# Towards atom diffraction through graphene

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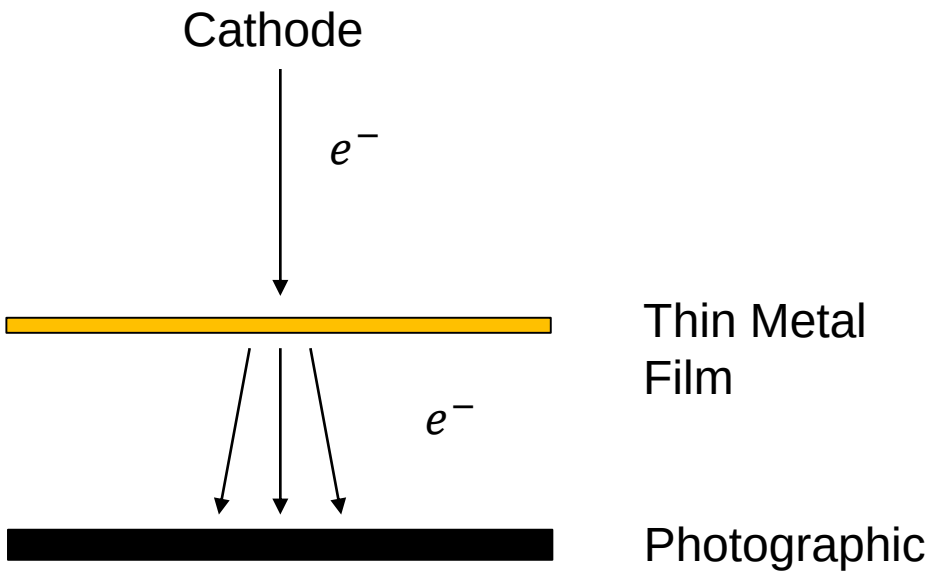
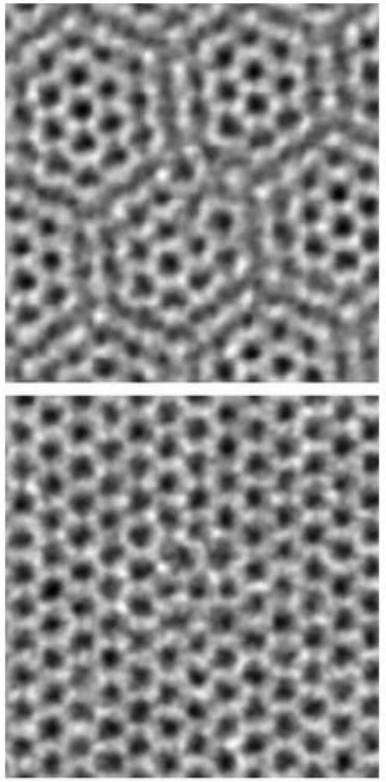
# From matter wave experiments to microscopy

G.P. Thomson’s electron diffraction experiment (1927)



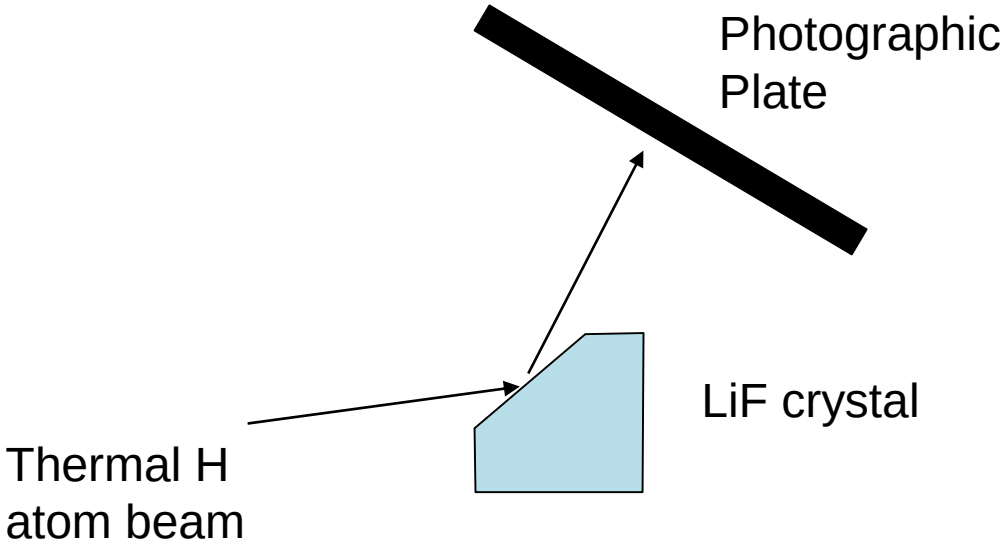

Transmission Electron Microscopy (TEM)



