EPFL

Diffraction and Imaging part IV

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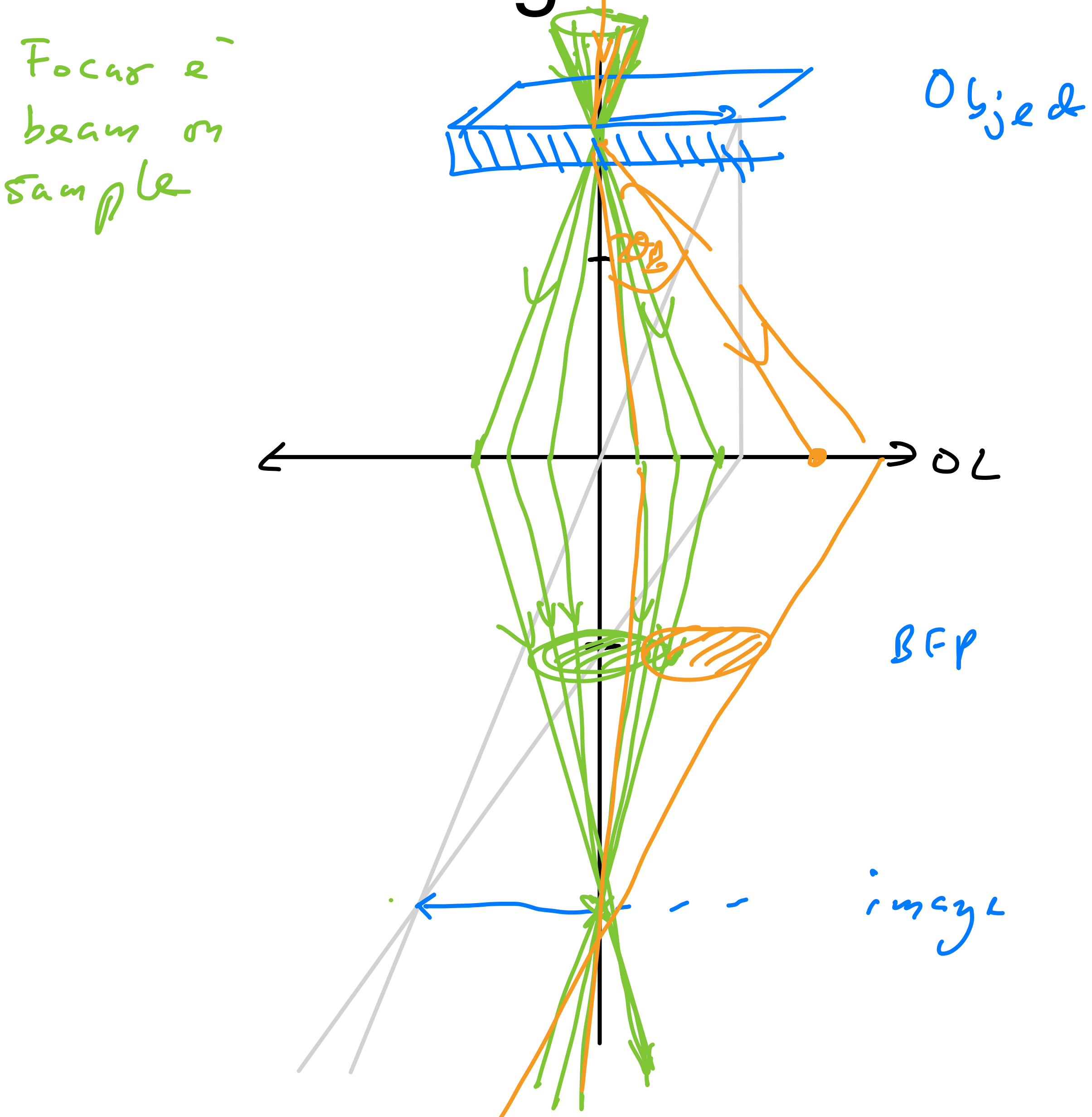
EPFL-IPHYS-LSME

Diffraction and imaging IV program

- Q and A from MOOC week 6 lectures and exercises
- Mini-lecture on:
  - Convergent beam electron diffraction (CBED)
- Demos: CBED (2-beam, zone axis) and FOLZ using silicon [0 0 1] sample

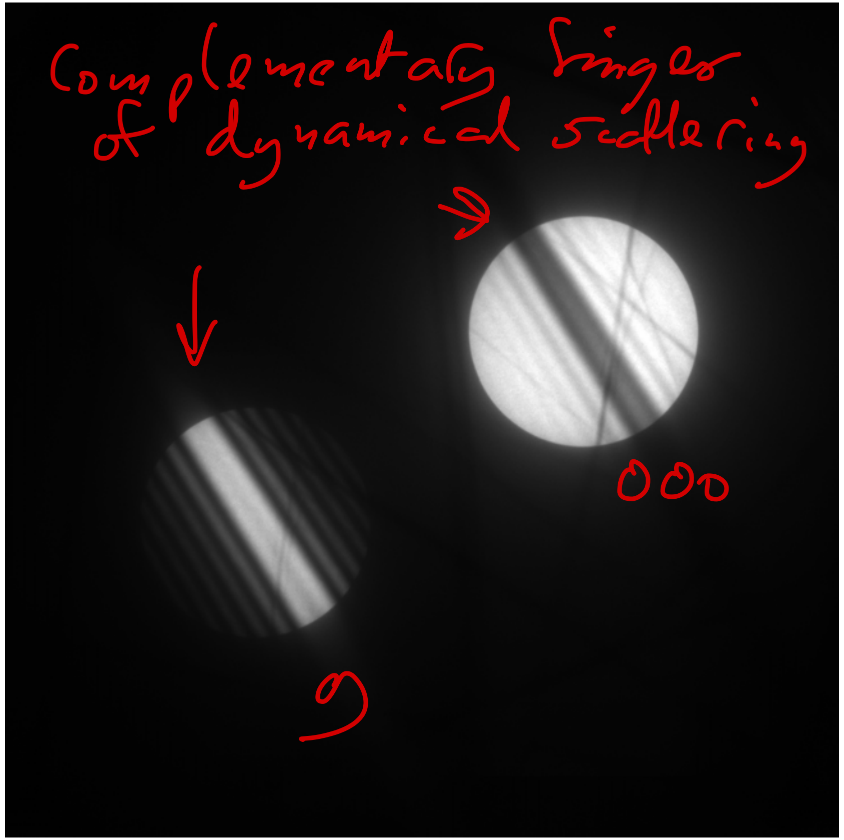
Convergent beam electron diffraction (CBED)



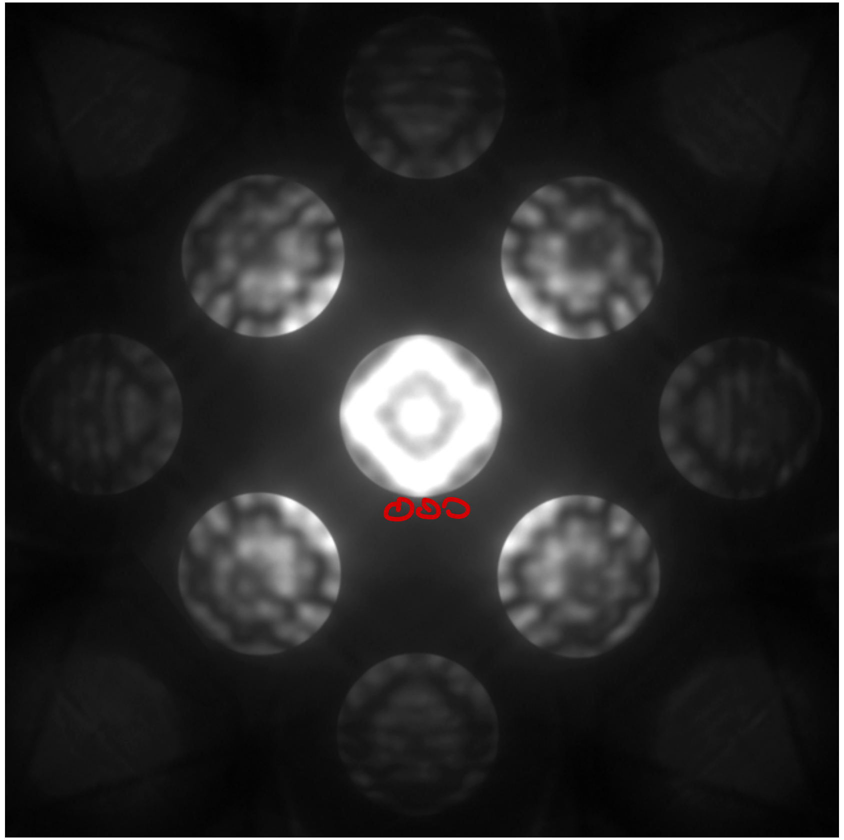
→ Pattern of Discs in BFP!

