APS-U emittance studies — optics consideration

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Coherent flux portion

$$\frac{F_C}{F} = \frac{\lambda^2}{(4\pi)^2\Sigma_x\Sigma'_x\Sigma_y\Sigma'_y}$$

$$\varepsilon_x = \sigma_x\sigma'_x$$

$$\varepsilon_y = \sigma_y\sigma'_y$$

β_x, β_y

$L = 4.8\ \mathrm{m}$

Electron ⊗ photon = Total

$$\sigma_x = \sqrt{\varepsilon_x\beta_x}$$

$$\sigma_y = \sqrt{\varepsilon_y\beta_y}$$

$$\sigma'_x = \sqrt{\varepsilon_x/\beta_x}$$

$$\sigma'_y = \sqrt{\varepsilon_y/\beta_y}$$

$$\sigma_r = \frac{\sqrt{2\lambda L_u}}{2\pi}$$

$$\sigma'_r = \sqrt{\frac{\lambda}{2L_u}}$$

$$\Sigma_x = \sqrt{\sigma_x^2 + \sigma_r^2}$$

$$\Sigma_y = \sqrt{\sigma_y^2 + \sigma_r^2}$$

$$\Sigma'_x = \sqrt{\sigma_x'^2 + \sigma_r'^2}$$

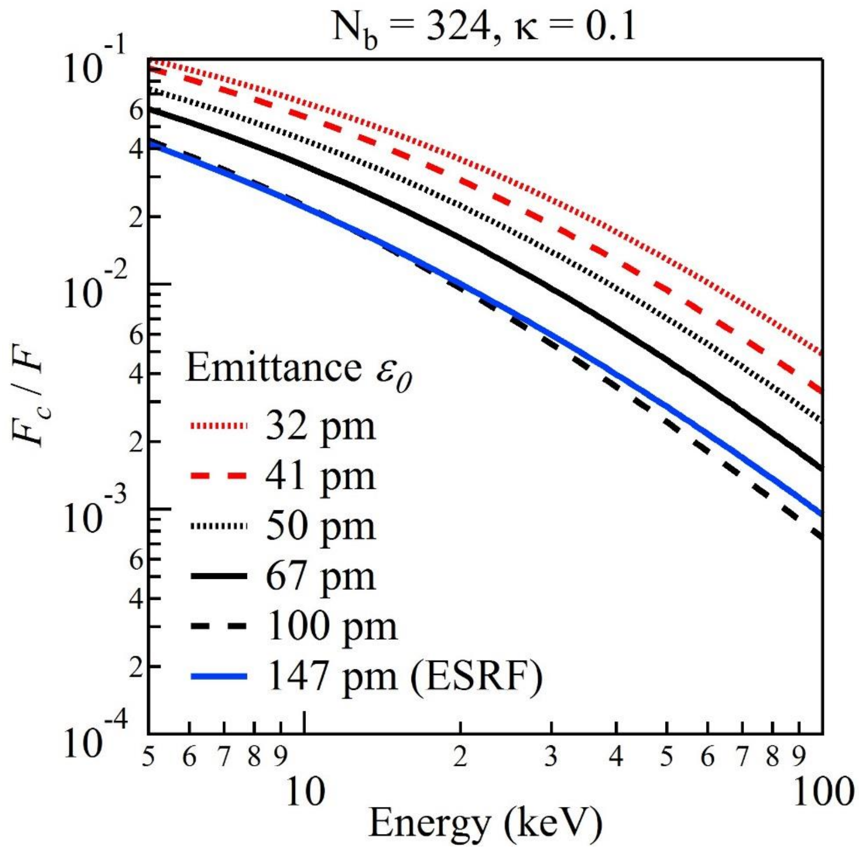
$$\Sigma'_y = \sqrt{\sigma_y'^2 + \sigma_r'^2}$$

