TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Mathematik und Naturwissenschaften, Institut für Strukturphysik

Electron Biprism in the Condenser System for CHIRALTEM Experiment

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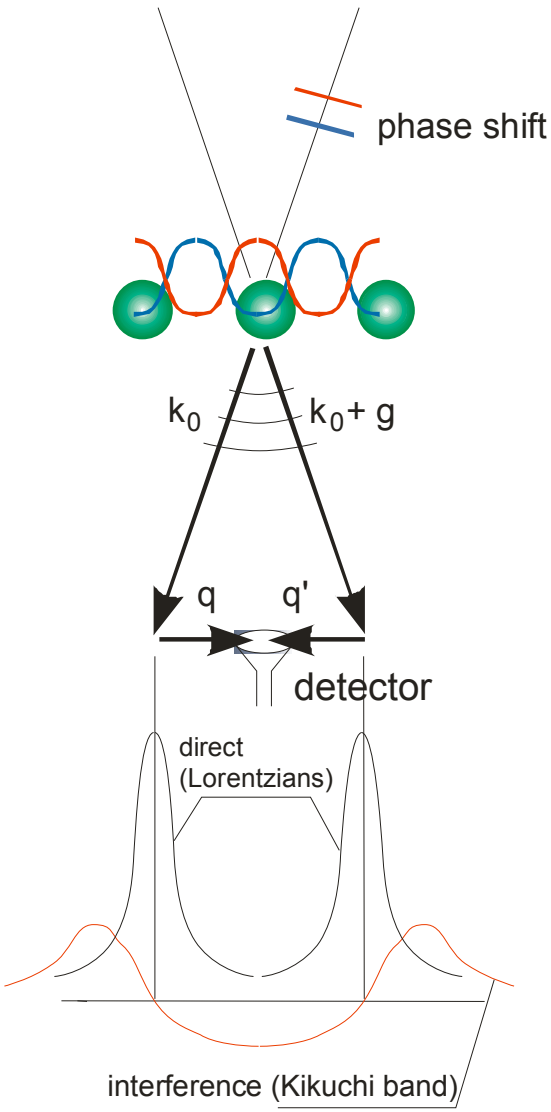
Motivation

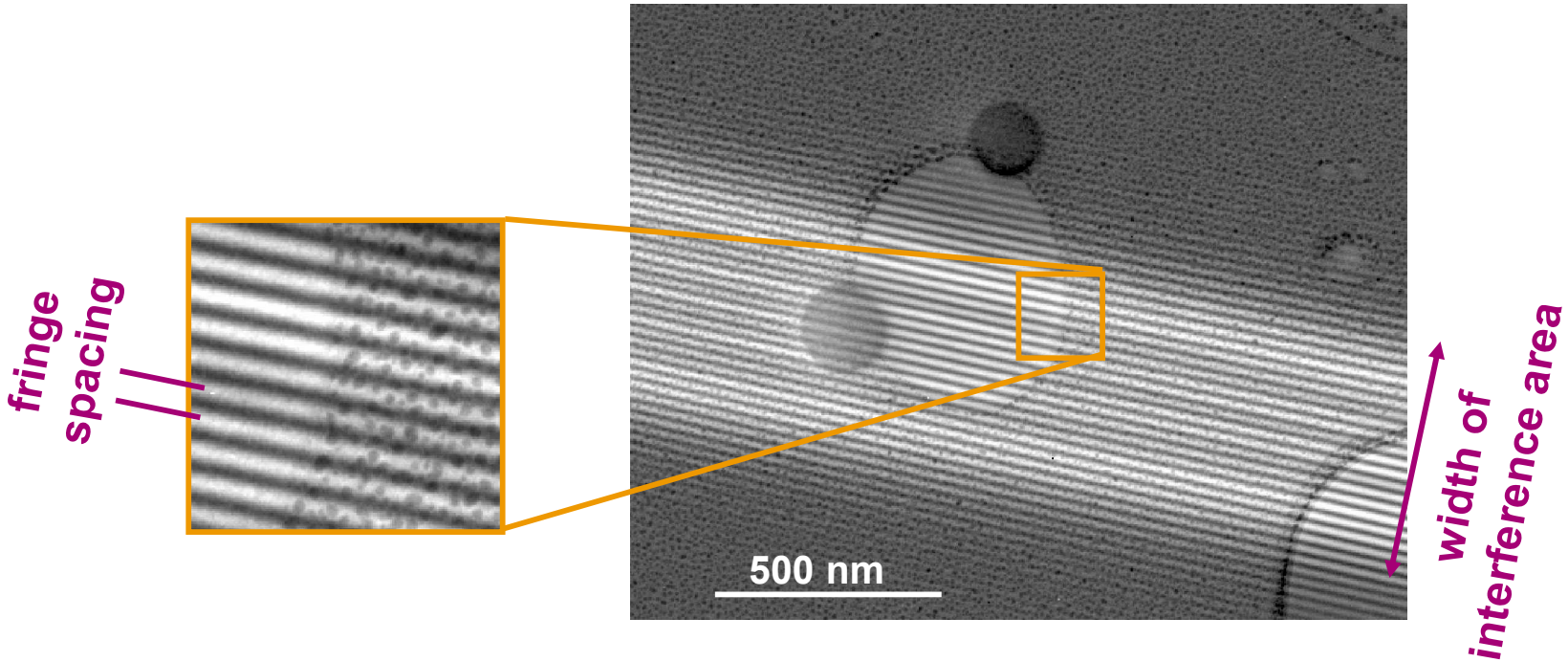

phase shift
k_0
$k_0 + g$
q
q'
detector
direct
(Lorentzians)
interference (Kikuchi band)

Goals

- **Illuminate specimen with two overlapping coherent electron waves**
  => Interference fringes on a specimen

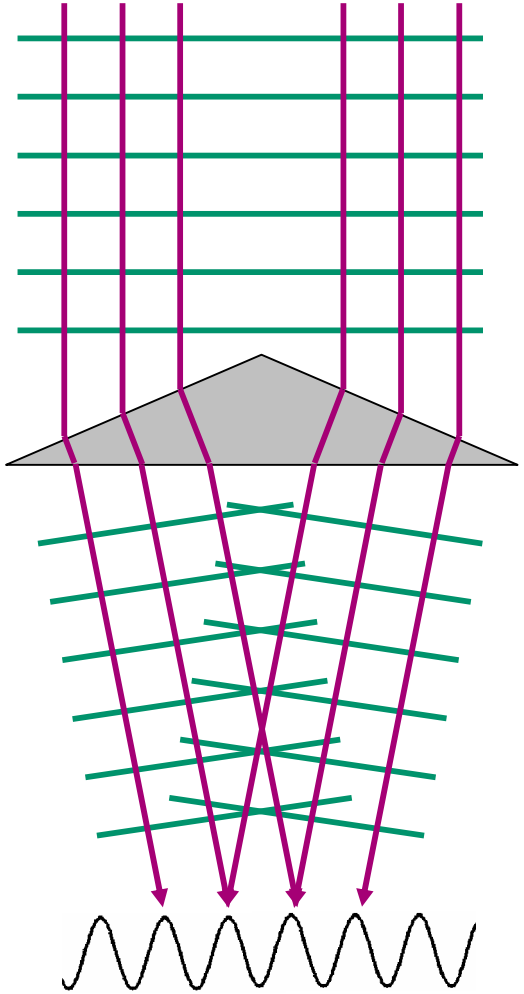
- **Control the width of the interference area and the fringe spacing**
  Target fringe spacing ~ 200 nm or ~ 0.1 nm

