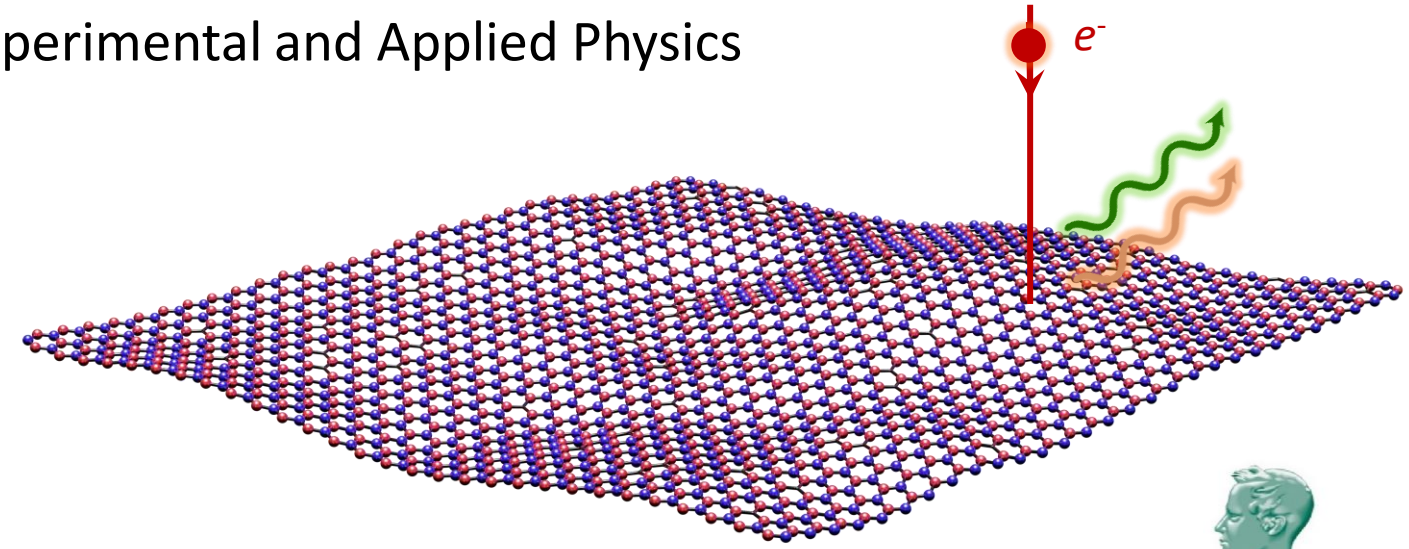
Quantenüberlagerung und Interferenzen bei Elektron-Licht-Wechselwirkungen

Nahid Talebi

Institute for Experimental and Applied Physics
Kiel University



UltraSpecT
(Consoidator Grant)

NanoBeam
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UltraCoherentCL
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FETProactive Ebeam

Deutsche Forschungsgemeinschaft

Alexander von Humboldt
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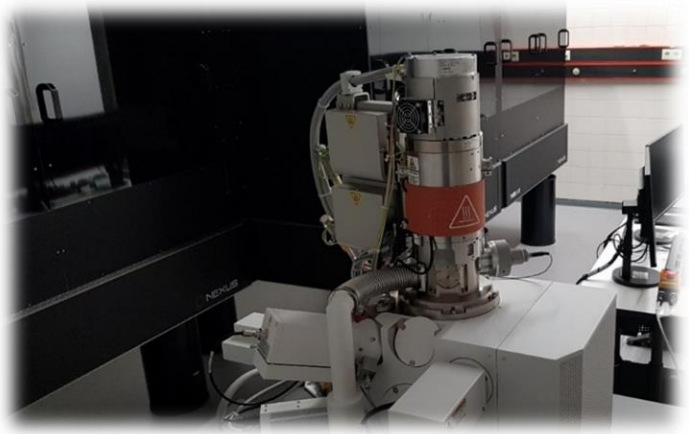
C A U Christian-Albrechts-Universität zu Kiel
Mathematisch-Naturwissenschaftliche Fakultät