Convergent beam electron diffraction (CBED)

- 2-beam CBED pattern (Si):



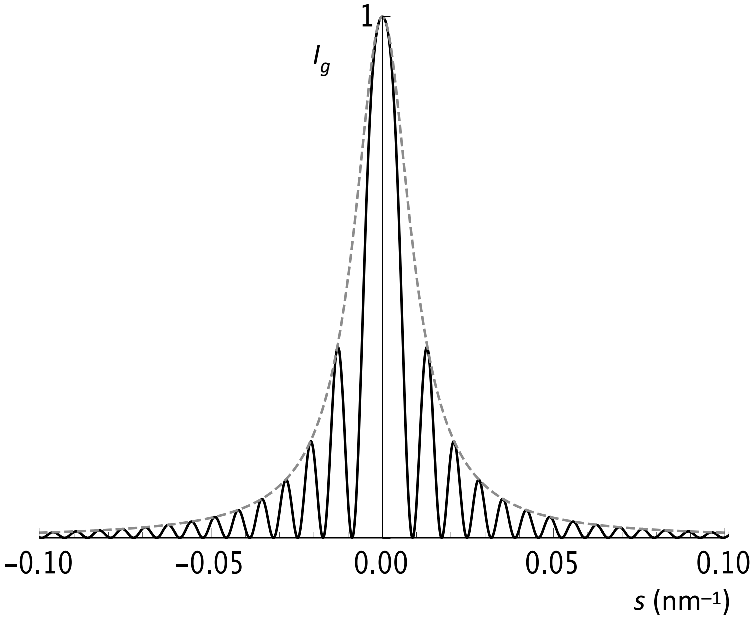
- [0 0 1] zone axis CBED pattern (Si):



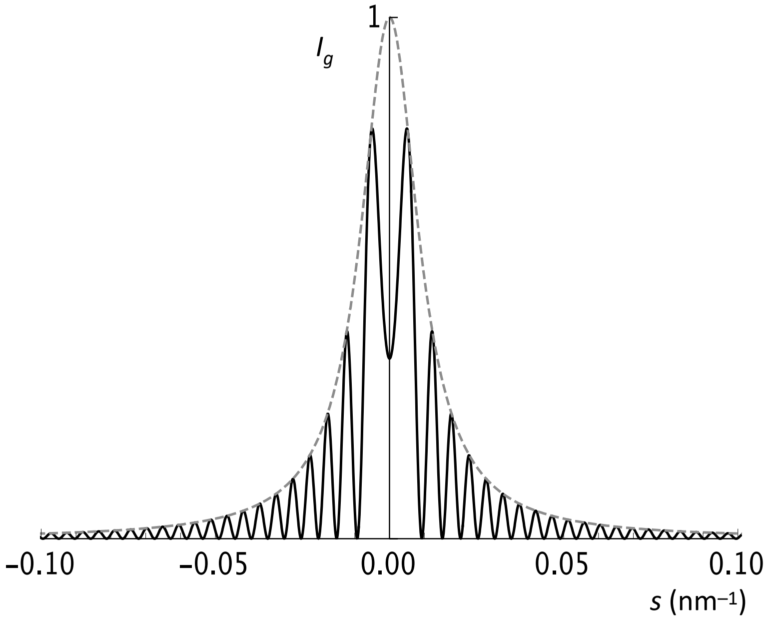
Recap: Beam intensities in 2-beam condition

- Intensity in diffracted beam: $I_g(t) = \frac{1}{1+\xi_g^2 s^2} \sin^2\left(\pi t \sqrt{\frac{1}{\xi_g^2} + s^2}\right)$
- Intensity in direct beam: $I_0(t) = 1 - I_g(t)$
- Model I_g vs s for ξ_g = 100 nm

t = 150 nm



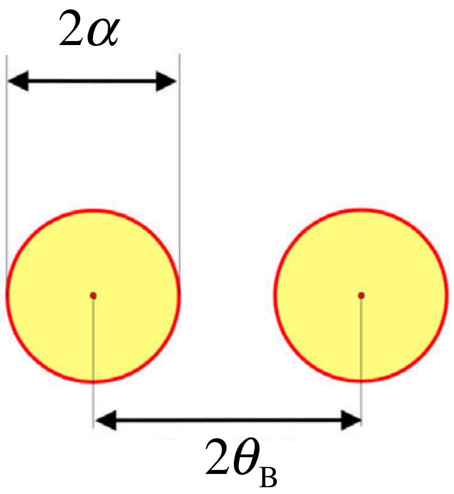
t = 220 nm

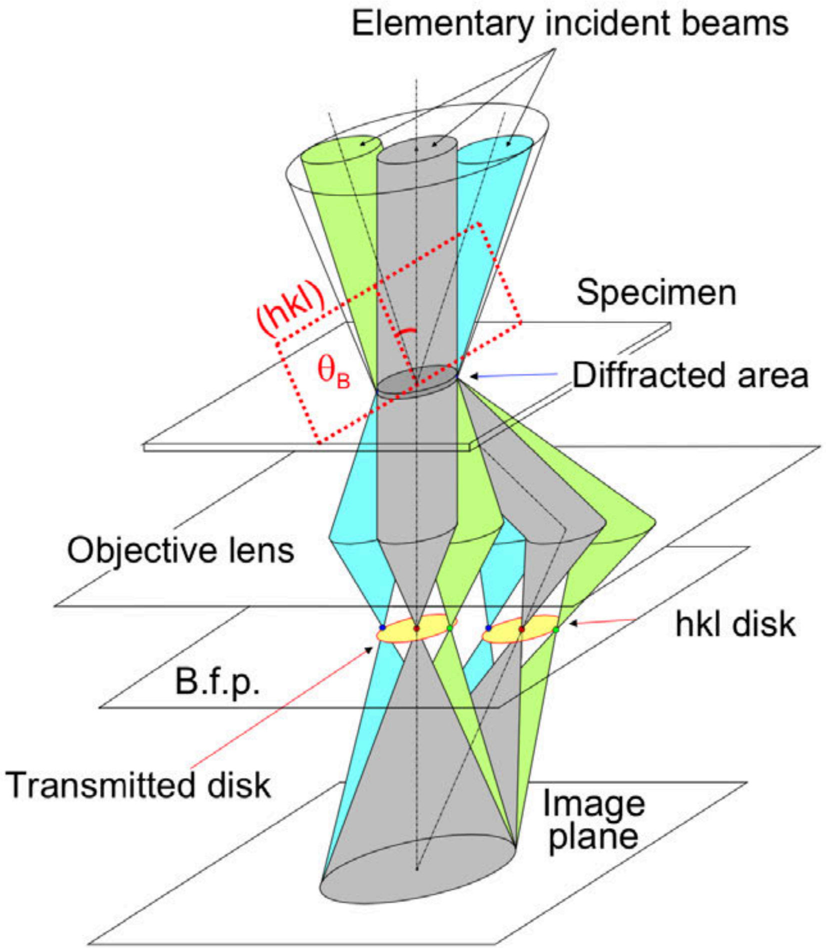


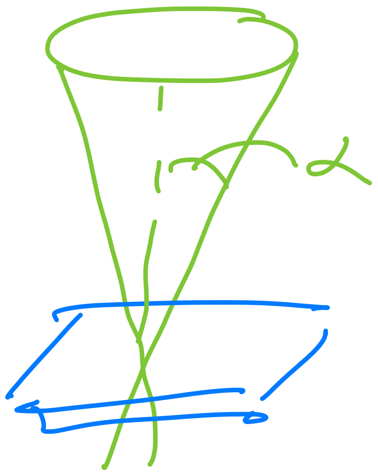
CBED 2-beam condition

- 2-beam illustration with semi-focused beam (from J.-P. Morniroli)

