Transverse coherence and polarization measurement of 131 nm coherent femtosecond pulses from a seeded FEL

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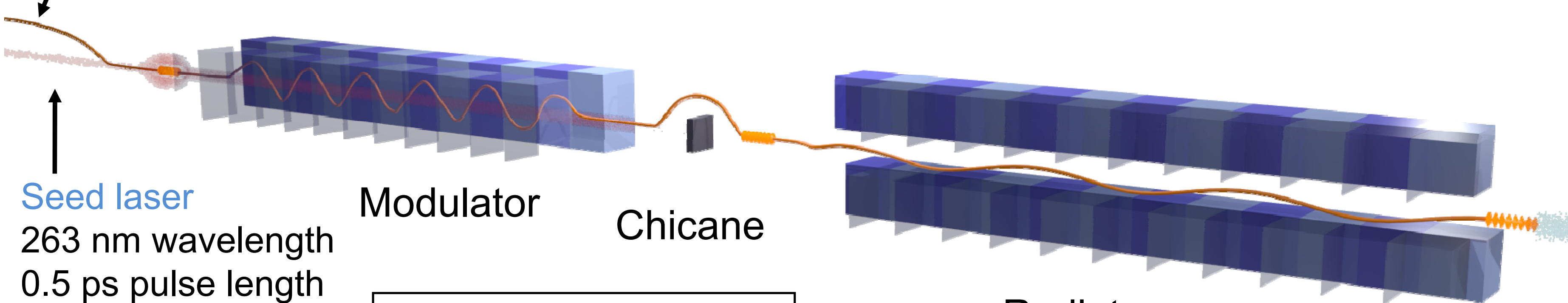
Overview

- Test FEL setup
- Measurement of transverse coherence
- Measurement of polarization state
- Summary

Test FEL undulator setup

Electron bunches with
1 ps bunch length
375 MeV energy
30 pC charge



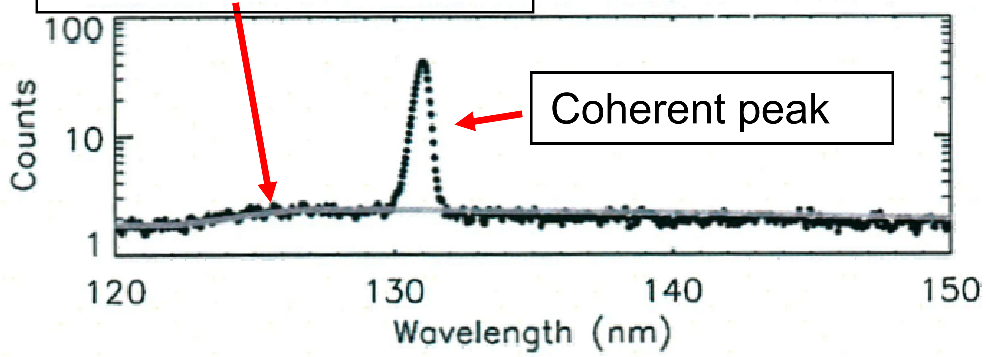
Seed laser
263 nm wavelength
0.5 ps pulse length
2 Hz repetition rate

