Challenges for emittance diagnostics for the ESRF low emittance lattice

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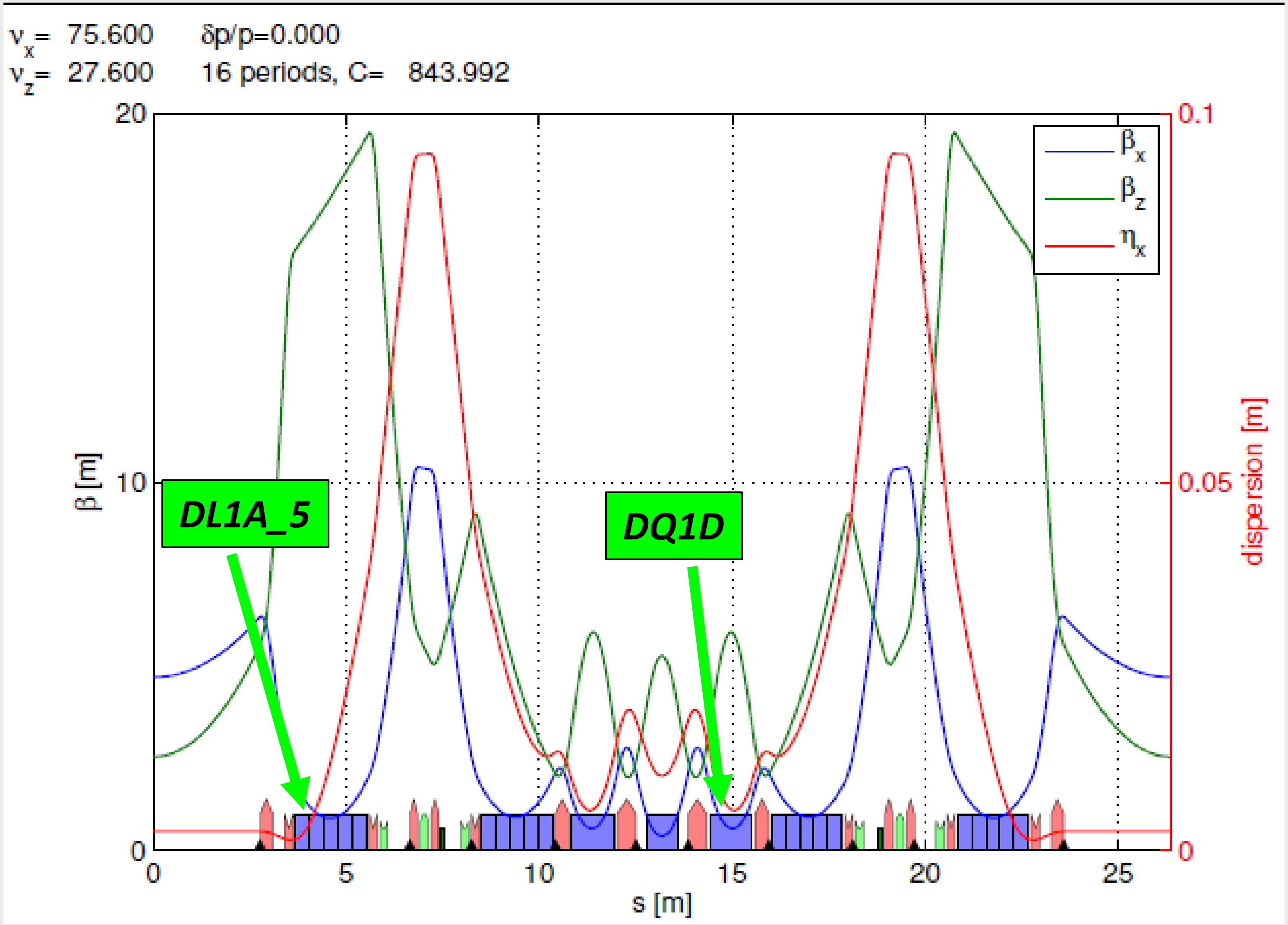
The ESRF will install a new low emittance lattice from 2019 onwards.
The horizontal design emittance of ε_x = 110 pm will give rise to a very small vertial emittance which in the extreme/ideal case of a perfectly well corrected machine may reach values of ε_z below 1 pm.