Nano-Optik-Forschung an der Universität Kiel

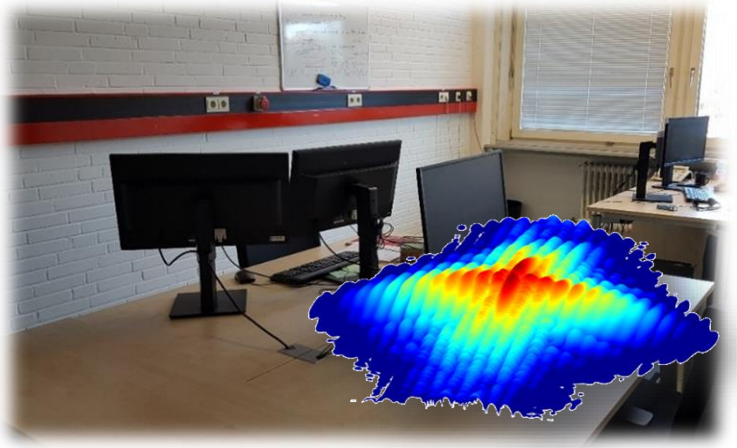
Ultraschnelle Elektronenspektroskopie

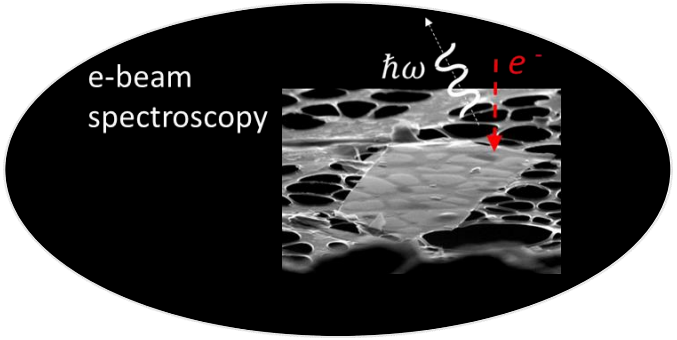


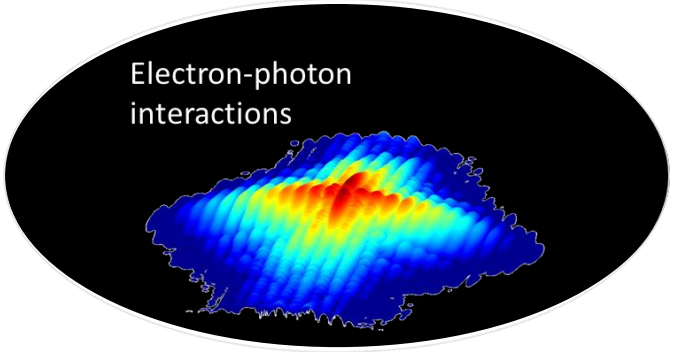
Kathodolumineszenz Spektroskopie

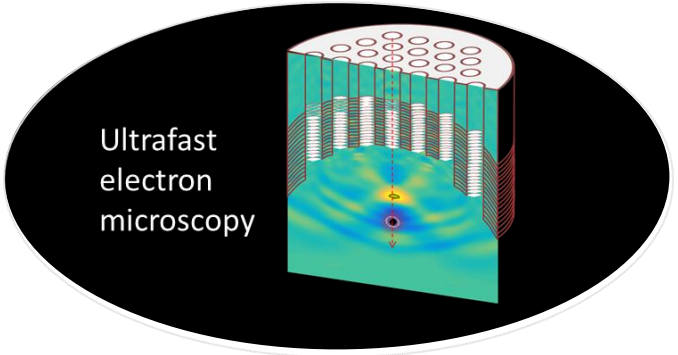
Dunkelfeld Spektroskopie

Numerische Entwicklungen

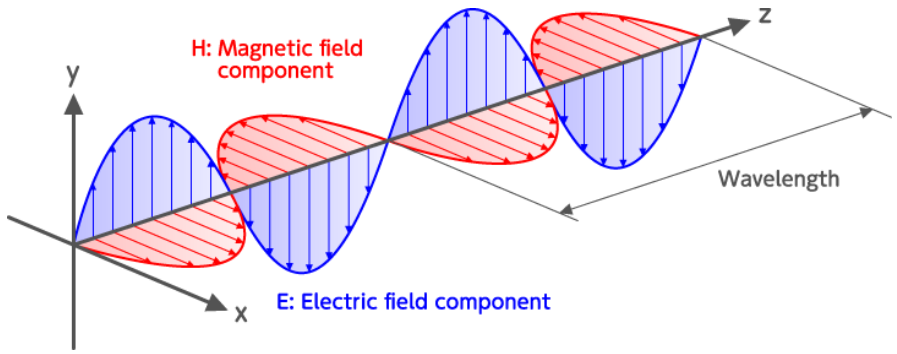




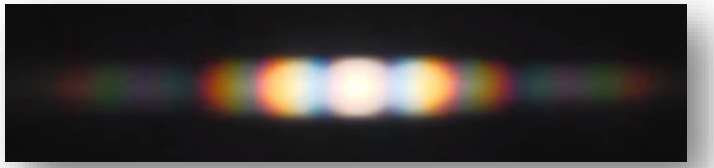


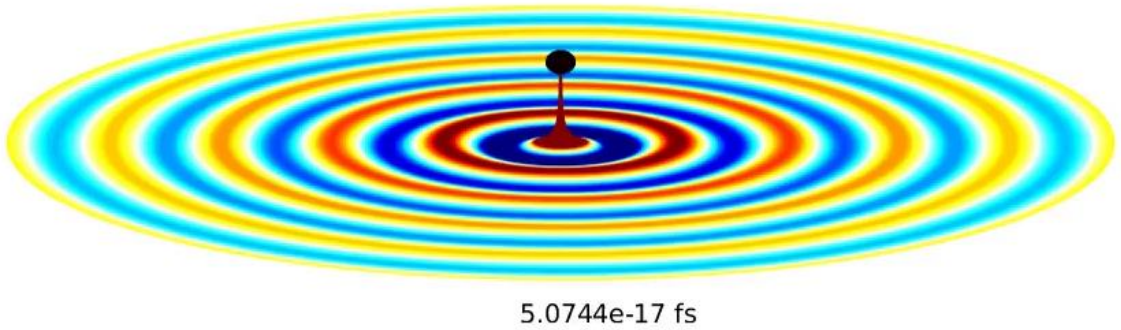


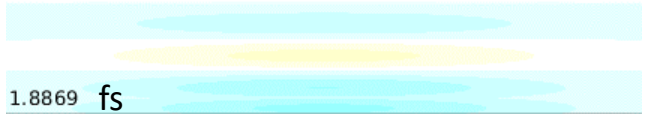
Licht als Welle (Klassische Lichttheorie)



James Clerk Maxwell (1864)



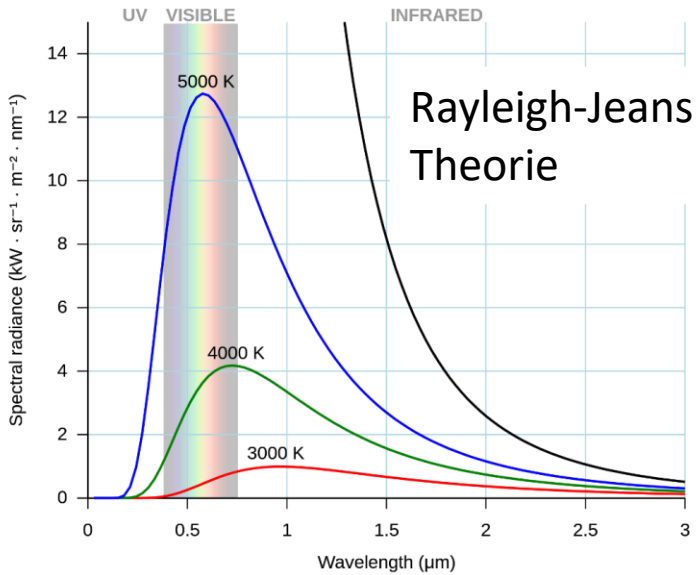




Doppelspaltexperiment

Licht als Teilchen

Ultravioletten Katastrophe



Rayleigh-Jeans Theorie

Die Lichtenergie ist quantisiert:

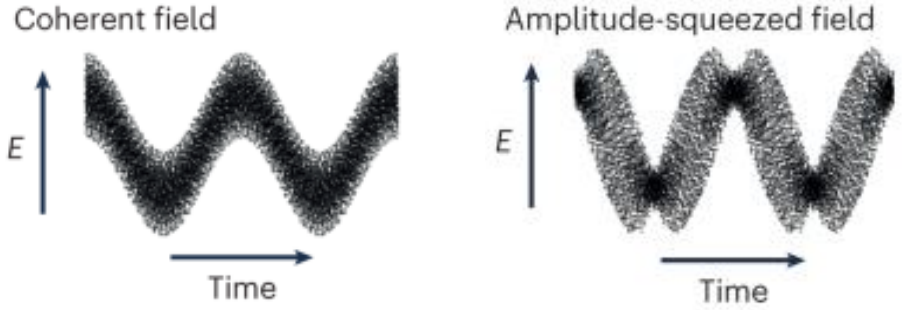
$$E_n = \left(n + \frac{1}{2}\right) h\nu$$

h: Planck-Konstante: 6,62607015× 10^{-34} J s

Photon: Ein Photon ist die kleinste unteilbare Einheit (Teilchen) von Licht, mit der quantisierten Energie $h\nu$.

Max Planck (1900)

Quantenzustände von Licht:

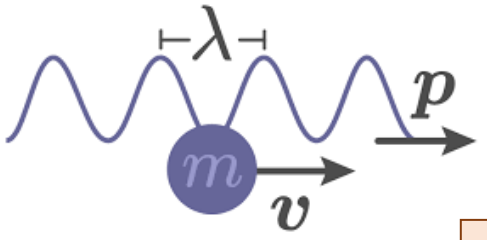


Nature Photonics **17** (2023) 463

Materie als Welle

Wellenlänge — Planck-Konstante — Geschwindigkeit — Masse

$$\lambda = \frac{h}{m \cdot v}$$



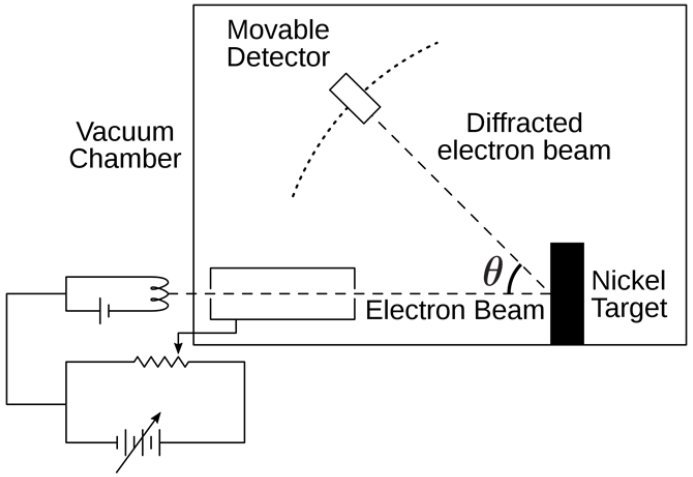
Für Elektron:

$$\begin{cases} v = 0,3c \\ m = 9,109 \cdot 10^{-31}\,\text{kg} \end{cases}$$

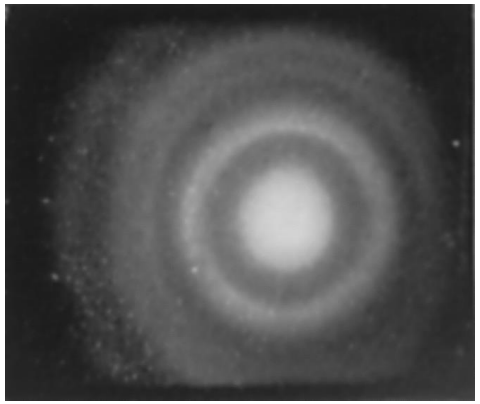
$$\Rightarrow \quad \lambda = 8,08\,\text{pm} = 8,08 \times 10^{-12}\,\text{m}$$

Louis-Victor de Broglie (1924)

Experimente sollten dieses Konzept überprüfen.



