Design of Coded Aperture Optical Elements for SuperKEKB X-ray Beam Size Monitors

E.Mulyani [1], J.W.Flanagan [1,2]

[1] Dept. Accelerator Science, School of High Energy Accelerator Science, SOKENDAI, Tsukuba, Ibaraki, JAPAN

[2] Accelerator Laboratory, KEK, Tsukuba, Ibaraki, JAPAN

Introduction

Precision measurement of vertical bunch has an important role in the design and operation of the electron storage rings (SuperKEKB, e+ e- collider).

For bunch by bunch beam profile monitoring with high resolution and fast response, we are developing an **x-ray imaging based on coded aperture (CA)**

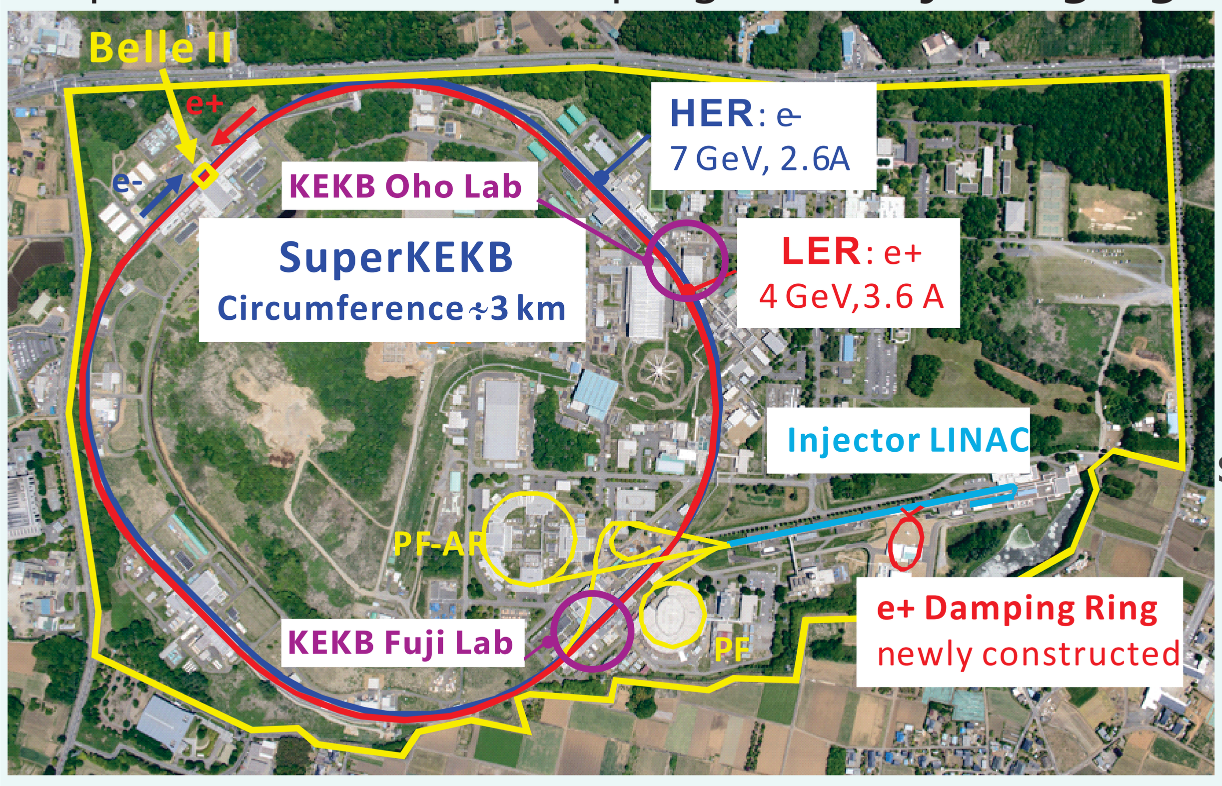


Fig 1. SuperKEKB layout (IPAC2015,Miura T)