- **Control phase shift between the two waves**
  Phase shift ± $\pi/2$

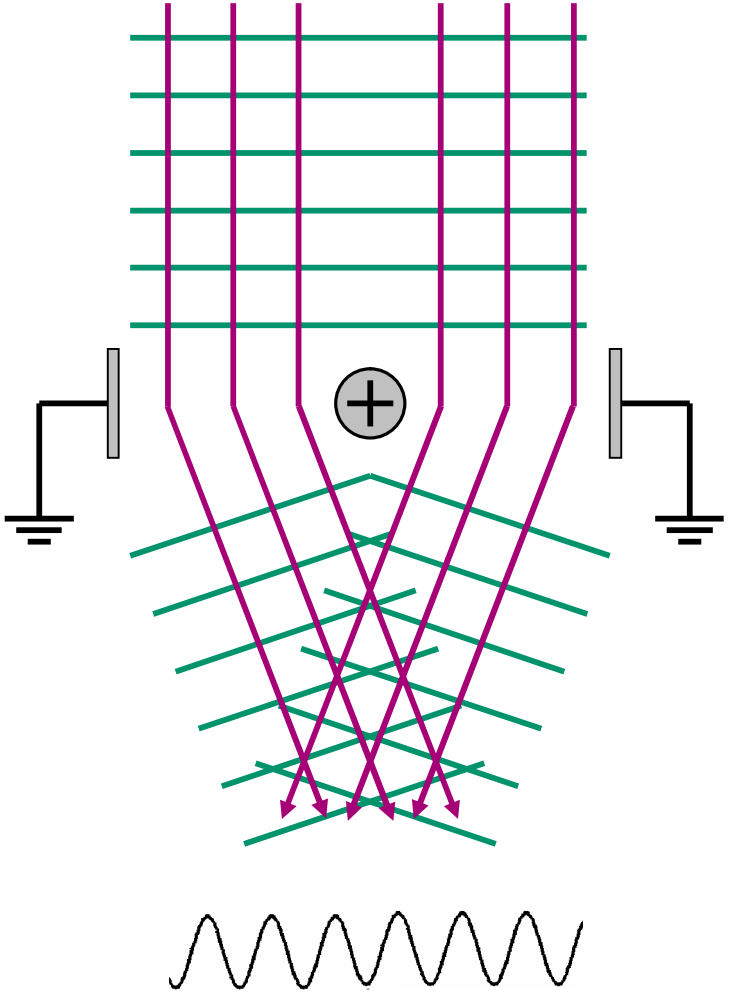


Electron Biprism - Principle of Operation

Optical Biprism



Electron Biprism



Biprism holder

Controlling the fringe spacing and interference width

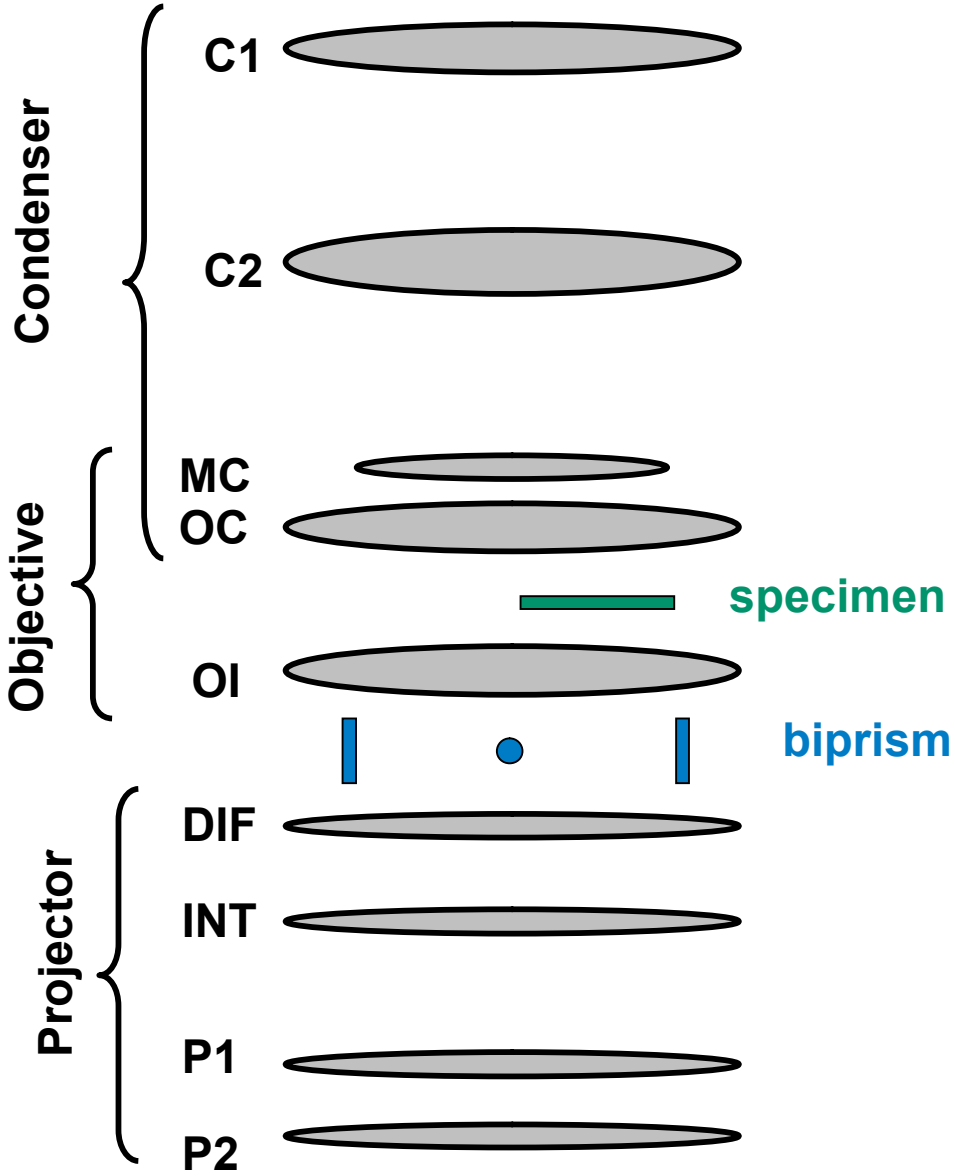
Optimisation

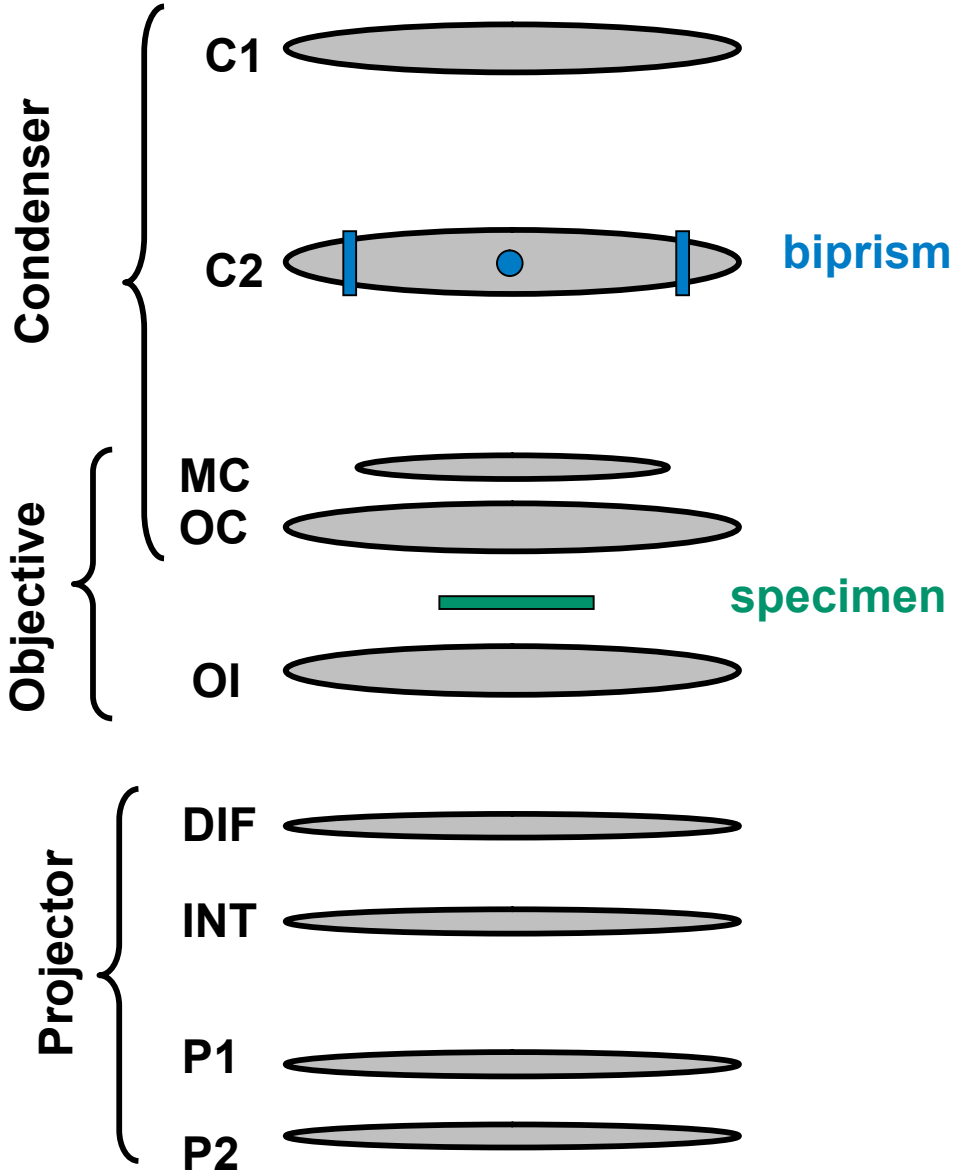
Biprism holder

Controlling the fringe spacing and interference width

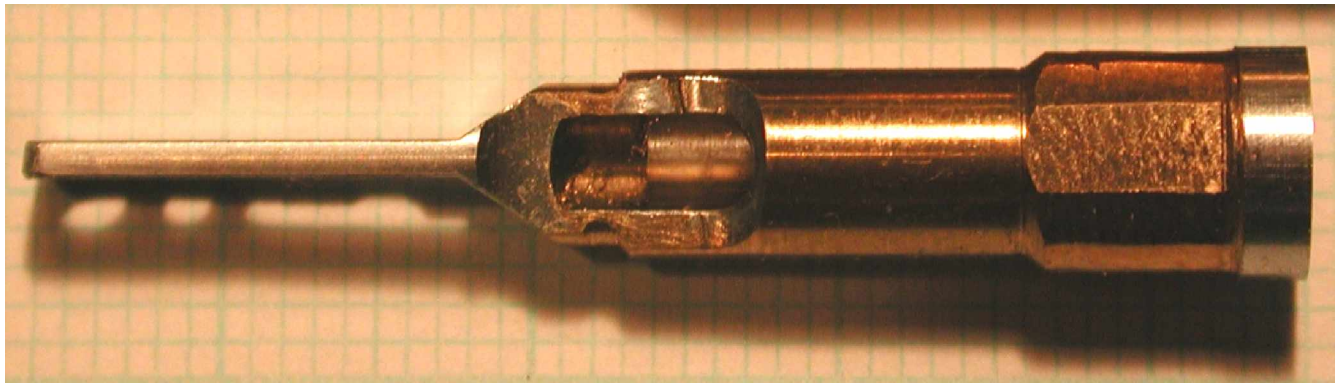
Optimisation

Holography vs. CHIRALTEM Setup

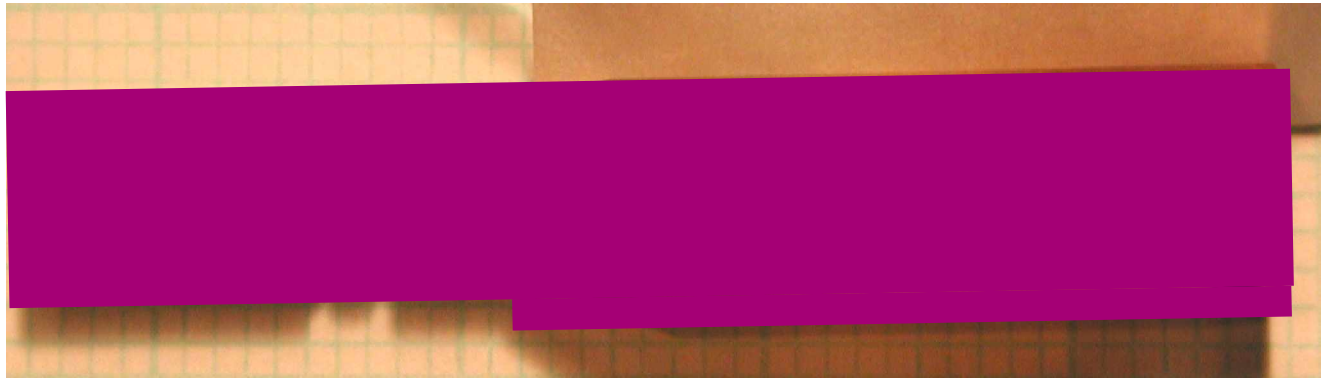




Biprism Holders



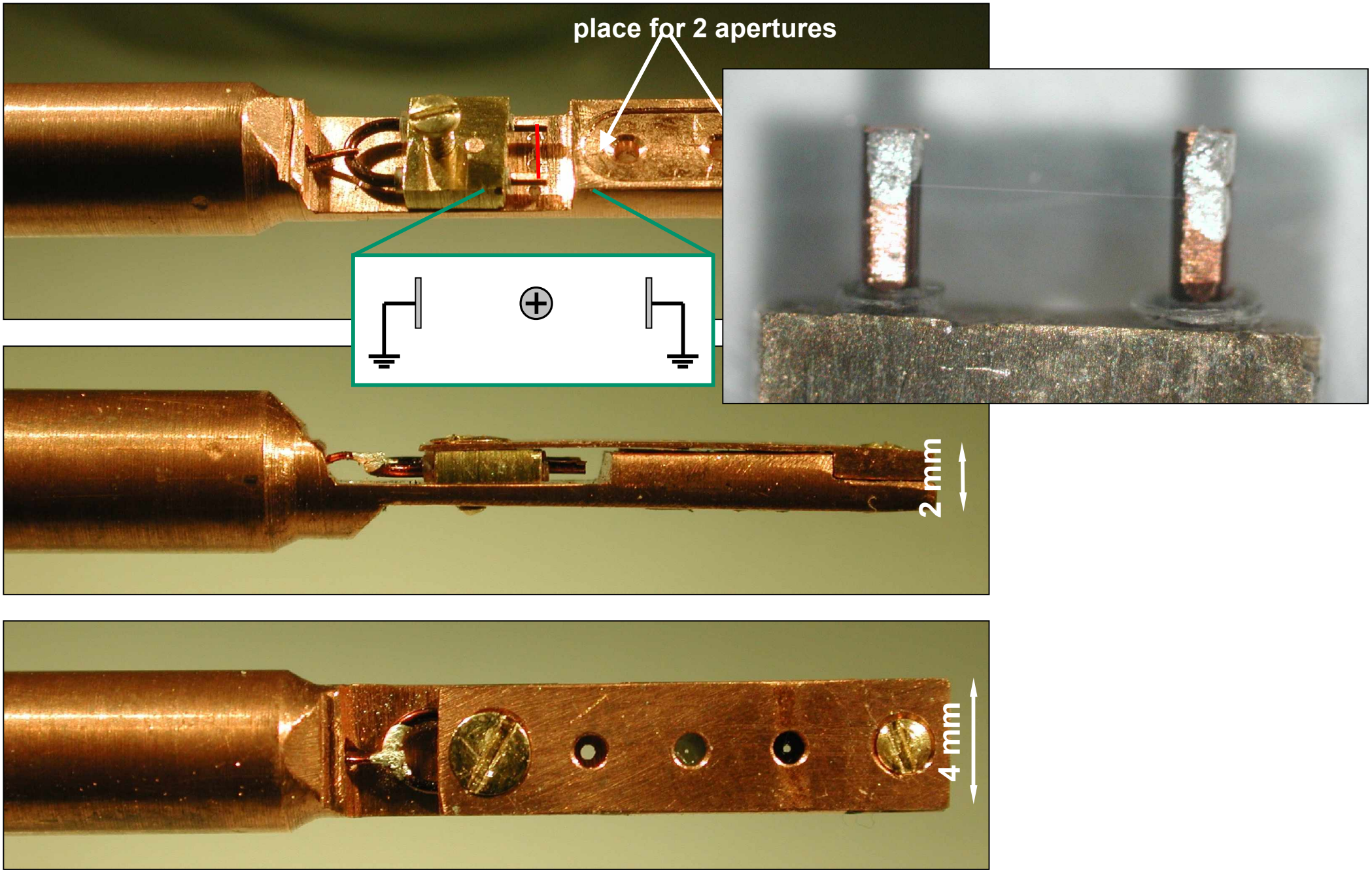
C2 Aperture holder



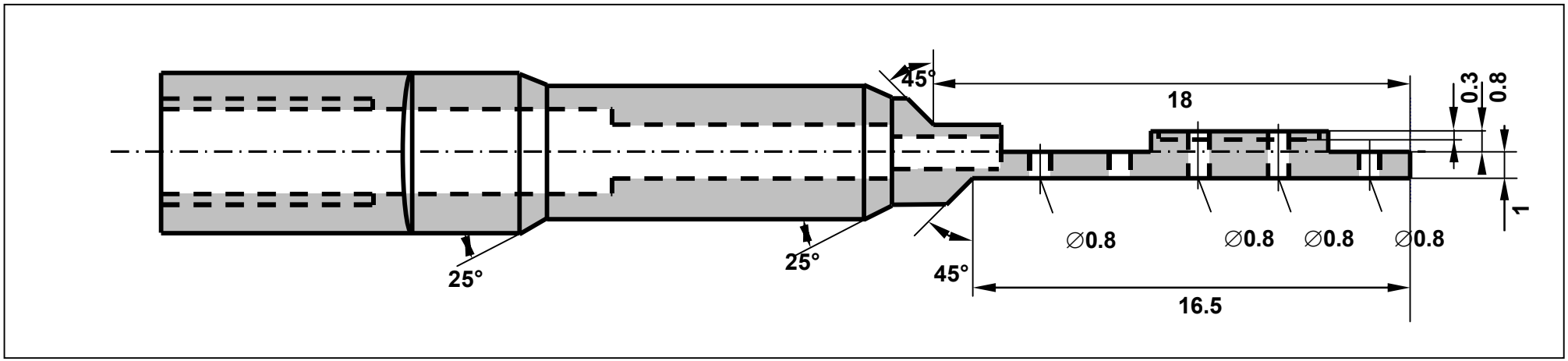
“Standard”
Triebenberg