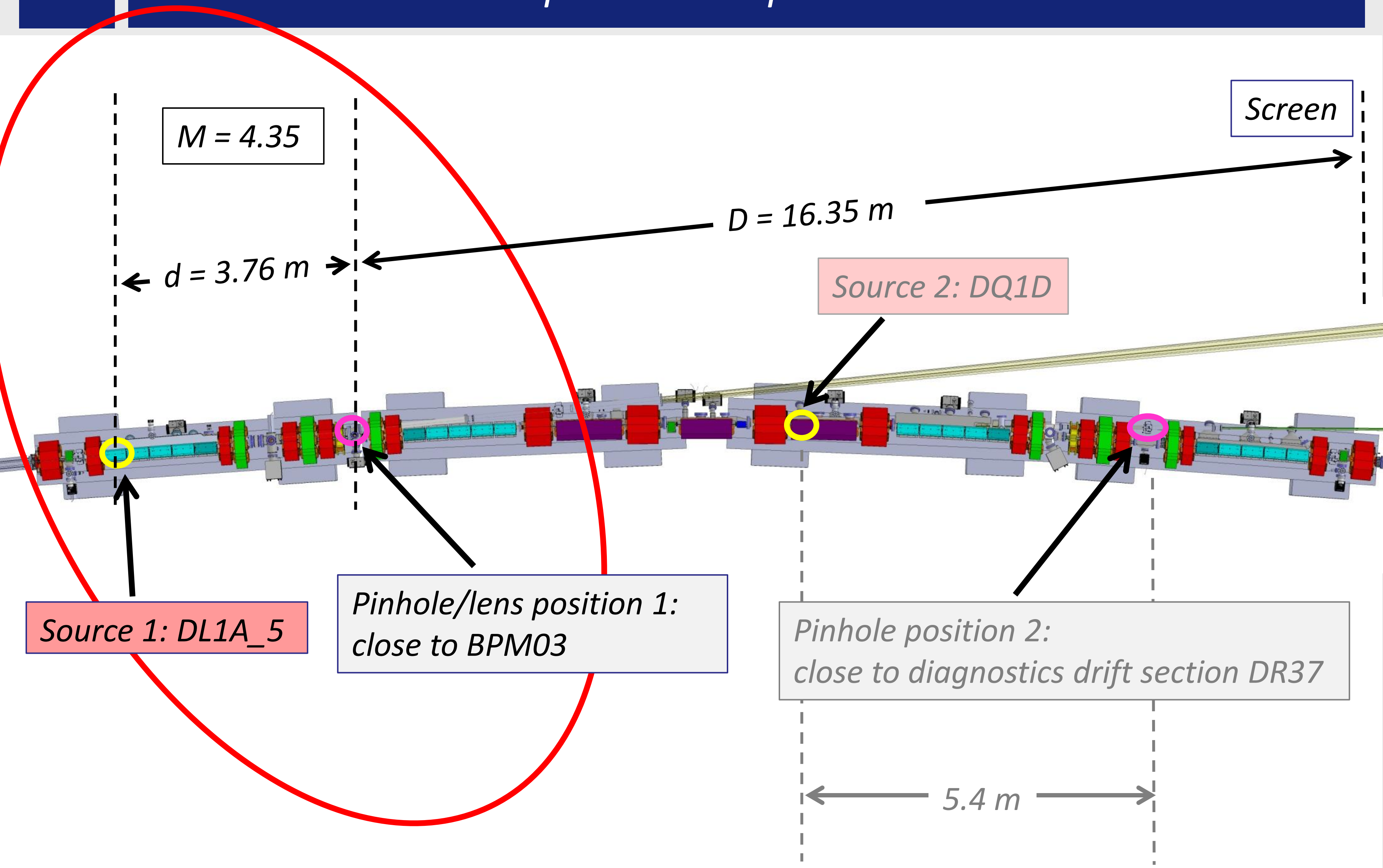
The measurement of such emittances is a challenge for mainly two reasons :