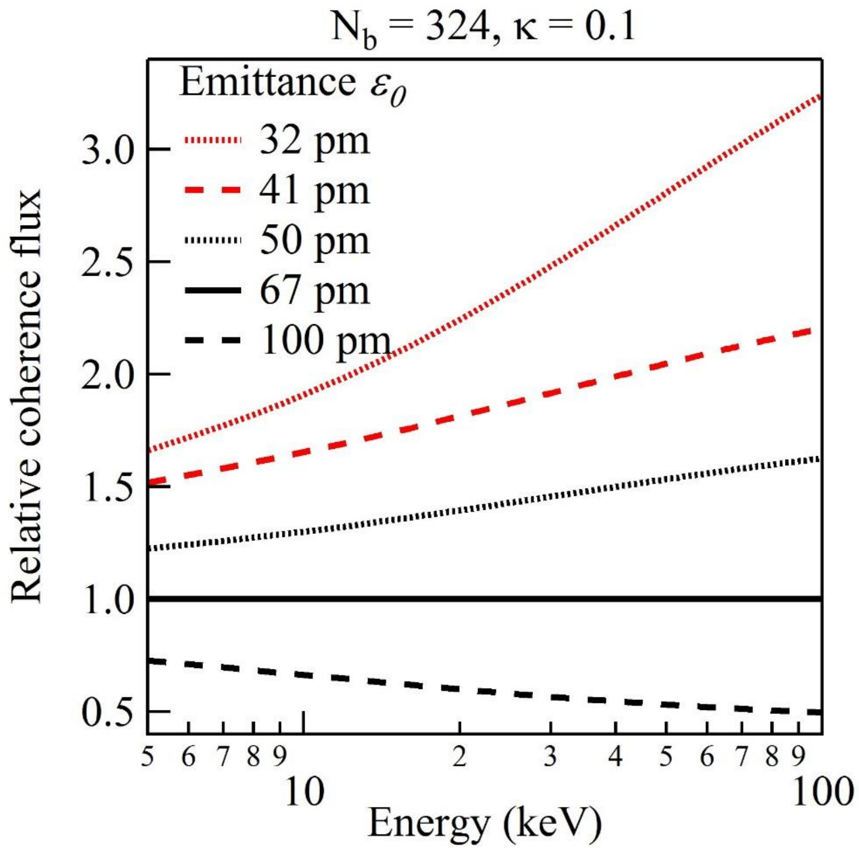
Mode	APS-U timing mode (N_b = 48)					APS-U brightness mode (N_b = 324)					ESRF
$\boldsymbol{\varepsilon_0}$ **(pm)**	32	41	50	67	100	32	41	50	67	100	147
$\boldsymbol{\kappa}$	1	1	0.98	0.98	0.98			0.1			0.035
$\boldsymbol{\varepsilon_x}$ **(pm)**	26	33.1	35.0	46.8	70.0	33.6	43.2	50.7	67.9	101.5	142
$\boldsymbol{\varepsilon_y}$ **(pm)**	26	33.1	34.3	45.9	68.6	3.3	4.3	5.1	6.8	10.2	5
$\boldsymbol{\beta_x}$	6	4.9	7	7	7	6	4.9	7	7	7	5.2
$\boldsymbol{\beta_y}$	2	1.9	2.4	2.4	2.4	2	1.9	2.4	2.4	2.4	2.4

Coherent flux portion (brightness mode)

$$\frac{F_C}{F} = \frac{\lambda^2}{(4\pi)^2 \Sigma_x \Sigma'_x \Sigma_y \Sigma'_y}$$