Consider convergent beam as parallel incident rays at different angles



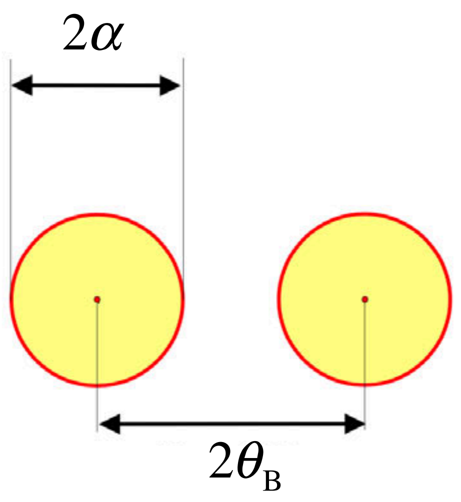


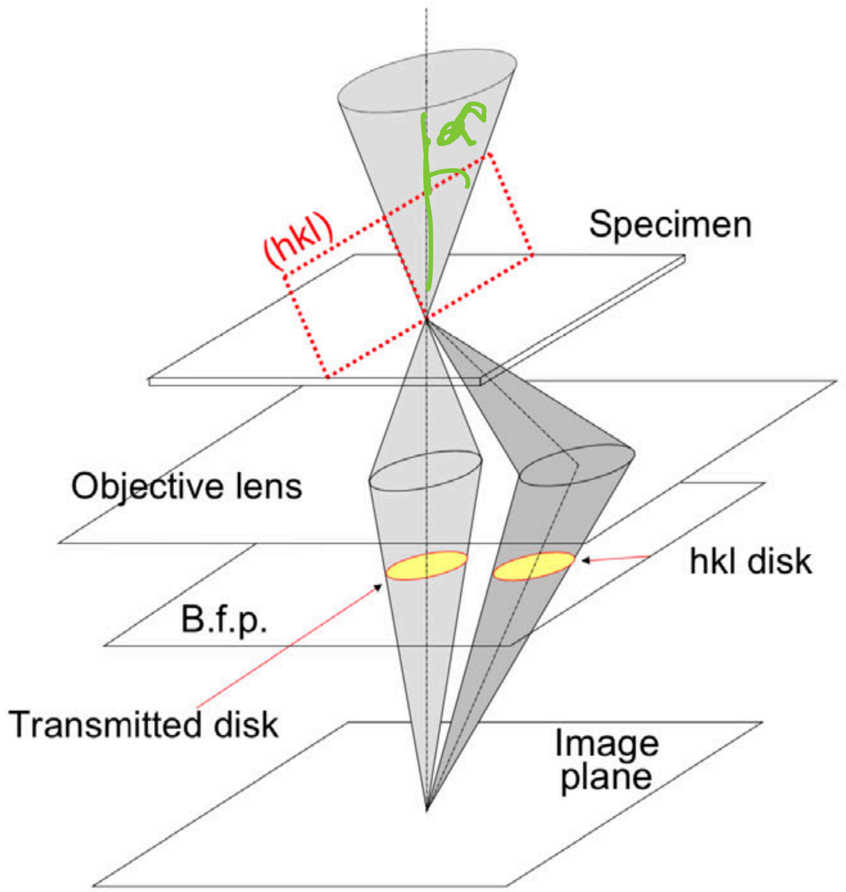


α : convergence semi-angle

CBED 2-beam condition

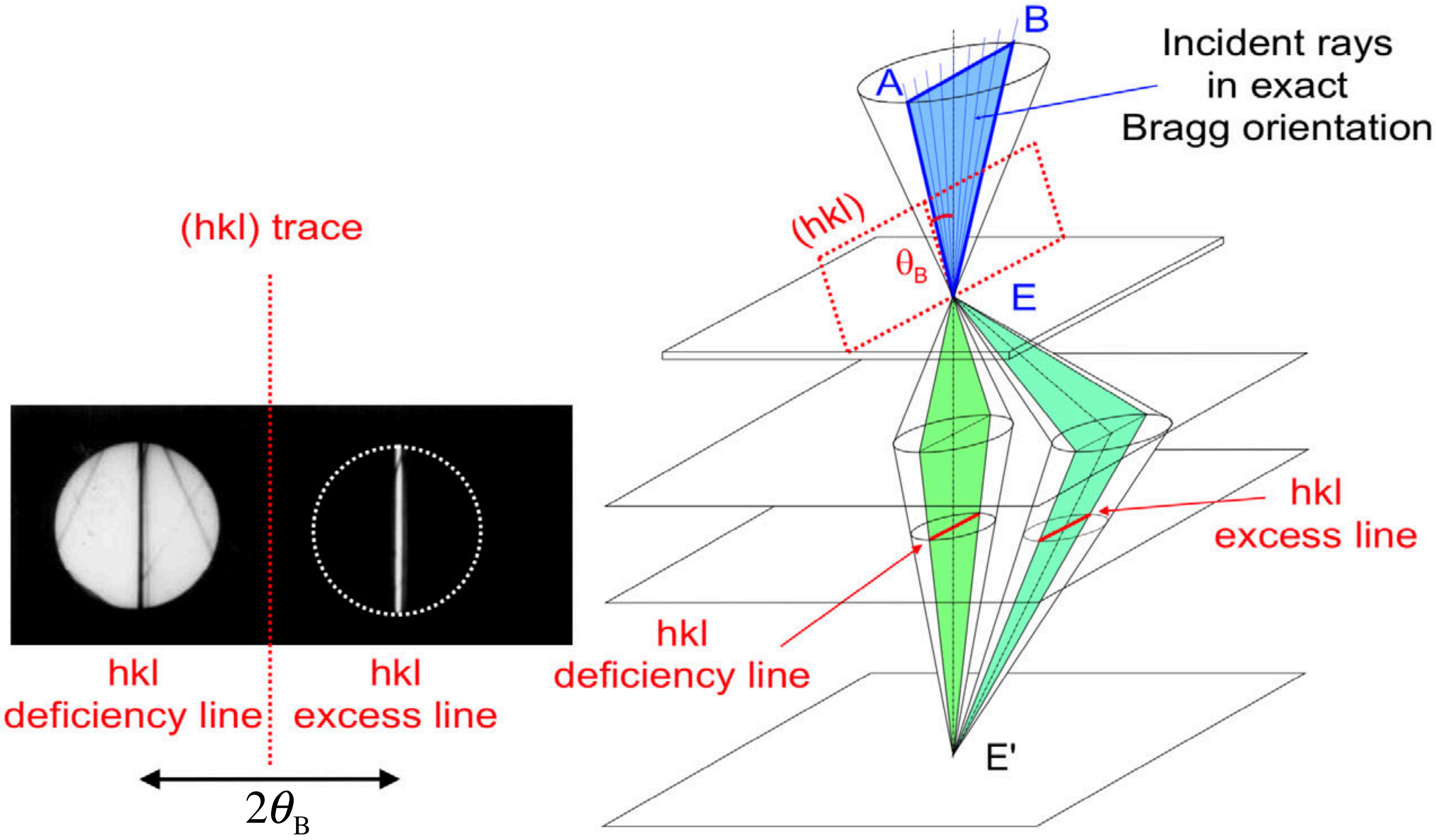
- 2-beam illustration with fully-focused beam (from J.-P. Morniroli)





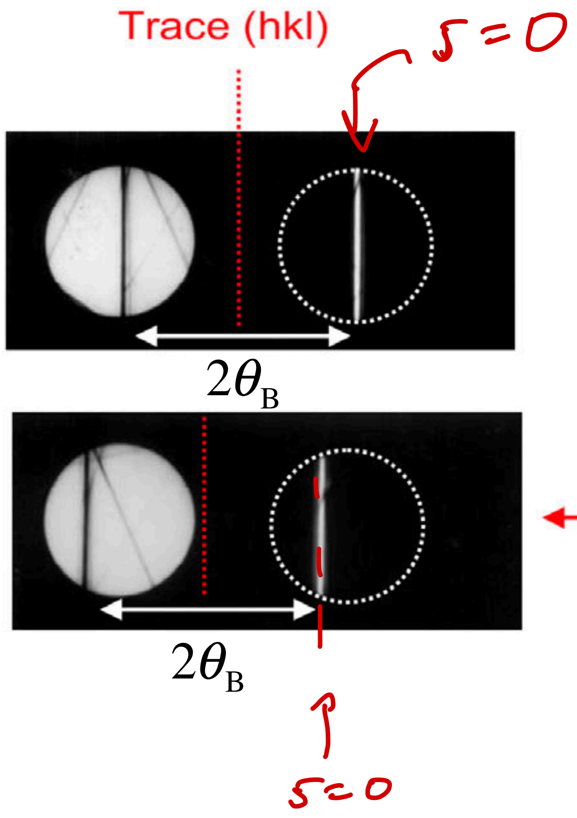
CBED 2-beam condition

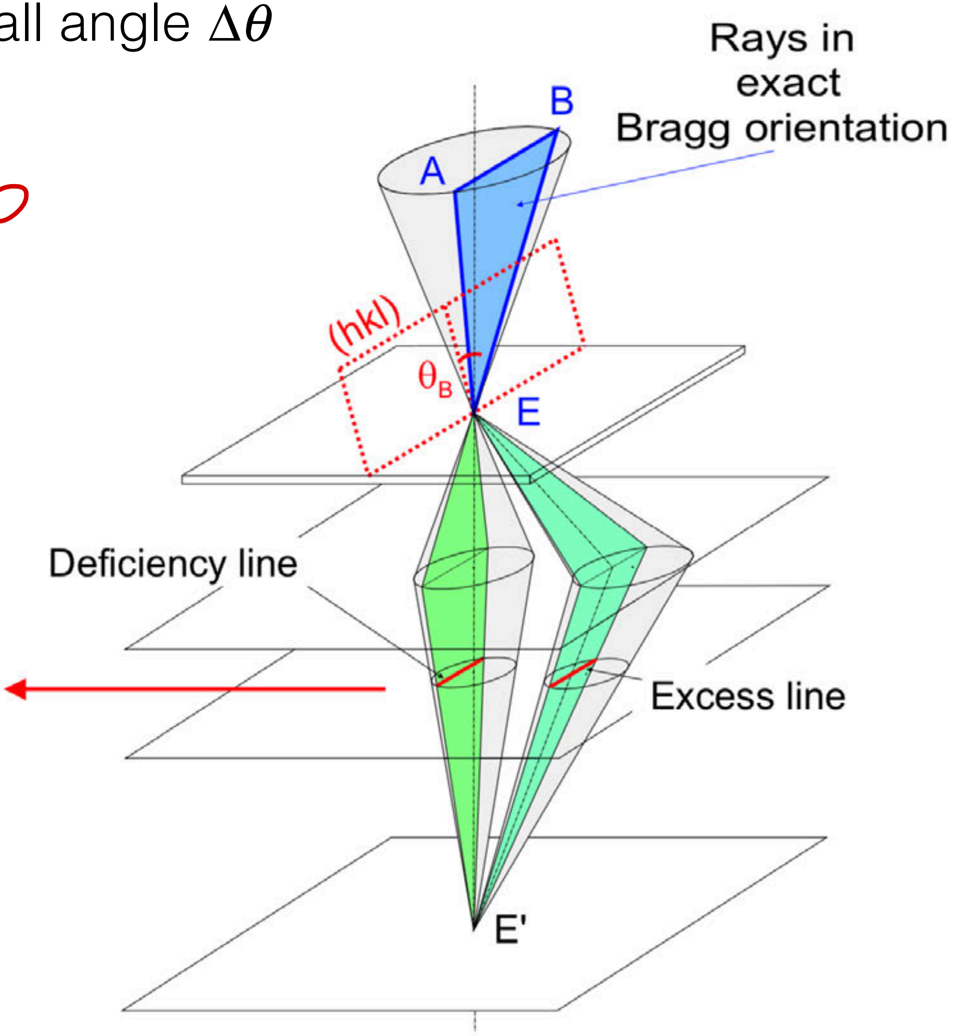
- 2-beam illustration with fully-focused beam (from J.-P. Morniroli)