biprism holder

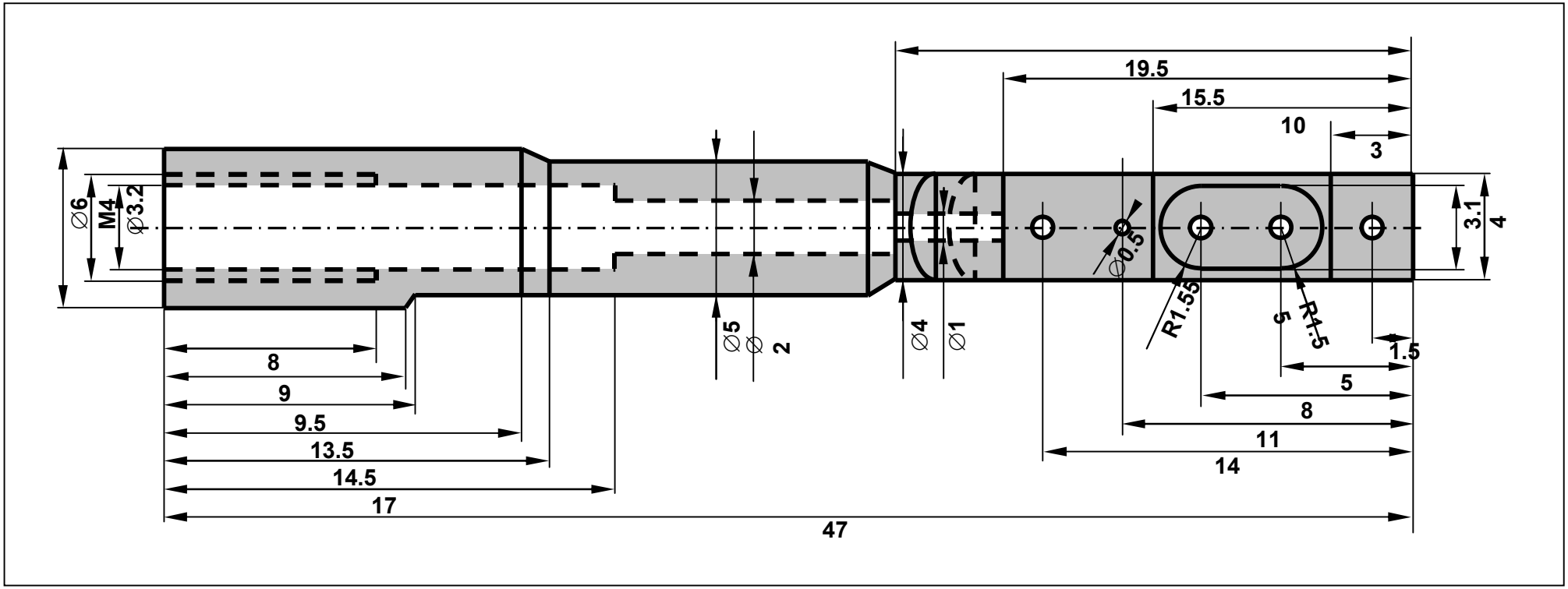
Standard
FEI
biprism holder

New Biprism Holder Construction



New Birpism Holder Construction – Technical Drawing

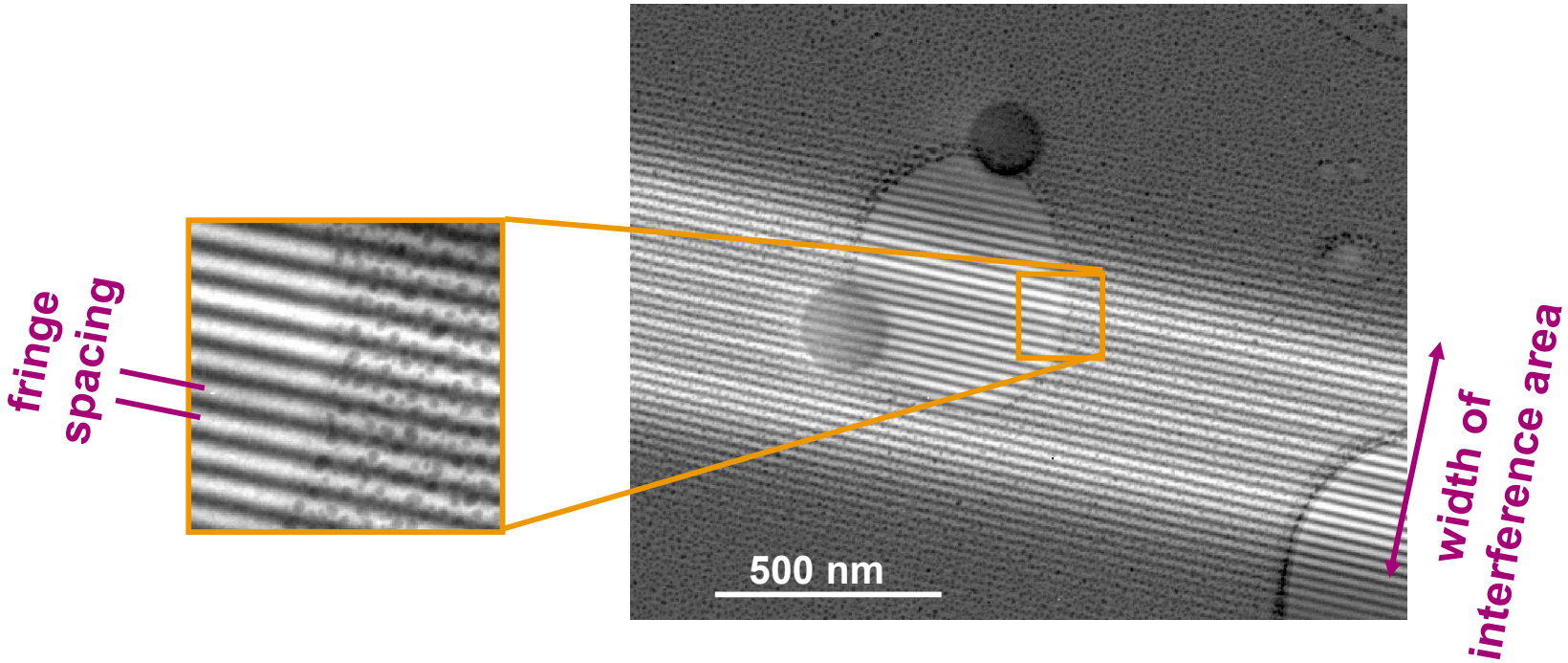




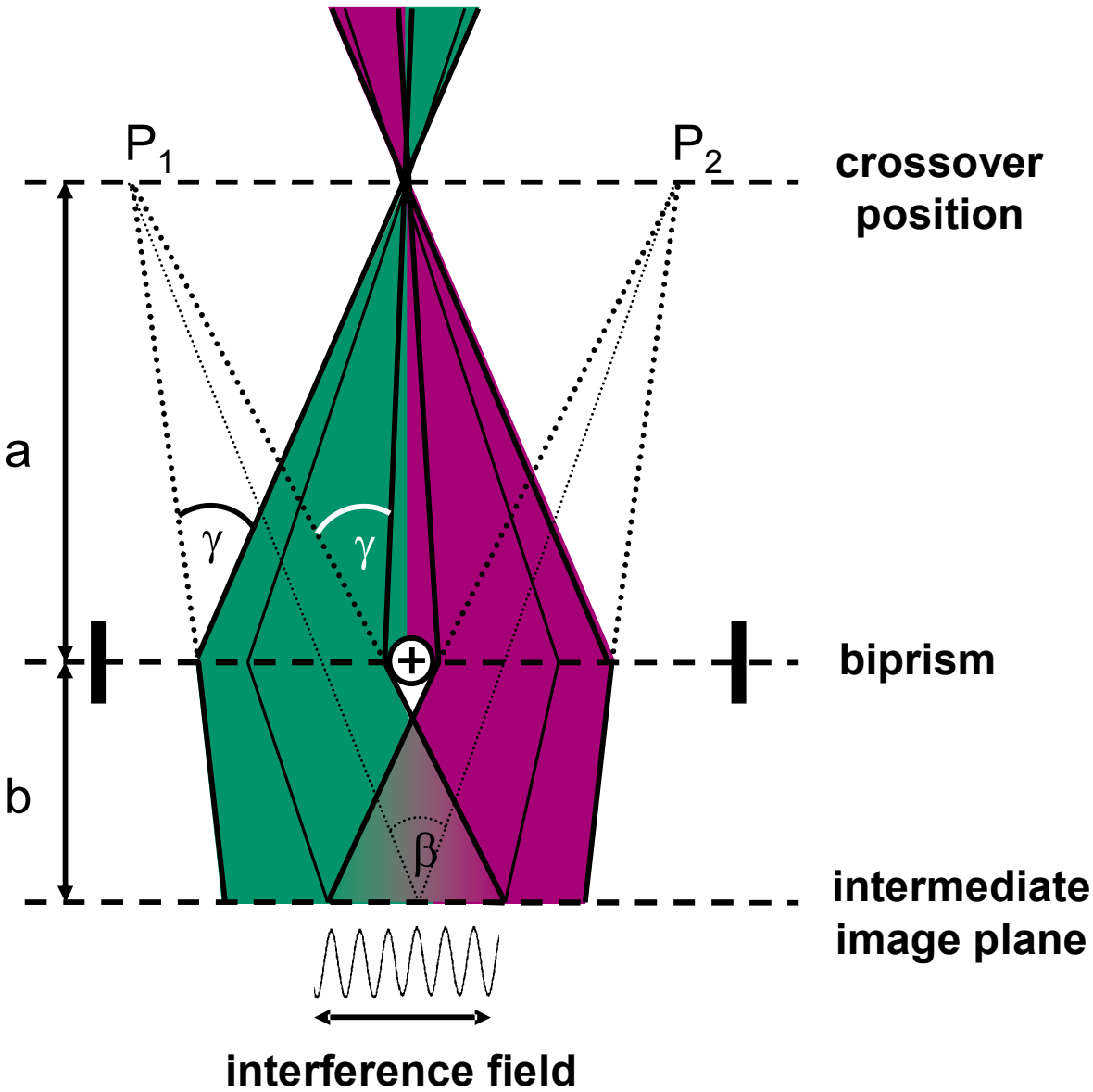
Biprism holder

Controlling the fringe spacing and interference width

Optimisation



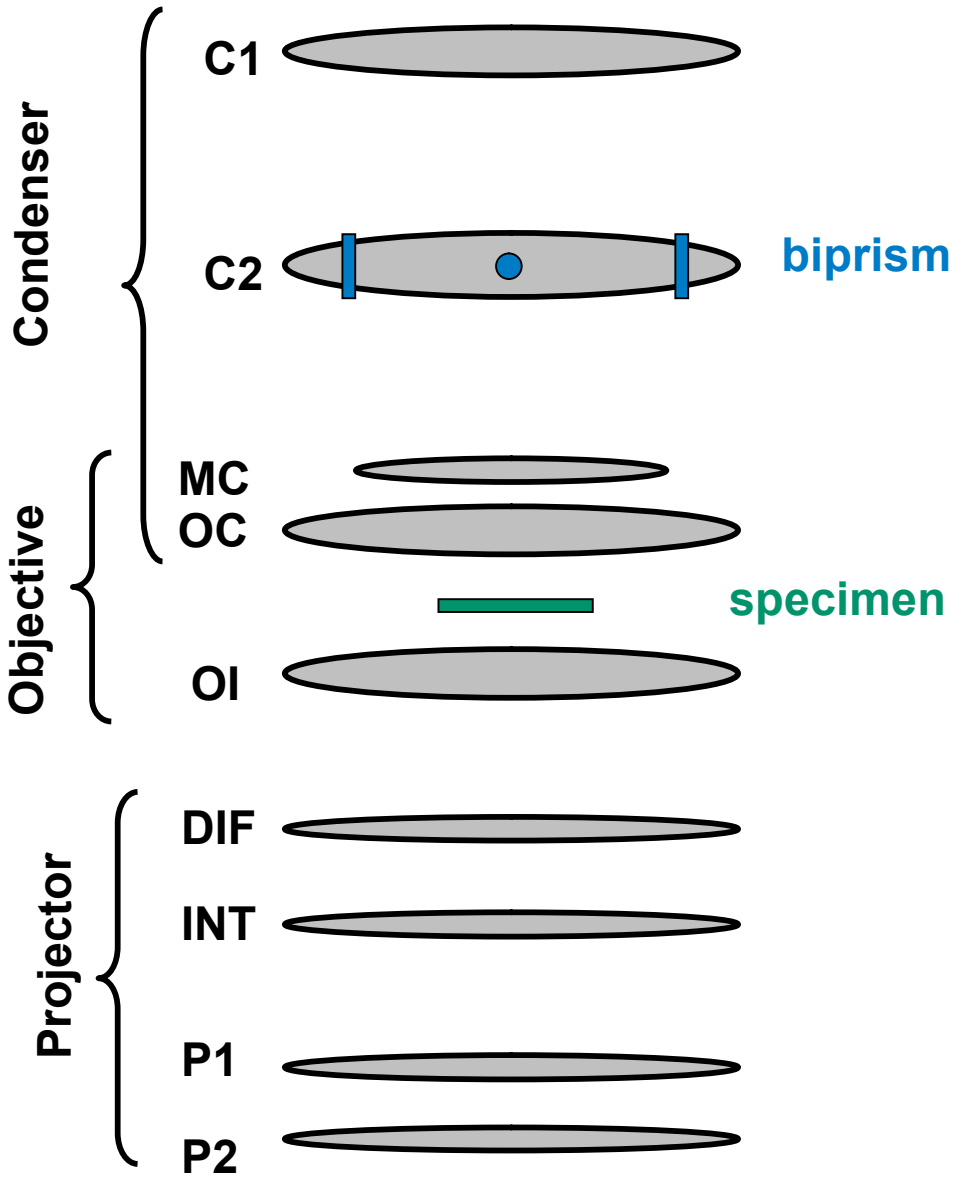
Electron Biprism - Control of Parameters



- **Width of interference field**
  $W = 2b\gamma_0 U_{bp} - 2r_f(b+a)/a$
- **Fringe spacing**
  $S = \lambda(a+b)/(2a\gamma_0 U_{bp})$
- **Deflection angle**
  $\gamma = \gamma_0 U_{bp}$

U_{bp} … biprism voltage
λ … wavelength of electron waves
$\gamma_0 = 3\times10^{-7}$ rad/V

