon flux at the optical table is measured using Schttoky photodiode with 600 ± 10 nm bandpass filter.

The photo diode sensitivity S ~ 0.3A/W (current/ light power)
→ light power P = 290 nA / S = 1 μW



The power from a single bunch (a 0.7 mA bunch) is approx.
→ 1/350 μWatt = 2.85 nW.

The energy emitted from a single bunch in a single turn is then:
→ E = 2.85 nW * 800ns = 1.8e-15 J = 11.25 keV

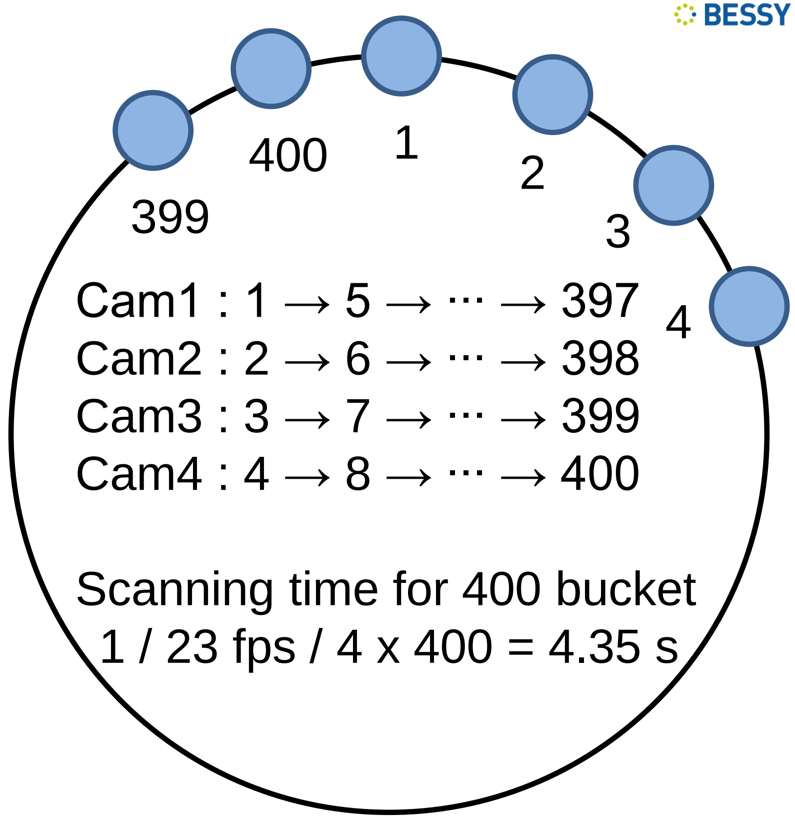
A 600 nm photon has approx. 2eV energy.
Thus, we find about 5.6 k photons / turn / bunch.

Data acquisition and scanning

XXRapidFrame
Based on 4 x 4 Picos ICCD camera
Exposure time: 200 ps to 80 s
Delay time: 0s, 10 ps to 80 s
Delay and Exposure time step: 10 ps
Low jitter : < 10 ps
Multiple gate repetition frequency:

- up to 200 kHz continuous
- up to 3.3 MHz in burst mode

Pixel size: 8.3 x 8.3 µm
High dynamic Range: 12 bit
Frame rate:12.5 / 20.0 / 23.0fps