CBED – *near* 2-beam condition

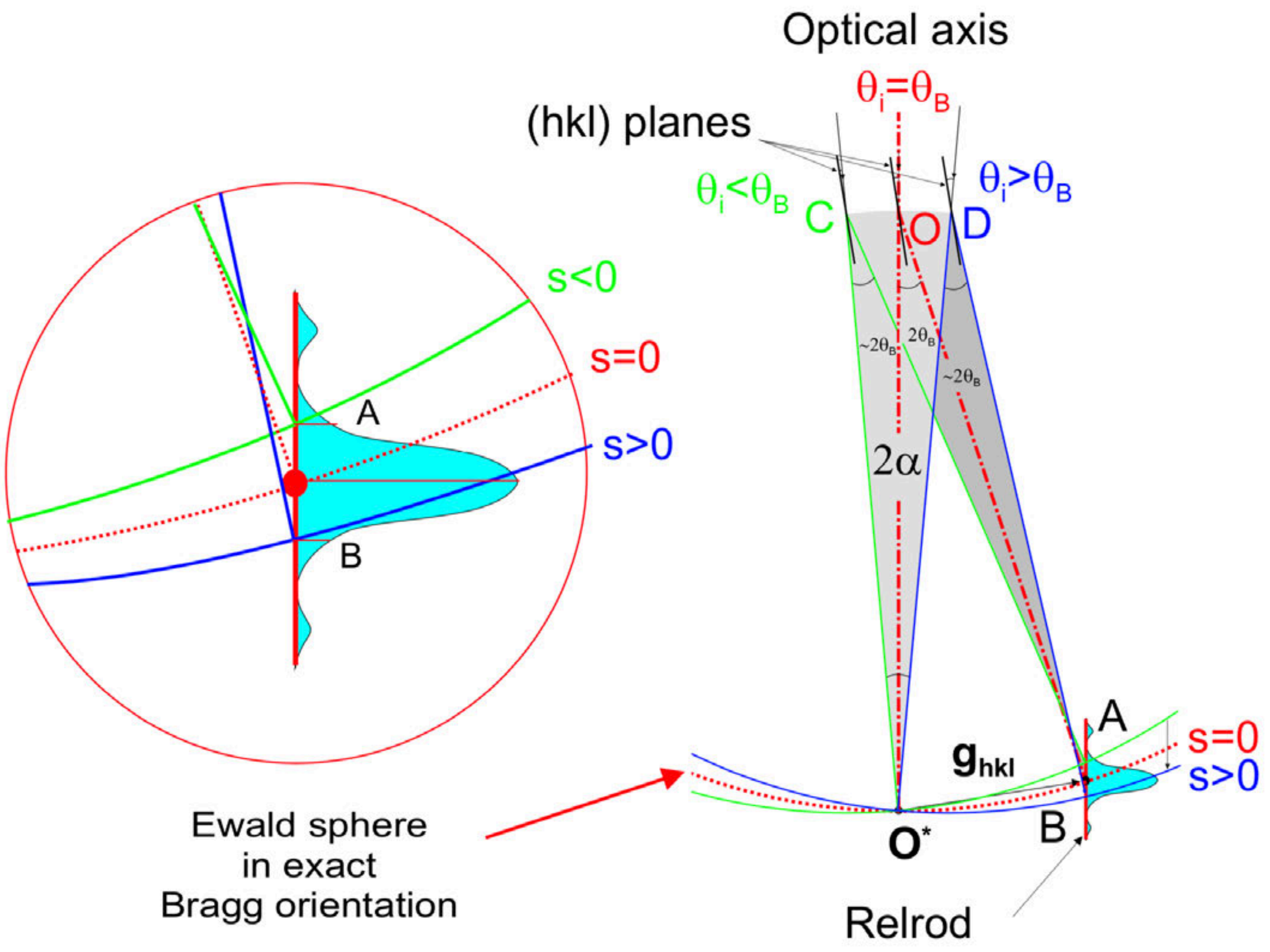
- Tilt Bragg-diffracting plane by small angle $\Delta\theta$