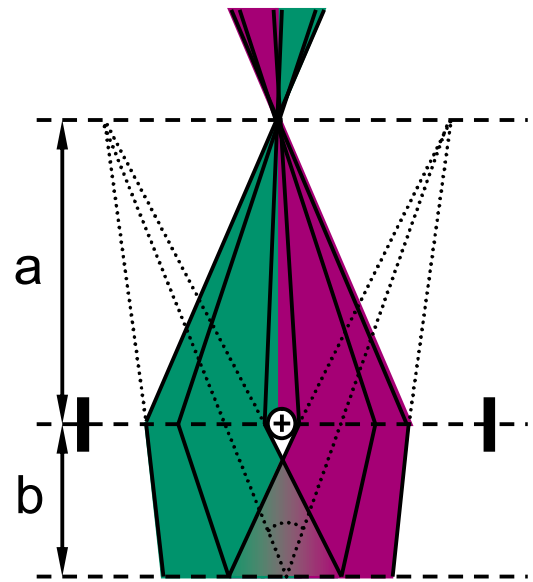
Optical System of CM200 Microscope



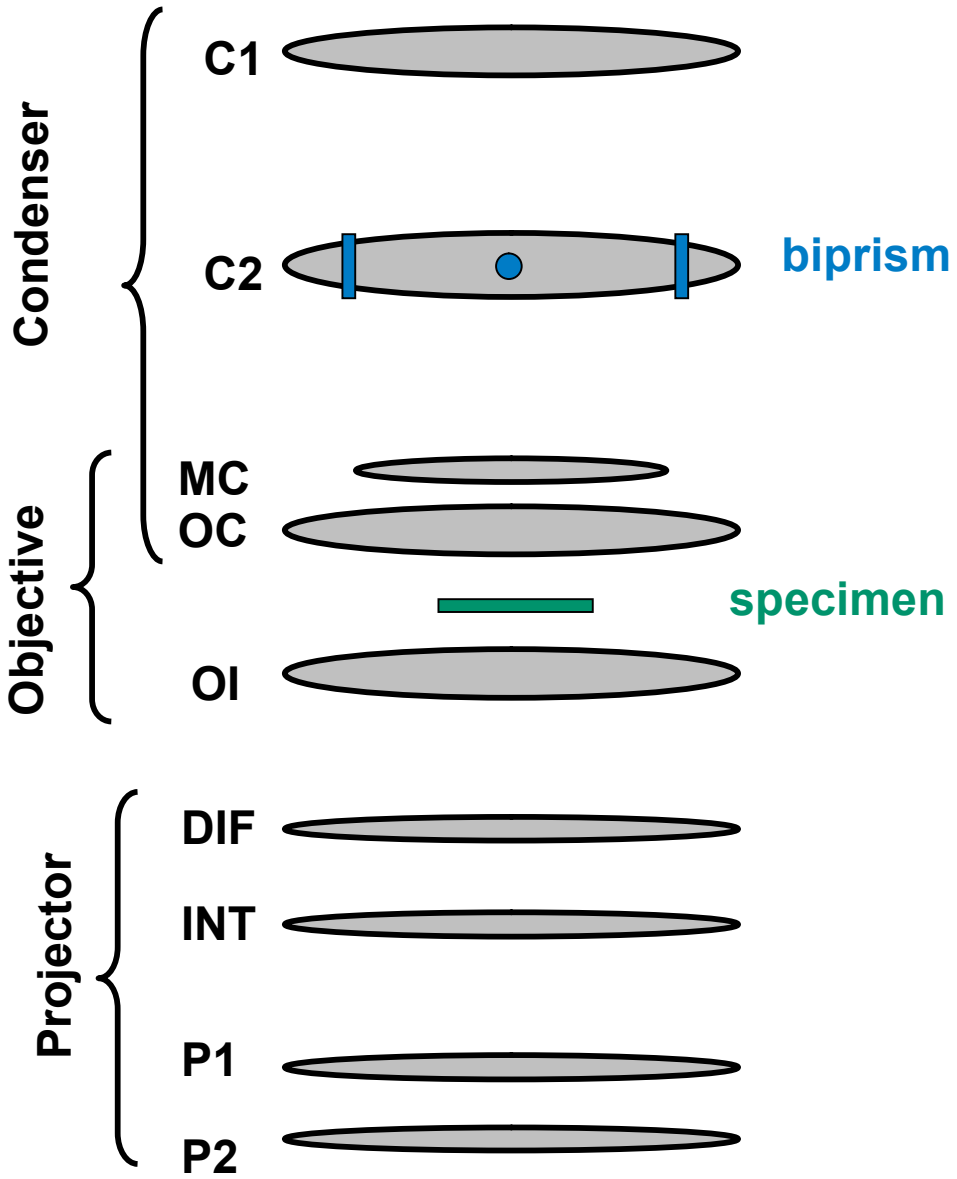
- **Problems**
  Biprism inside the lens
  Coupling of condenser & objective

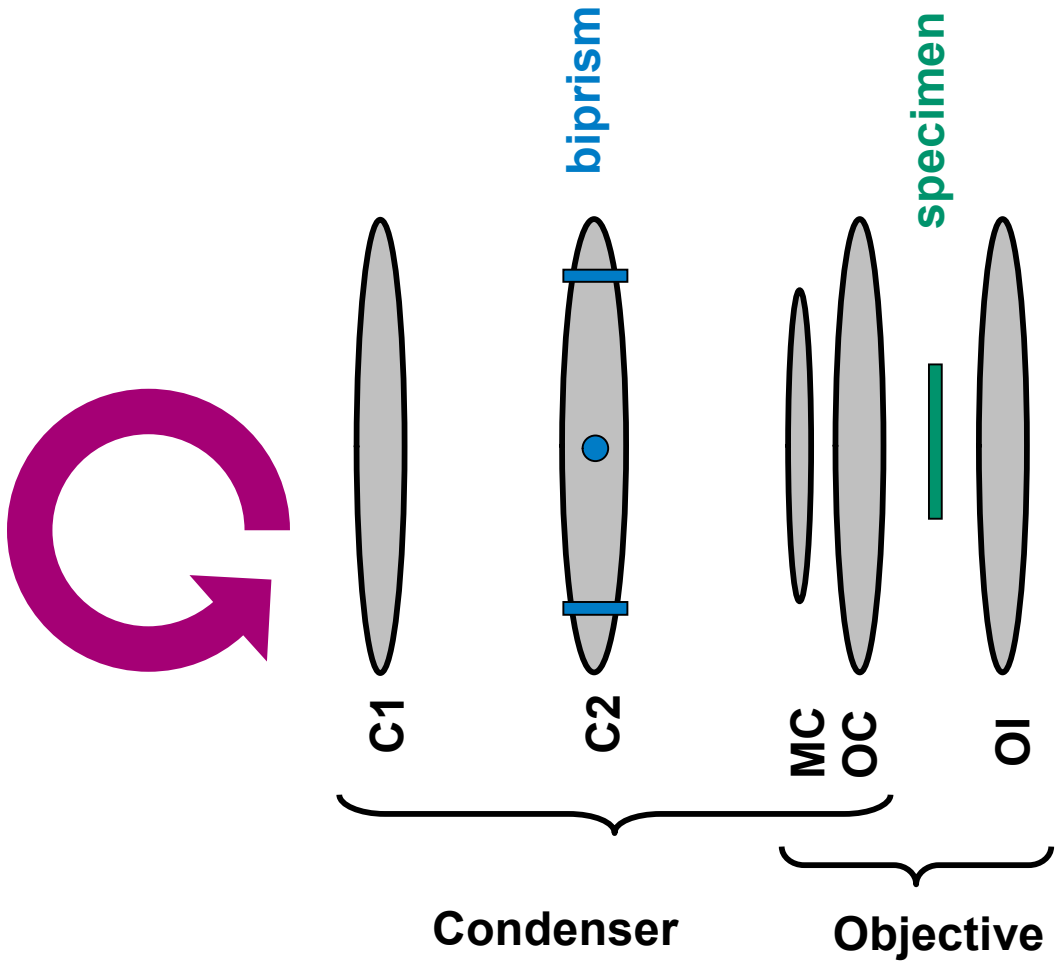
- **Control of parameter a**
  C1, C2 excitation
  Gun lens, extractor voltage

- **Control of parameter b**
  MC, OC excitation

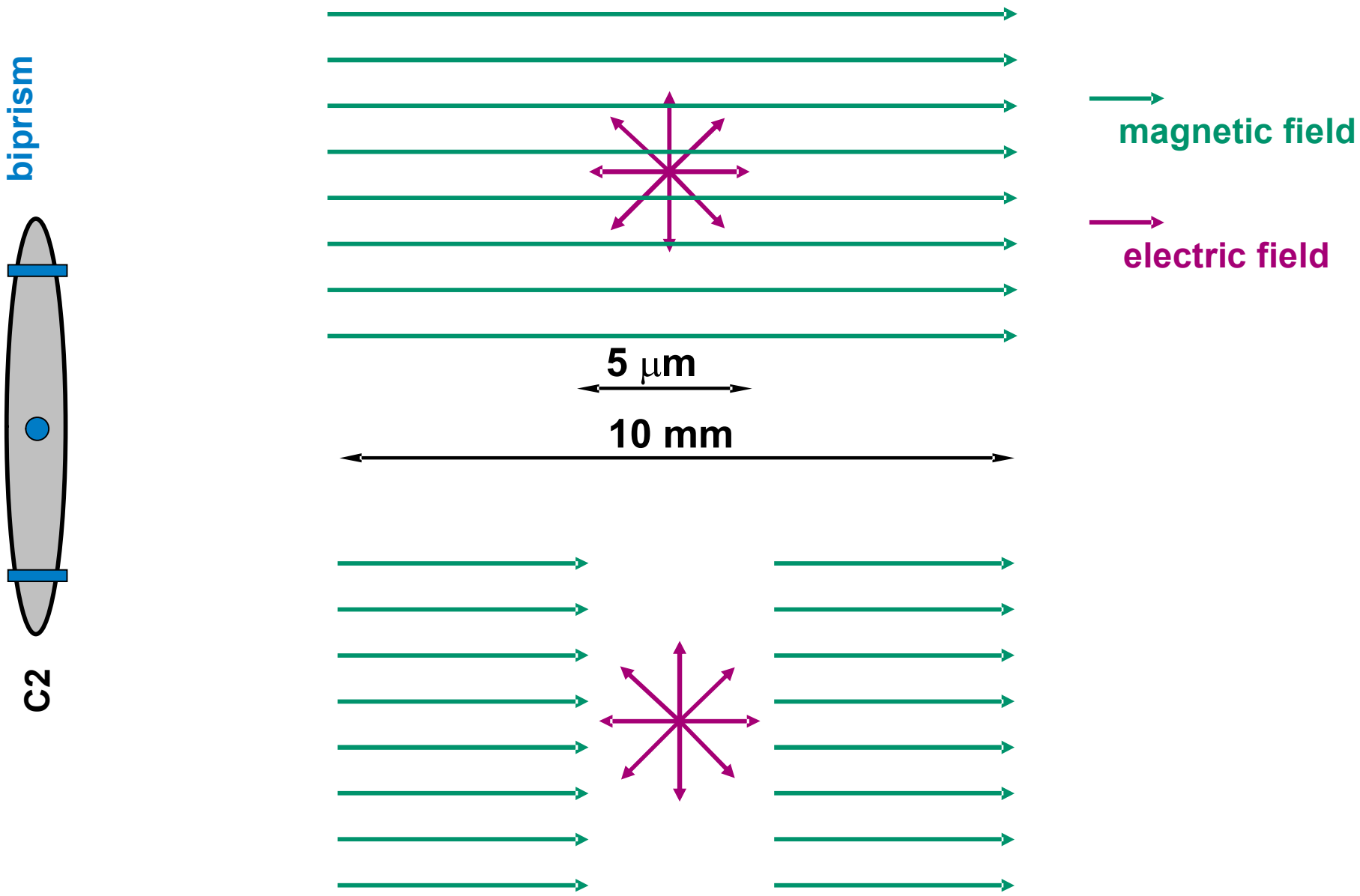


Rotating the Coordinate System



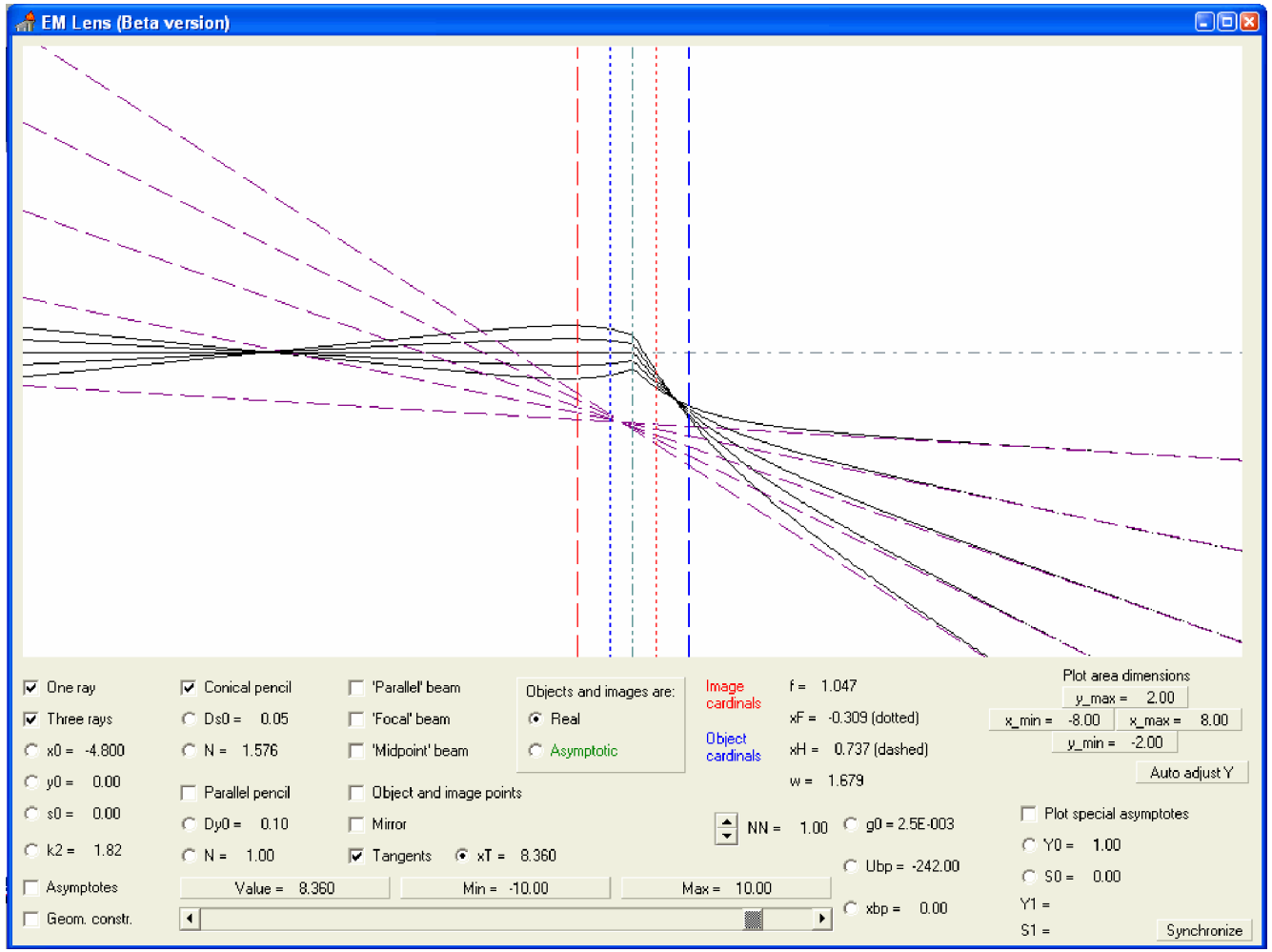


Thin Biprism Approximation



Biprism in the C2 Lens - An Equivalent Model

Program for plotting of beams in a Glaser-field lens



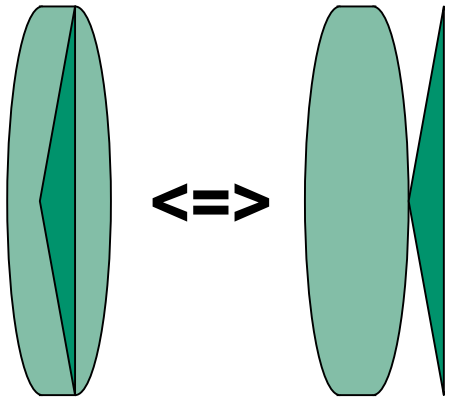
Approximation of a thin biprism =>

Analytical calculation:

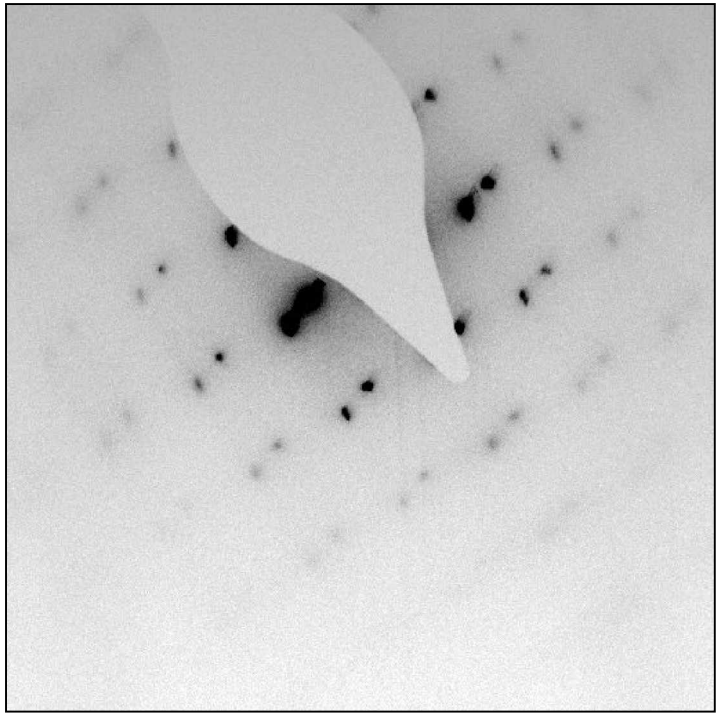
Biprism in a lens

is *optically equivalent* to

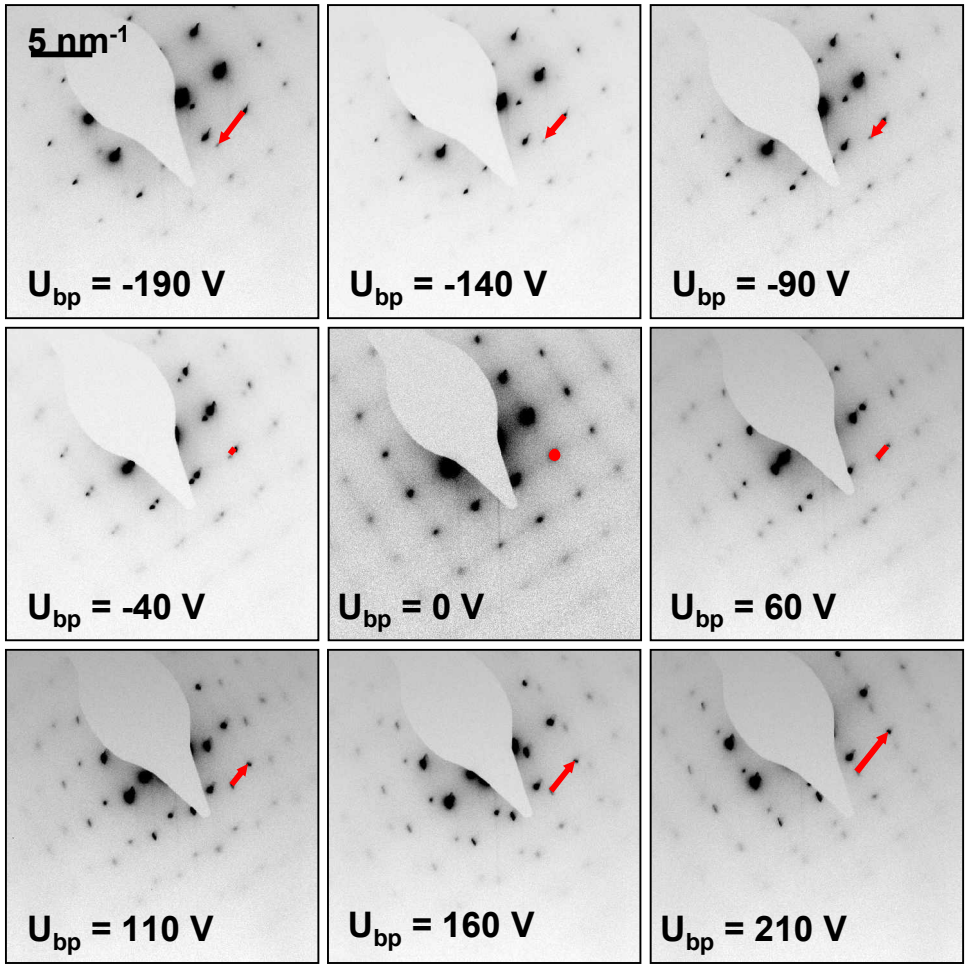
biprism behind the lens



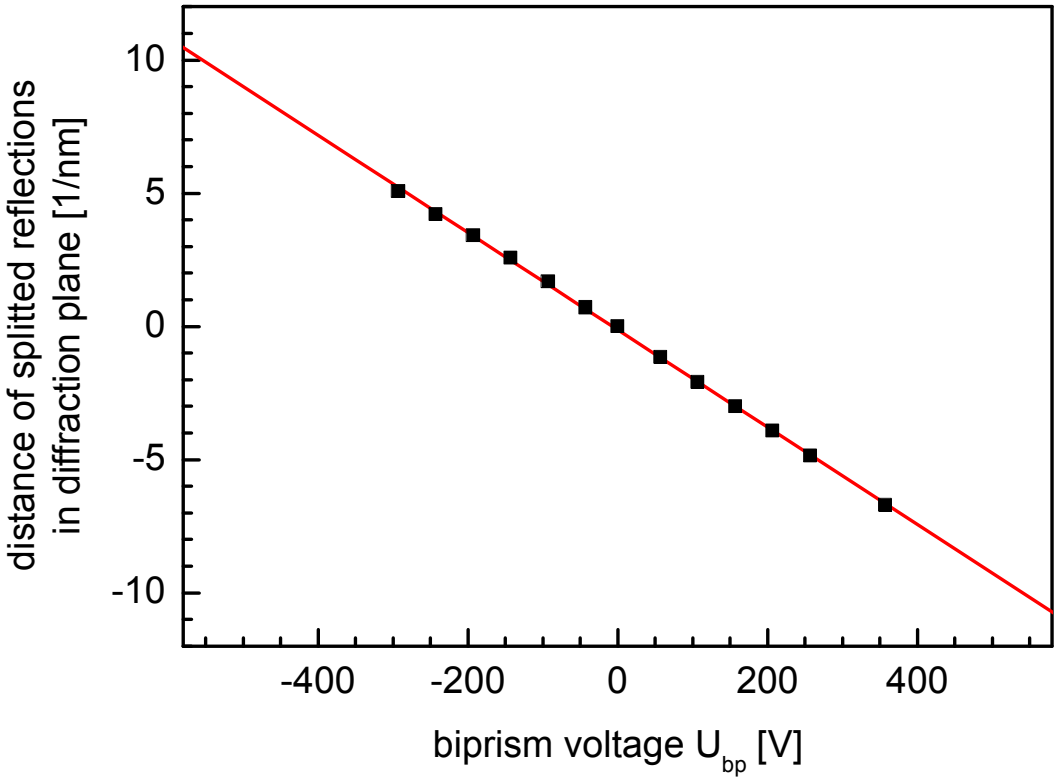
Diffraction Mode



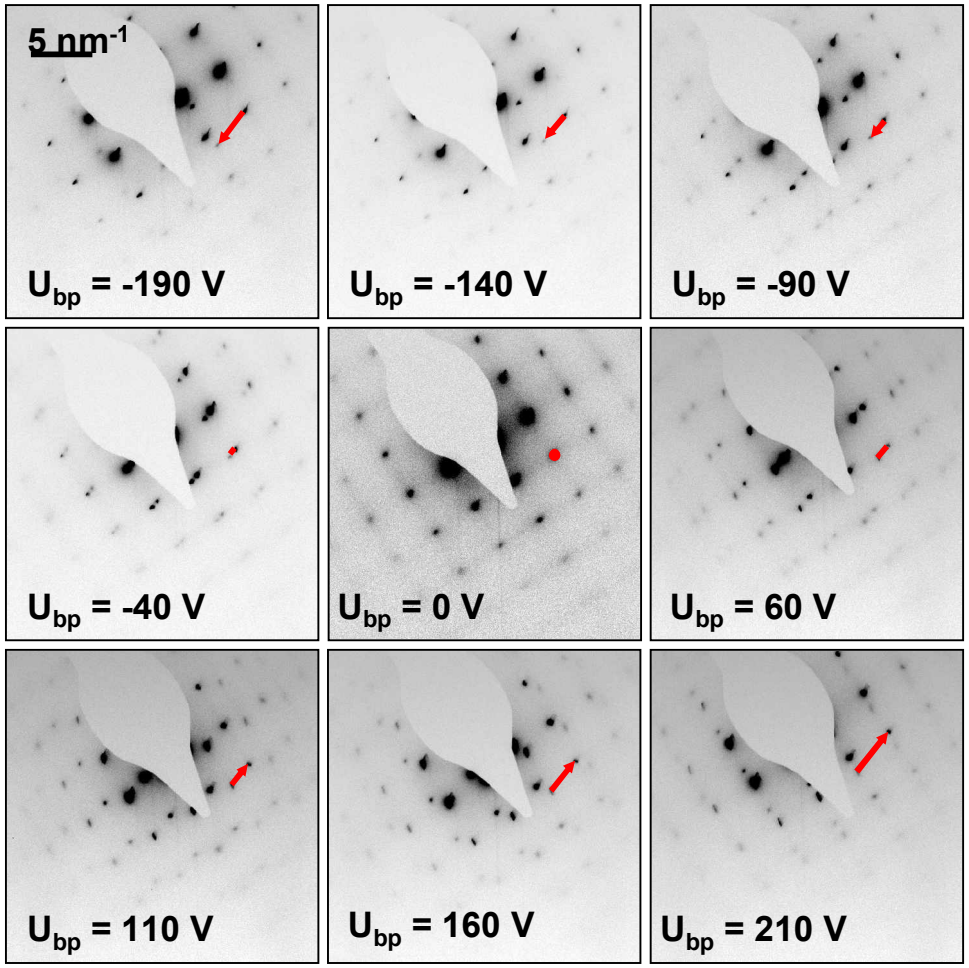
Diffraction pattern of <001> silicon



Diffraction Mode



Diffraction pattern of <001> silicon



Deflection angle

$\gamma \sim U_{bp}$

In diffraction plane

$\Delta k = 0.018\ nm^{-1}/V\ U_{bp}$

Imaging Mode - Biprism Diagram

Width of interference field

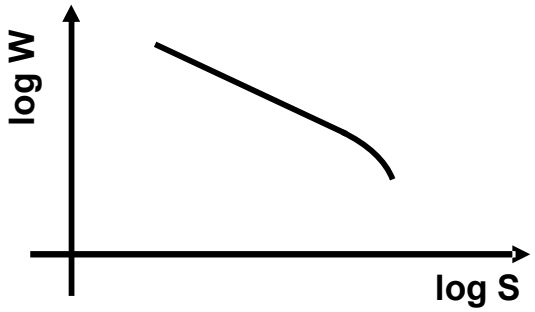
$W = A\,U_{bp} - B$

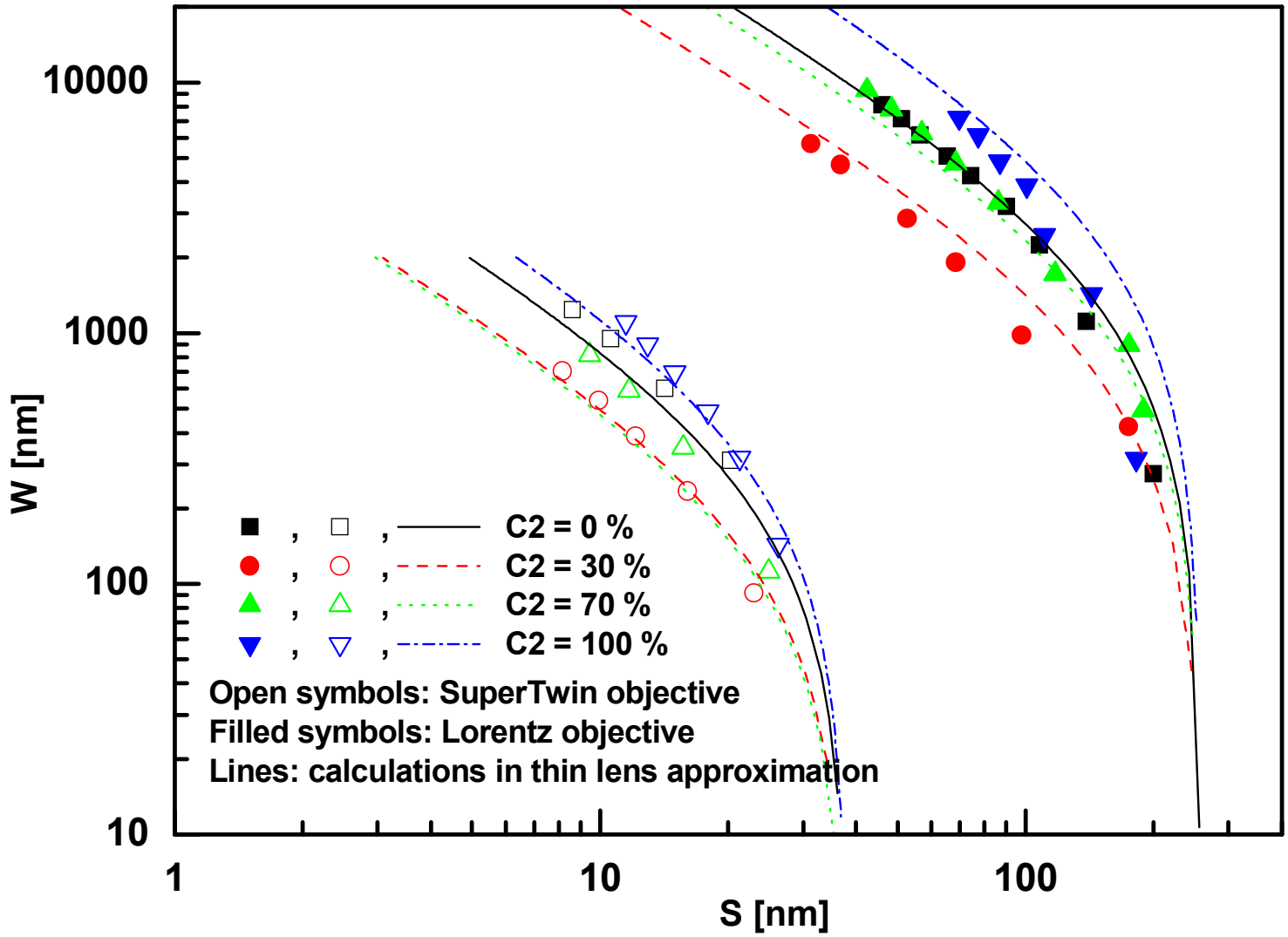
Fringe spacing

$S = C/U_{bp}$

B = 0:

$W = CA/S$



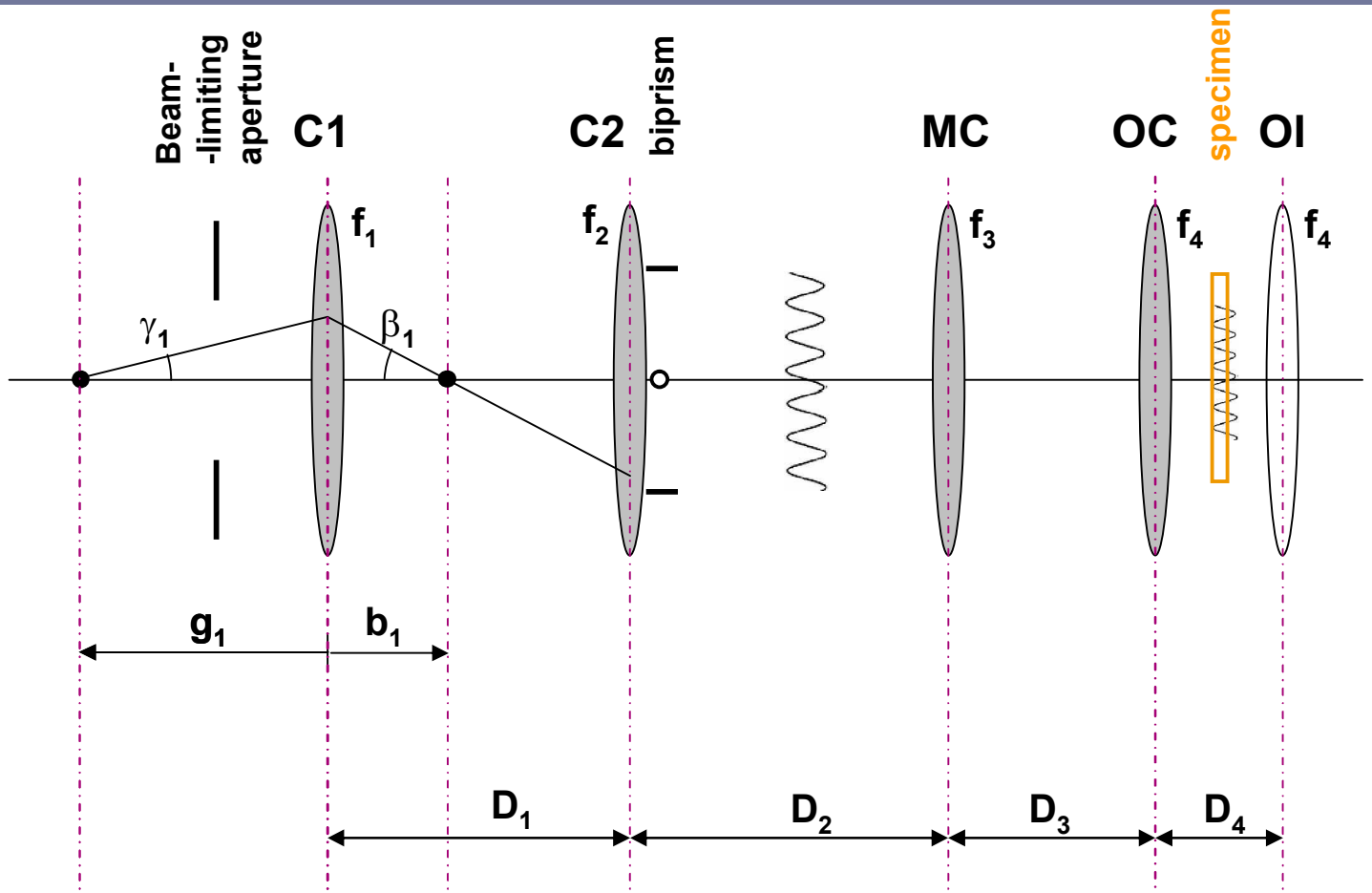


Biprism holder

Controlling the fringe spacing and interference width

Optimisation

Optical System of the Condenser (FEI CM200)



Imaging equation

$1/f = 1/g + 1/b$

Magnification

$M = 1 - b/f$

Angular magnification

$\beta/\gamma = 1 - g/f$

Free parameters

Lens focal distances: f_1, f_2, f_3, f_4

Biprism voltage: U_{bp}

Position of the first crossover: g_1

Imaging conditions

Fringe spacing of a certain value

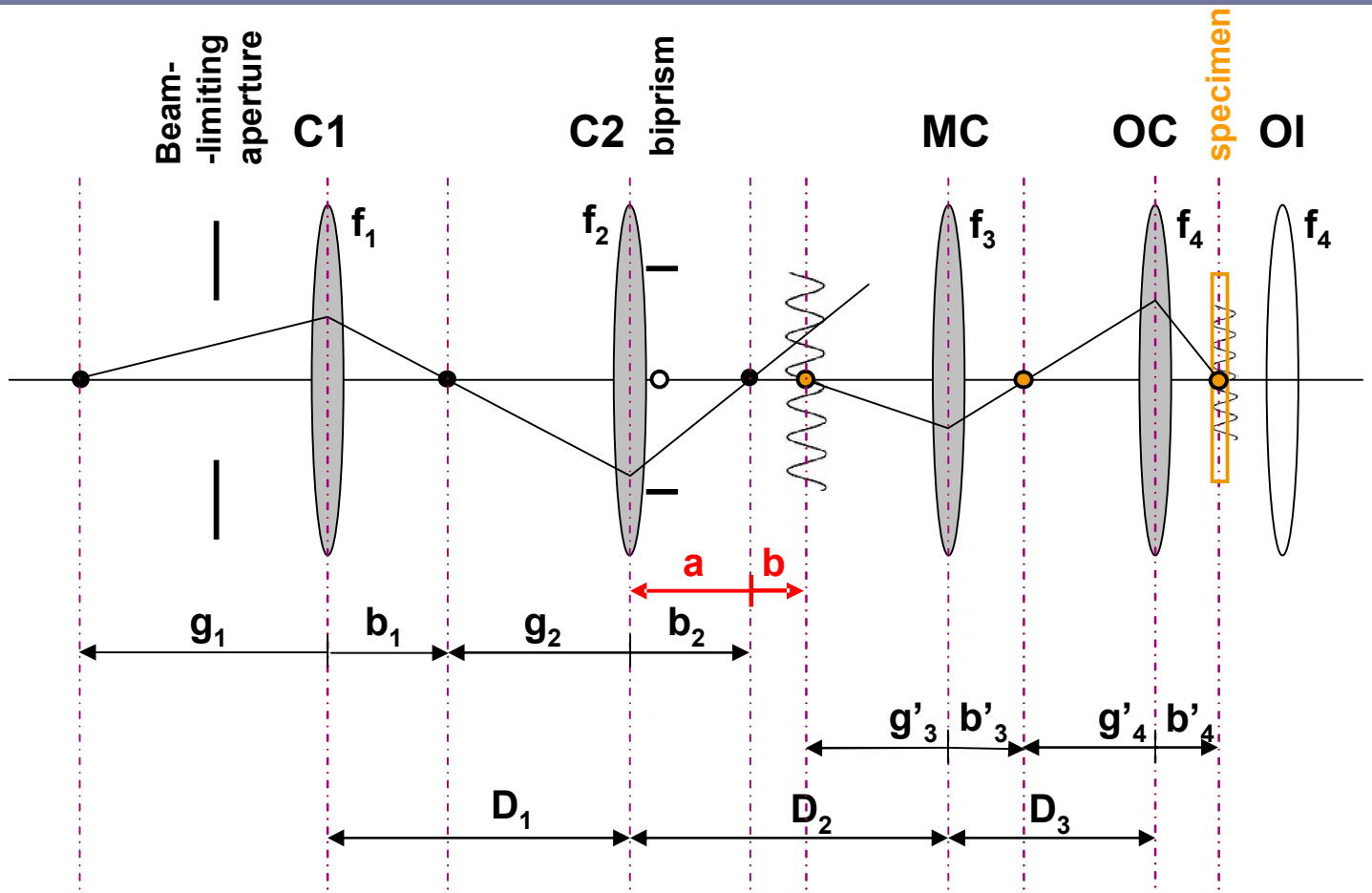
Certain number of fringes

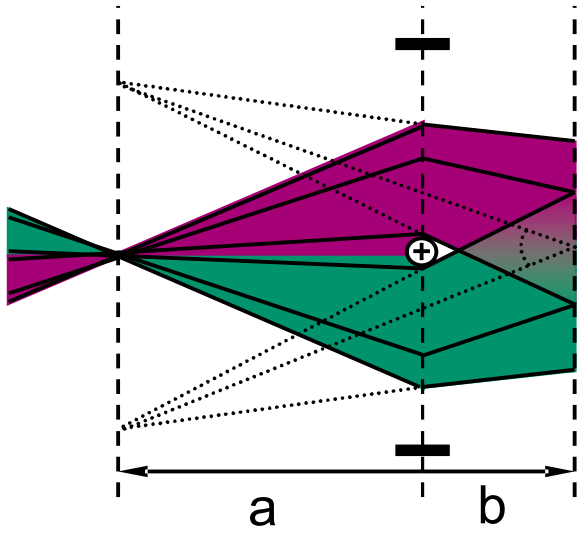
Parallel illumination of the specimen

Maximum intensity at the specimen

Certain minimal magnetic field at the specimen

Condition for the Fringe Spacing





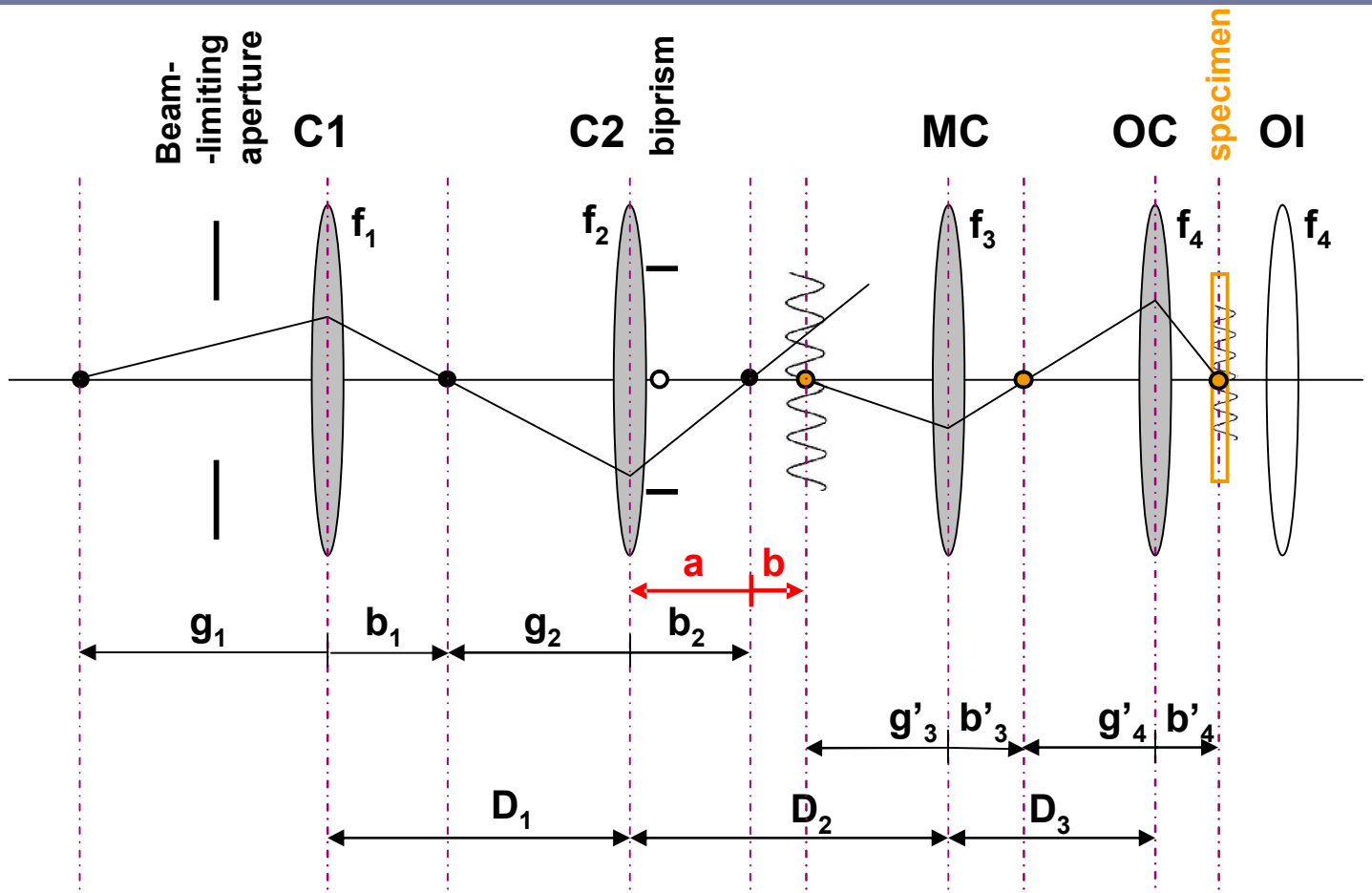
$$S = \lambda \frac{a+b}{2\alpha\gamma_0 U_{bp}}$$

$$s = S\left(1 - \frac{b_4' + D_3}{f_3} - \frac{b_4'}{f_4} + \frac{D_3 b_4'}{f_3 f_4}\right)$$

$$b = D_2 - \frac{f_3 D_3 b_4' - f_3 f_4 (D_3 + b_4')}{f_3 b_4' + (D_3 + b_4') f_4 - f_3 f_4 - D_3 b_4'}$$

$$a = -\frac{-D_1 g_1 f_2 + (D_1 + g_1) f_1 f_2}{f_1 (D_1 + g_1) + f_2 g_1 + f_1 f_2 - D_1 g_1}$$