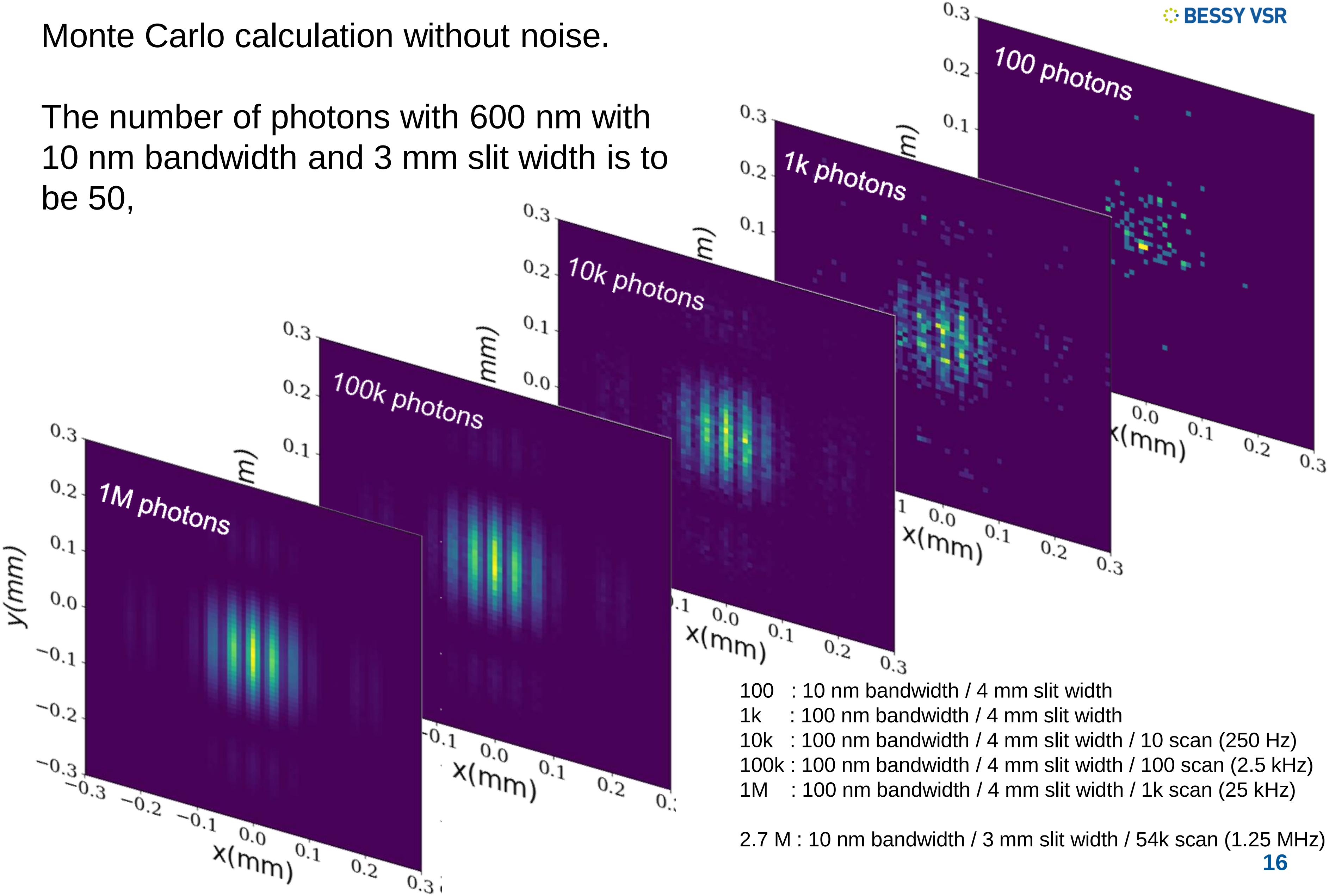
# of gate repetition rate / frame (23 fps) with burst mode
→ 1 / 23 fps * 1.25 MHz = 54 k

# of photons / frame (23 fps) with burst mode
→ 5.6 k photons * (area ratio) * 54 k
= 6.8 * 10^5 photons / frame

Constrain of photon number [w/o noise]

Monte Carlo calculation without noise.

The number of photons with 600 nm with 10 nm bandwidth and 3 mm slit width is to be 50,