1. *the small source beam sizes and*
2. *the very limited space available in the mechanical layout of the new lattice.*

Available dipole source points for emittance monitors



Possible dipole source positions in a SR cell

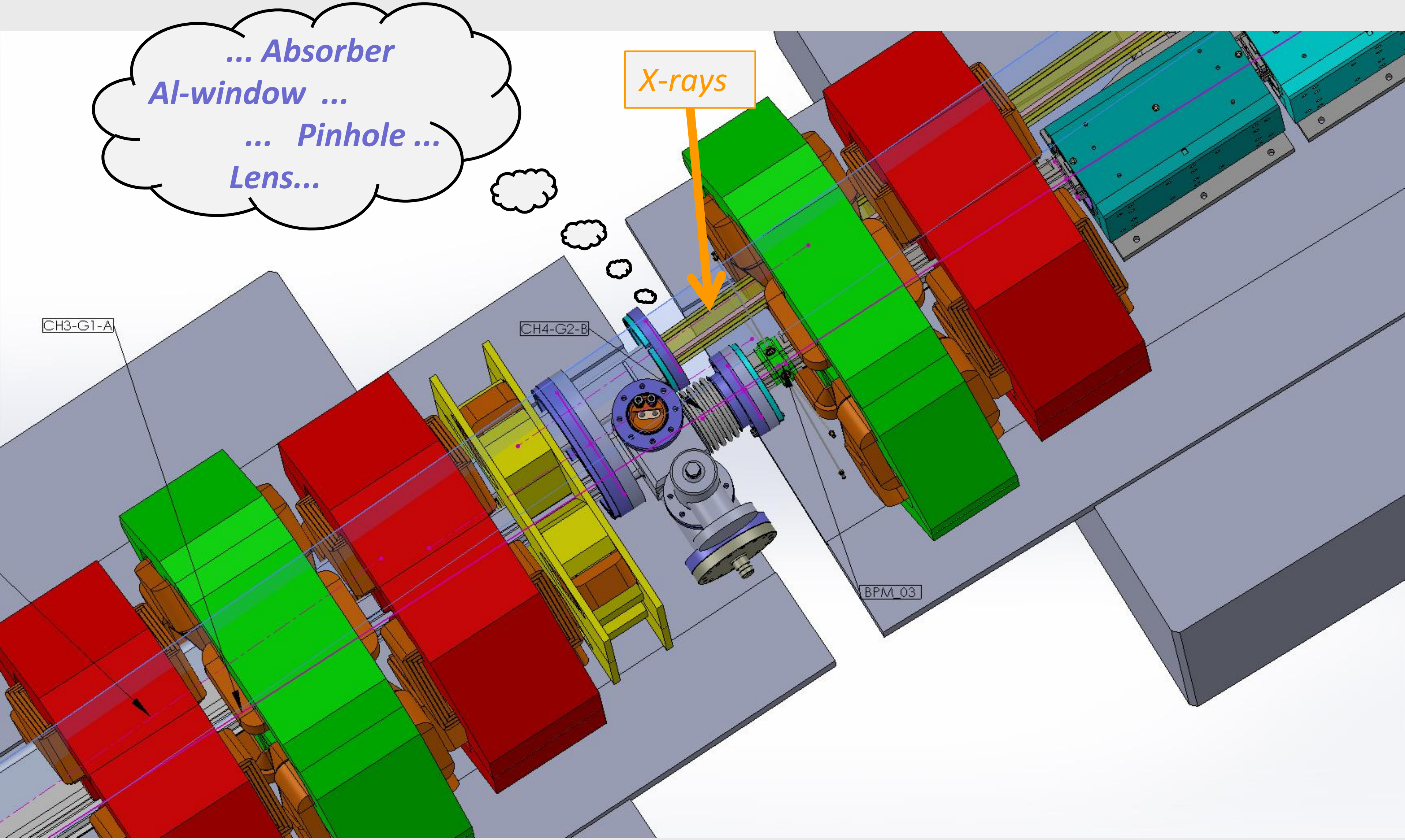


Expected vertical emittances and beam sizes @ DL1A_5

ε_x = 110 pm **σ_x @ source = 11 μm** **Σ_x in image plane = 48 μm**

		Perfectly corrected lattice	User Service Mode
coupling	--	0.001	0.047
σ_z @ source	μm	1.4	9
ε_z	pm	0.1	5
Σ_z in image plane	μm	6	40