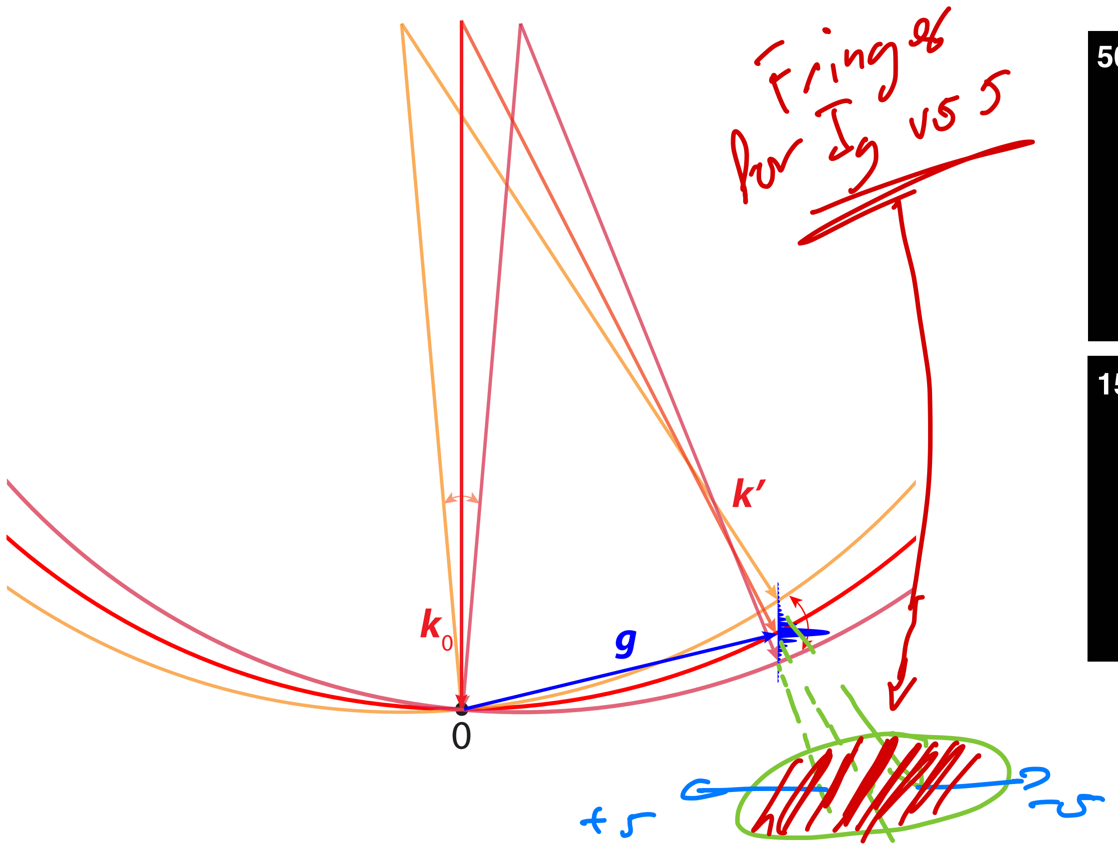
CBED: measure I_g vs s

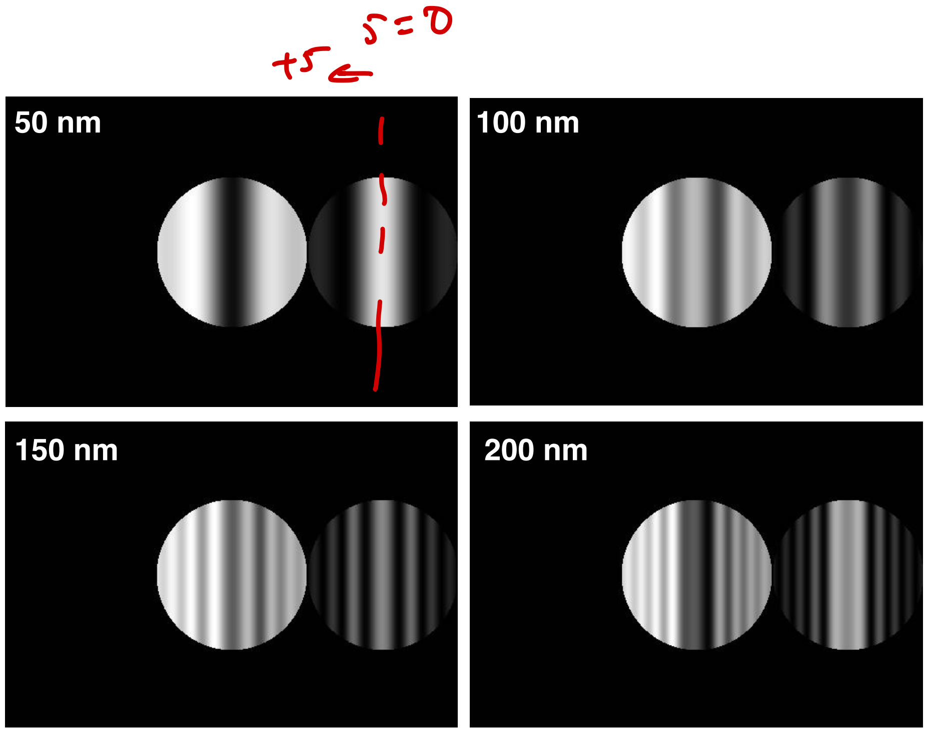
- Diffracted beam CBED disc contains different ray paths that have sampled different excitation errors s
- Illustrate with Ewald sphere construction (diagram from J.-P. Morniroli)
- $\Longrightarrow$ we can measure I_g vs s along a chord in the CBED disc for reflection $\boldsymbol{g}$



CBED: thickness fringes

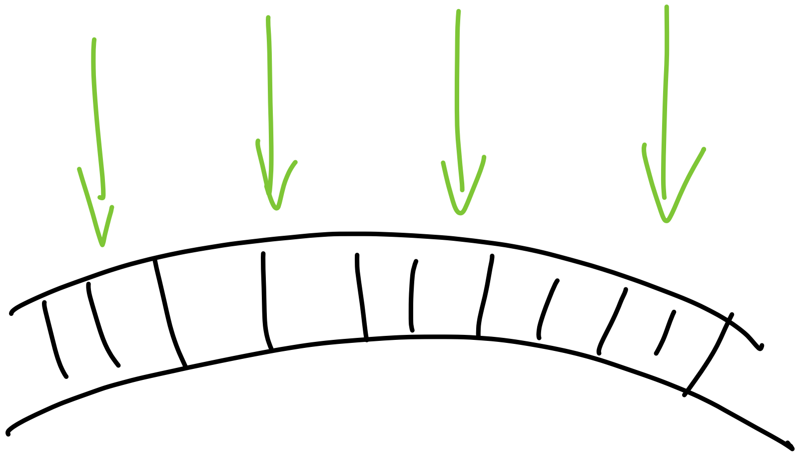
- 2-beam condition: CBED discs with 1-D fringes
- Intensity and spacing of fringes depends on dynamical scattering
  $\Longrightarrow$ can use to measure sample thickness t



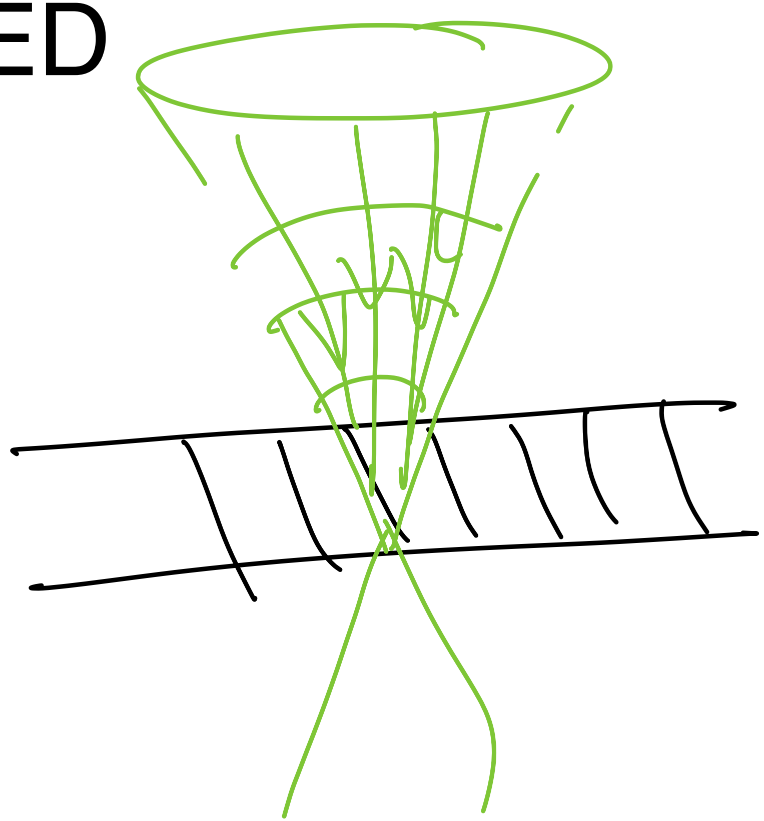


Bloch wave simulations made with JEMS
for Al with $\vec{g}_{002}$ excited for indicated t

Bend contours ⟺ CBED



Bend xtal planes with parallel beam

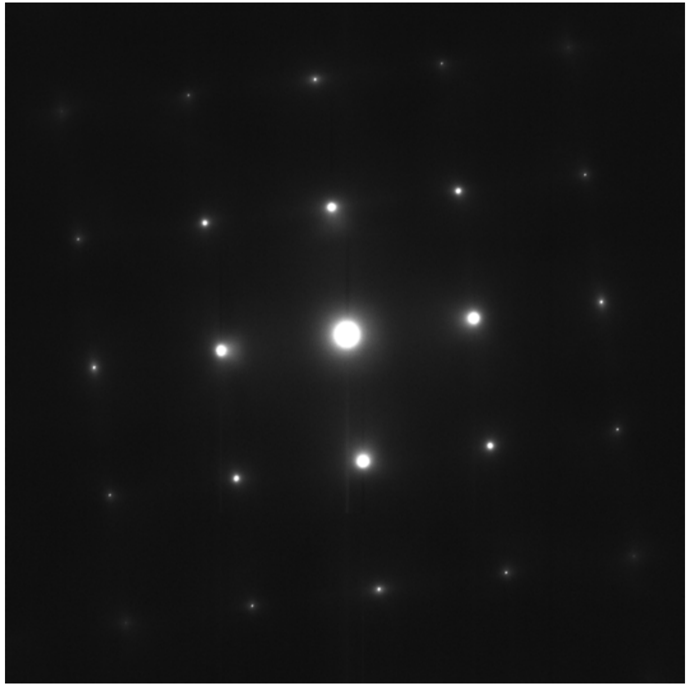


Bend incident beam

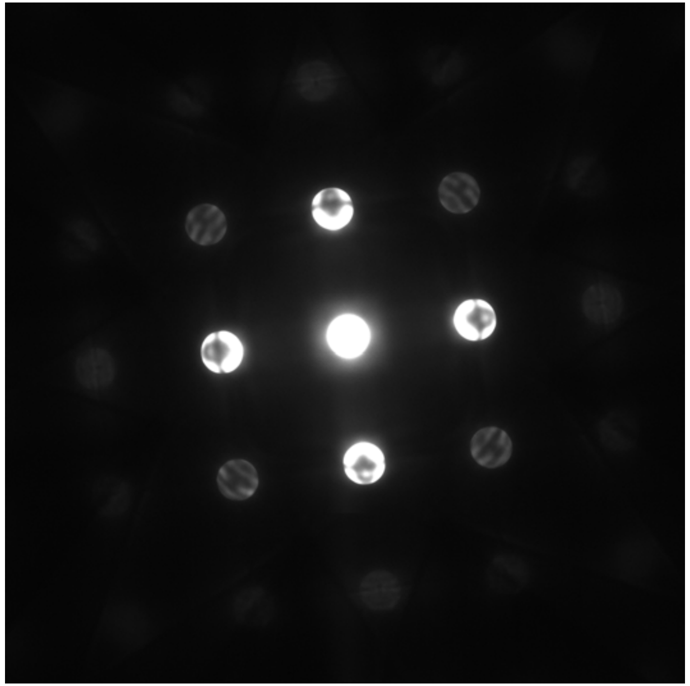
Zone axis CBED

- Instead of spot pattern, obtain disc pattern
- Larger convergence semi-angle $\alpha \Longrightarrow$ larger discs