Normalized to ε_0 = 67 pm case

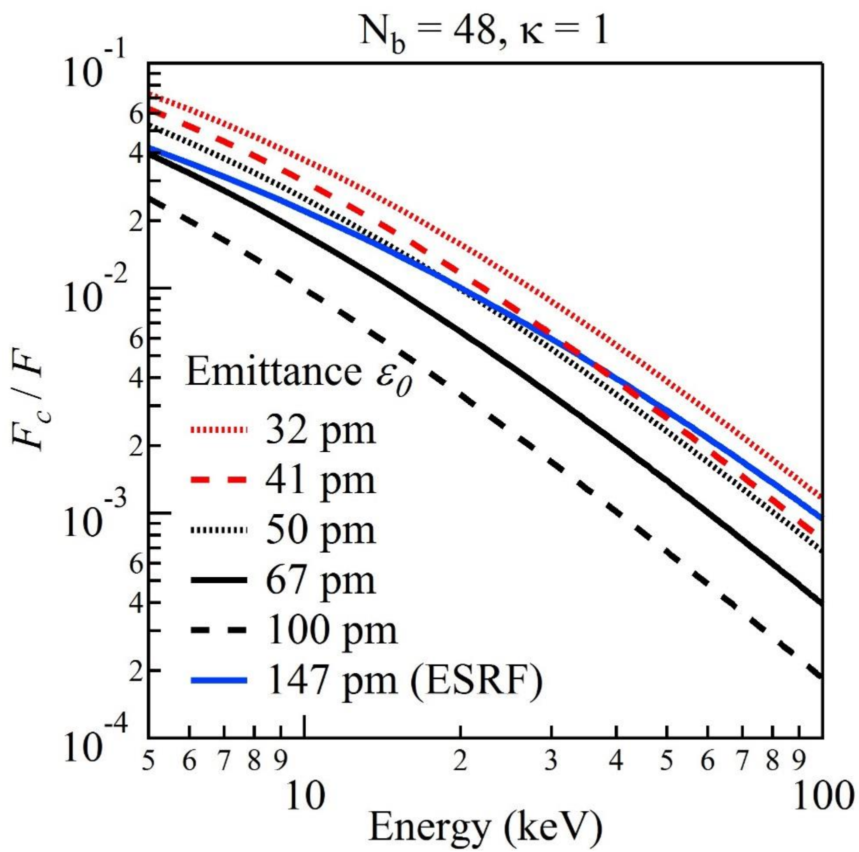


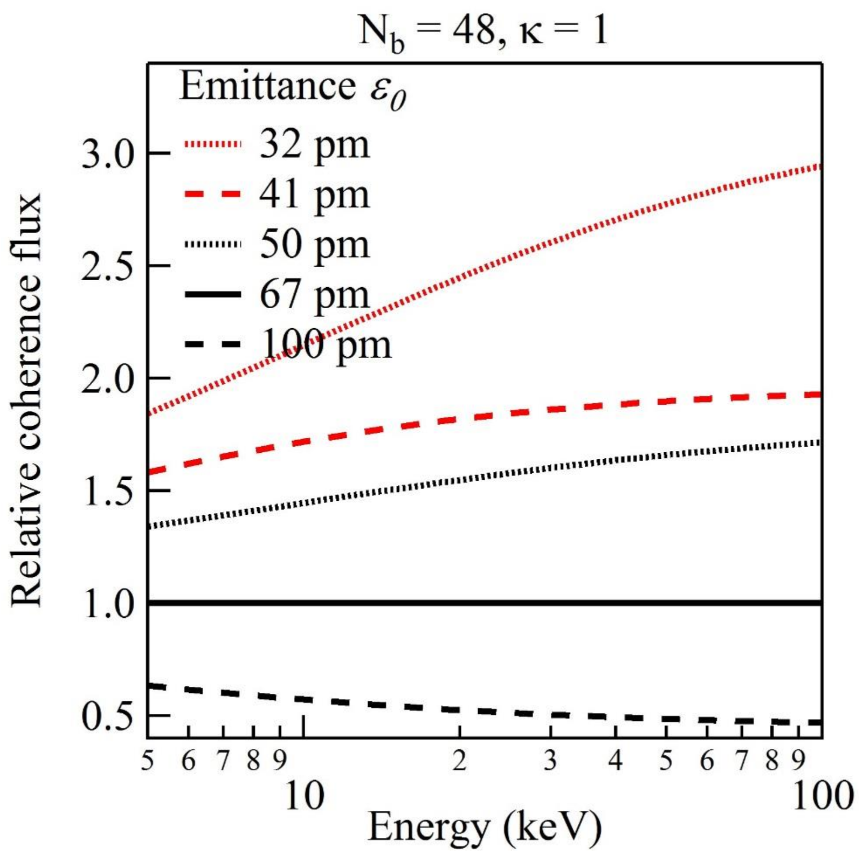


Coherent flux portion (timing mode)

$$\frac{F_C}{F} = \frac{\lambda^2}{(4\pi)^2 \Sigma_x \Sigma'_x \Sigma_y \Sigma'_y}$$