Davisson, et. Al, *Nature* **119** (1927) 558



Proceedings of the Royal Society A **117** (1928) 778

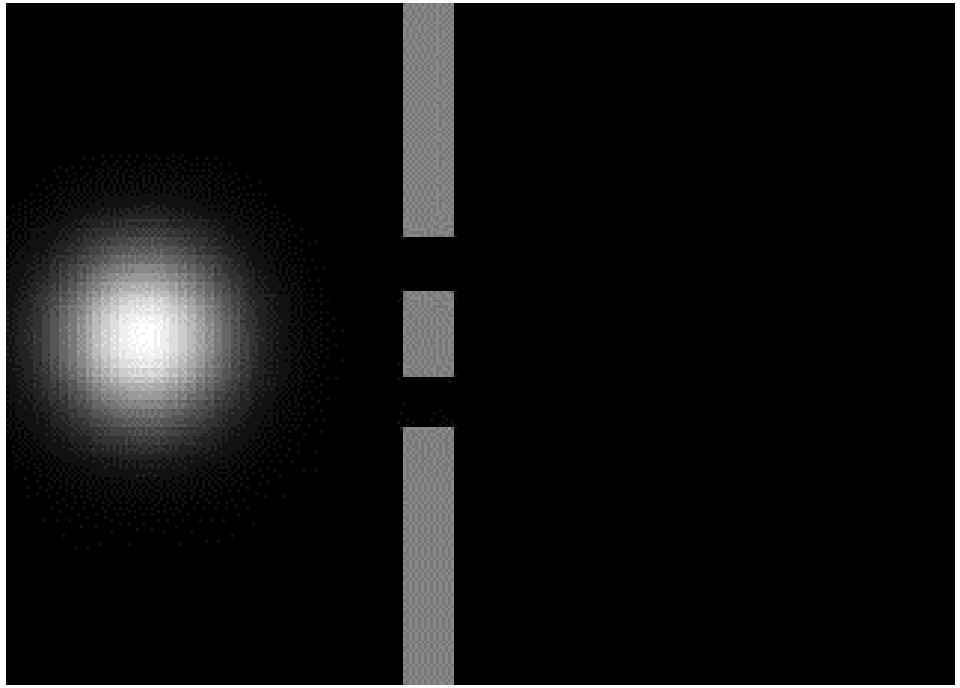
The Nobel Prize in Physics 1937

Photo from the Nobel Foundation archive.
Clinton Joseph Davisson
Prize share: 1/2

Photo from the Nobel Foundation archive.
George Paget Thomson
Prize share: 1/2

Theoretische Model

- Das Wellenverhalten von Quantenteilchen wird durch die Schrödinger-Gleichung beschrieben.



Überlagerungsprinzip

$$\psi = \psi_1 + \psi_2$$

Erwin Schrödinger (1926)

$\psi(\text{Raum}, \text{Zeit})$: Wahrscheinlichkeitsamplitude (Wellenfunktion), die angibt, die Elektronen zu einem bestimmten Zeitpunkt und an einem bestimmten Ort zu finden!

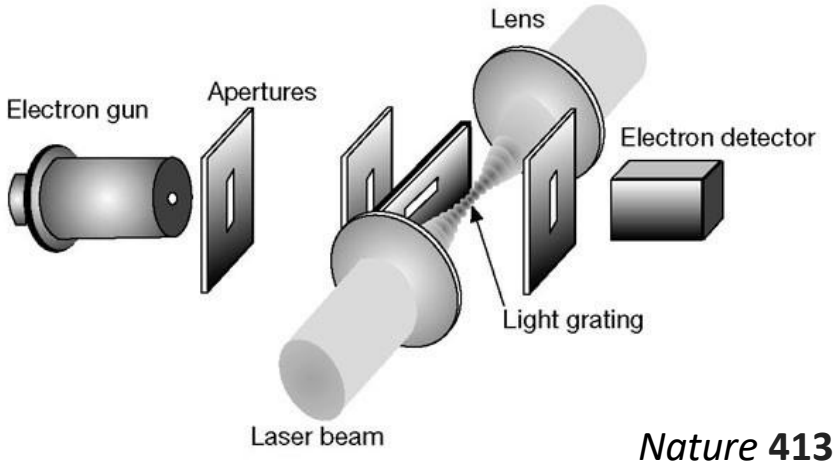
$|\psi(\text{Raum}, \text{Zeit})|^2$: Wahrscheinlichkeit

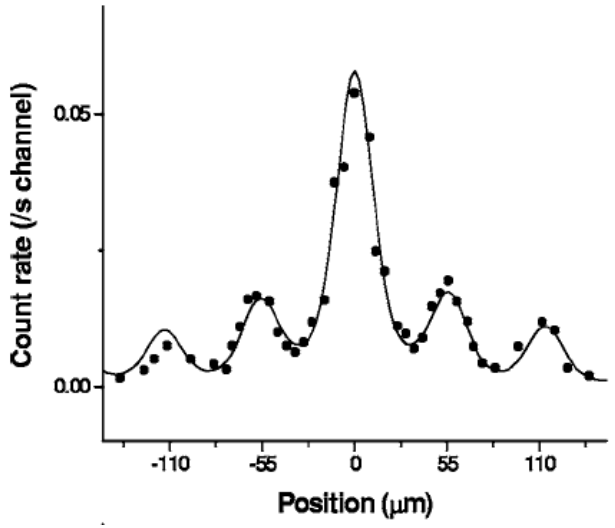
Elektron-Photon-Wechselwirkungen: Kapitza-Dirac Effekt

The reflection of electrons from standing light waves. By P. L. KAPITZA, Ph.D., Trinity College, Messel Professor of the Royal Society, and Professor P. A. M. DIRAC, St John's College.

[*Received* 24 March, *read* 1 May 1933.]