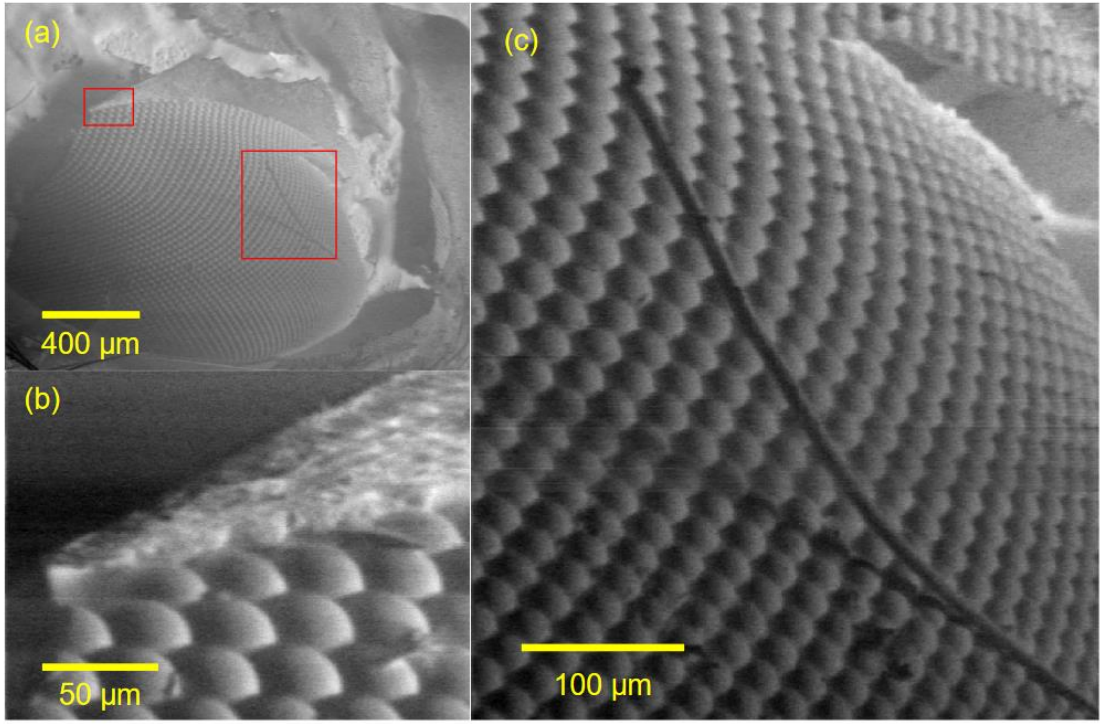
Uni-ulm.de, Zubeltzu et al, Phys. Rev. B 88, 245407 (2013)

# From matter wave experiments to microscopy

T.H. Johnson’s hydrogen diffraction experiment (1930)

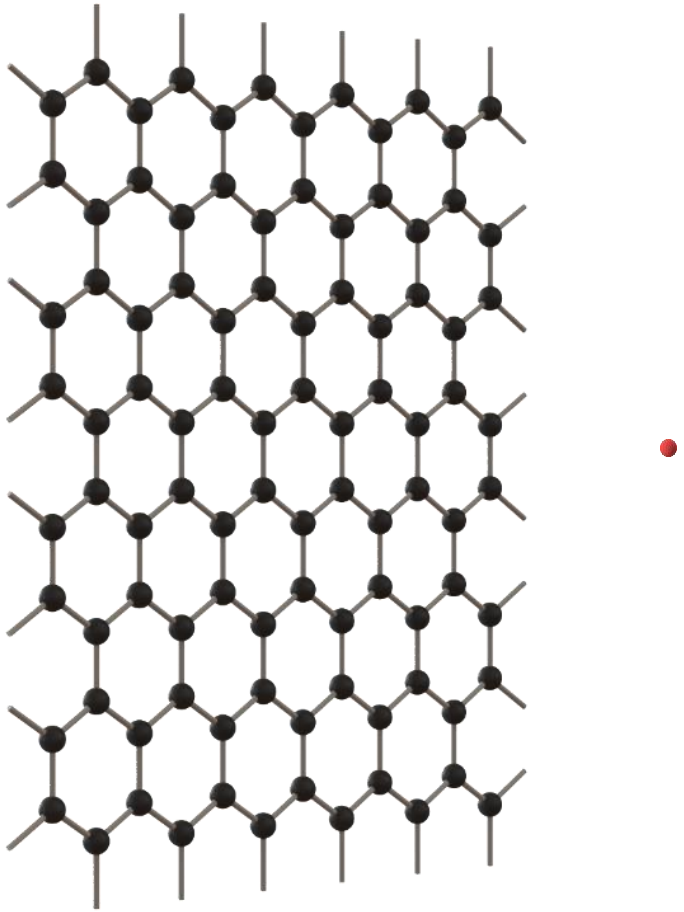



Scanning Helium Microscopy




M. Bergin PhD thesis University of Cambridge (2018)

# Atom transmission through 2D Material



2D Material of Choice: Graphene

- Robust
- Commercially available
- Interesting for numerous applications
- Small lattice spacing: 246 pm

