# Effect of tilt on zone plate performance

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# Outline

# Introduction

# Focusing X-Rays

- Ref. index$\rightarrow$ complex,slightly $< 1$
- Zone plates$\rightarrow$ monochromatic diffractive optics.
- Alternate rings of low/high ref. index materials placed such that the outgoing waves constructively interfere with each other at the focal spot.

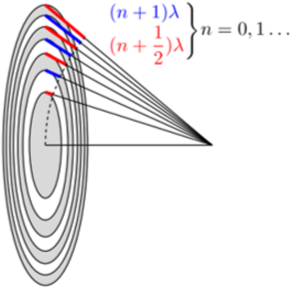
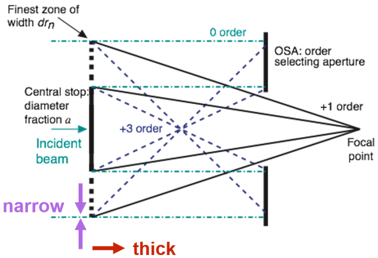



Illustration of zone plate [1]

[1] Jacobsen [2019]

# Factors affecting efficiency & resolution

- Spatial resolution limited to finest, outermost zone width.
- Zones must be thick enough along beam direction to produce a phase shift of $\pi$, several um at hard x-ray energy.

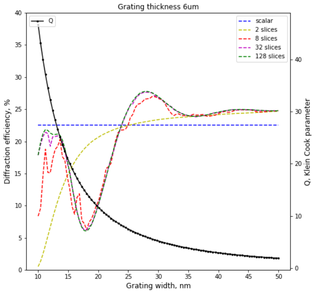



Thickness vs efficiency [2]

[2] Jacobsen [2019]

# Scalar theory is not enough

- Scalar approximation assumption $\rightarrow$ interaction between x-rays and the optic can be treated as one-step diffraction.
- Klein-Cook param. : $Q_{K-C}$ indicator of "diffraction regime"[3].




Volume effects in 1d gratings

[3] Klein und Cook [1967]

# Motivation for tilt misalignment study

- As Aspect ratios of zone plates go up[4], tilt misalignment needs to be understood better.
- Analytic limits[5] from literature do not account for volume diffraction effects.
- Local bragg angle for each zone $\rightarrow$ not the focus here.

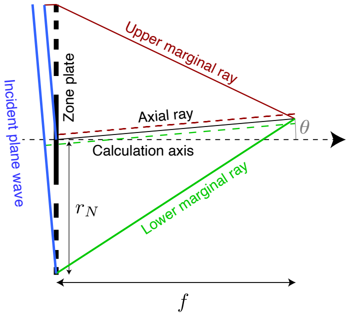
[4] Chang und Sakdinawat [2014]; Li et al. [2017]; Parfeniukas et al. [2017]

[5] Myers Jr. [1951]; Young [1972]

# Analytic limits

# Analytic limits

- Derived by using path difference between (upper) marginal, axial ray [6]

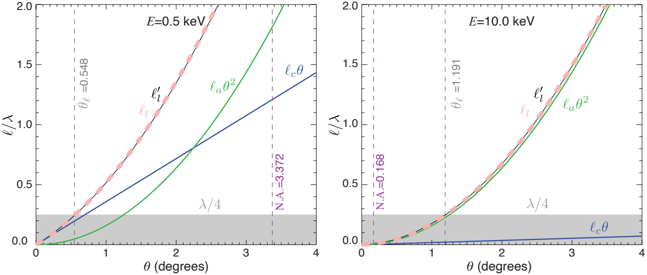



Volume effects in 1d gratings

[6] Myers Jr. [1951]; Young [1972]

# Expected behavior

- coma at soft xray, astigmatism at hard xray.

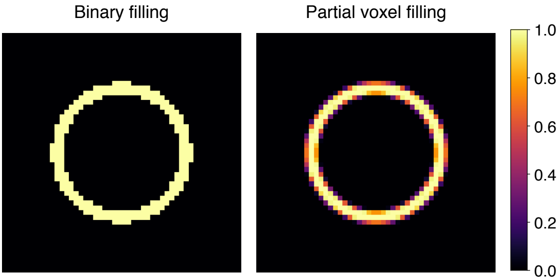



Path length terms

# Implementation

# Partial Filling

- No binary filling.

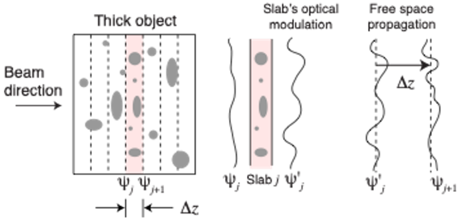



Partial fil

# Multislice

**Algorithm 1:** Optic simulation using the multislice method.

```
/* initialize                          */
ψ(x, y) ← 1
/* diffraction within optic            */
for n=1,N do
    SliceDiff(n)
    PropShort(Δz)
end
/* Propagate exit wave by a focal
   length f to the focal plane         */
PropLong(f)
```




Multi-slice schematic [7]

[7] Jacobsen [2019]

# Multislice

**Procedure** `SliceDiff(`$n$`)`

`/* Apply refractive effect of slice using */`

$\psi(x,y) = \psi(x,y) \odot \exp\left[i\,\frac{2\pi\Delta_z}{\lambda}\left(\delta(x,y) + i\beta(x,y)\right)\right]$ ;