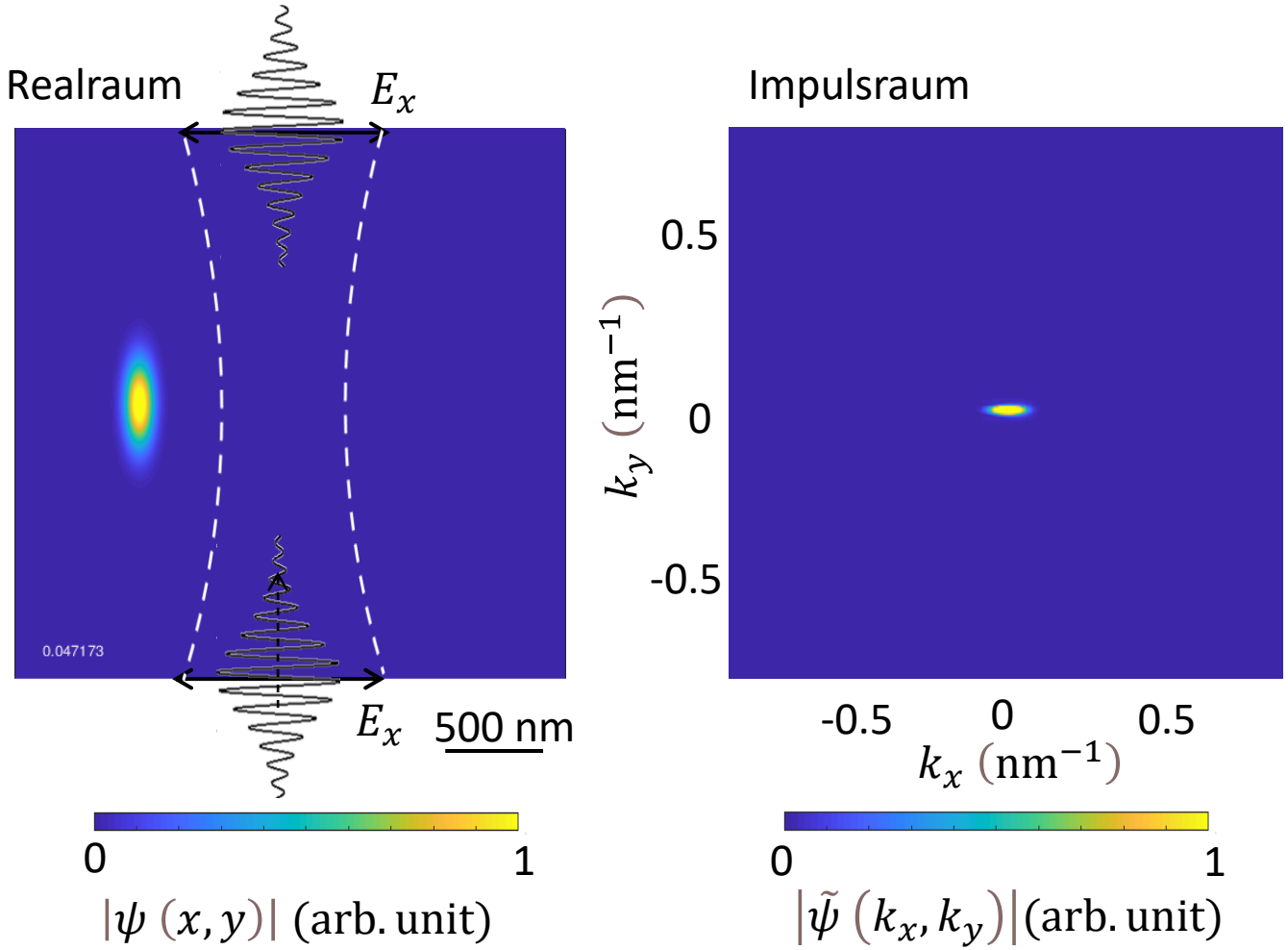
It is well known that a beam of light falling on a reflecting mirror forms standing waves. This effect has been very beautifully made use of in Lippmann's colour photography process. The standing light waves, in this case, produce a periodic effect in the emulsion of the photographic plate which, when developed, scatters light and produces a similar colour effect. Instead of using a beam of light, it would seem possible to scatter electrons from the emulsion and obtain a reflection of electrons similar to that of a space grating. But it seemed to us that it would be of much greater interest to consider an experiment in which electrons are reflected from the standing waves of light. The direct scattering of free electronic waves by light has strictly never been observed, and it was thought possible that by this method, owing to the interference of the electrons and to the fact that the scattered electrons are focussed to one spot, the magnification of the phenomenon would be sufficient

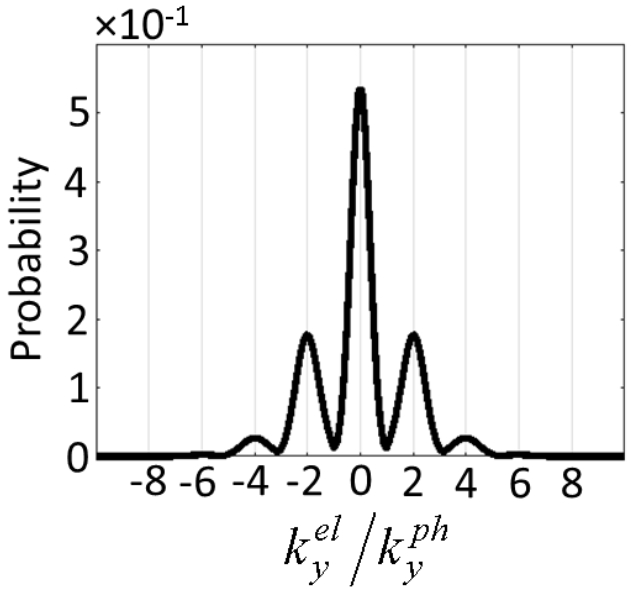




Nature **413** (2001) 142–143

Kapitza-Dirac Effekt: Simulation





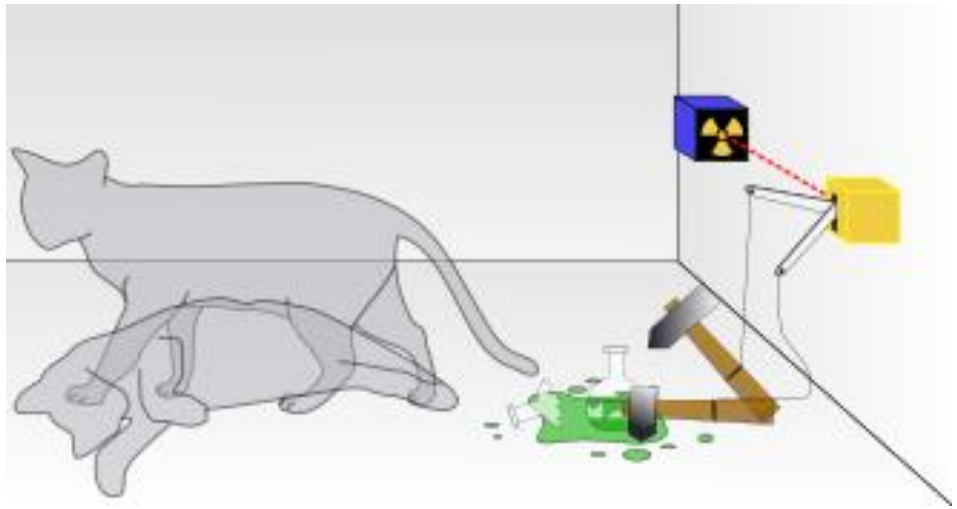
"Near-Field-Mediated Photon-Electron Interactions," *Springer series in Optical Sciences,* (2019)

J. Opt. **19** (2017) 103001

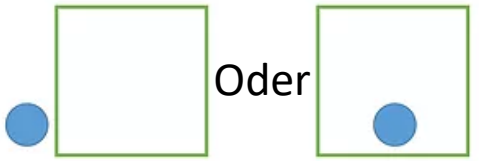
Schrödinger’s Cat und Überlagerungsprinzip

Einstein–Podolsky–Rosen paradox

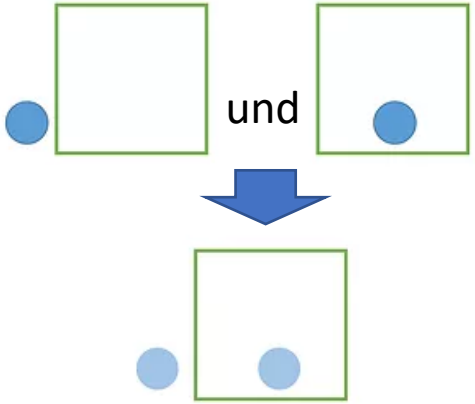
In einer vollständigen Theorie gibt es ein Element, das jedem Element der Realität entspricht. Eine hinreichende Bedingung für die Realität einer physikalischen Größe ist die Möglichkeit, sie mit Sicherheit vorhersagen zu können, ohne das System zu stören.