Window for atom transmission through graphene:

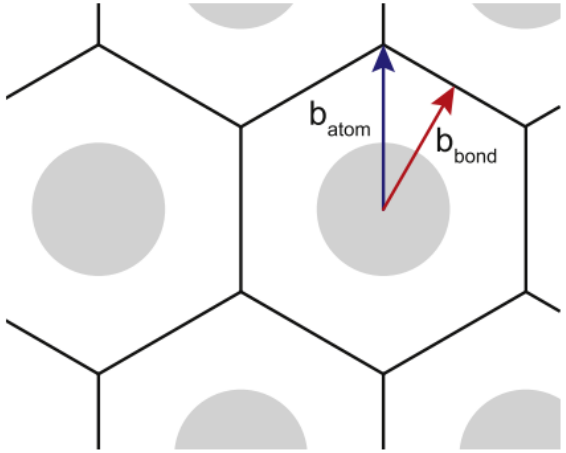
- Energy above potential barrier
  For hydrogen: $E > 3.75\ \mathrm{eV}$, $v > 27\,000\ \mathrm{m/s}$
- Energy below sputtering threshold
  For hydrogen: $E < 80\ \mathrm{eV}$, $v < 121\,000\ \mathrm{m/s}$

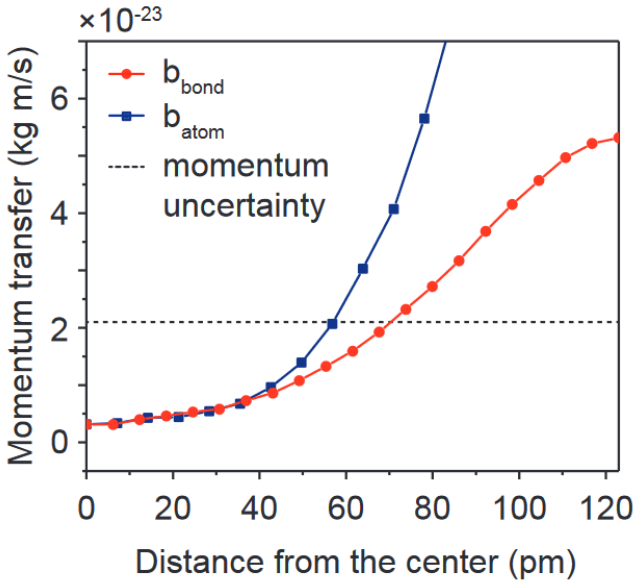
$$\lambda_{dB} = \frac{h}{\sqrt{2mE}} = 3.2 - 14.7\ pm$$

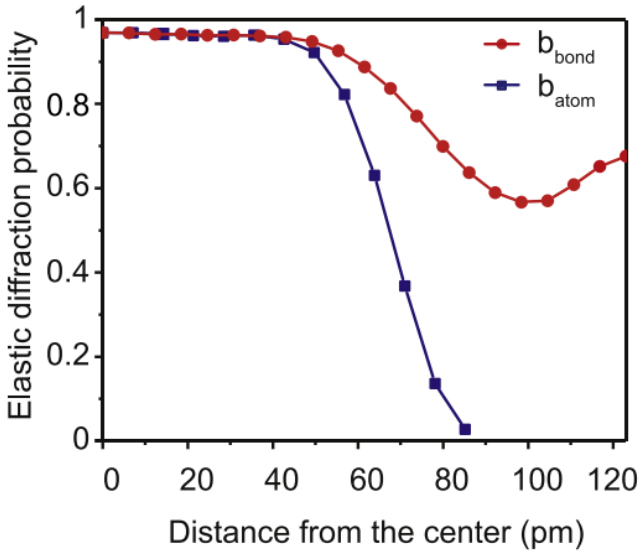
Brand *et al.*, New J. Phys. **21** 033004 (2019)