**return**;

**Procedure** `PropShort(`$\Delta_z$`)`

`/* Free space propagation from source` $s$ `to destination` $d$ `plane */`

$\psi_s(x,y) \xrightarrow{\mathcal{F}} \Psi(u,v)$;

$\Psi(u,v) = \Psi(u,v) \odot \exp\left[-i\,\frac{2\pi\Delta_z}{\lambda}\sqrt{1-\lambda^2(u^2+v^2)}\right]$;

$\Psi(u,v) \xrightarrow{\mathcal{F}^{-1}} \psi_d(x,y)$;

**return**;

**Procedure** `PropLong(`$f$`)`

`/* Free space propagation from source` $s$ `to destination` $d$ `plane */`

$\psi'(x,y) = \psi_s(x,y) \odot \exp\left[-i\,\frac{2\pi f}{\lambda}\sqrt{x_s^2 + x_s^2 + f^2}\right]$;

$\psi'(x,y) \xrightarrow{\mathcal{F}} \Psi'(x,y)$;

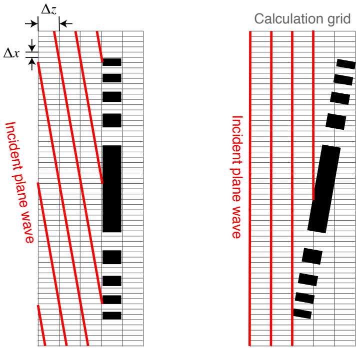
$\Psi_d(x,y) = \Psi'(x,y) \odot \exp\left[-i\,\frac{2\pi f}{\lambda}\sqrt{x_d^2 + x_d^2 + f^2}\right]$;

$\psi_d(x,y) = \frac{i\Delta_x^2}{\lambda f}\Psi_d(x,y)$;

**return**;

# Approaches

- Two approaches.




A: optic-aligned

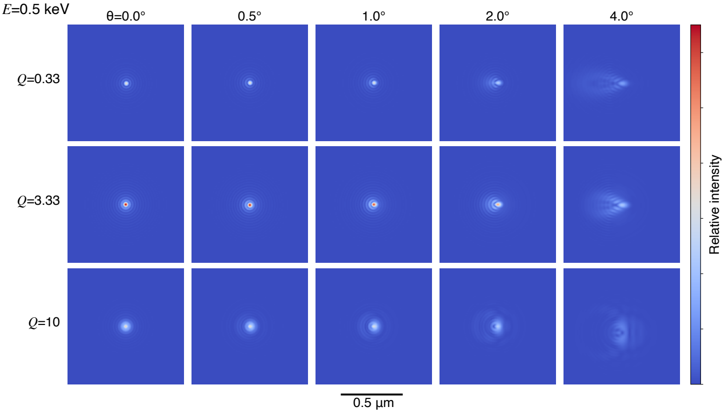
B: wavefield-aligned

Approaches

# Results

# soft x-ray

- Coma predicted.

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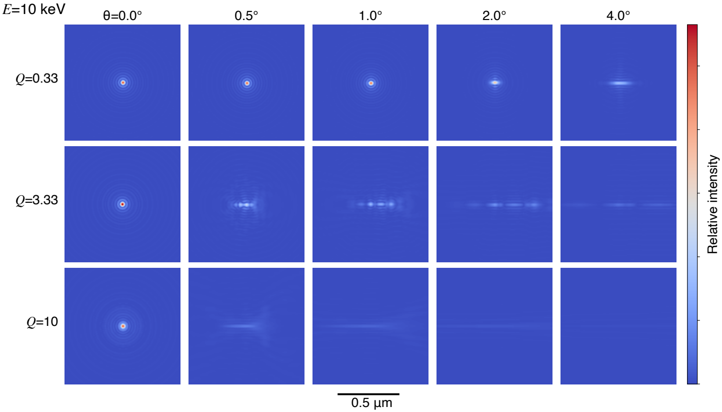
# hard x-ray

- Astigmatism predicted.

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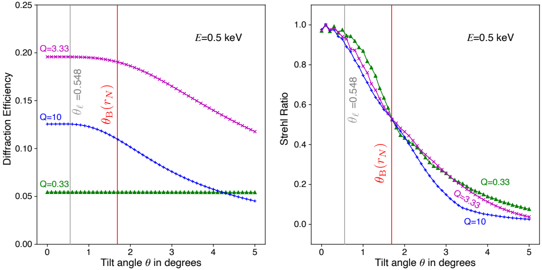
# soft x-ray

- Limit agrees with analytic expectation.

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# hard x-ray

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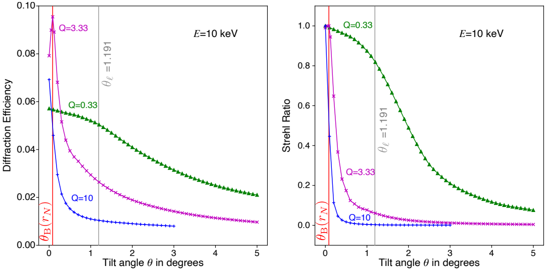


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# Acknowledgements


- Kenan Li SLAC
- Michael Wojcik APS,ANL.
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