Pinhole/lens position option 1 (DL1A_5) - ID beam port



X-ray Pinhole

Resolution determined by :

1. *diffraction from pinhole (minimum pinhole size)*
2. *projection shadow (upper limit of pinhole size)*

Detectability limited by :

1. *beam size on detection screen (magnification M = D/d)*
2. *photon flux*

Pinhole: optimum size and resolution

Optimum pinhole size
= equilibrium between diffraction limit
and projected shadow:

$$A_{opt} = \sqrt{\sqrt{3}\,\frac{\lambda d D}{d + D}} = 10\ \mu m \quad [*]$$

Minimum resolvable beam size
and emittance
using pinhole with A_{opt}*:*

$$\sigma_{\min} = \sqrt{\frac{\lambda d}{2\sqrt{3}}\,\frac{D + d}{D}} \qquad \varepsilon_{\min} = \frac{\sigma_{\min}^2}{\beta}$$

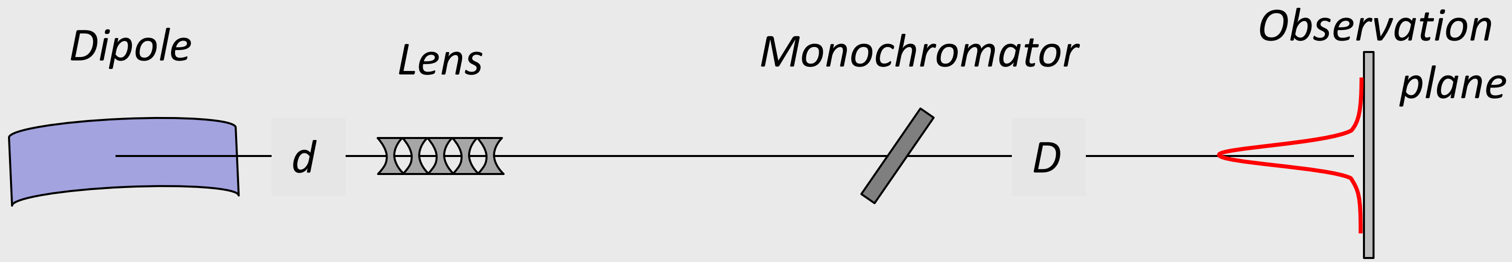
Implementation at DL1A_5 source:

(B = 0.67 T, β_z *= 16.6 m,* β_x *= 1.5 m, d = 3.76m, D = 16.35 m)*

σ_{min} = 5 μm	→	**$\varepsilon_{z,\,min}$ = 1.5 pm**	☹	*(O.K. for USM)*
		$\varepsilon_{x,\,min}$ = 16.0 pm	☺	*O.K.*

[*] Note from P. Elleaume

X-ray lens



Resolution determined by :

1. *diffraction limited imaging resolution of the lens*
2. *lens abberations*
3. *imperfections of monochromator*
4. *depth of field (object plane)*

Detectability limited by :

1. *beam size on detection screen (magnification M = D/d)*
2. *photon flux*

CRL: theoretical resolution limit

Minimum resolvable source size:

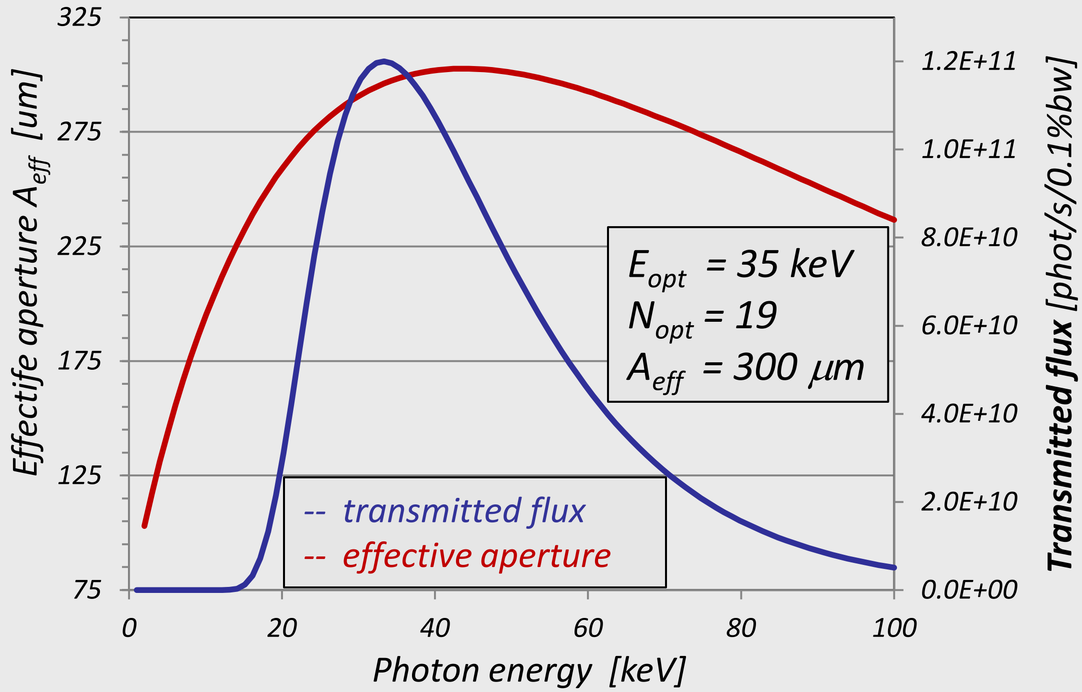
(A_{eff} : effective lens aperture = $f(E_{ph}, N)$)

$$\sigma_{\min} = \frac{\lambda d}{2A_{eff}}$$

Implementation at DL1A_5 source:

($B = 0.67$ T, $\beta_z = 16.6$ m, $\beta_x = 1.5$ m, $d = 3.76$m, $D = 16.35$ m)

Photon energy optimised on maximum transmitted flux.
(Number of lenses N adapted to each photon energy.)



σ_{min} **= 0.25 µm**

↓

$\varepsilon_{z,\,min}$ **= 0.003 pm**

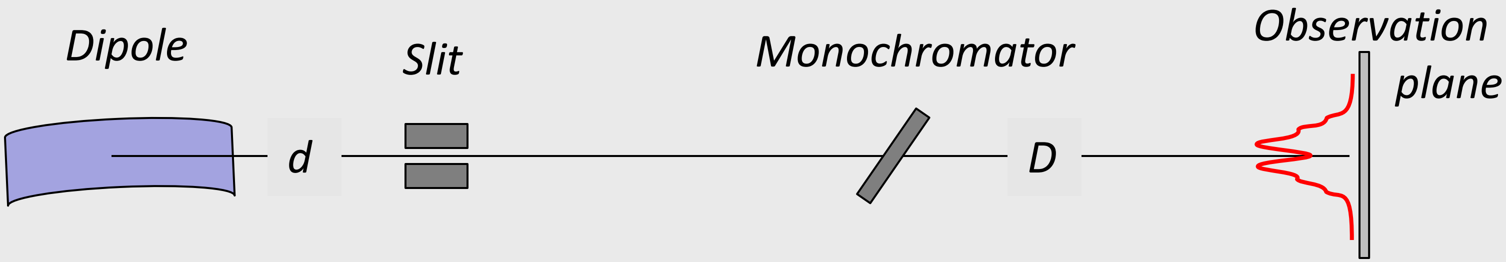
☺☺☺

BUT in reality???

↓

- lens quality?
- monochromator?
- depth of field effects?