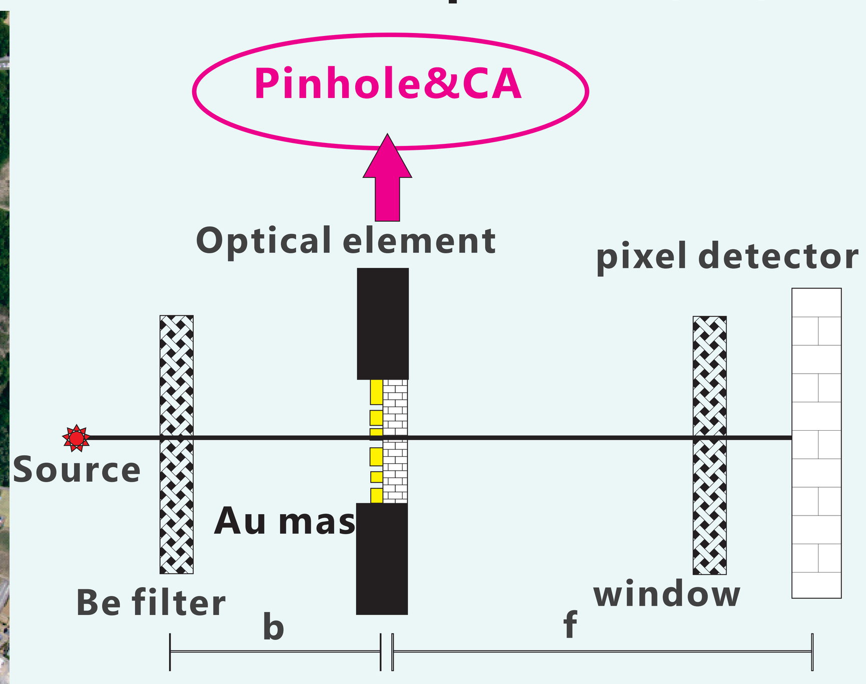


Fig 2. Schematic of x-ray beam size monitor

What and Why CA?

- Consists of pseudorandom array of pinholes (aperture) that projected a mosaic of pinholes camera onto a detector, the image is then decoded using the known mask pattern to reconstruct the original image.
- It offers greater open aperture than a single pinhole, for greater photon throughput and better statistical resolution for single shot measurement.

Aim

To design coded aperture optical elements for SuperKEKB that provide 1 - 2 micron resolution for 10 - 25 micron vertical beam sizes.

Simulation Methods

Parameter	LER	HER	UNIT
Beam Energy	4	7	GeV
Source bend radius (ρ)	31.74	106	m
Distance form source to mask (b)	9.43	10.33	m
Distance form mask to detector (f)	31.38	32.35	m
Au thickness	20	20	μm
Total Be filter thickness	0.7	16.2	mm
Diamond thickness	600	600	μm
Air gap	10	10	cm

What the detector sees

$$\begin{bmatrix} A_\sigma \\ A_\pi \end{bmatrix} = \frac{\sqrt{3}}{2\pi}\gamma\frac{\omega}{\omega_c}\left(1+X^2\right)\left(-i\right)\begin{bmatrix} K_{2/3}(\eta) \\ \frac{iX}{\sqrt{1+X^2}}K_{1/3}(\eta) \end{bmatrix}$$

Source SR wavefront amplitudes

To calculate the wavefront amplitude from each source point for each pixel in detector, converted to detected flux (Kirchhoff integral over mask)

$$A_{\sigma,\pi}\,(\text{detector}) = \frac{iA_{\sigma,\pi}\,(\text{source})}{\lambda} \times \int_{mask} \frac{t(y_m)}{r_1 r_2} e^{i\frac{2\pi}{\lambda}(r_1+r_2)} \left(\frac{\cos\theta_1+\cos\theta_2}{2}\right) dy_m$$

$$\frac{\chi^2}{\nu} = \frac{1}{N-n-1}\sum_{i=1}^{N}\frac{\left[s_i' - s_i\right]^2}{\sigma_i^2}$$

Degree of freedom χ^2 , from difference between two images/signal height for each channel.

The resolution is defined as the change in beam size, where the χ^2 per degree of freedom is one.

Mask Design and Results

The detector is 128 channels of silicon with 2 mm of sensing depth, and a pixel pitch of 50 μm.