Condition for the Number of Fringes



NS = W

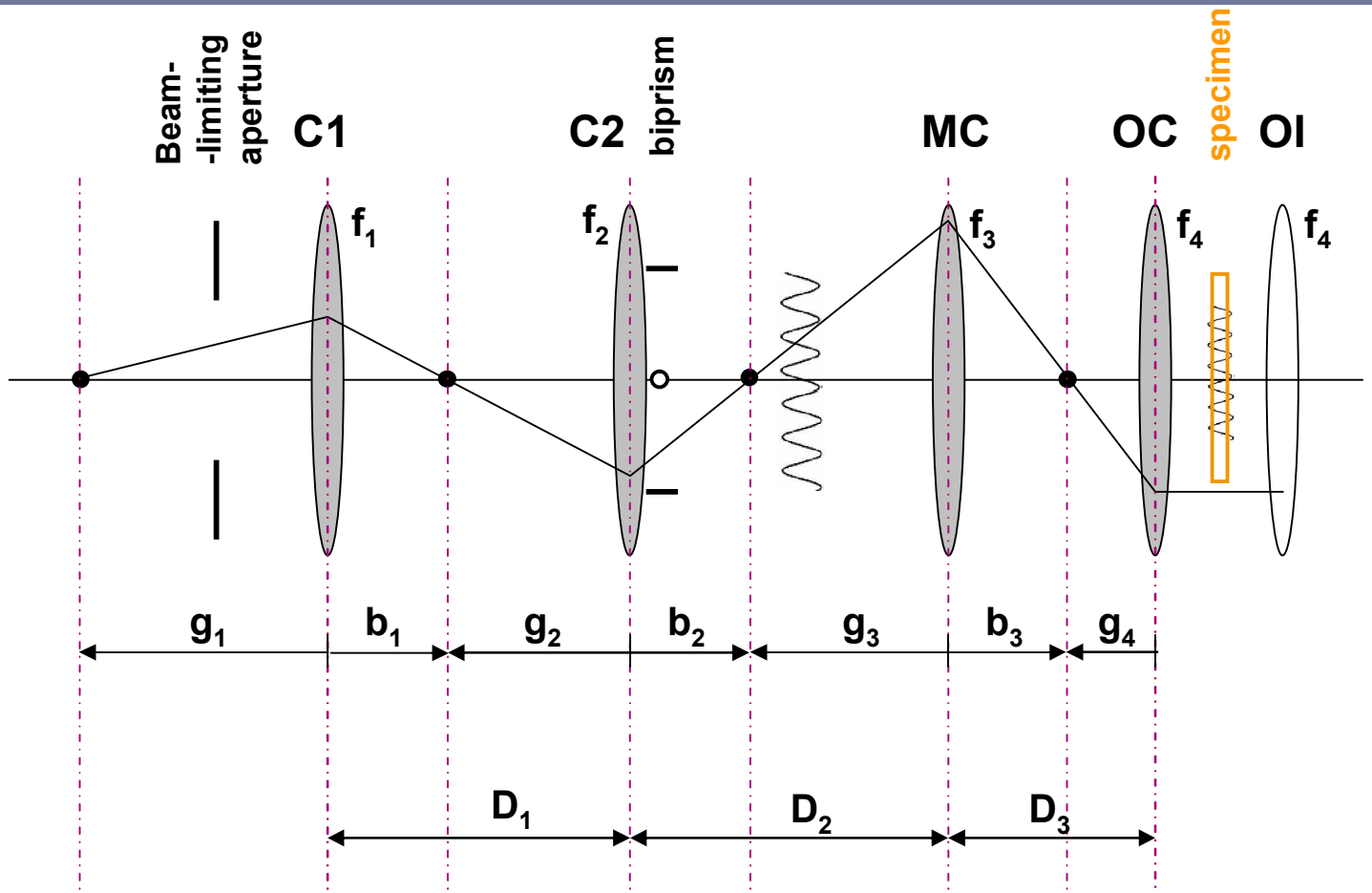
N … number of fringes

$$N\lambda(a+b) = 4ab\gamma_0^2 U_{bp}^2 - 4\gamma_0 U_{bp} r_f (a+b)$$

$$b = D_2 - \frac{f_3 D_3 b_4' - f_3 f_4 (D_3 + b_4')}{f_3 b_4' + (D_3 + b_4') f_4 - f_3 f_4 - D_3 b_4'}$$

$$a = -\frac{-D_1 g_1 f_2 + (D_1 + g_1) f_1 f_2}{f_1 (D_1 + g_1) + f_2 g_1 + f_1 f_2 - D_1 g_1}$$

Condition for the Parallel Illumination

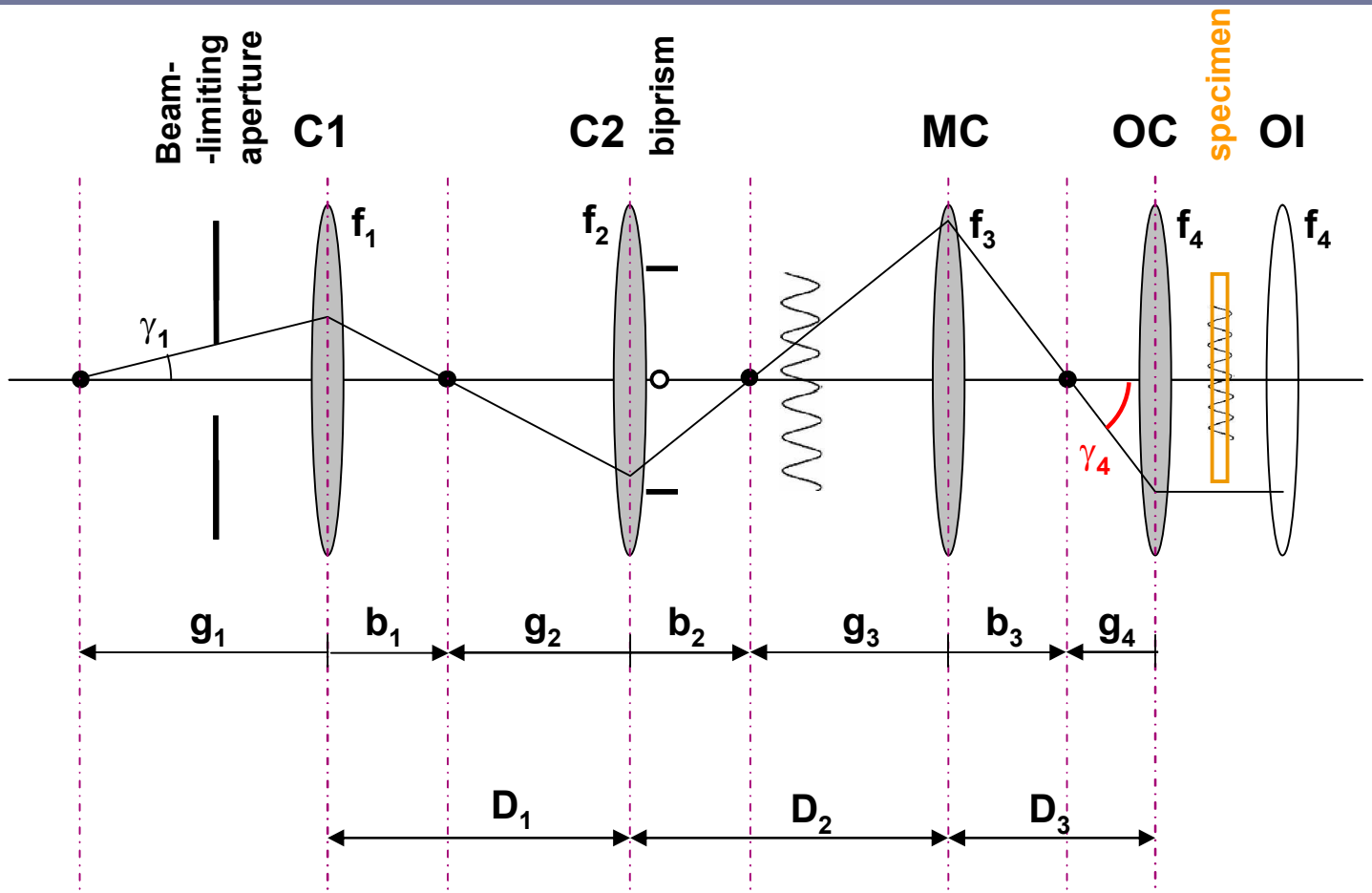


$g_4 = f_4$

$$\frac{(D_3 - f_4) f_3}{D_3 - f_4 - f_3} - a = D_2$$

$$a = -\frac{-D_1 g_1 f_2 + (D_1 + g_1) f_1 f_2}{f_1 (D_1 + g_1) + f_2 g_1 + f_1 f_2 - D_1 g_1}$$

Condition for the Intensity at the Specimen



γ_4 => minimum

$$\gamma_4 = \gamma_1 \left(1 - \frac{g_1}{f_1}\right)\left(1 - \frac{D_1}{f_2} + \frac{f_1}{f_2}\frac{g_1}{f_1 - g_1}\right)\left(1 - \frac{D_2 + a}{f_3}\right)$$

$$a = -\frac{-D_1 g_1 f_2 + (D_1 + g_1) f_1 f_2}{f_1 (D_1 + g_1) + f_2 g_1 + f_1 f_2 - D_1 g_1}$$

Summary of All Conditions

$$s_0 = \lambda \frac{a+b}{2a\gamma_0 U_{bp}} \left(1 - \frac{b_4' + D_3}{f_3} - \frac{b_4'}{f_4} + \frac{D_3 b_4'}{f_3 f_4} \right)$$

Desired fringe spacing s_0

$$N\lambda(a+b) = 4ab\gamma_0^2 U_{bp}^2 - 4\gamma_0 U_{bp} r_f (a+b)$$

Desired number of fringes N

$$\frac{(D_3 - f_4) f_3}{D_3 - f_4 - f_3} - a = D_2$$

Parallel illumination

$$\gamma_1 \left(1 - \frac{g_1}{f_1} \right) \left(1 - \frac{D_1}{f_2} + \frac{f_1}{f_2} \frac{g_1}{f_1 - g_1} \right) \left(1 - \frac{D_2 + a}{f_3} \right) \rightarrow \min$$

Maximum intensity

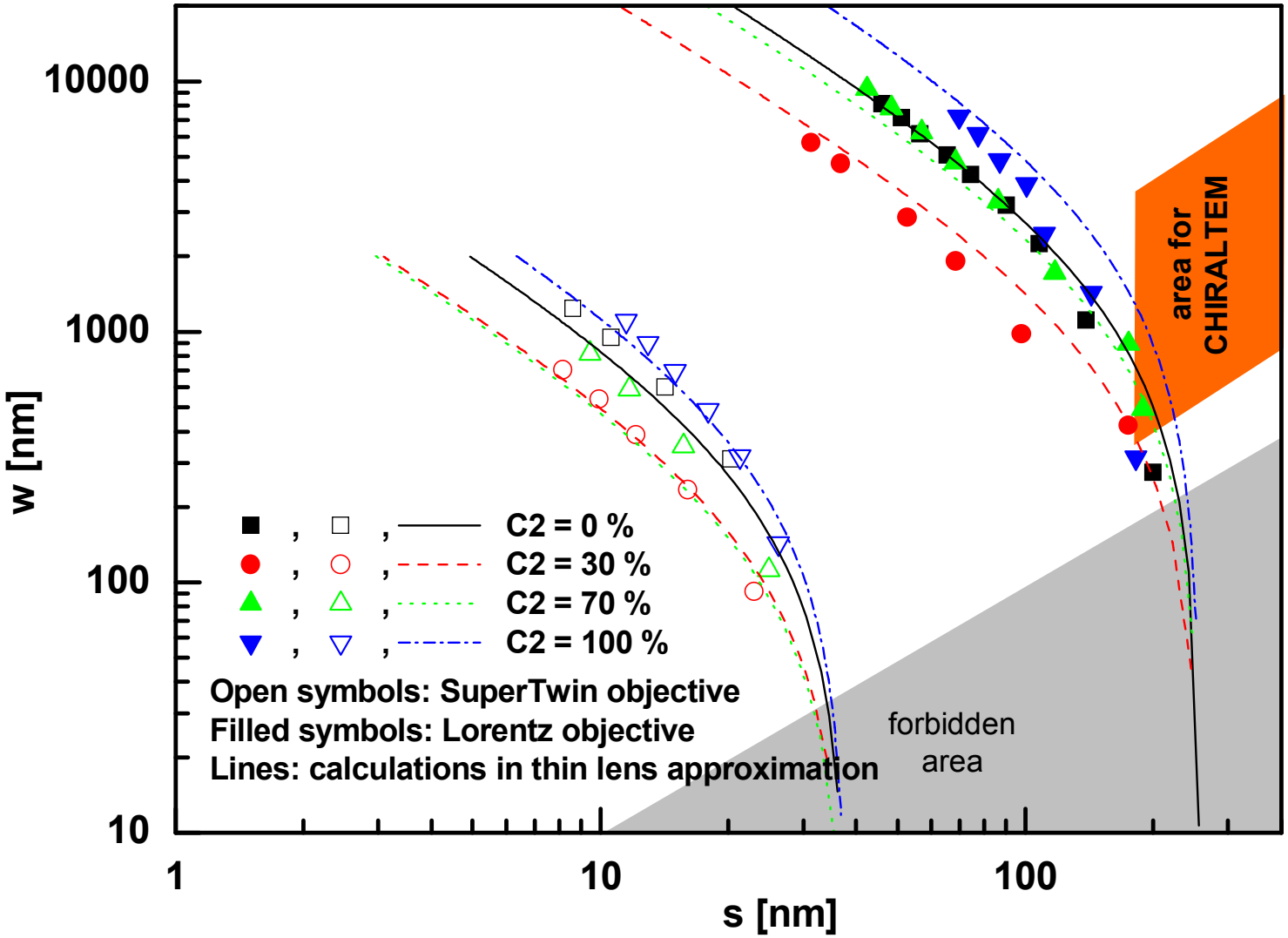
$$f_4 < f_{4,\lim}$$

Limit of the magnetic field

$$a = -\frac{-D_1 g_1 f_2 + (D_1 + g_1) f_1 f_2}{f_1 (D_1 + g_1) + f_2 g_1 + f_1 f_2 - D_1 g_1}$$