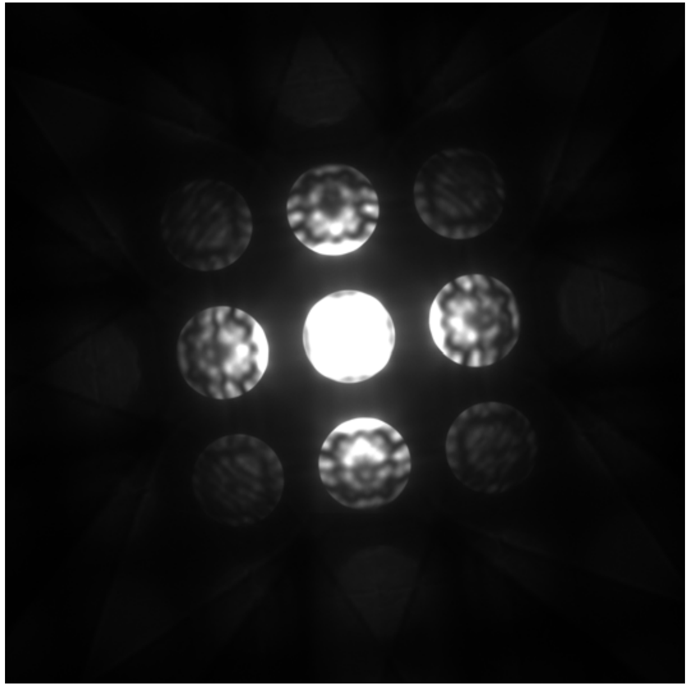
Parallel beam SADP Si [001]



$\alpha \approx 1.6$ mrad



$\alpha \approx 4$ mrad

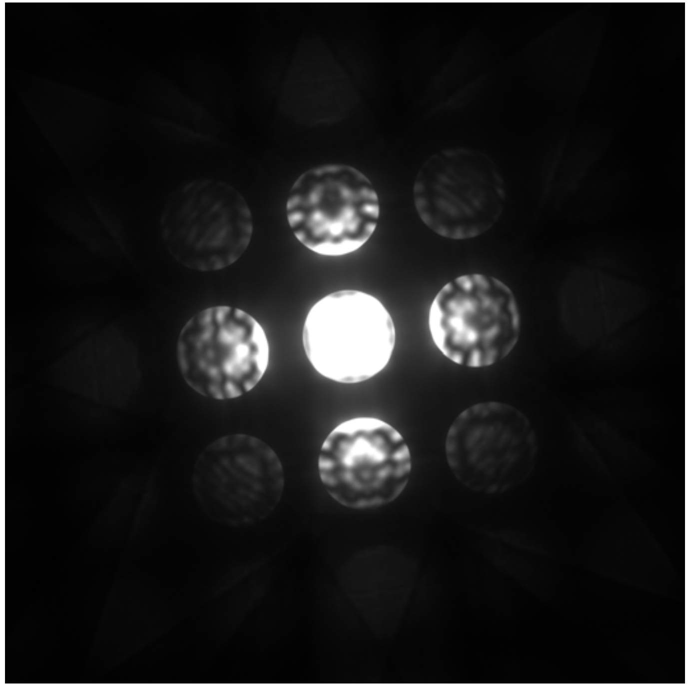


- See complex fringe patterns in discs from dynamical scattering, and symmetry

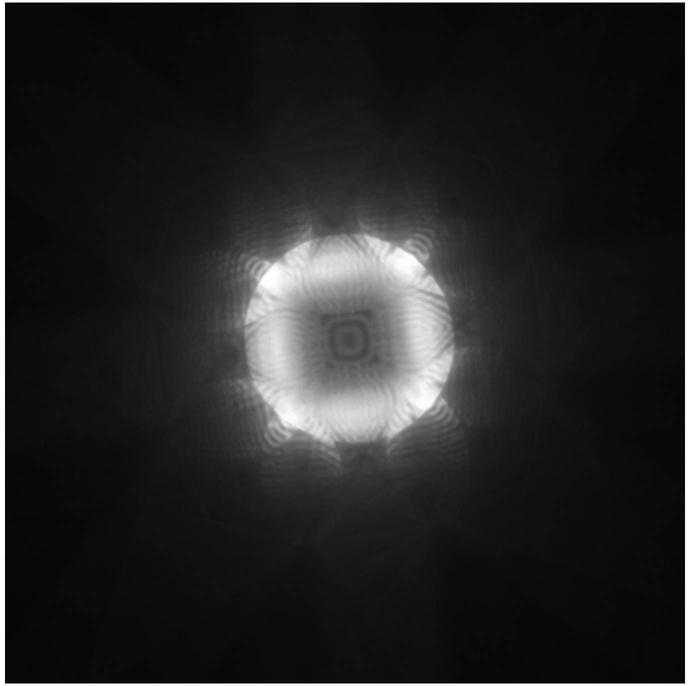
EPFL Zone axis CBED

- Instead of spot pattern, obtain disc pattern
- Larger convergence semi-angle $\alpha \implies$ larger discs