Normalized to ε_0 = 67 pm case





Coherent flux – optics effect

- Possible source of coherent flux reduction:
    1. optics angular vibration (σ_{vib})
    2. optics slope error (σ_{SE})
- Assume a vertical or horizontal reflection optics (mirror or monochromator) is located p = 30 m from the source and the optics accepts the full beam, the virtual source size is broadened by

$$\Delta\sigma_x \text{ or } \Delta\sigma_y = 2p\sigma_{\mathrm{vib}} \text{ or } 2p\sigma_{\mathrm{SE}}$$

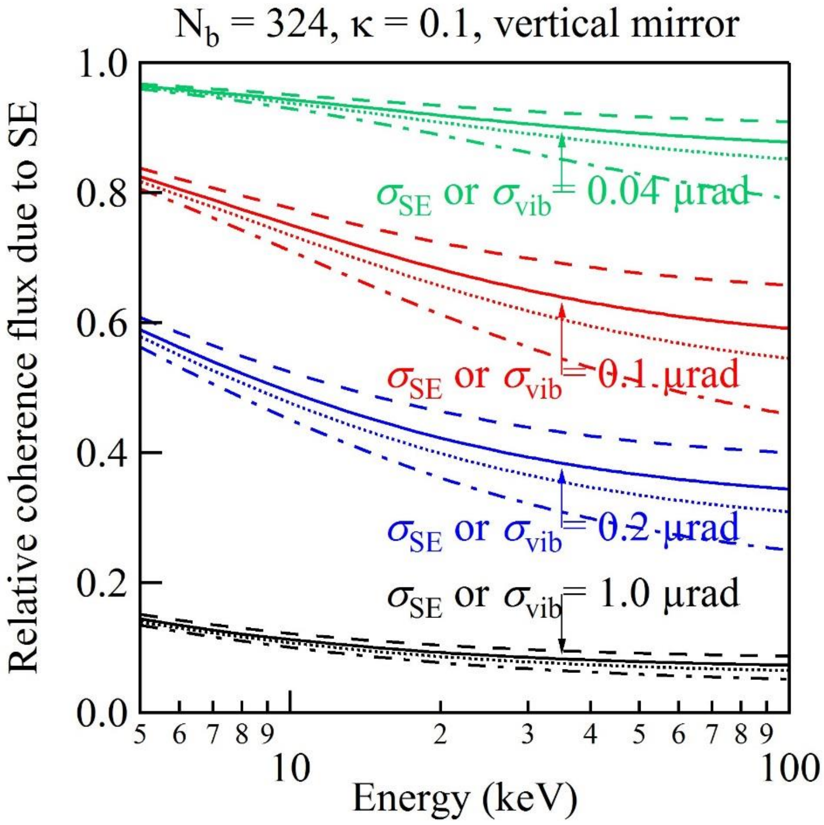
- The coherence flux is reduced to:

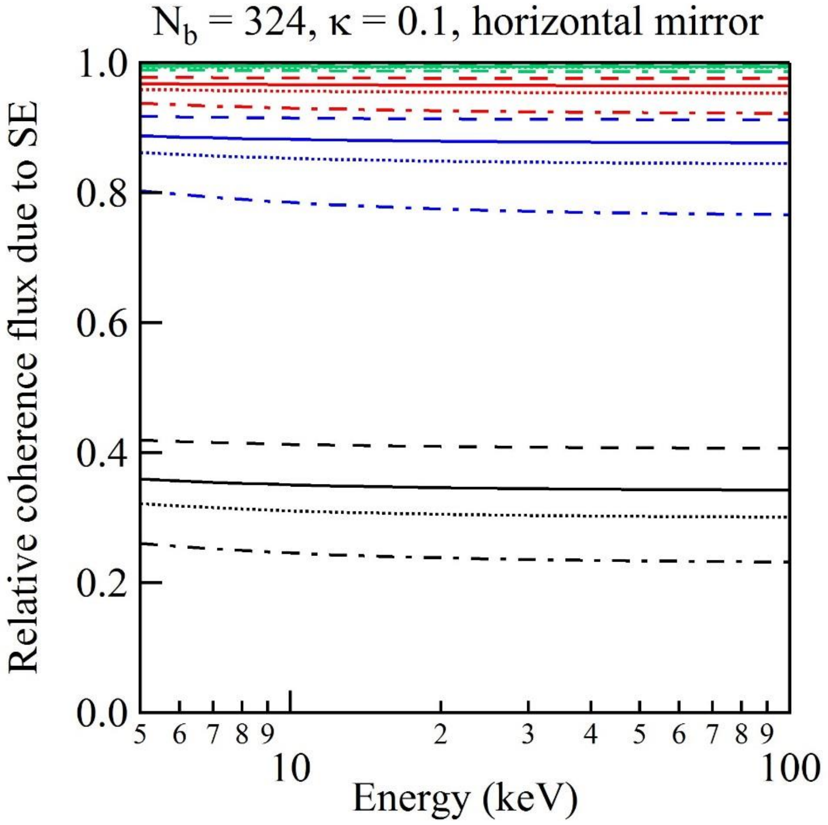
$$\frac{F_c\Sigma_x}{\sqrt{\Sigma_x^2 + \Delta\sigma_x^2}} \text{ or } \frac{F_c\Sigma_y}{\sqrt{\Sigma_y^2 + \Delta\sigma_y^2}}$$