klassische Teilchen

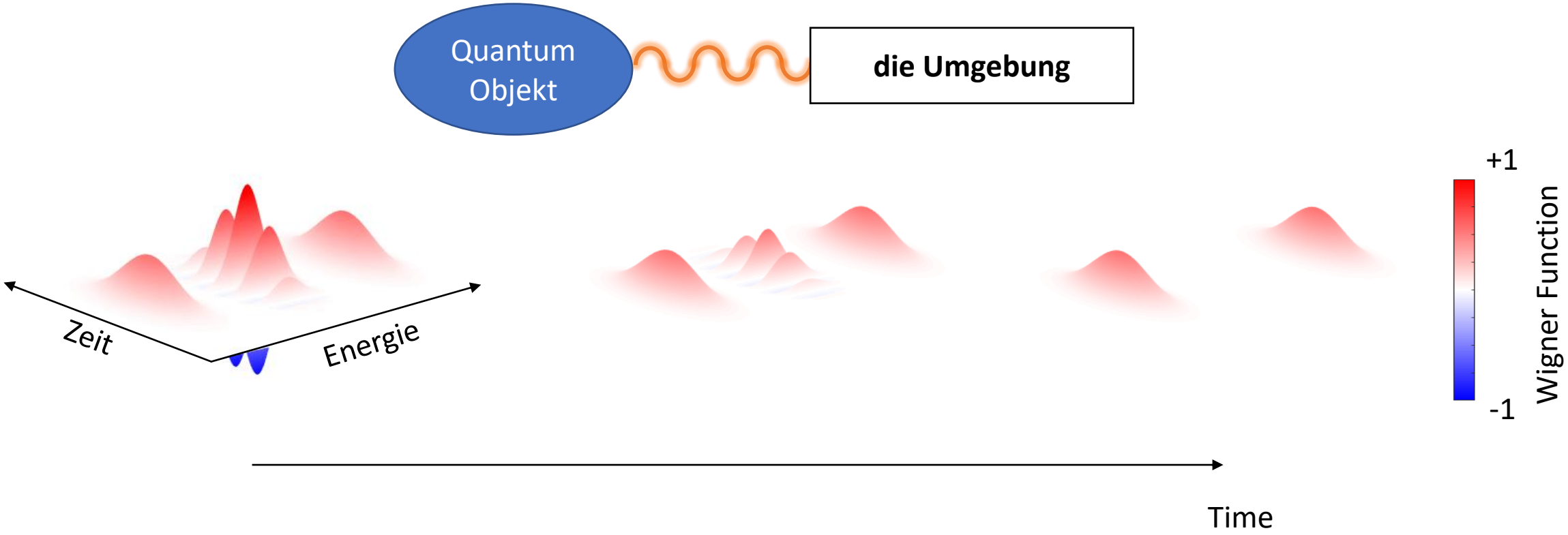


Quantenmechanische Teilchen

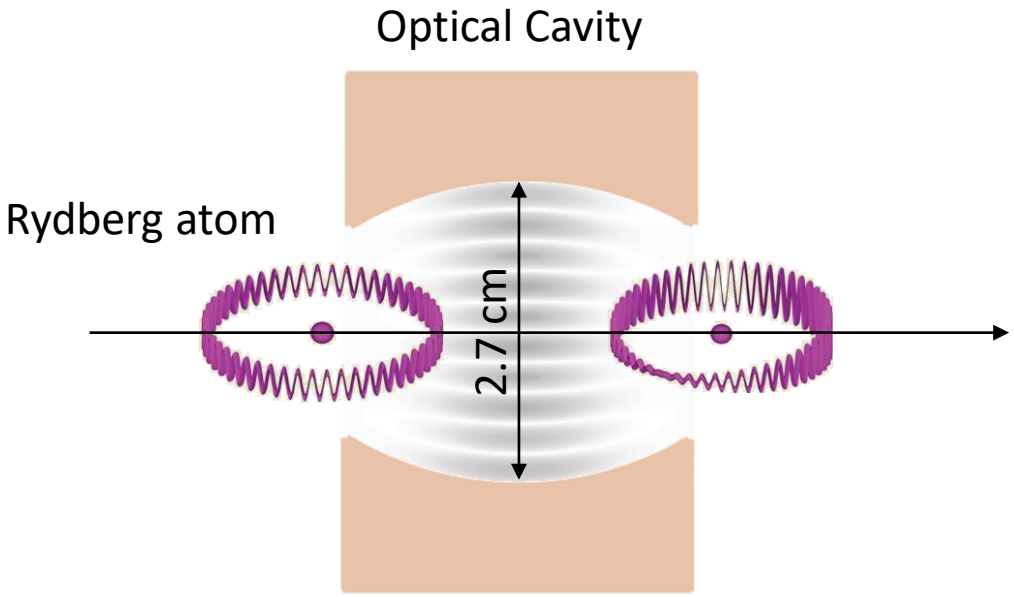


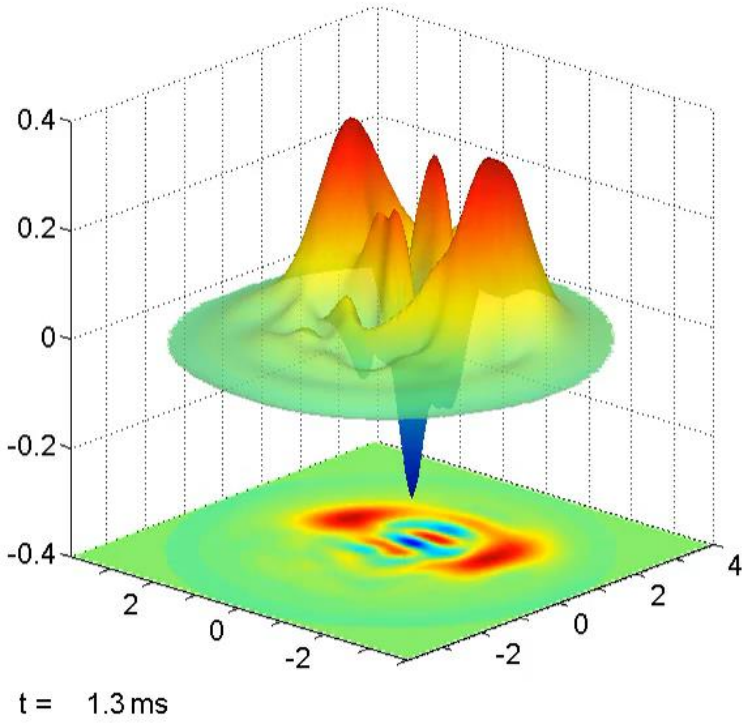
- Kann man eine Quantenüberlagerung makroskopischer Systeme wie einer Katze oder eines Menschen erzeugen?