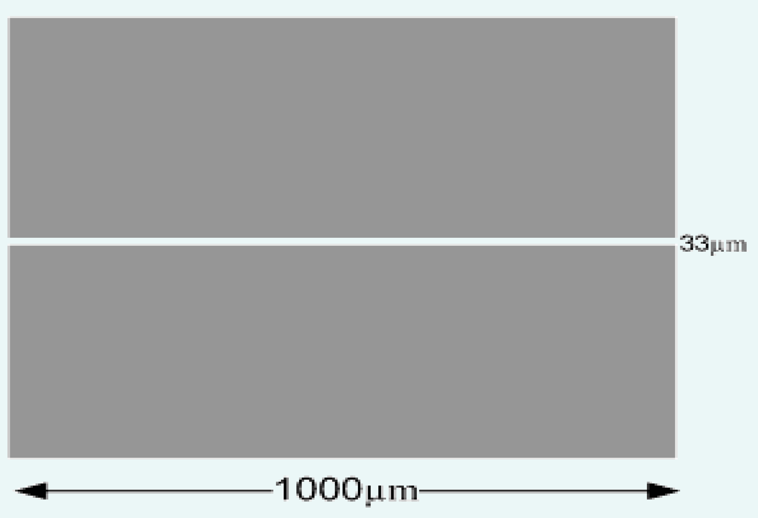


Fig 3. Single pinhole

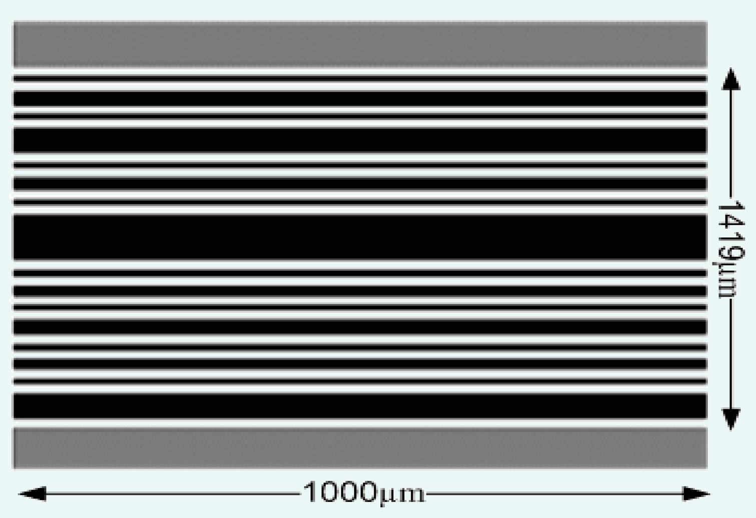


Fig 3. CA1 mask with 17 slits

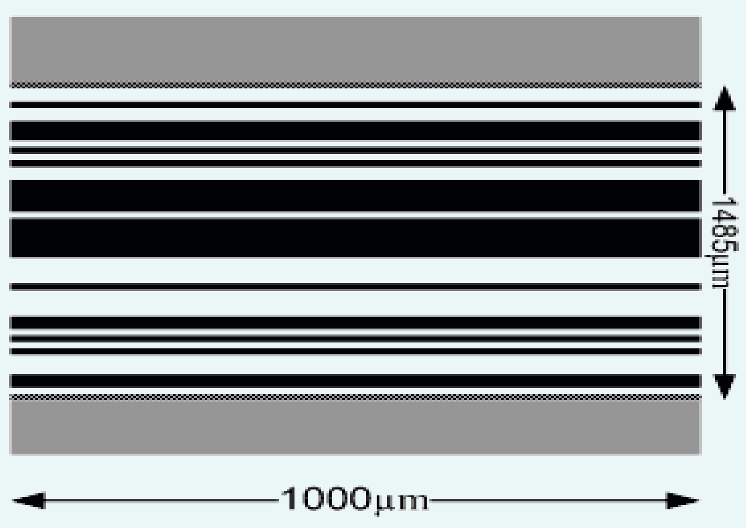
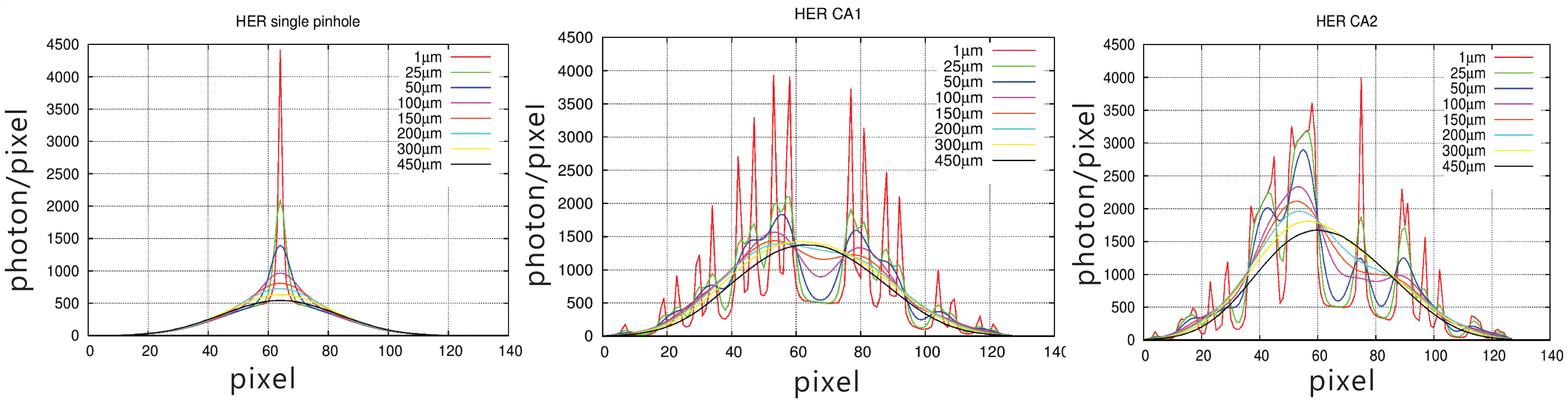
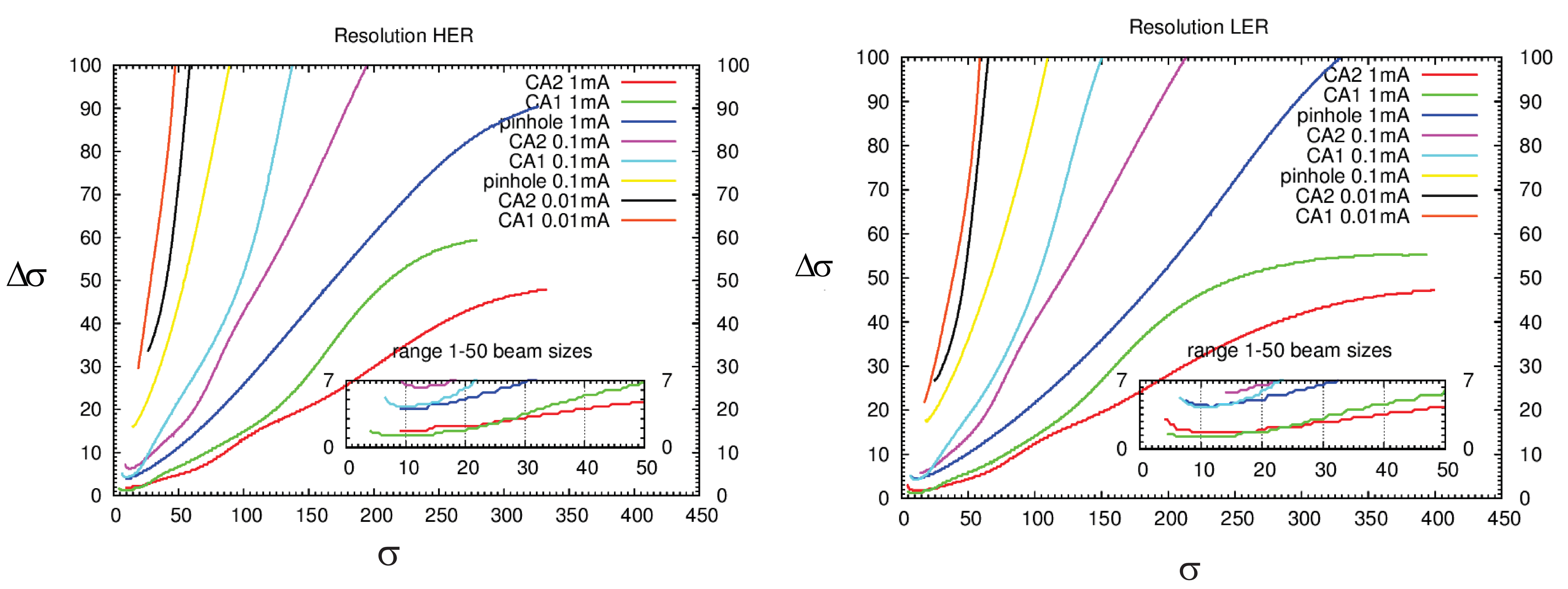