Modulator

Chicane

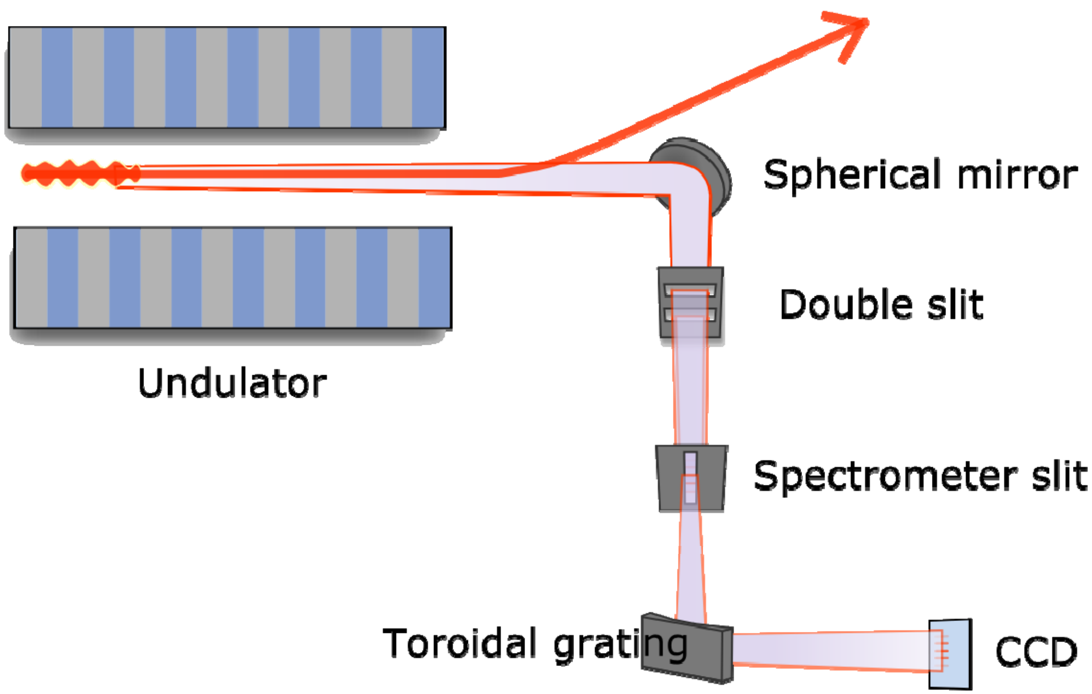
Radiator
APPLE-II type undulator

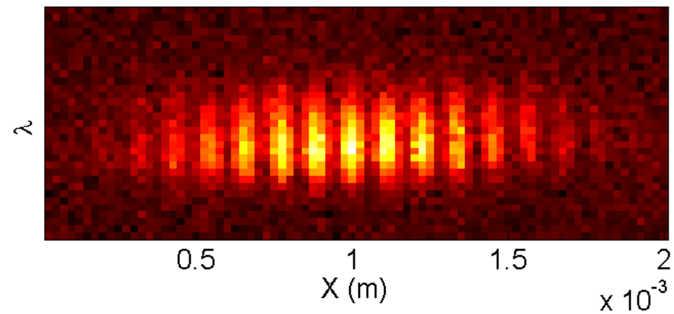
Spontaneous emission / low coherence part