# Atom transmission through graphene

Coherent transmission



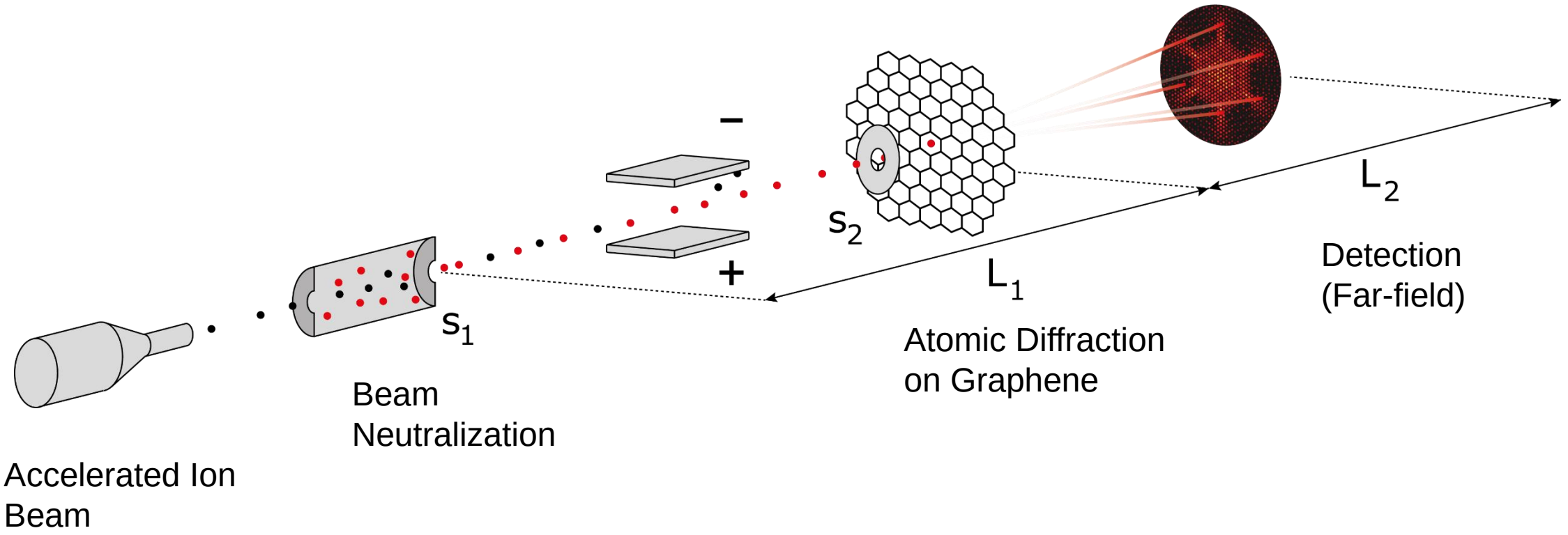




Results of ab initio calculations of molecular dynamics within the Born-Oppenheimer approximation

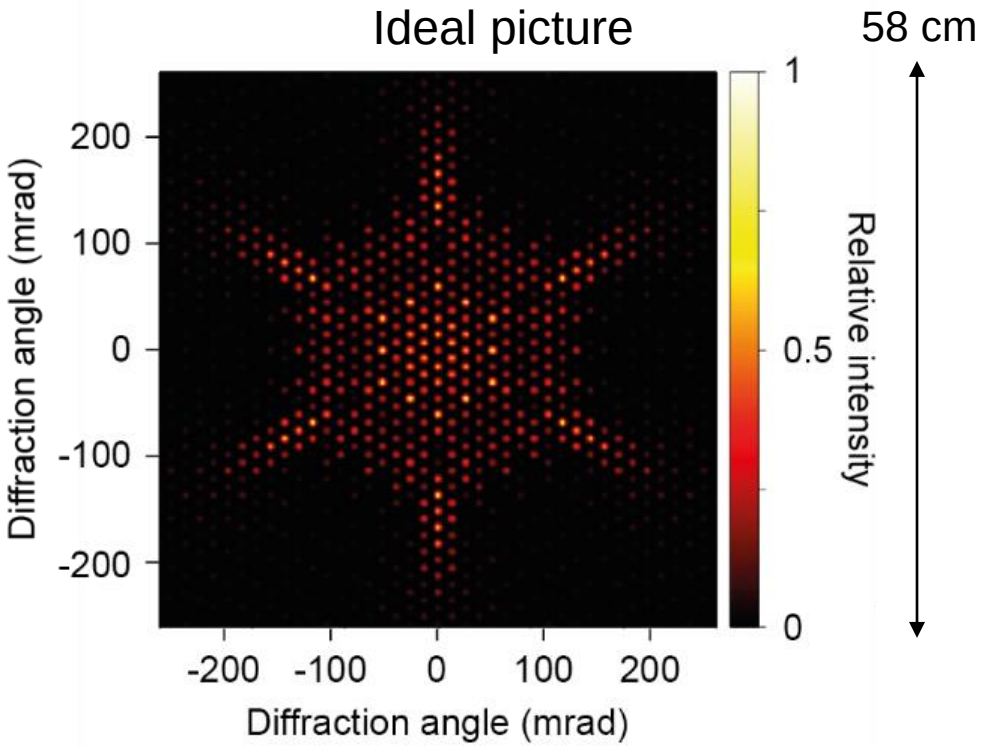
Brand *et al.*, New J. Phys. **21** 033004 (2019)