Coherent flux – optics effect

- **APS-U brightness mode**

-·-·- $\varepsilon_0 = 32$ pm, ······ $\varepsilon_0 = 50$ pm, — $\varepsilon_0 = 67$ pm, - - - $\varepsilon_0 = 100$ pm

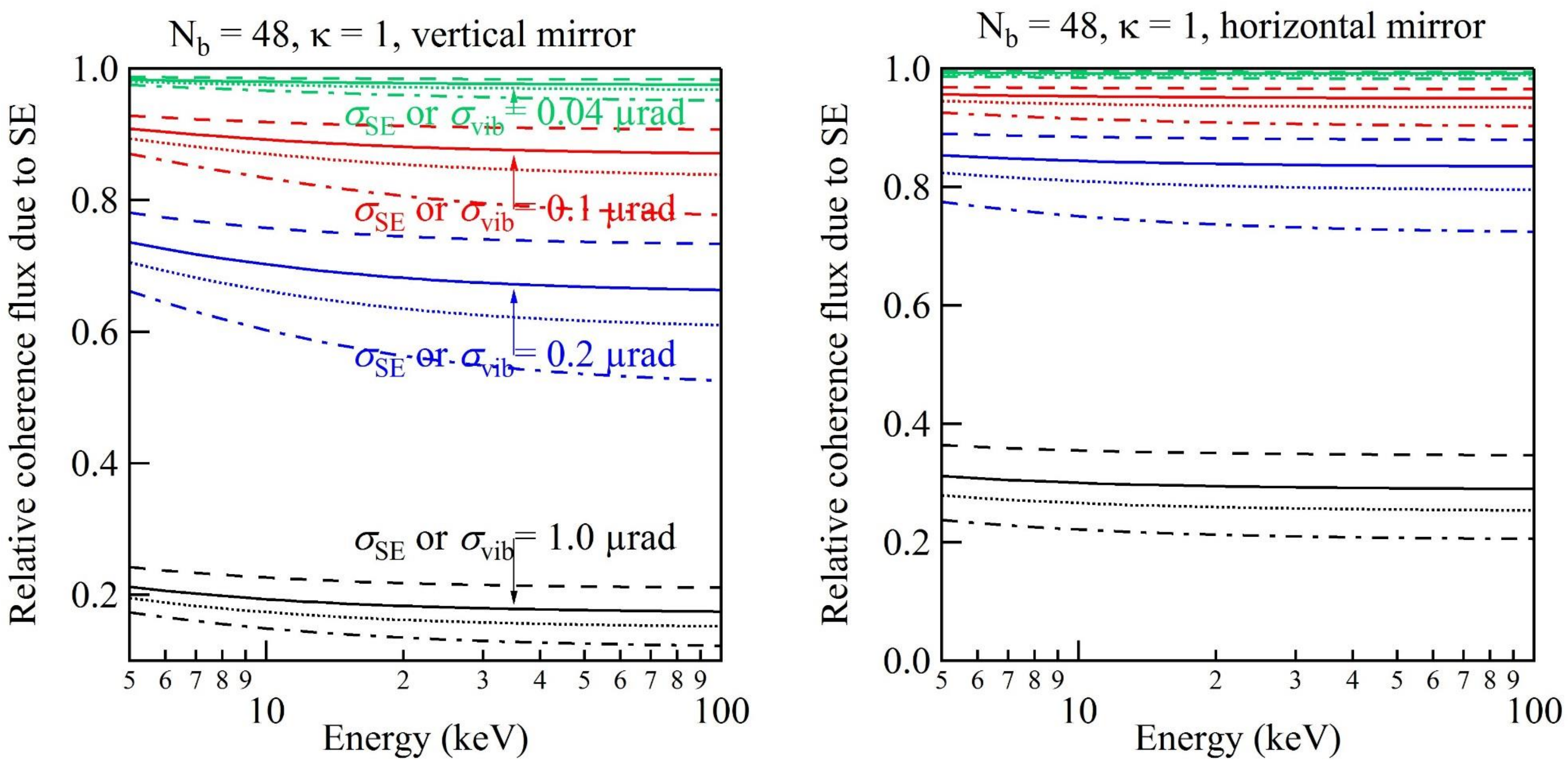




Coherent flux – optics effect

- **APS-U timing mode**

$- \cdot \cdot -\ \varepsilon_0 = 32$ pm, $\cdots\cdots\ \varepsilon_0 = 50$ pm, $—\ \varepsilon_0 = 67$ pm, $- - -\ \varepsilon_0 = 100$ pm



Beam focusing studies

- Source emittance:

Mode	APS-U timing mode (N_b = 48)					APS-U brightness mode (N_b = 324)					ESRF
ε_0 (pm)	32	41	50	67	100	32	41	50	67	100	147
κ	1	1	0.98	0.98	0.98			0.1			0.035
ε_x (pm)	26	33.1	35.0	46.8	70.0	33.6	43.2	50.7	67.9	101.5	142
ε_y (pm)	26	33.1	34.3	45.9	68.6	3.3	4.3	5.1	6.8	10.2	5