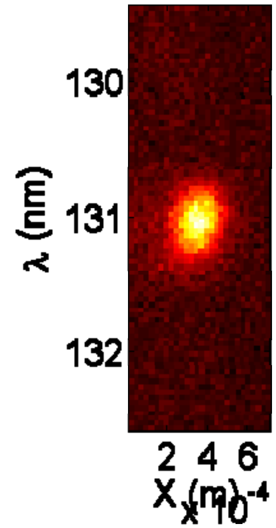


Coherent peak

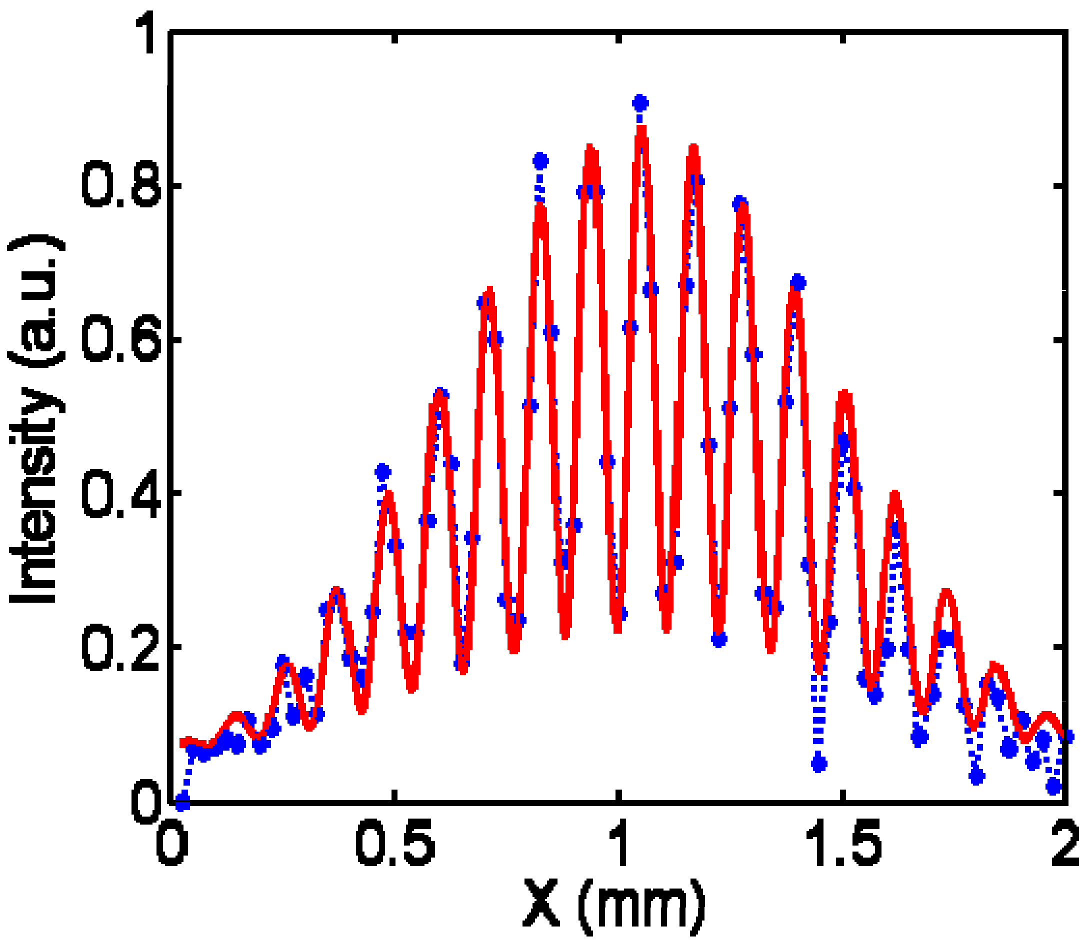
Experimental setup behind Radiator



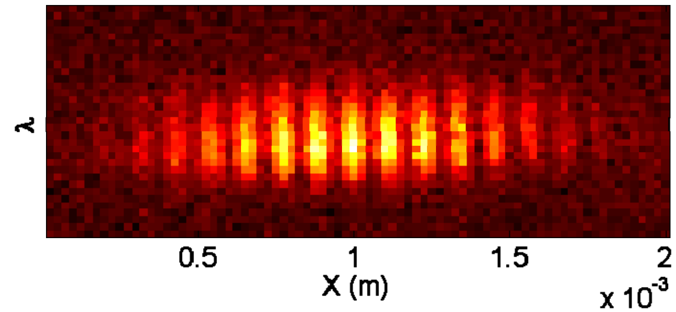




Coherent signal at 131 nm, 40 μm by 400 μm slits

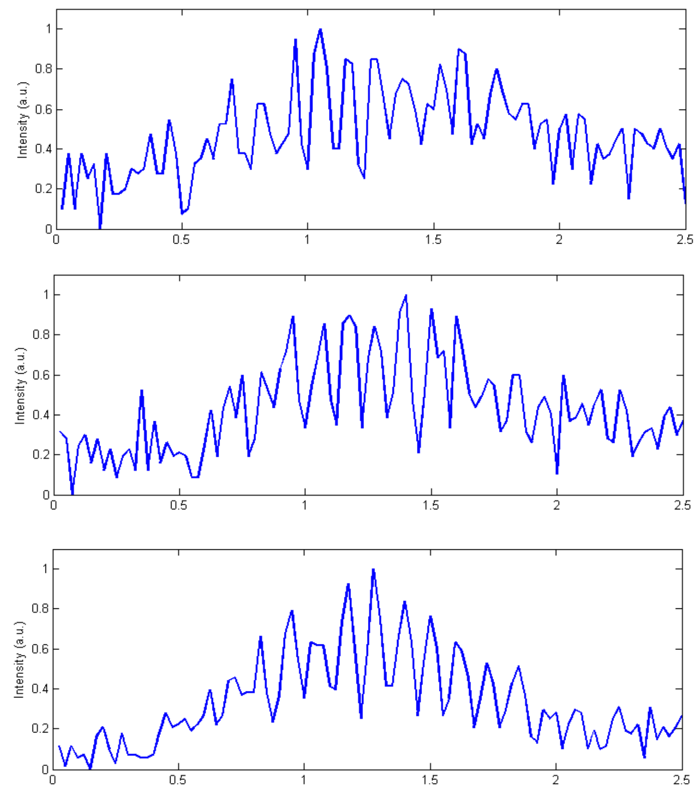


- 40s exposure (80 shots)
- Far-field diffraction pattern is fitted to the experimental data
- Fringe visibility υ = 0.67



Short exposures: 4 shots with 40 μm by 400 μm slits

- Pointing instabilities shifts intensity at slits → fringe visibility reduced
- Long exposures average over uneven intensity distributions