X-ray Fresnel diffraction from a slit



Resolution determined by :

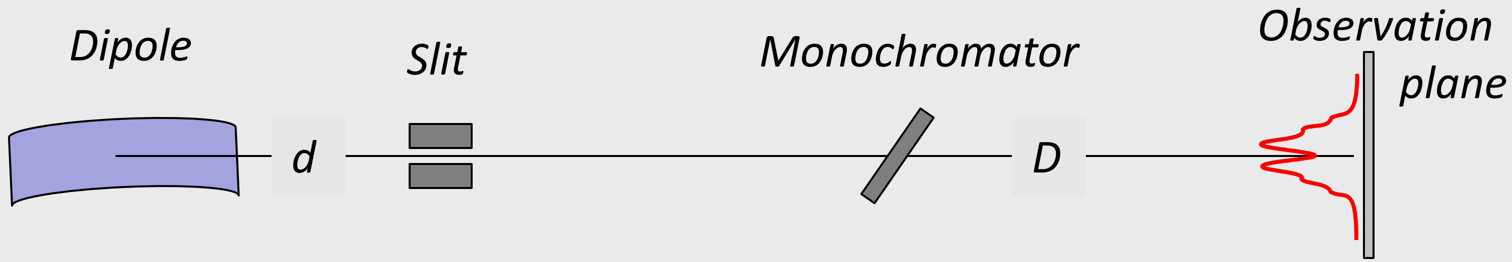
1. *photon energy*
2. *slit size*
3. *simulations*
4. *imperfections of monochromator*

Detectability limited by :

1. *beam size on detection screen*
2. *photon flux*
3. *CCD camera: high contrast, high resolution*

References:
[1] M. Masaki et al., "X-ray Fresnel diffractometry for ultrlow emittance diagnostics of next generation synchrotron light sources", PR Special Topics – Accelerators and Beams, 18, 042802 (2015)
[2] O. Chubar, "X-ray interference methods of electron beam diagnostics", Proceedings DIPAC 2001, Grenoble, p.88, CT09

X-ray Fresnel diffraction from a slit



Optimum slit size for obtaining a « simple » double-lobed diffraction pattern [1]:

$$a \approx \sqrt{7\lambda \frac{dD}{d+D}}$$

Simulations with SRW for the ESRF low emittance lattice:

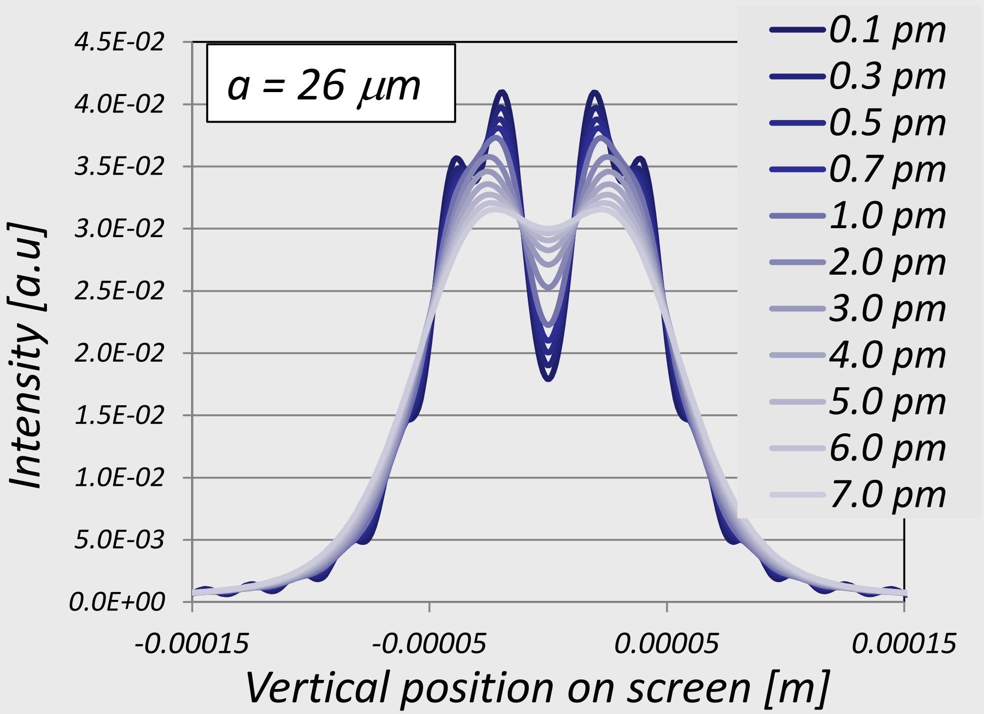
d	= 3.76 m	D	= 16.35 m
E_{beam}	= 6 GeV	A	= 200 mA
E_{ph}	= 40 keV	ε_x	= 0.11 pm