- 4.8 m long undulator, at 20 keV

Electron	σ_y (μm)	7.2	7.9	9.1	10.5	12.8	2.6	2.9	3.5	4.0	4.9	3.5
	σ_y' (μrad)	3.6	4.2	3.8	4.4	5.3	1.3	1.5	1.5	1.7	2.1	1.4
Photon	σ_r (μm)			3.9					3.9			3.9
	σ_r' (μrad)			2.5					2.5			2.5
Total	Σ_y (μm)	8.19	8.83	9.87	11.19	13.41	4.66	4.82	5.22	5.60	6.28	5.2
	Σ_y' (μrad)	4.41	4.89	4.56	5.06	5.92	2.85	2.95	2.93	3.05	3.27	2.9

- Two cases:
  1. Demagnification focusing: p = 70 m, q = 700 mm, L_m = 400 mm, θ = 3.0 mrad
  2. Diffraction limited focusing: p = 70 m, q = 70 mm, L_m = 70 mm, θ = 3.0 mrad

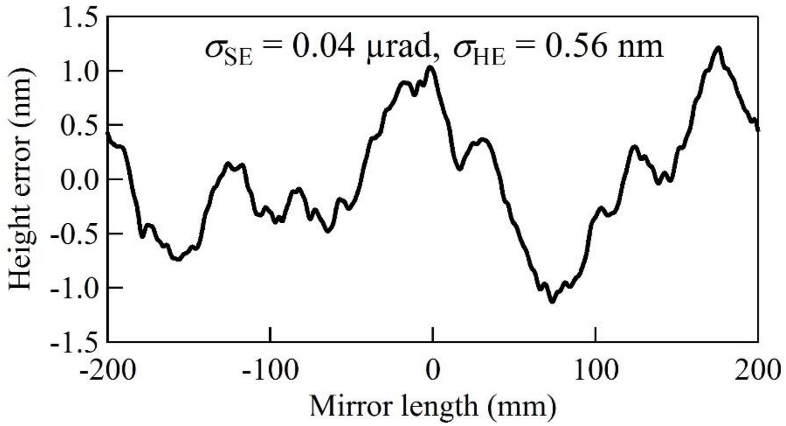
Demagnification dominated focusing

p = 70 m, q = 700 mm, L_m = 400 mm

HYBRID simulation results with an ideal mirror as well as with different slope errors focusing in vertical direction.