Quantenüberlagerung und Dekohärenz



Dekohärenz - Mapping





© The Nobel Foundation. Photo: U. Montan

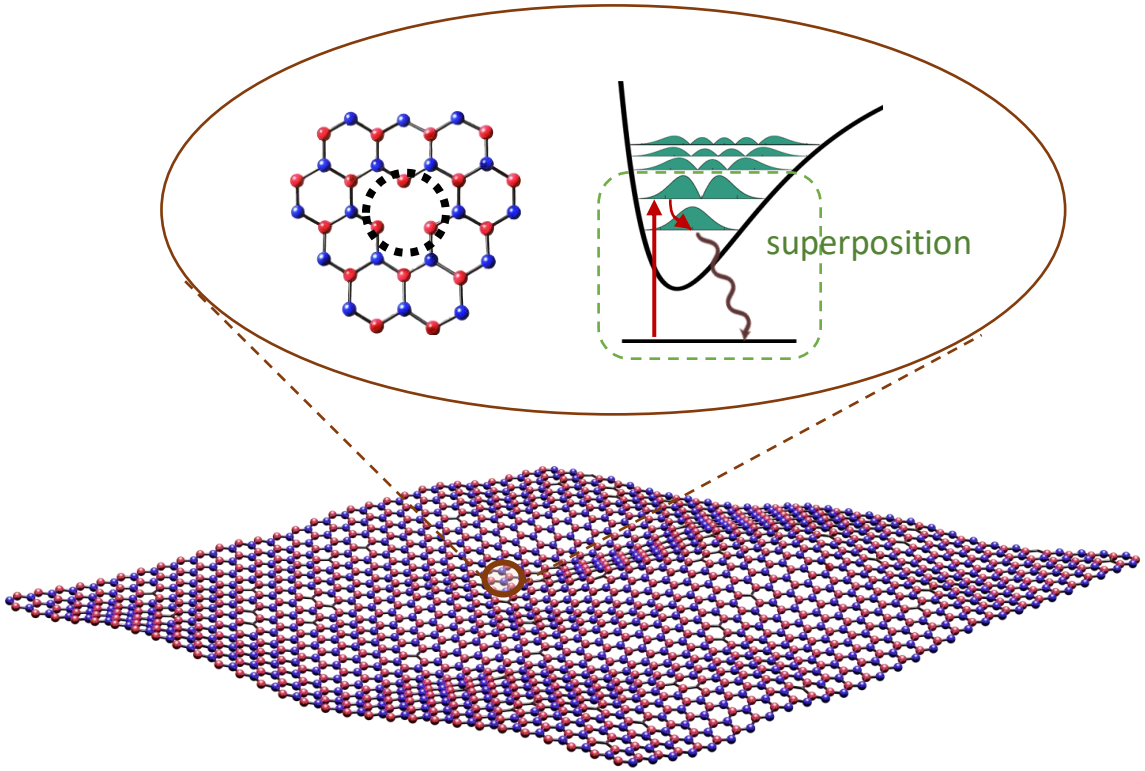
Serge Haroche

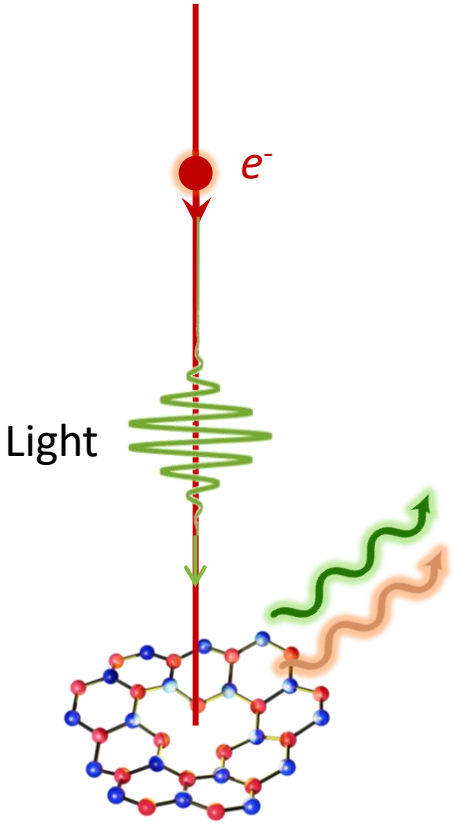
Prize share: 1/2

- Rydberg-atom beam
- Time resolution: millisecond

Nature **455** (2008) 510

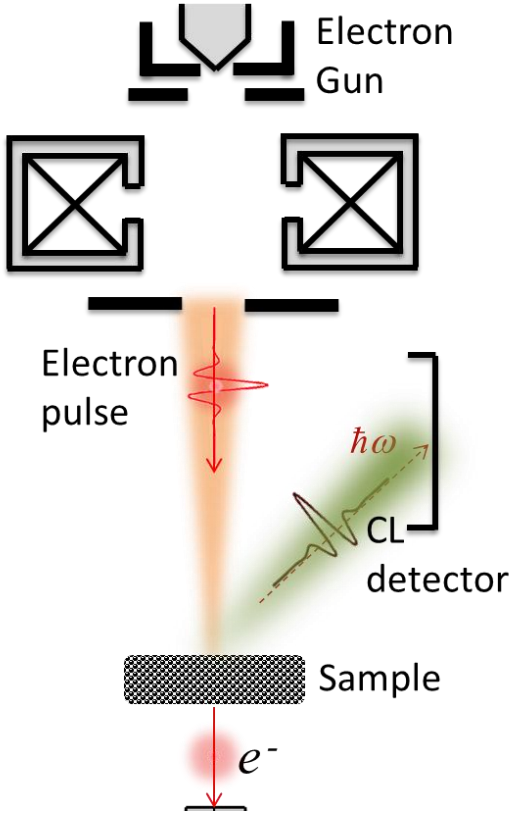
Dekohärenz-Kartierung mit Elektronenstrahlen

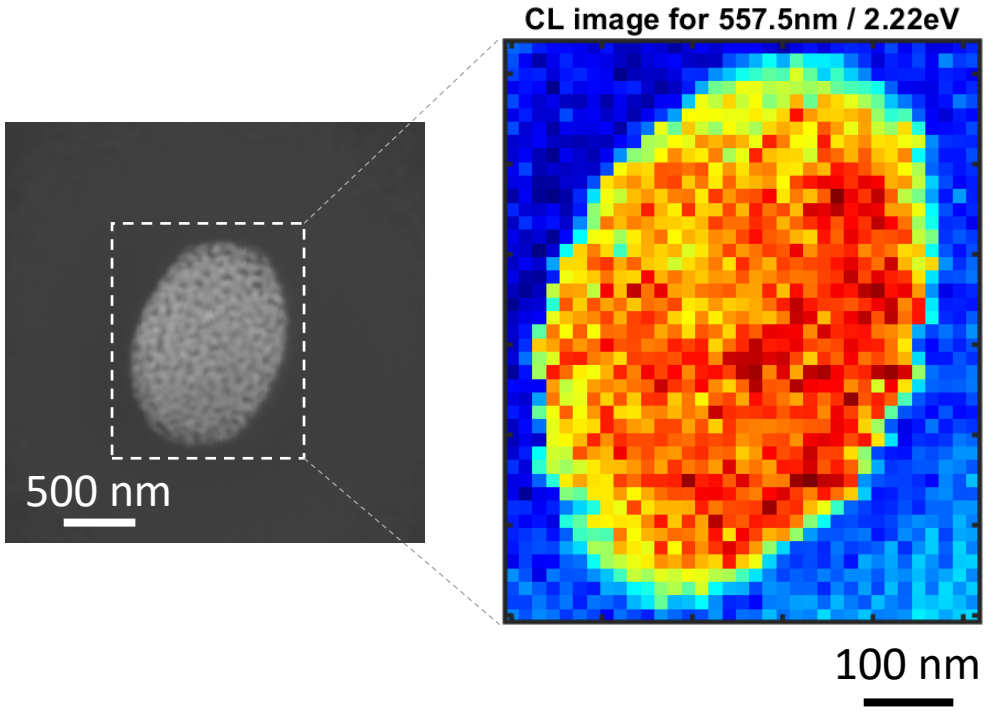




Atomic defect

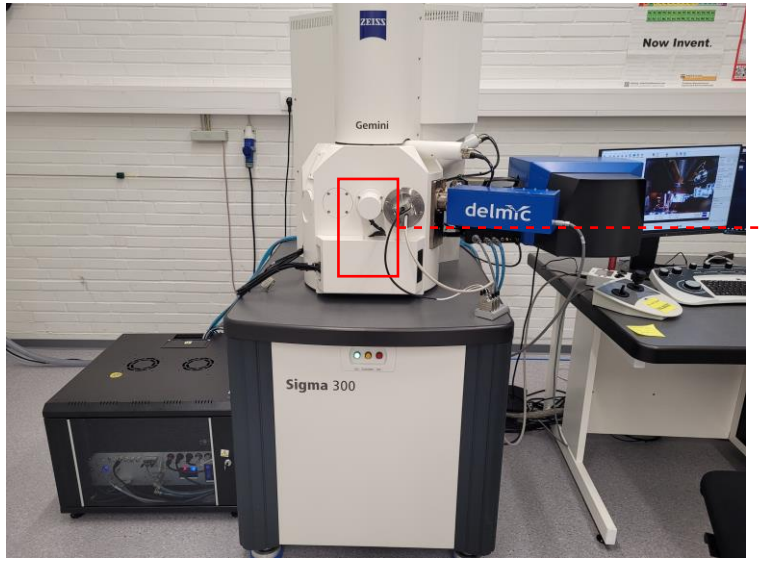
Warum Elektronen?