Other slits

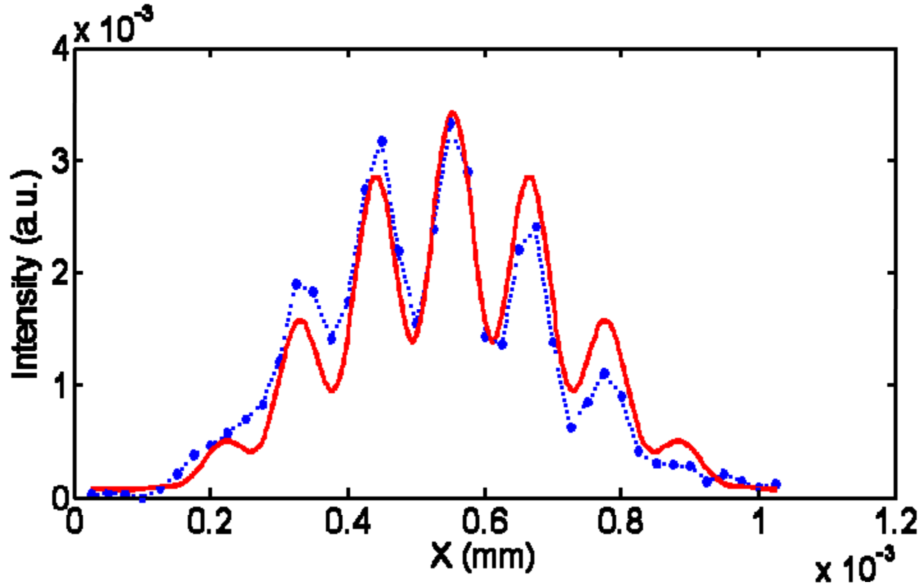
Slit separation 800 µm:

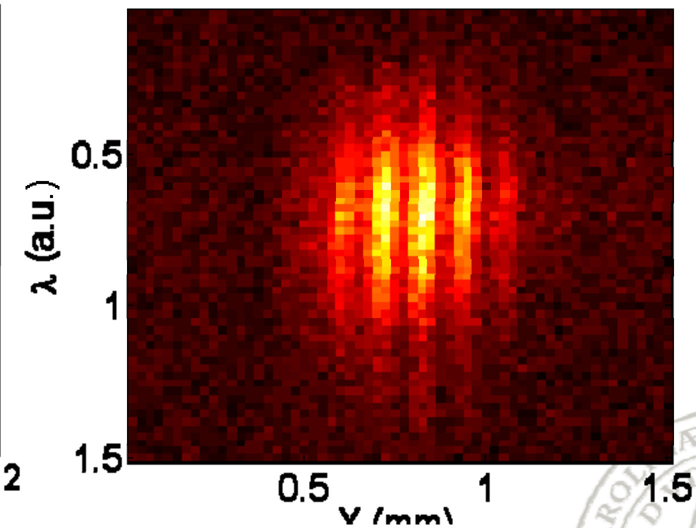
- Very low intensity
- no diffraction pattern visible

  → beam too small for large slit separation

Slit separation 400 µm, slit width 100 µm:

- Diffraction pattern has very narrow envelope, low resolution on CCD

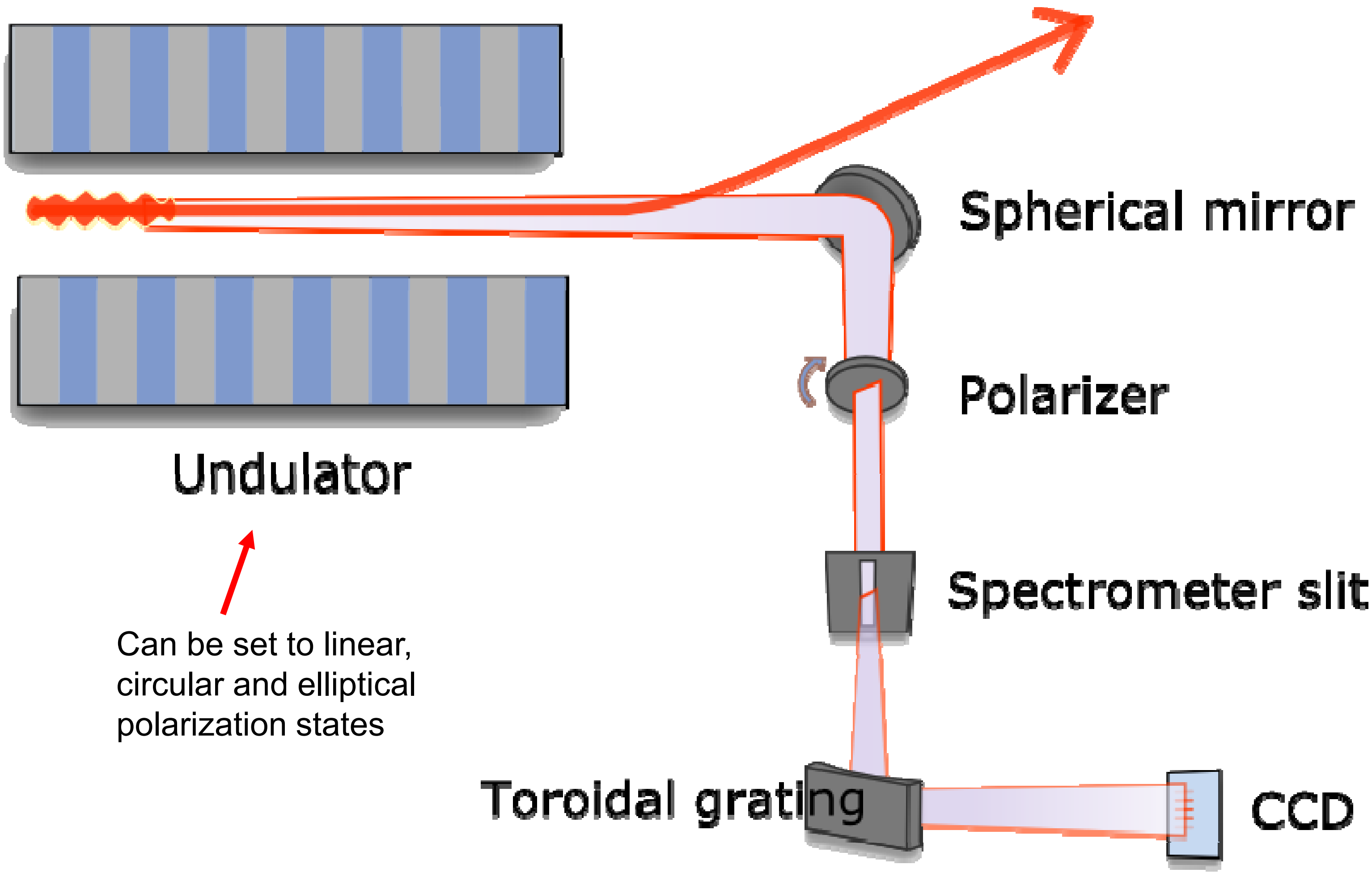


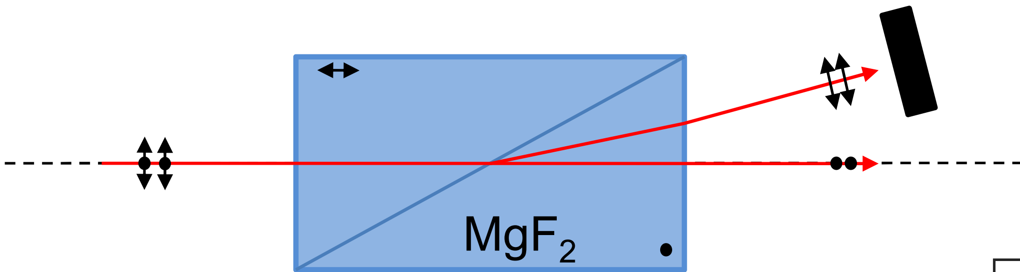


Conclusions

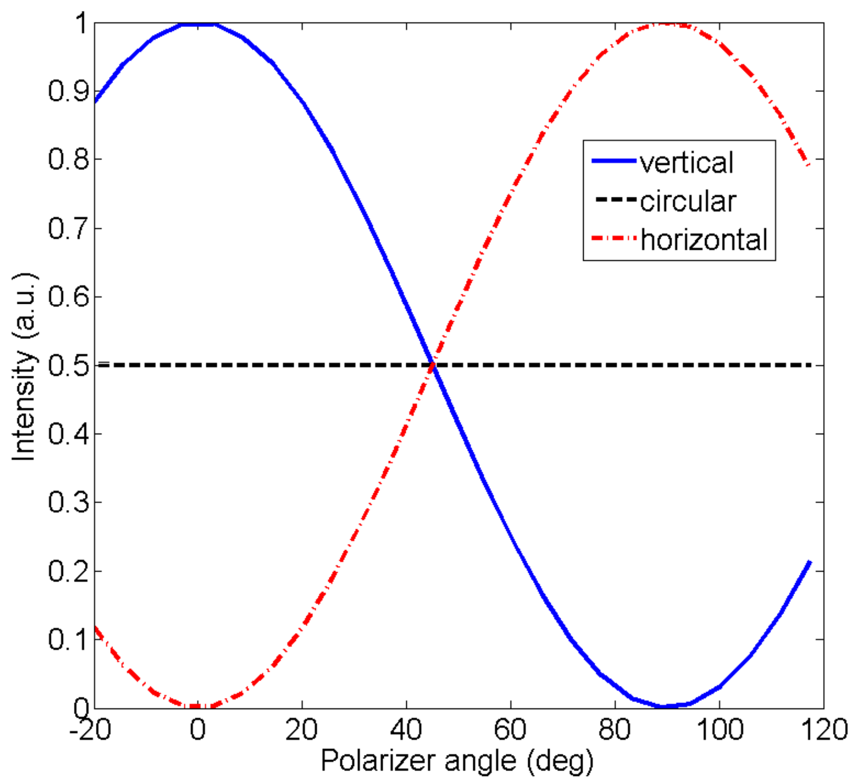
- High degree of coherence, fringe visibility 0.67
- Coherence deteriorated because of stability issues, averaging over many shots