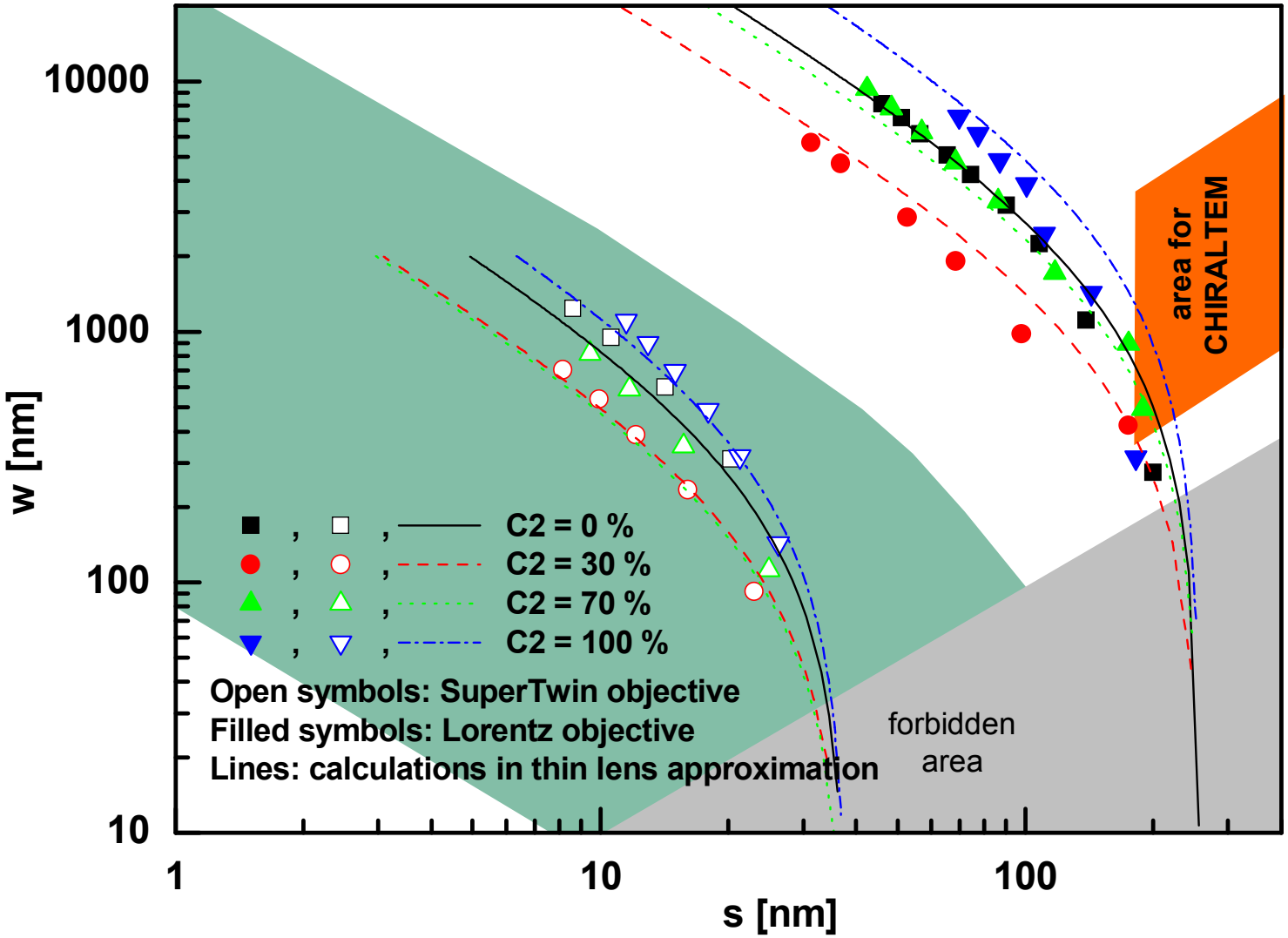
$$b = D_2 - \frac{f_3 D_3 b_4' - f_3 f_4 (D_3 + b_4')}{f_3 b_4' + (D_3 + b_4') f_4 - f_3 f_4 - D_3 b_4'}$$

Possible W-S values: Brute Force Method



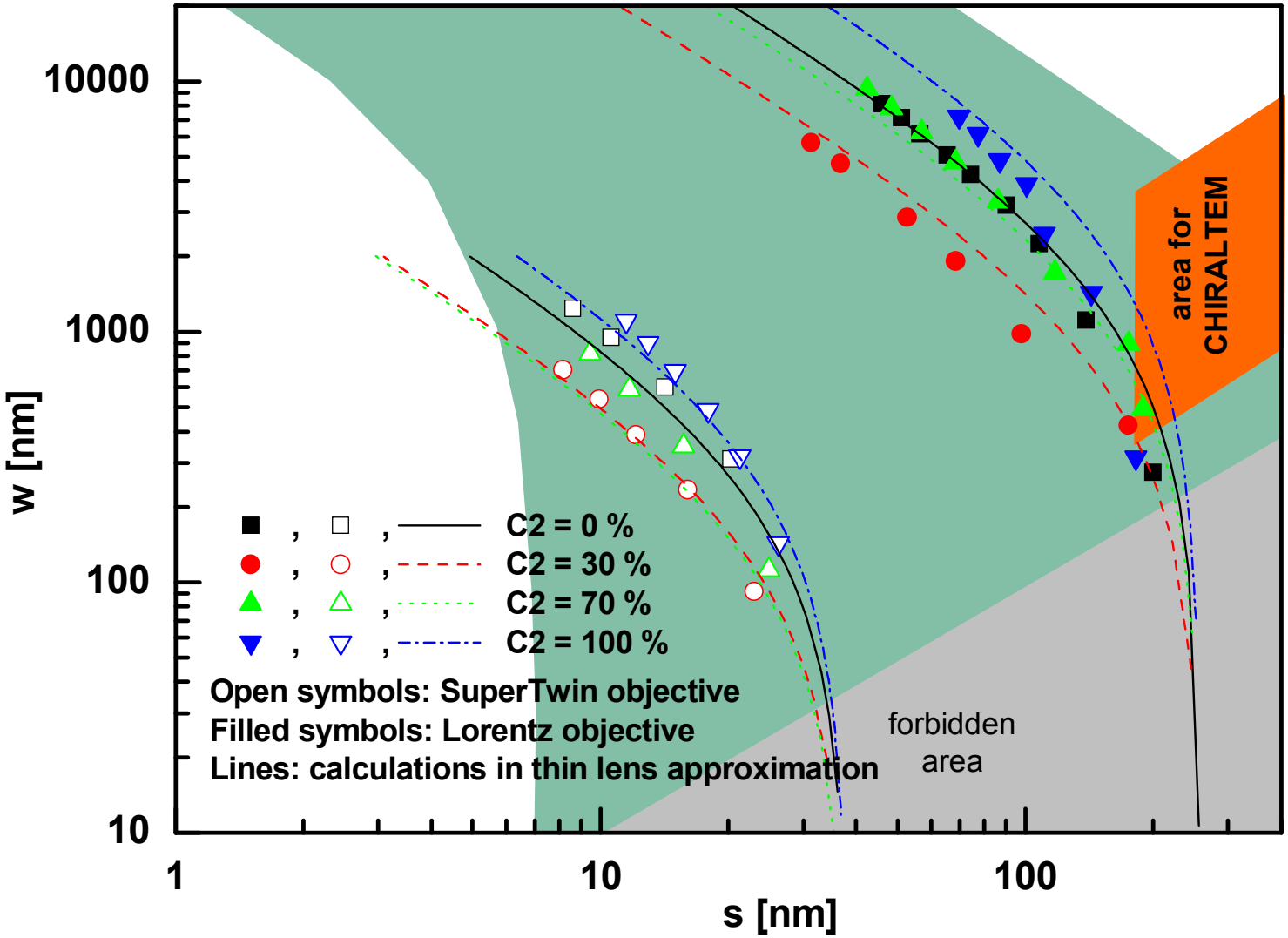
Possible W-S values: Brute Force Method

Standard objective lens (SuperTwin)



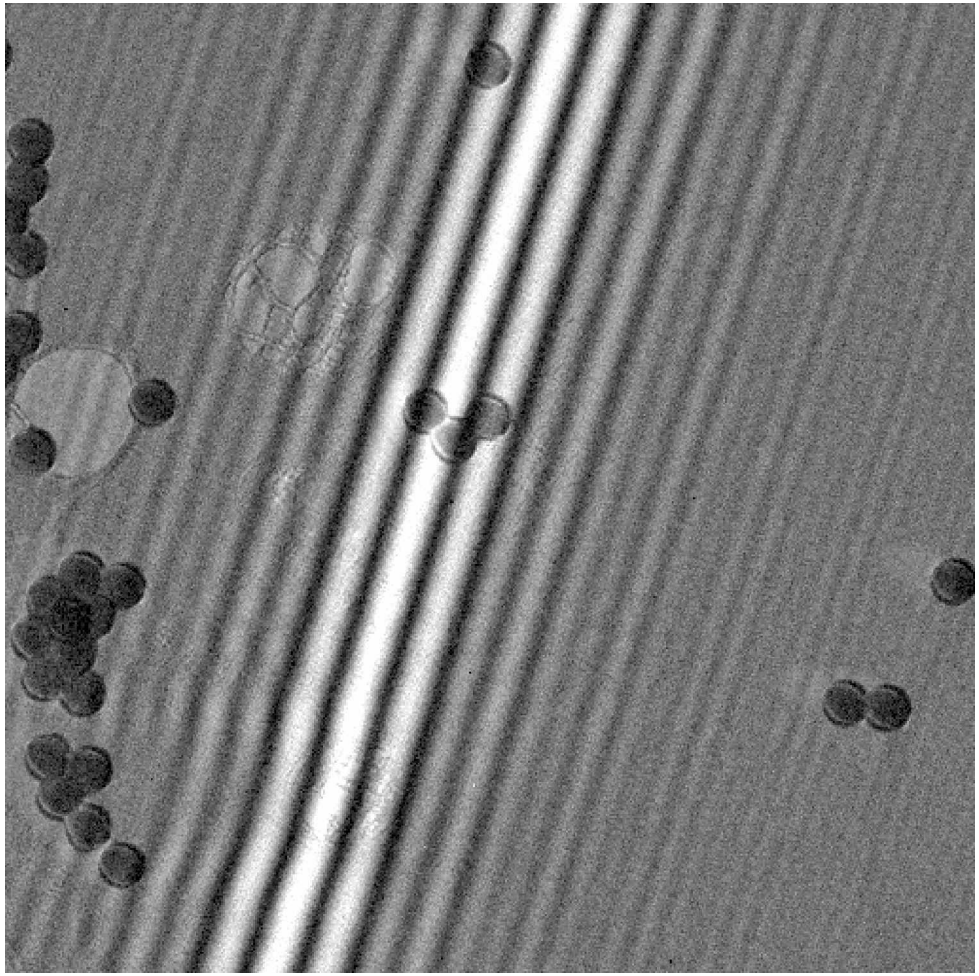
Possible W-S values: Brute Force Method

Lorentz objective lens



Summary

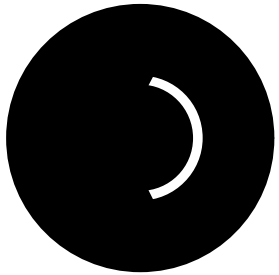
Desired fringe spacing of 200 nm reached with objective lens switched off

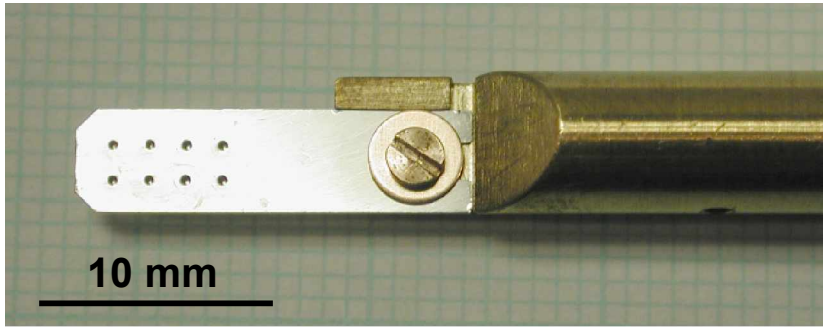


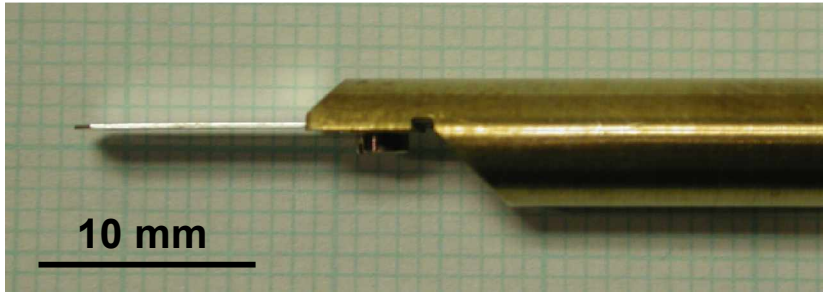
Outlook

Optimise hardware to increase intensity

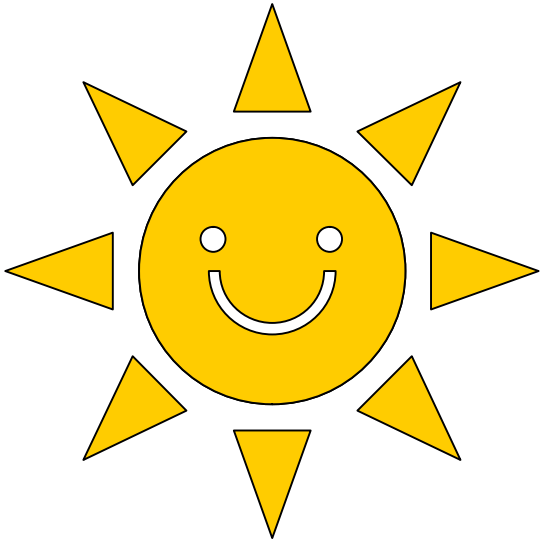
Croissant-shape contrast aperture in rotatable holder







Grid-shape SA aperture



Acknowledgement

Dr. Peter Tiemeijer, FEI Company,
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