# Experimental principle



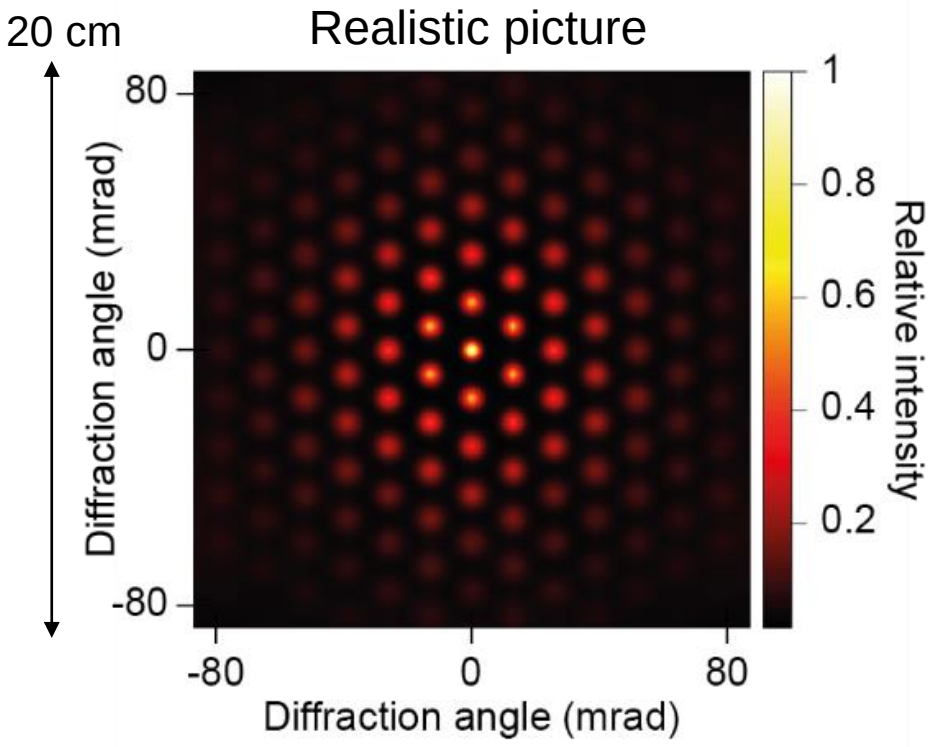

Brand *et al.*, New J. Phys. **21** 033004 (2019)

# Simulated detector signal




Decoherence induced by

- Thermal vibrations
- Finite beam coherence
- Inelastic interactions



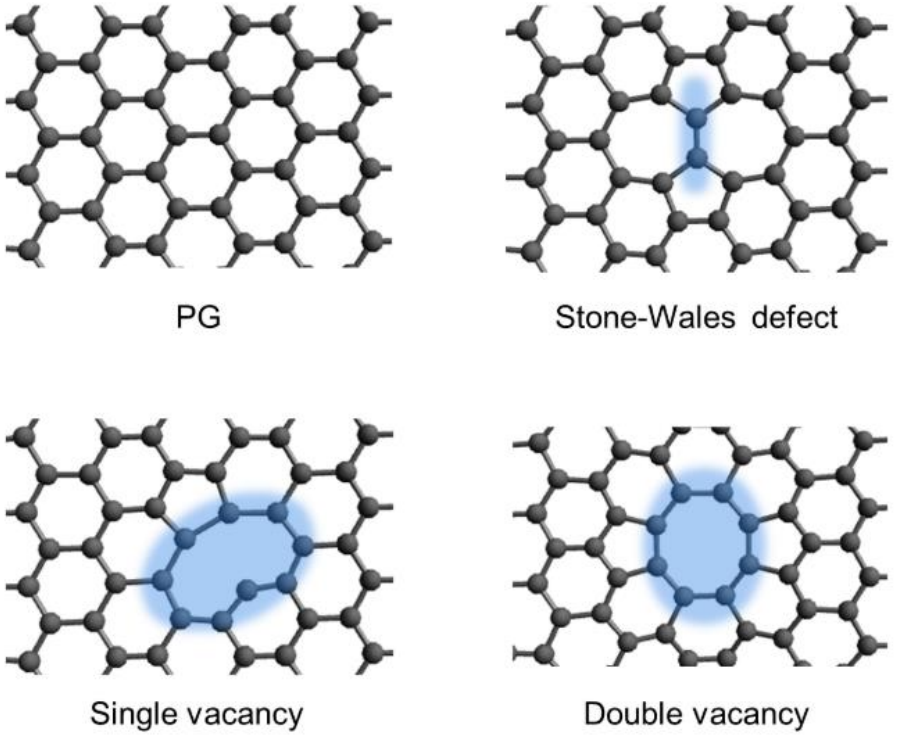

Brand *et al.*, New J. Phys. **21** 033004 (2019)