Measurement of the polarization state of the coherent FEL emission





Intensity vs. Polarizer angle for different polarization states:



Rochon prism is used as a linear polarizer:

- Prism refracts polarization components which are parallel to the extraordinary axis
- Prism can be rotated around axis with motorized translation stage
- Intensity behind polarizer depends on polarization state and polarizer angle

Problem: Orthogonal polarization states are not equally well transmitted through the beamline

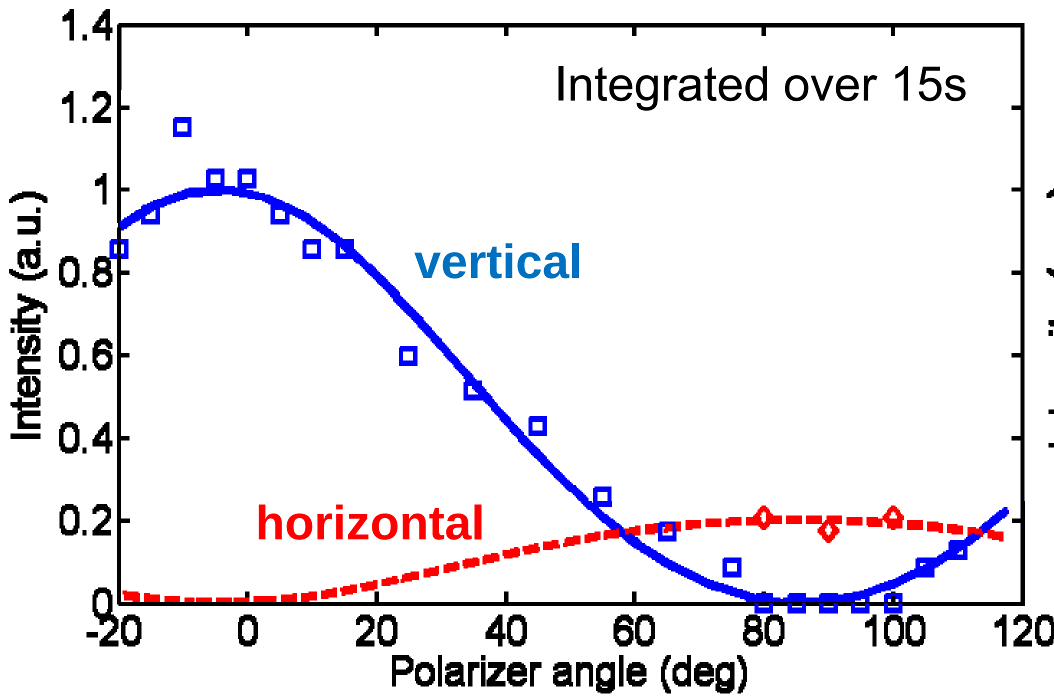
1. Setup Jones matrix for optical components and allow for reduced transmission coefficents for horizontal polarization
   - Spherical mirror
   - Polarizer
   - Toroidal grating