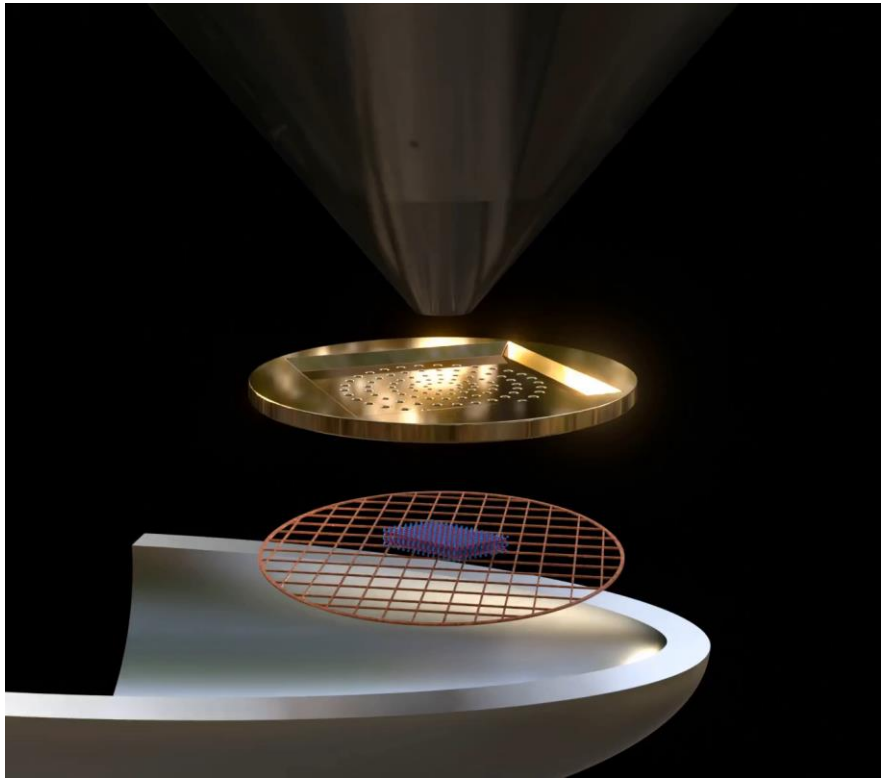




- Kathodolumineszenz ist das Licht, das bei der Wechselwirkung von Elektronenstrahlen mit Materie entsteht.
- Die Kathodolumineszenzspektroskopie ermöglicht die Charakterisierung des in Materie eingefangenen Lichts mit einer räumlichen Auflösung von etwa 1 nm.

Dekohärenz-Kartierung mit Elektronenstrahlen



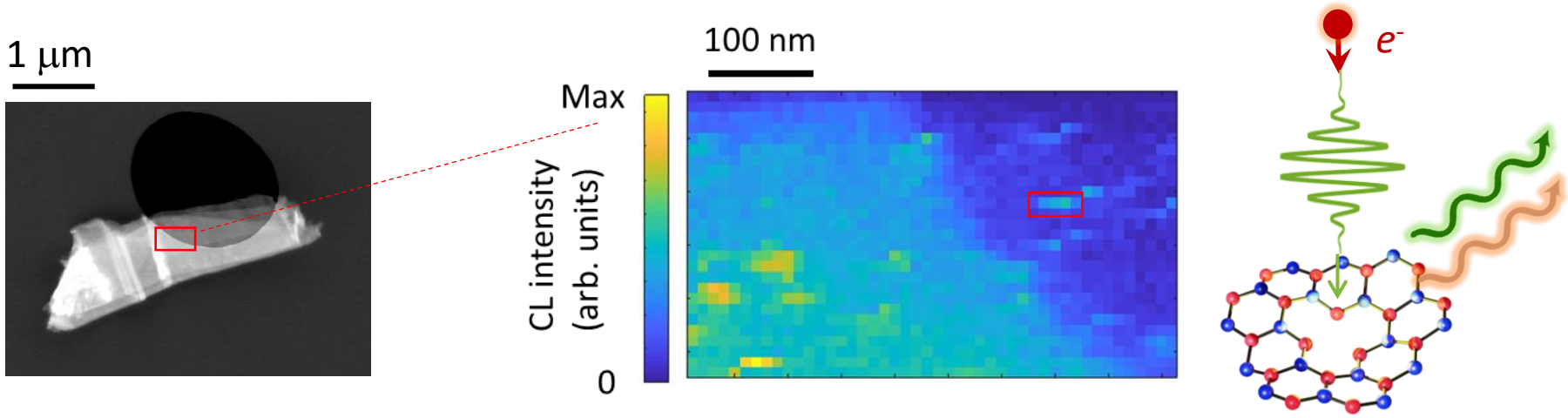


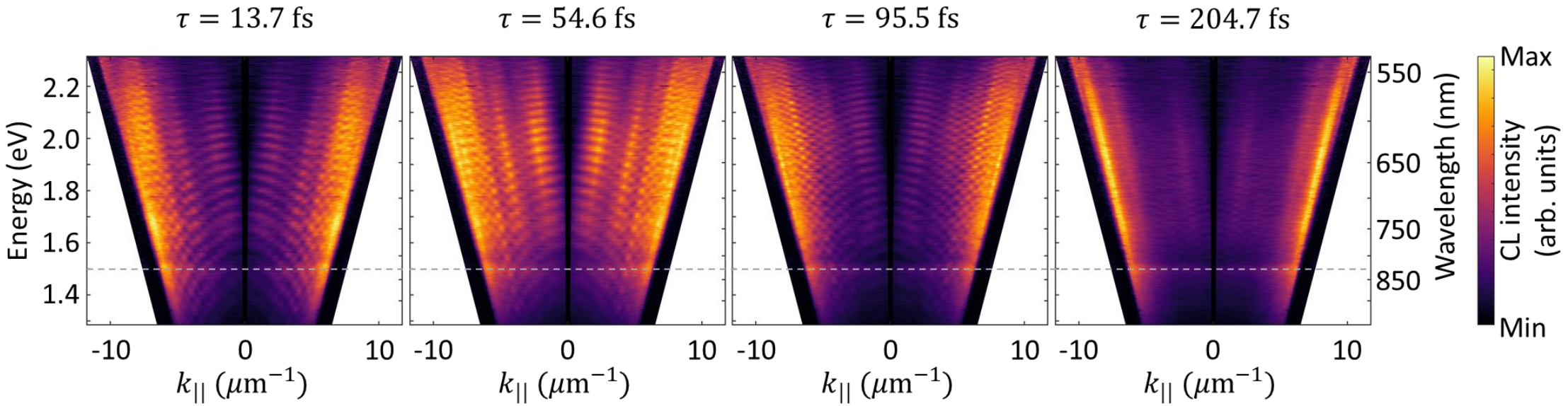
NanoBeam

Nature Physics **19** (2023) 869–876

Method and device for time-resolved pump-probe electron microscopy, International Patent PCT/EP2015/001509 (2016)