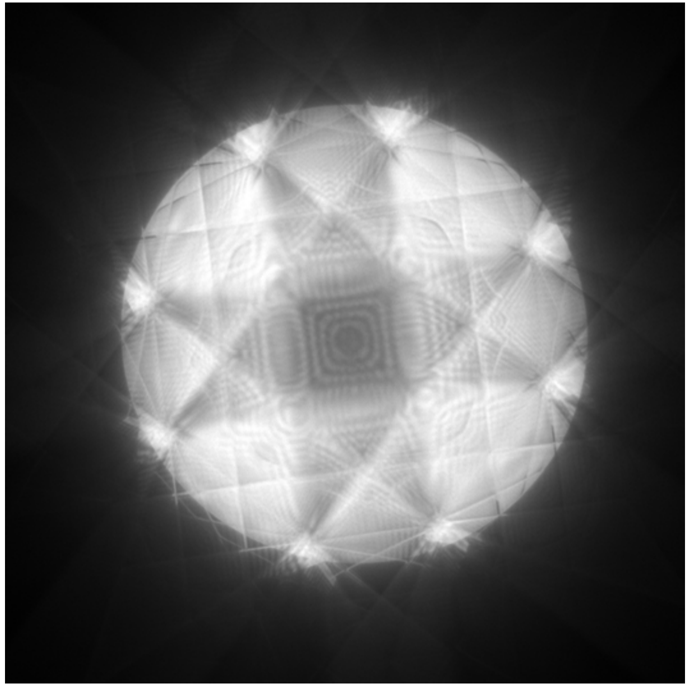
$\alpha \approx 4$ mrad



$\alpha \approx 9$ mrad



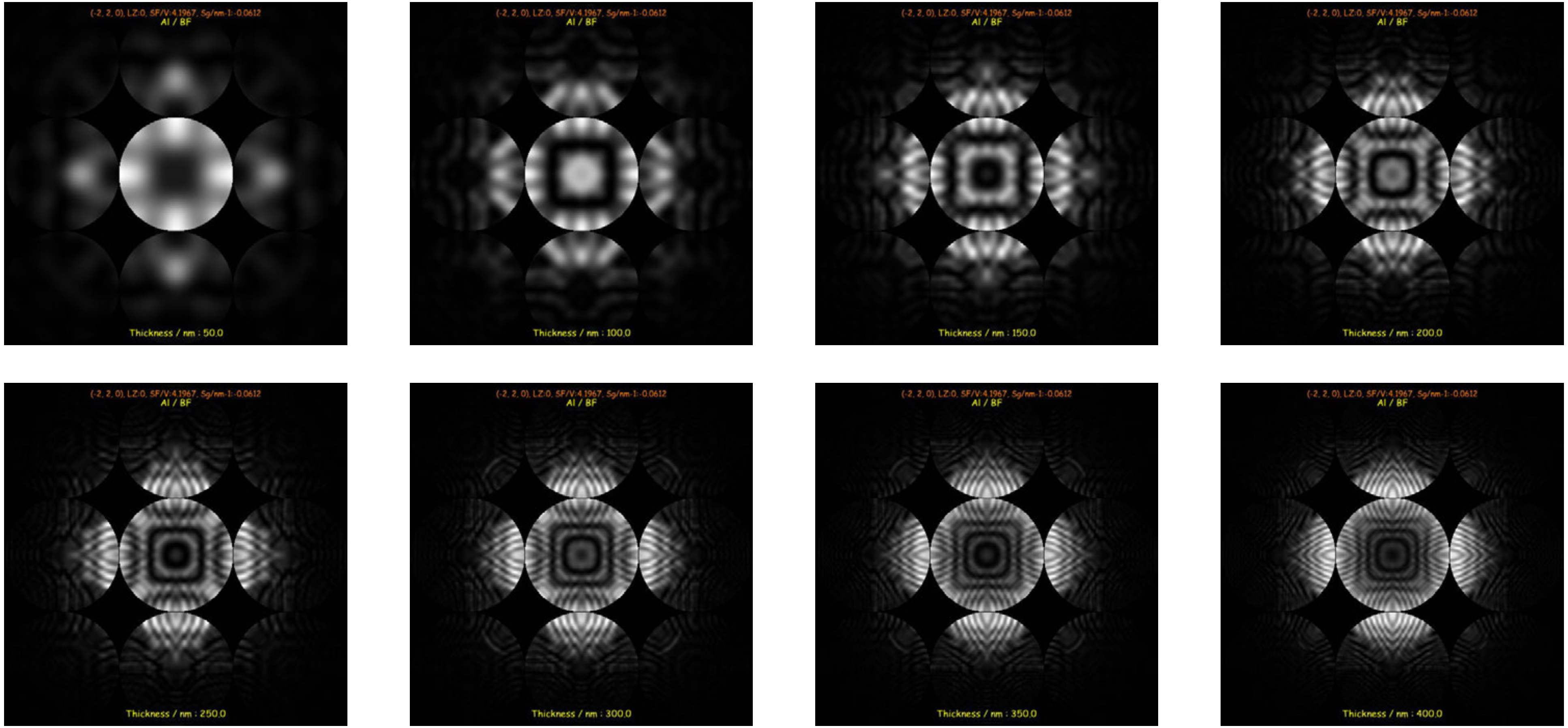
$\alpha \approx 19$ mrad



- See complex fringe patterns in discs from dynamical scattering, and symmetry

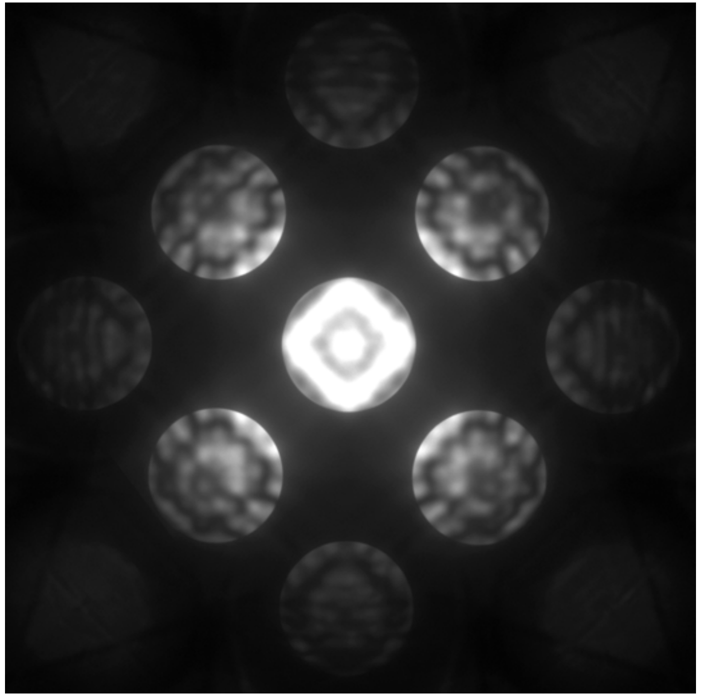
Zone axis CBED thickness effect

- Measure sample thickness by comparing experimental data to Bloch wave simulations
- Example 1: Bloch wave simulations for Al on [0 0 1] zone axis:

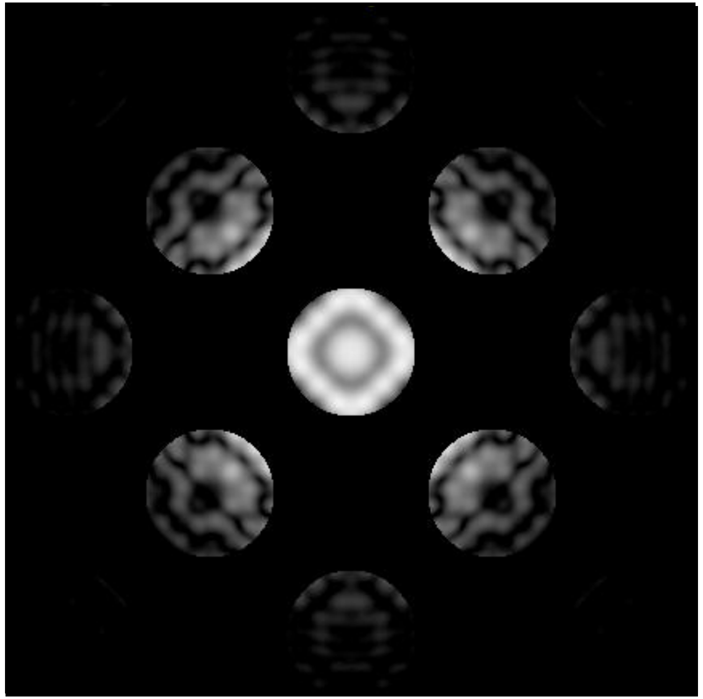


Zone axis CBED thickness effect

- Measure sample thickness by comparing experimental data to Bloch wave simulations
- Example 2: experiment vs simulation for Si on [0 0 1] zone axis:



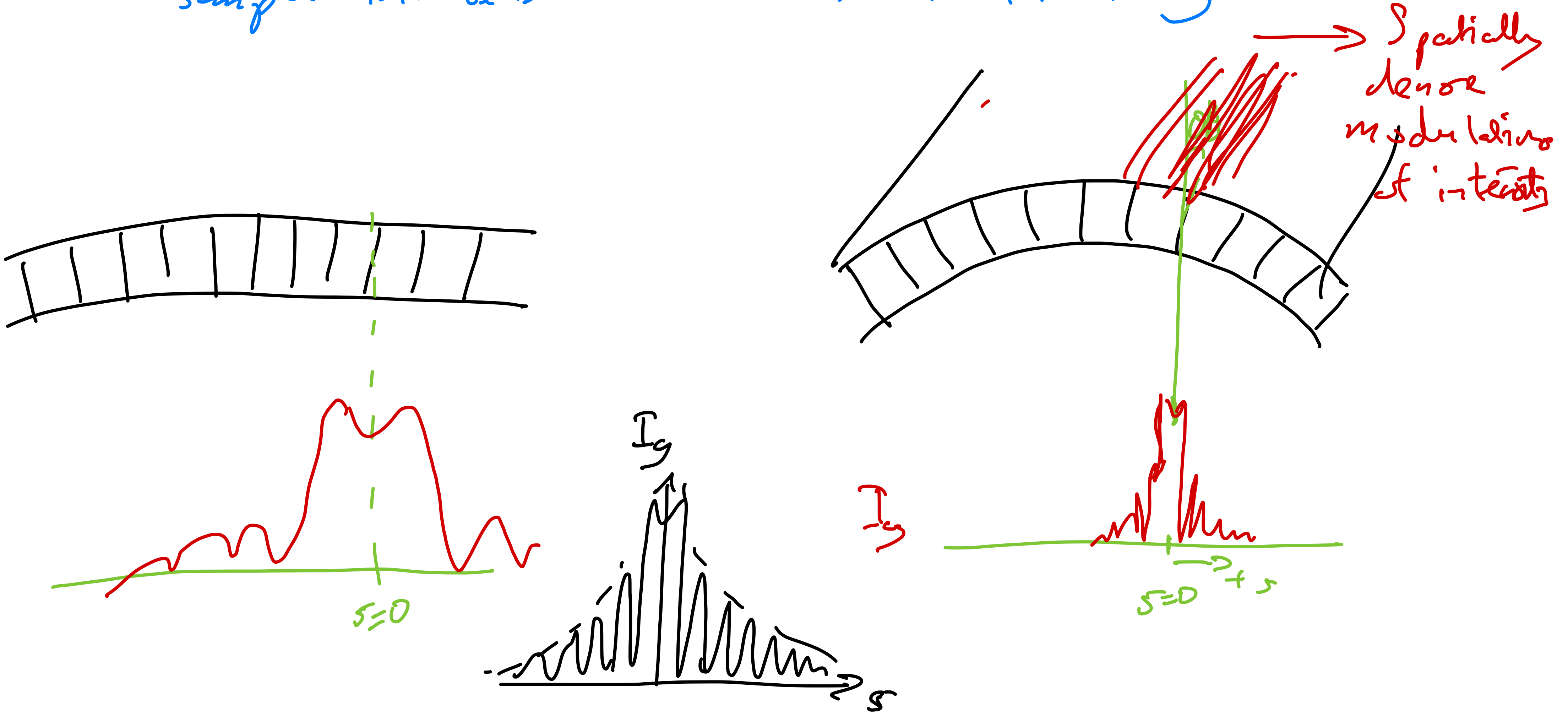
Experiment

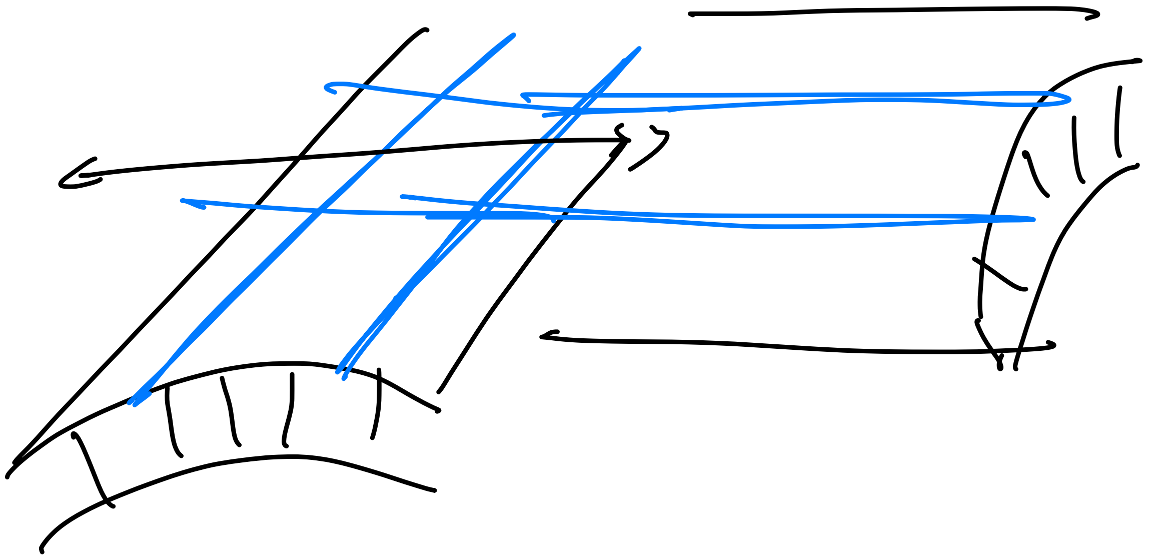


Simulation: 200 kV; t = 126nm;
α = 4.1 mrad

- Note: easier to compare to simulations when discs not strongly overlapped

How does local curvature of the crystalline sample influence modulation of intensity?