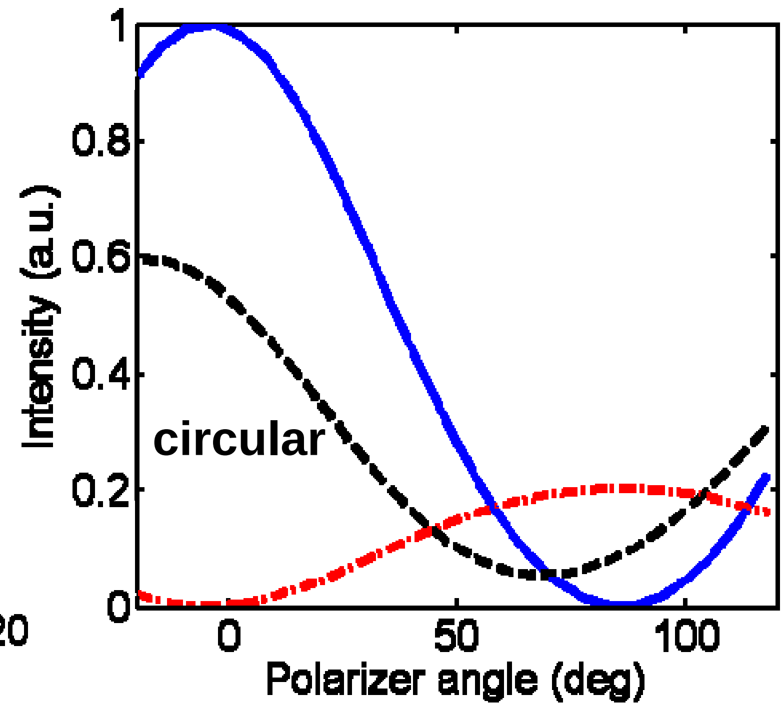
2. Calculate intensity on CCD for linear polarization states

3. Fit to experimental data to determine transmission coefficients

4. Calculate intensity curve for elliptical polarization state to data

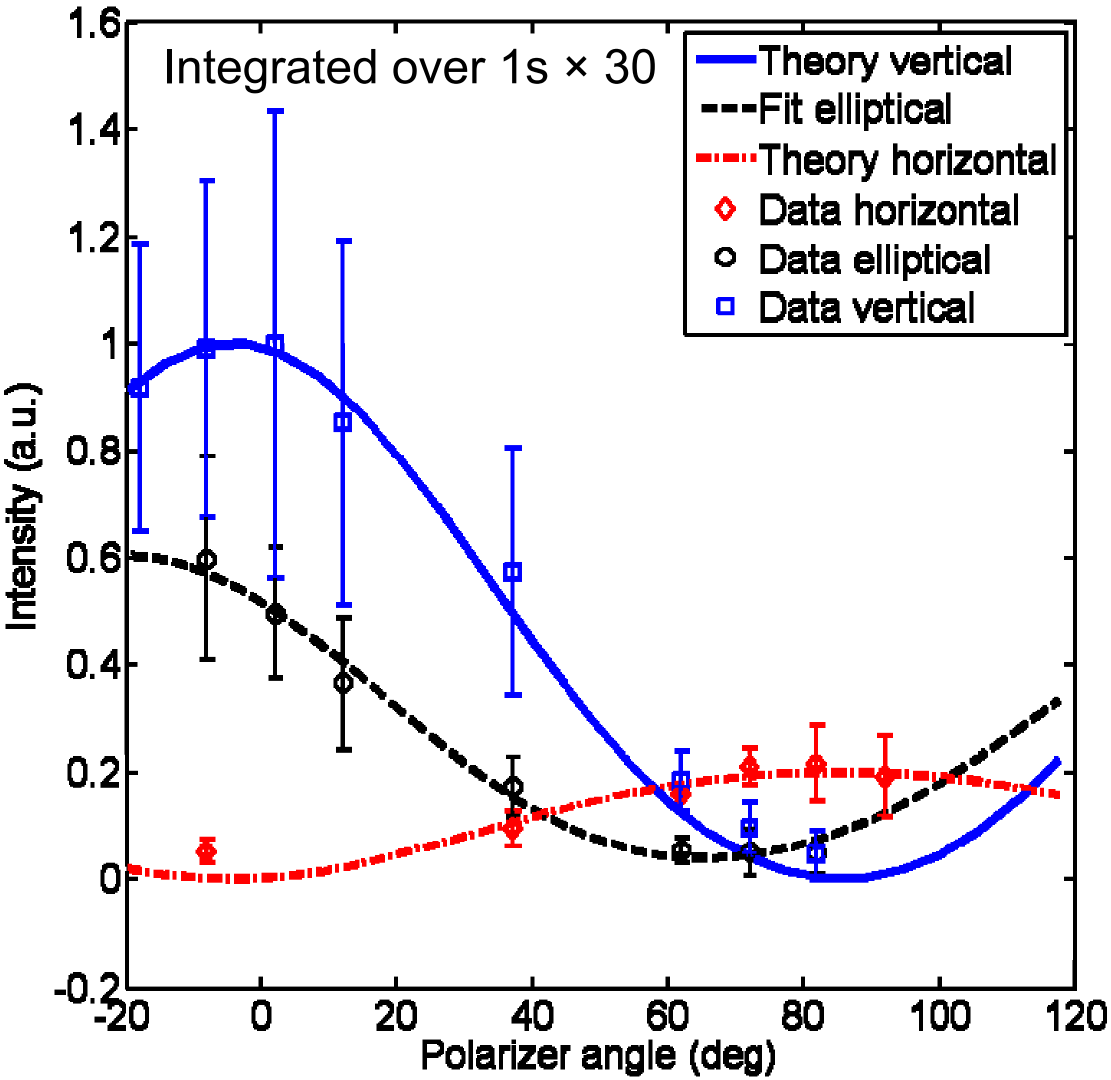
Determine transmission coefficients for the horizontal / vertical polarization