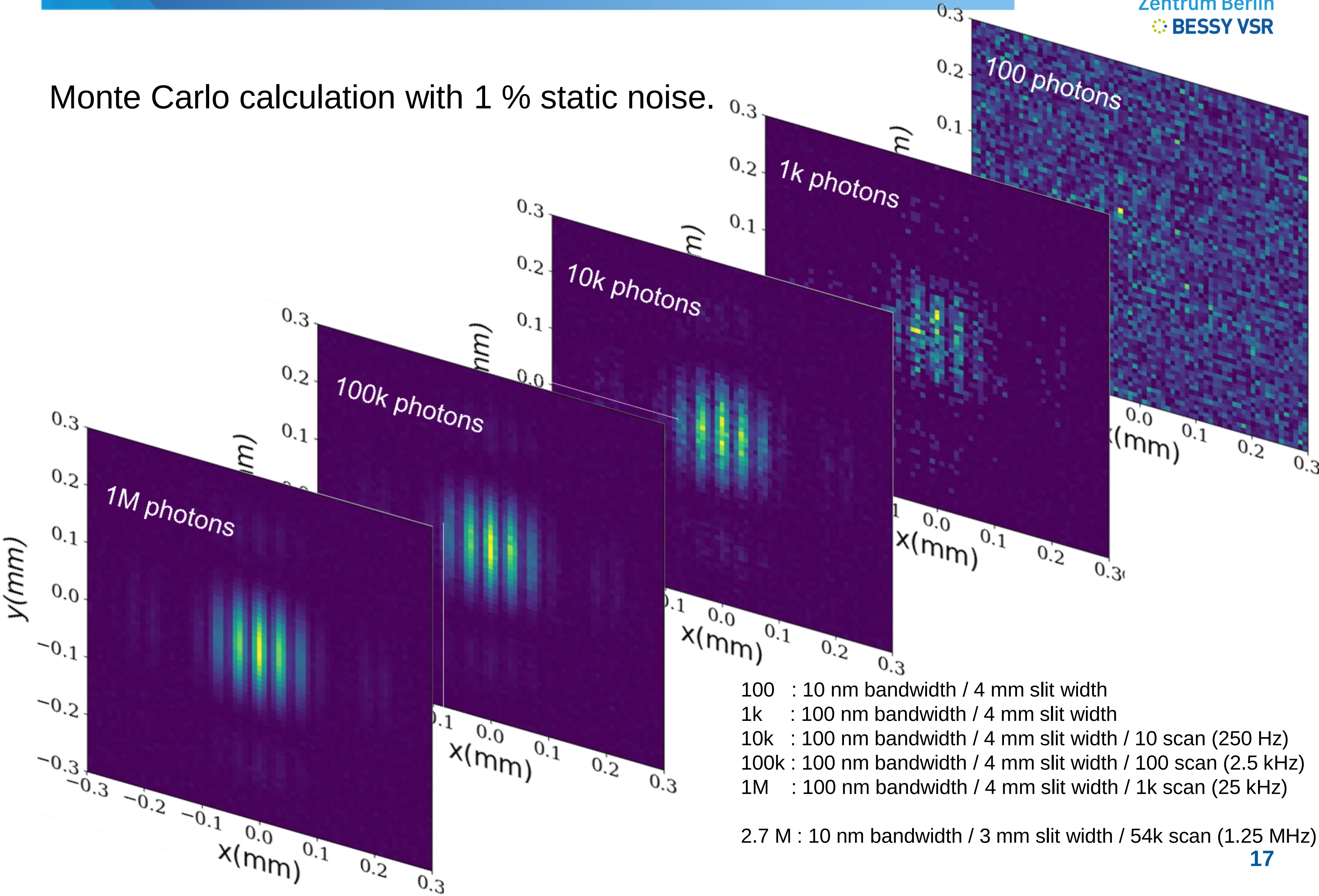


100 : 10 nm bandwidth / 4 mm slit width
1k : 100 nm bandwidth / 4 mm slit width
10k : 100 nm bandwidth / 4 mm slit width / 10 scan (250 Hz)
100k : 100 nm bandwidth / 4 mm slit width / 100 scan (2.5 kHz)
1M : 100 nm bandwidth / 4 mm slit width / 1k scan (25 kHz)

2.7 M : 10 nm bandwidth / 3 mm slit width / 54k scan (1.25 MHz)

Constrain of photon number [with noise]

Monte Carlo calculation with 1 % static noise.



100 : 10 nm bandwidth / 4 mm slit width
1k : 100 nm bandwidth / 4 mm slit width
10k : 100 nm bandwidth / 4 mm slit width / 10 scan (250 Hz)
100k : 100 nm bandwidth / 4 mm slit width / 100 scan (2.5 kHz)
1M : 100 nm bandwidth / 4 mm slit width / 1k scan (25 kHz)

2.7 M : 10 nm bandwidth / 3 mm slit width / 54k scan (1.25 MHz)

Summary

The interferometer technique based bunch resolved profile monitor is being developed for understanding the injection process as well as combining BESSY VSR and low-α to generate short pulses in the sub-ps range.

Many knobs are optimized to reduce a resolution and systematic error. The measurement result with the general CCD camera is agreed well with the present pinhole camera.

Beam experiments with an ICCD camera will be performed at a new platform in 2018.

Thank you very much for your attention!