Fig 4. CA2 mask with 12 slits



Figs 5, 6 and 7. Simulated detector image show a number of photon/pixel for various beam sizes at HER with pinhole, CA1 and CA2 at 1 mA



Figs 8 and 9. Resolution of vertical beam sizes in HER and LER at 1 mA

- We calculated the resolutions for all optical elements with the number of photons (for hole regions):
- LER = 1942.96 photon/turn/mA/bunch
- HER = 3341.63 photon/turn/mA/bunch
- For CA1 at 10-25 μm beam sizes, resolution are estimated 1.25-2.25 μm (for both rings)

1. Pinhole size was optimized by simulating detector images for a point source in both rings, with various pinhole (slit) sizes. The minimum widths PRFs were found to be the same (within 1 μm) at 33 μm for both rings, so this size pinhole was taken as the optimum for both rings.

2. Pairs of 33 μm slits were simulated, with varying separations between the pairs.

3. A series of multi-slit patterns were devised by hand, incorporating a suitable range of slit separations to cover the dynamic range of interest, with emphasis on covering the smallest beam sizes.

Summary

- The CA1 elements that we have designed for use at SuperKEKB are estimated to provide 1.25-2.25 microns resolution for 10-25 microns of vertical beam sizes at 1 mA bunches.
- For larger beam sizes (> 30 μm), CA2 mask is better than CA1.
- The pinhole and CA masks are in fabrication for use at SuperKEKB. The study of the resolutions available with these mask patterns will be refined to incorporate noise and low-count (Poisson) statistics, and compared with data taken following beam commissioning in Spring 2016.

contact persons:
mulyani@post.kek.jp
john.flanagan@kek.jp