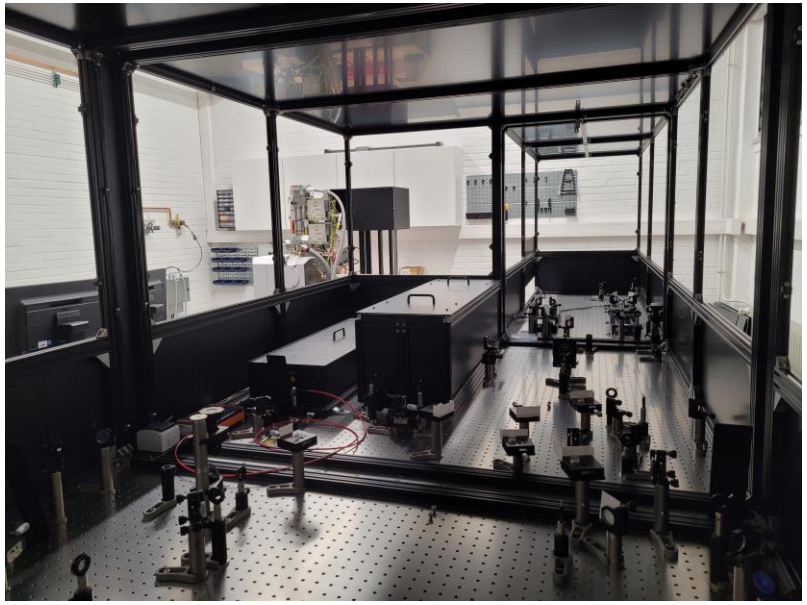
Decoherence Mapping with Electron Beams

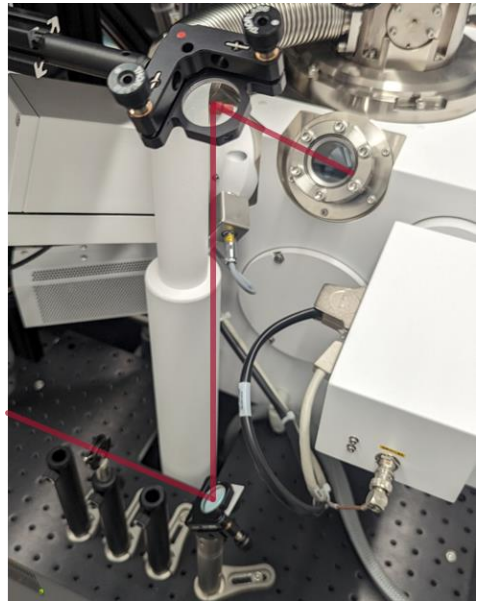


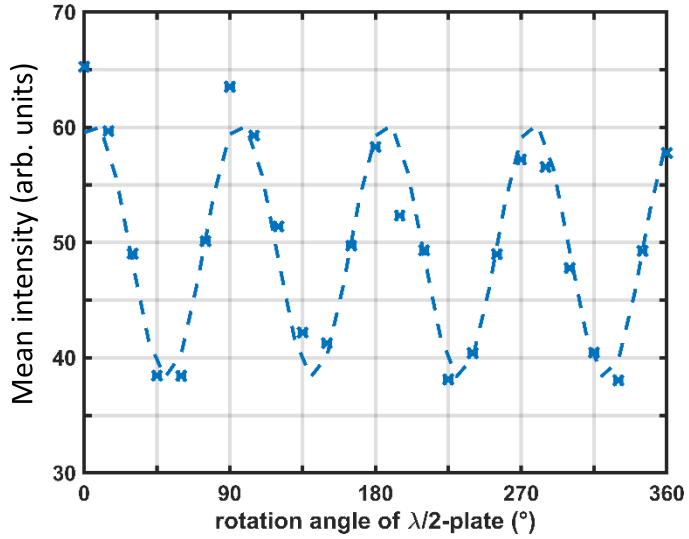


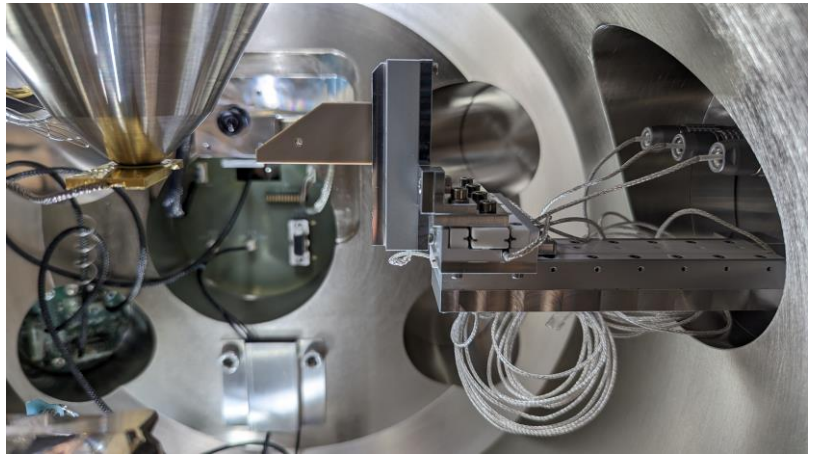
arXiv:2404.09879

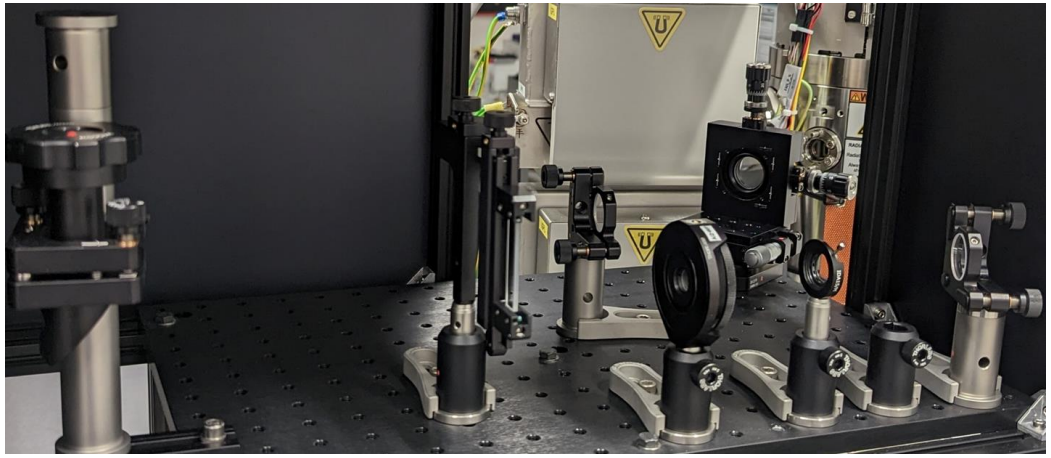
Ausblick: Die Kombination von Laser- und Elektronenstrahlen



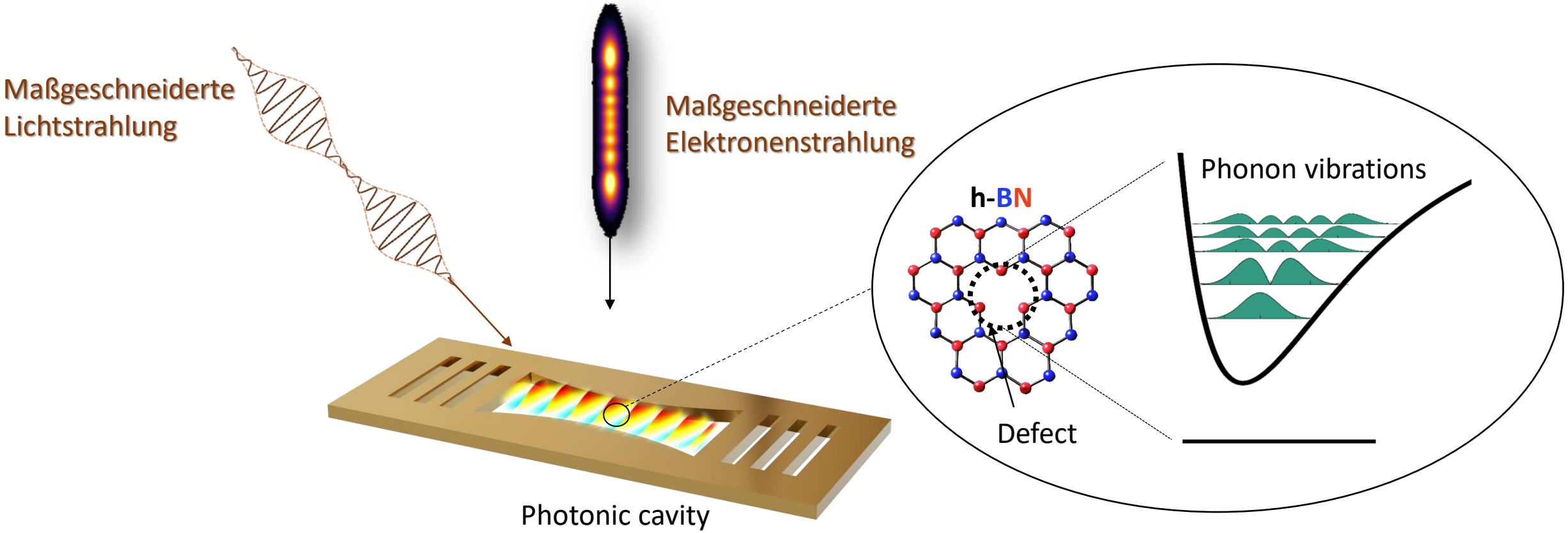








Nächste Schritte



“Everything is theoretically impossible, until it is done.” – Robert A. Heinlein.

Quantenphysik in AG Nanooptik

“The reward of the young scientist is the emotional thrill of being the first person in the history of the world to see something or to understand something. Nothing can compare with that experience.”
– Cecilia Payne-Gaposchkin

UltraSpecT
(Consoidator Grant)

NanoBeam
(Starting Grant)

UltraCoherentCL
(PoC-Grant)

FETProactive Ebeam

Alexander von Humboldt
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VolkswagenStiftung
(Momentum Grant)