# Information extracted from diffraction pattern

- Lattice constant and periodicity
  - Of radiation-sensitive materials
  - Of organic membranes

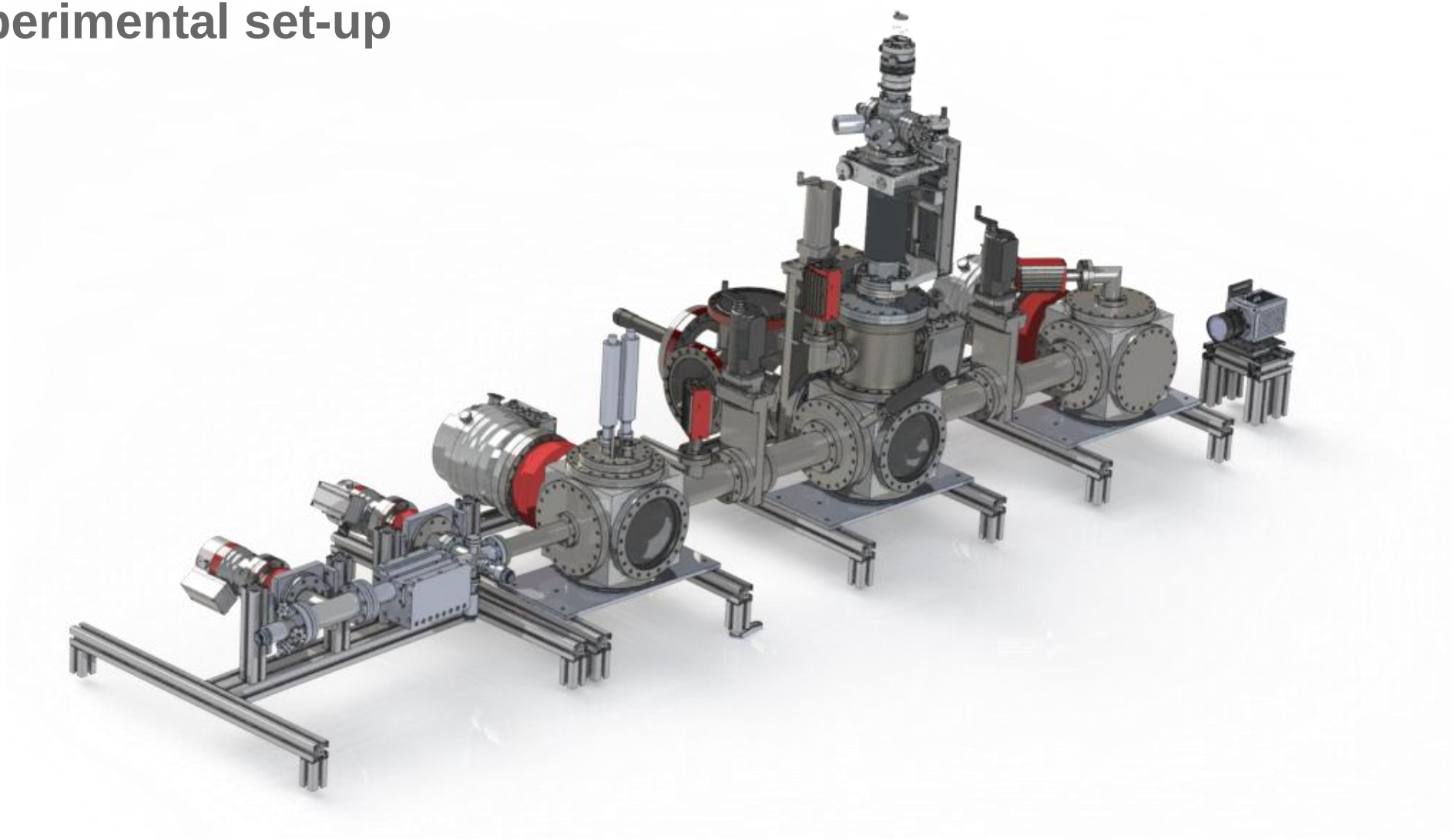
- Atom-membrane interaction:
  - Energy dependent transmission propability
  - Coupling to membrane‘s degrees of freedom