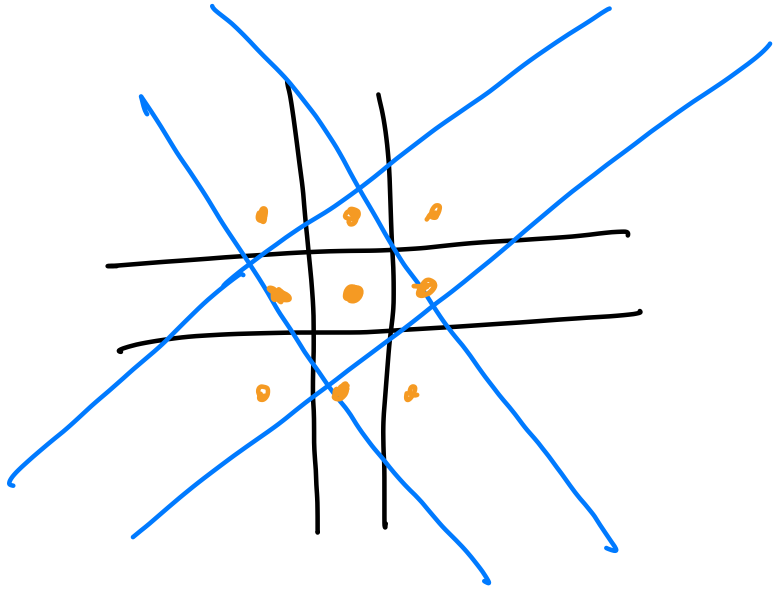
Suppose FCC [001]

(200) →

(020)

(220) •

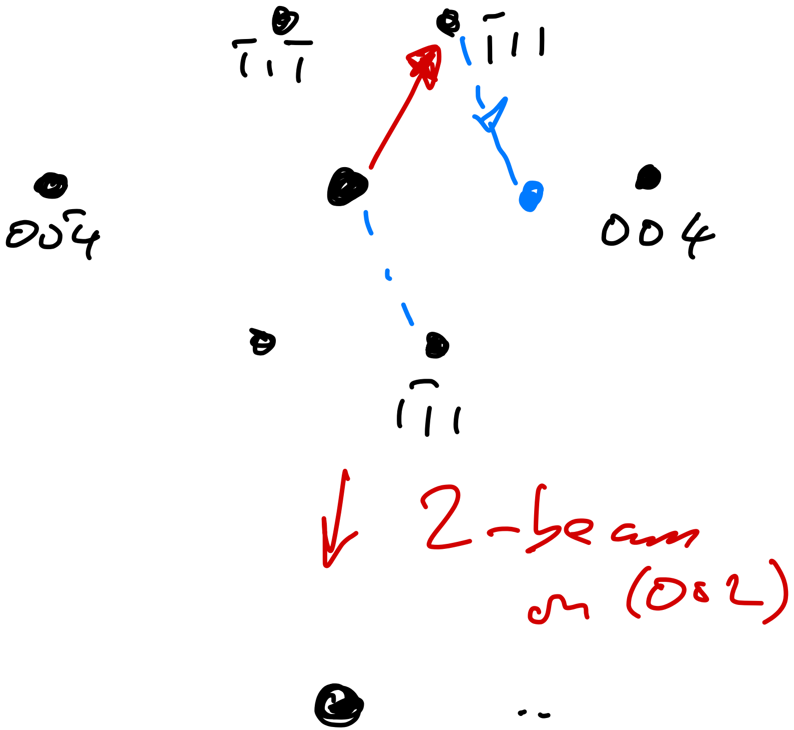
$(2\bar{2}0)$ -

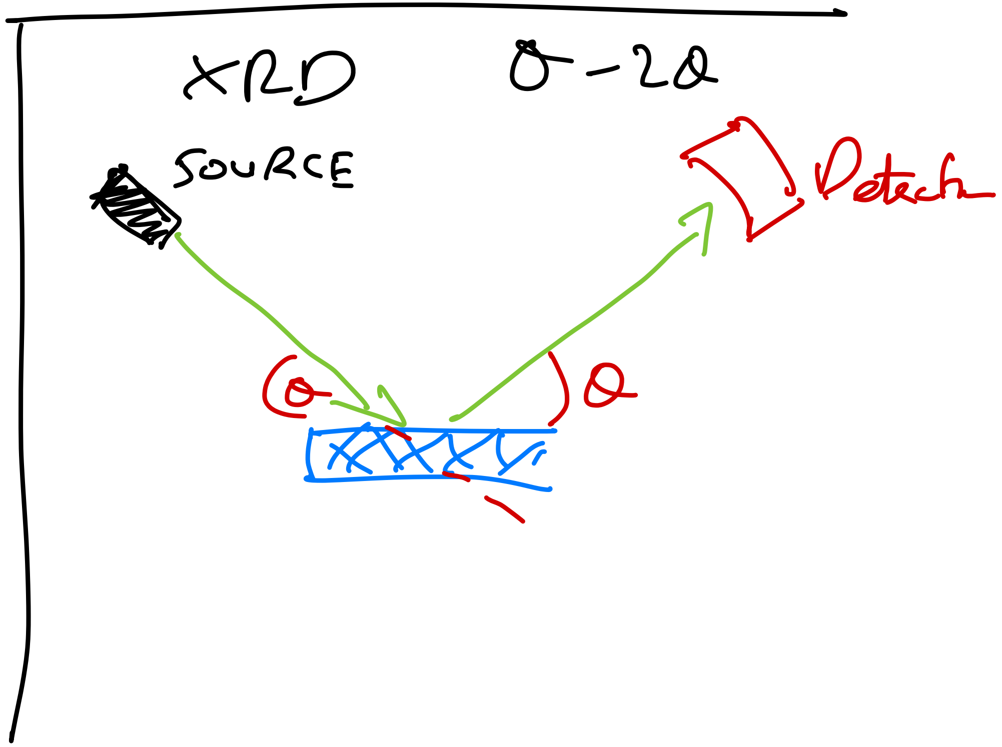


Double diffraction

Si [110]

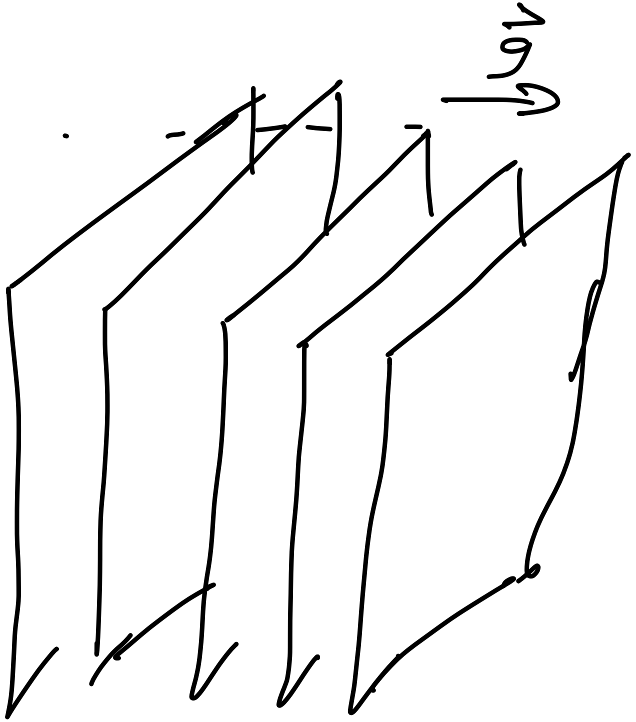
$$\bar{1}11 + 1\bar{1}1 = 002$$





Systematic row ?? – Parallel to one set of planes

(200) →



SADP:

$$n\lambda \simeq 2\theta \cdot d_{hkl}$$

$$\Rightarrow \lambda \simeq 2\theta\, d_{nh\,nk\,nl}$$

Real sample

Very focused beam samples very small and "perfect" region