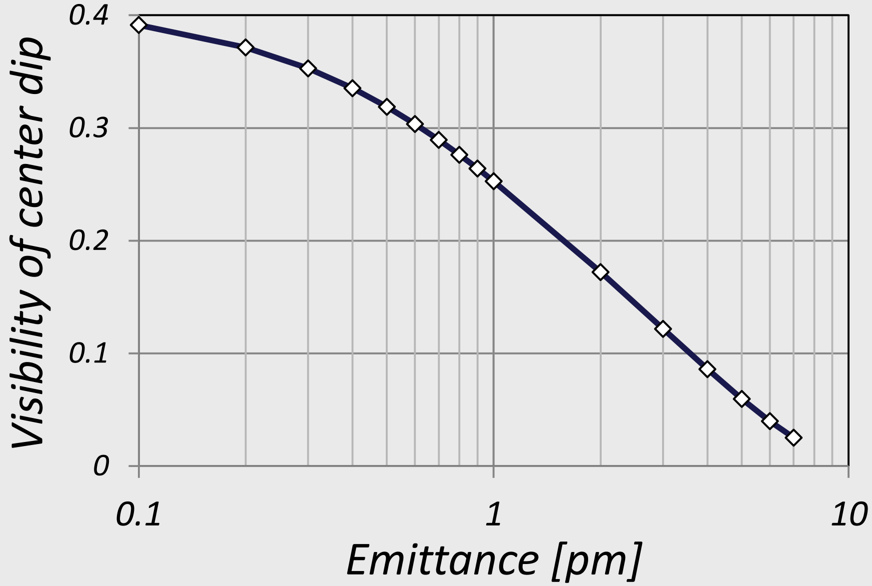
→ $a = 26\ \mu m$

[1] M. Masaki et al., "X-ray Fresnel diffractometry for ultrlow emittance diagnostics of next generation synchrotron light sources", PR Special Topics – Accelerators and Beams, 18, 042802 (2015)

X-ray Fresnel diffraction from a slit

Simulations with SRW for the ESRF low emittance lattice:





Conclusions

ε_x = 110 pm | σ_x @ source = 11 μm | Σ_x in image plane = 48 μm

		Perfectly corrected lattice	User Service Mode
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X-ray diffraction

X-ray lens

Pinhole

Positive: X-ray pinhole, lens, X-ray diffraction can be done at the same location, no special beamline or setup needed!

Requirements for energy spread measurement:

2 locations s_1 and s_2 of horizontal beam size measurement with $\eta(s_1) < \eta(s_2)$

→ η_1 @ DL1A_5 = 0.0015 m
→ η_2 @ DQ1D = 0.0126 m

Contribution of dispersion to the total beam size at the source:

		DL1A_5	DQ1D
σ_{tot}	[μm]	13	17
σ_{disp}	[μm]	1.4	12
$\sigma_{disp}/\sigma_{tot}$	[%]	11	70

→ 1 pinhole @ DL1A_5 + 1 pinhole @ DQ1D
→ Energy spread calculated from the two measured beam sizes σ_1 and σ_2:

$$\sigma_e = \sqrt{\frac{\beta_2\sigma_1^2 - \beta_1\sigma_2^2}{\beta_2\eta_1^2 - \beta_1\eta_2^2}}$$