- Temporal evolution of membrane
  - Doping
  - Milling
  - Defect dynamics



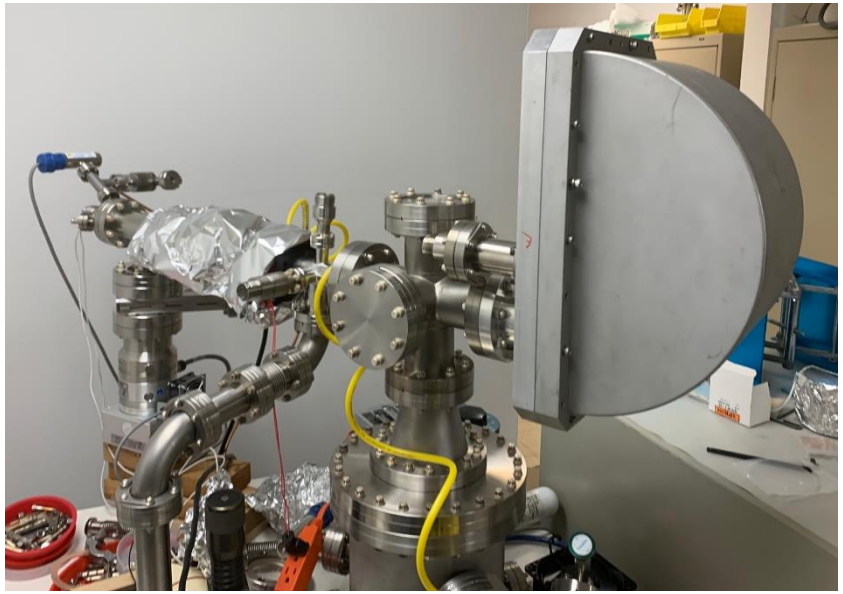

Lin. PhD thesis Aix Marseille Universite (2014)

# Experimental set-up

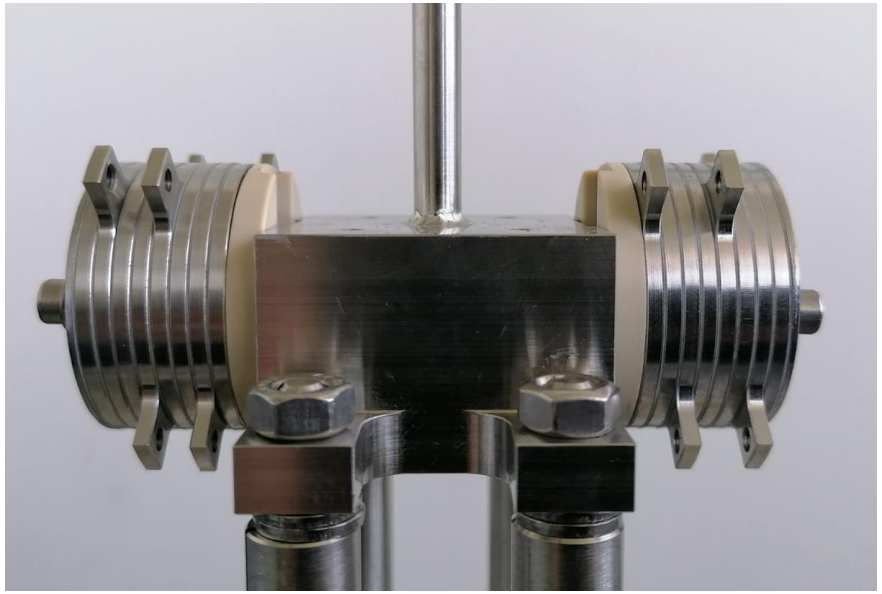


# Atom beam preparation

Ion Gun
- 5 to 3000 eV ion energy
- 100 nA ion current
- Operated with variable gases

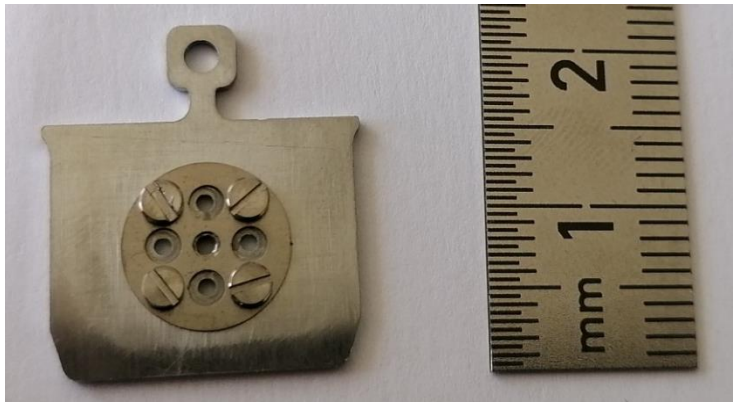


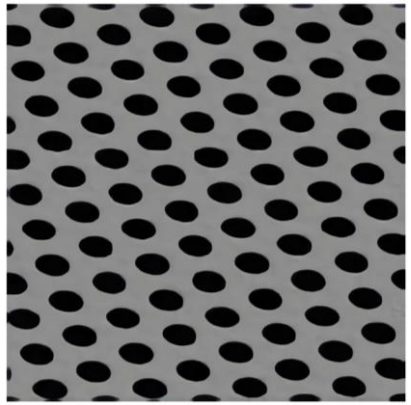
Charge Exchange Cell
- Resonant Charge Exchange with buffer gas (Ar)
- Beam steering and collimation



