Coherence measurements at P04

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Collaboration between:
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Axel Rosenhahn (Analytical Chemistry Group, Ruhr-University Bochum)
Ivan Vartanyants (Coherent Imaging Group)
Outline

- Theory of spatial coherence measurements

- First P04 experiment
  - Comparison of NRAs and Double Pinholes

- Second P04 experiment
  - Additional investigation with NRAs

- Summary
Spatial coherence

\[\text{Intensity} \downarrow \quad \text{Coherence Factor} \downarrow\]

*Incoherent field*

*Coherent field*
Young's Experiment

Double pinholes diffraction intensity distribution $I(q)$

Fourier transform of $I(q)$
Young’s Experiment

J.W. Goodman, Statistical optics

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Young’s Experiment

J.W. Goodman, Statistical optics

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Non-Redundant Array of Slits

1 experiment with 5 slits

= 10 experiments with 2 slits

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P04 beamline (PETRA III) experiment

A  Undulator tuned to 400 eV

Undulator

Plane mirror

Exit slits

Aperture

Detector

Exit slit openings: 40 µm and 230 µm

* Vacuum chamber constructed by Hans Peter Oepen group (Hamburg University)
Data: Typical Intensity Scans

NRA

Double pinholes

Detector plane  Fourier Transform
Data: Typical Intensity Scans

NRA

Double pinholes

Detector plane

Fourier Transform

Second harmonics (monochromator)
Data: Typical Intensity Scans

NRA

Double pinholes

Detector plane

Fourier Transform

Second harmonics (monochromator)
Data: Typical Intensity Scans

Detector plane

$I(q)$

Momentum transfer $q$, $\mu$m$^{-1}$

Fourier Transform

$\hat{I}(\Delta x)$

Slits separation $\Delta x$, $\mu$m

NRA

Double pinholes

$I(q)$

Momentum transfer $q$, $\mu$m$^{-1}$
Data: Beam Profile Scans

- Performed on double pinholes separated by 15 µm
- FWHM found with double Gauss functions fits

Exit slit 40 µm

Exit slit 230 µm
Results: NRA & D.P. are identical

E = 400 eV

Exit Slit width 40 µm

\[ l_{c}^{\text{NRA}} = 4.3 \pm 0.2 \, \mu\text{m} \]
\[ l_{c}^{\text{DP}} = 3.8 \pm 0.2 \, \mu\text{m} \]
\[ \zeta^{\text{NRA}} = 0.41 \pm 0.04 \]
\[ \zeta^{\text{DP}} = 0.38 \pm 0.03 \]

Exit Slit width 230 µm

\[ l_{c}^{\text{NRA}} = 2.3 \pm 0.1 \, \mu\text{m} \]
\[ l_{c}^{\text{DP}} = 2.1 \pm 0.1 \, \mu\text{m} \]
\[ \zeta^{\text{NRA}} = 0.06 \pm 0.01 \]
\[ \zeta^{\text{DP}} = 0.06 \pm 0.01 \]
P04 beamline experiment

- Exit slit cut out 396.5, 400 and 403 eV fraction of the beam
- Beam defining slit opening varied

* Vacuum chamber constructed by Hans Peter Oepen group (Hamburg University)
Beam defining slit variation

$E = 396.5\ eV,\ 400\ eV,\ 403\ eV$

Exit Slit width 230 $\mu m$

Features of coherence dependence on beam defining slit opening observed
Aim – measure spatial coherence prior to ptychography experiment
Second experiment at P04

Undulator energy
500 eV

Exit slit opening
1. 50 μm
2. 100 μm
3. 200 μm

NRA orientation
a. Horizontal
b. Vertical

* HORST chamber constructed by Axel Rosenhahn group (Ruhr-University Bochum)
P04 diffraction patterns

Typical diffraction image

Fourier transform

Area for further analysis
P04 Vertical coherence

Exit slit:

- 50 μm
  - FWHM = 7 μm
  - Coherence:
    - \( l_c = 7.5 \) μm
    - \( \zeta = 0.73 \)

- 100 μm
  - FWHM = 12.6 μm
  - Coherence:
    - \( l_c = 4.2 \) μm
    - \( \zeta = 0.37 \)

- 200 μm
  - FWHM = 29.5 μm
  - Coherence:
    - \( l_c = 2.4 \) μm
    - \( \zeta = 0.10 \)
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Coherence measurements at P04  13.06.2014

**P04 Horizontal coherence**

**Exit slit:**
- 50 μm
- 100 μm
- 200 μm

**FWHM estimated as 100 μm**
<table>
<thead>
<tr>
<th>Energy</th>
<th>NRA Direction</th>
<th>Exit slits separation</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>50 µm</td>
</tr>
<tr>
<td>500 eV</td>
<td>Vertical</td>
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<td>P04</td>
<td>$l_c = 8.1$ µm</td>
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<td>U49</td>
<td>$l_c = 2.3$ µm</td>
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<td>P04</td>
<td>$\zeta = 0.80$</td>
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<tr>
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<td>P04</td>
<td>$l_c = 12.5$ µm</td>
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<td>$\zeta = 0.15$</td>
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<tr>
<td></td>
<td>U49</td>
<td>$\zeta = 0.03$</td>
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Conclusions

1. NRA allows to measure full spatial coherence function in one exposure
2. Results with NRAs and double pinholes are identical
3. NRA method works especially well with large beams
4. This approach can be effectively used prior to any coherent imaging experiment
5. May be useful for measuring single pulse coherence properties of FELs
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Thank you for your attention!
S1. Temporal coherence

[Diagram showing radiation passing through a double pinhole and a detector]
S2. Two-dimensional NRA

S3. Non-uniformity of coherence
S3. Non-uniformity of coherence

![Graph showing non-uniformity of coherence with data points and lines indicating measurements at different scales in μm (50, 100, 200).]
S4. More data on coherence

Energy:
- 396.5 eV
- 400 eV
- 403 eV