1. σ_{SE} = 0.04 μrad
2. σ_{SE} = 0.1 μrad
3. σ_{SE} = 0.2 μrad

LCLS mirror specification



		Timing mode (N_b = 48)					Brightness mode (N_b = 324)				
ε_0 (pm)		32	41	50	67	100	32	41	50	67	100
Mirror acceptance		97%	96%	94%	91%	86%	100%	100%	100%	100%	99%
Ideal size (nm) RMS		86	93	103	116	138	51	51	56	59	66
Comparison to ε_0 = 67 pm		-26%	-20%	-11%	0%	19%	-14%	-12%	-6%	0%	11%
Size broadening due to slope error	σ_{SE} = 0.04 μrad	8.7%	7.6%	6.5%	4.9%	3.3%	24%	23%	14%	12%	9.2%
	σ_{SE} = 0.1 μrad	57%	50%	47%	38%	30%	129%	124%	123%	113%	97%
	σ_{SE} = 0.2 μrad	191%	175%	152%	127%	99%	379%	366%	338%	314%	276%

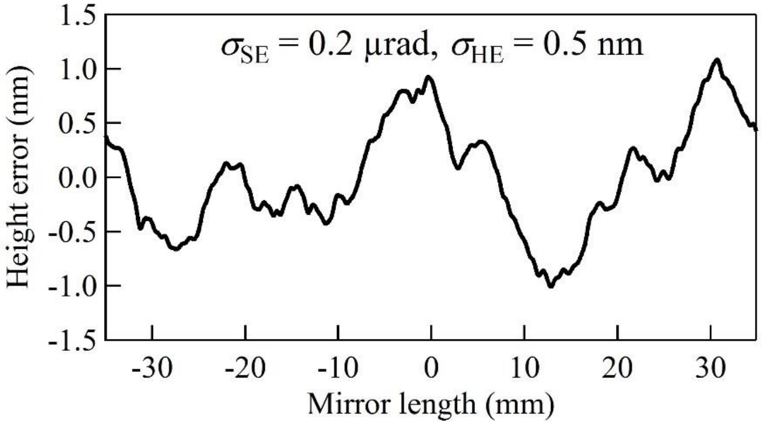
Diffraction limited focusing

p = 70 m, q = 70 mm, L_m = 70 mm

HYBRID simulation results with an ideal mirror as well as with different height errors focusing in vertical direction.

1. σ_{HE} = 0.5 nm
2. σ_{HE} = 1.0 nm
3. σ_{HE} = 2.0 nm

Scaled LCLS mirror



		Timing mode (N_b = 48)					Brightness mode (N_b = 324)				
ε_0 (pm)		32	41	50	67	100	32	41	50	67	100
Mirror acceptance		28%	26%	27%	25%	23%	41%	40%	40%	39%	37%
Ideal size (nm) RMS		18	18	19	19	21	16	16	16	17	17
Comparison to ε_0 = 67 pm		-8%	-8%	-4%	0%	7%	-2%	-1%	-1%	0%	4%
Size broadening due to height error	σ_{HE} = 0.5 nm	26%	25%	24%	21%	21%	31%	30%	30%	30%	29%
	σ_{HE} = 1.0 nm	135%	133%	128%	121%	109%	153%	151%	151%	150%	144%
	σ_{HE} = 2.0 nm	403%	401%	384%	366%	337%	447%	444%	444%	439%	423%

Remarks

- Reducing the source emittance benefits mostly the coherent flux, especially at high photon energies.
- The optics vibration and slope error can cause the loss of coherent flux. Horizontally bounced optics is preferred.
- For the beam focusing, reducing electron source emittance does not have linear effects on focal sizes. The smallest achievable size is also limited by the photon (undulator radiation) size and the diffraction limit of the optics.
- The currently available state-of-the-art mirror could satisfy most of the needs of APS-U. Reducing source emittance will require better optics, which need more studies.

Thank you!