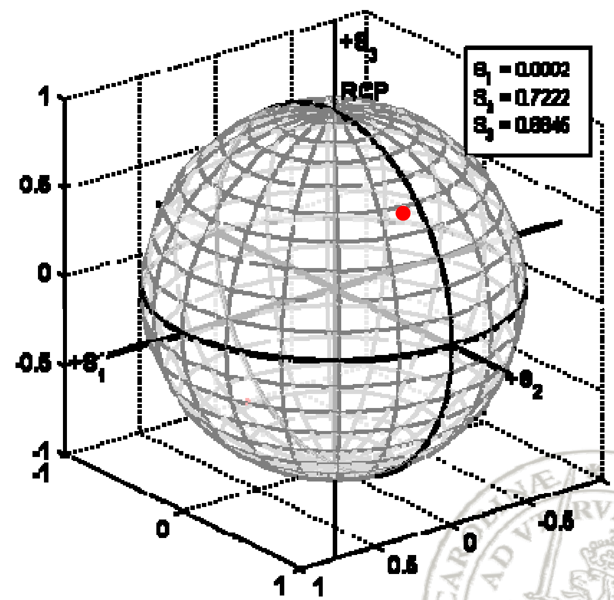


Reflectivities for horizontal polarization state:
Spherical mirror: 0.85
Toroidal grating: 0.53

Coherent emission



- Data fits well to curves
- Large error due to RF instability
- ”circular” polarization state is significantly elliptical!



Summary

- Demonstrated coherence of the seeded FEL emission:
  fringe visibility of $\upsilon = 0.67$ was observed

- Used a Rochon prism as a polarizer at 131 nm to measure polarization state, polarization state was found to be elliptical..
  possible reasons: Misalignment of the electron trajectory

- Very few changes made to existing setup!

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Young's Double slit

Double slits cut into stainless steel foil, 4 different sizes:
40µm x 400µm , 40µm x 800µm, 100µm x 400µm, 100µm x 800µm

Intensity at distance *z* behind slit: $$I(x) = I_0 \left(\frac{sin(k_d x)}{k_d x} \right)^2 (1 + \nu cos(k_D x)) + I_b$$

with $k_d = \frac{\pi d}{\lambda z}$ $k_D = \frac{2\pi D}{\lambda z}$ and $\nu = \frac{2\sqrt{I_1 I_2}}{I_1 + I_2} |g_{12}|$

d: size of the slits, D: slit distance

complex degree of coherence (↑ $|g_{12}|$)

Jones formalism

Complex amplitude of electric field of light traveling in z-direction:

$$\vec{E}(z,t) = \begin{pmatrix} \tilde{E}_x \\ \tilde{E}_y \end{pmatrix} e^{i(kz-\omega t)}$$

Jones vector: $\vec{J} = \begin{pmatrix} \tilde{E}_x \\ \tilde{E}_y \end{pmatrix}$

Jones vectors for vertical, horziontal and elliptical polarization:

$$J_V = \begin{pmatrix} 1 \\ 0 \end{pmatrix},\ J_H = \begin{pmatrix} 0 \\ 1 \end{pmatrix},\ J_E = \begin{pmatrix} cos(\Theta)e^{i\alpha_x} \\ sin(\Theta)e^{i\alpha_y} \end{pmatrix}$$

$$\vec{J}_{out} = \begin{pmatrix} 1 & 0 \\ 0 & y \end{pmatrix} \begin{pmatrix} cos(\theta)^2 & cos(\theta)sin(\theta) \\ cos(\theta)sin(\theta) & sin(\theta)^2 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ 0 & x \end{pmatrix} \vec{J}_{in}$$

Intensity: $I = |J_{x,out}|^2 + |J_{y,out}|^2$