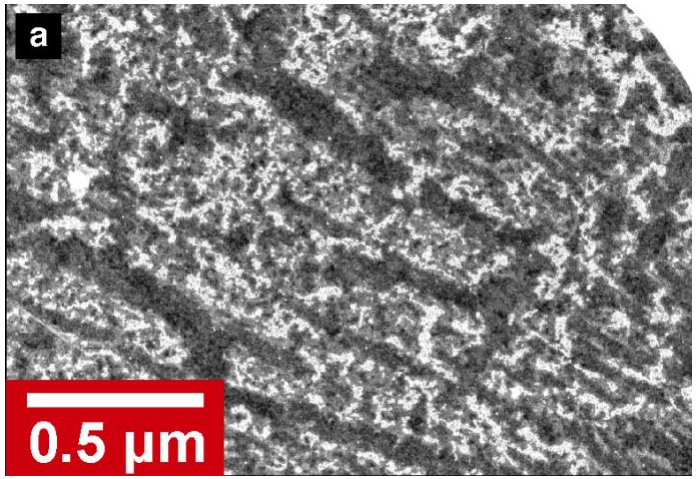
# Diffraction grating

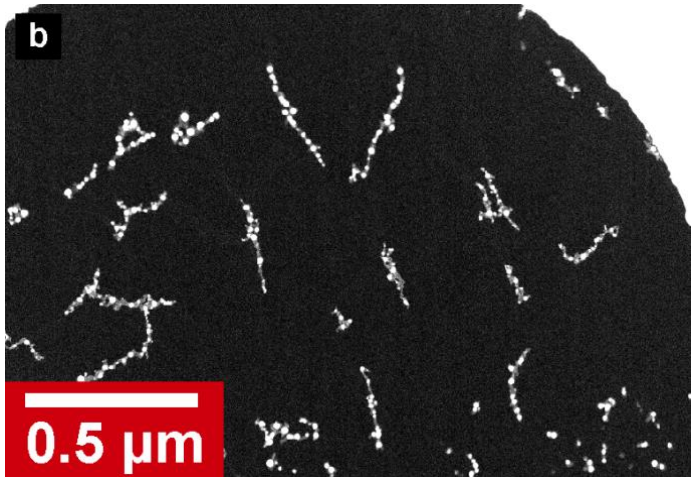
- Membranes mounted on TEM grids
- 2.5µm diameter holes of free standing graphene
- Probe mount:
  - 5 axis manipulation
  - liquid nitrogen cooling
  - heating up to 700°C



- Laser cleaning of membranes

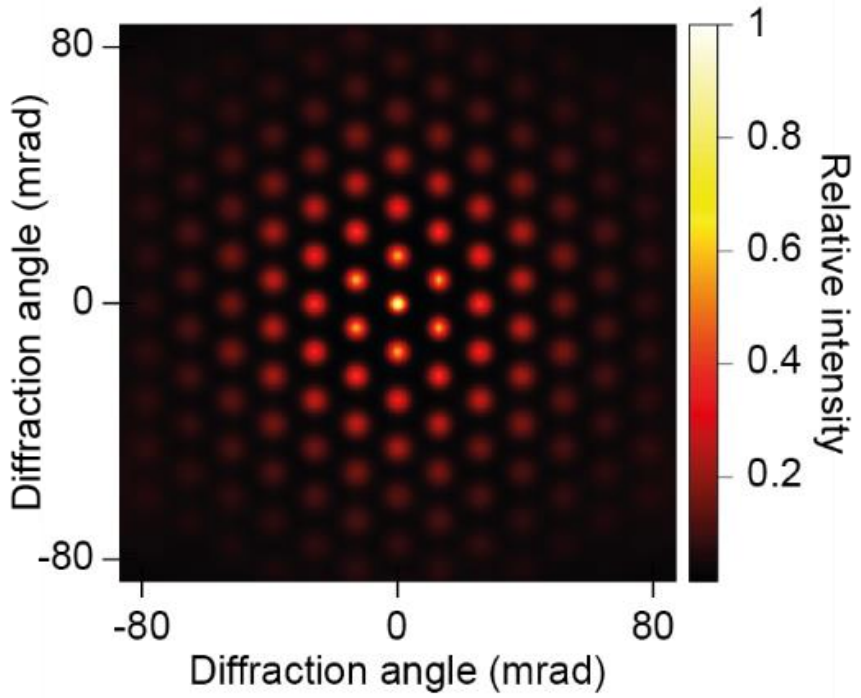


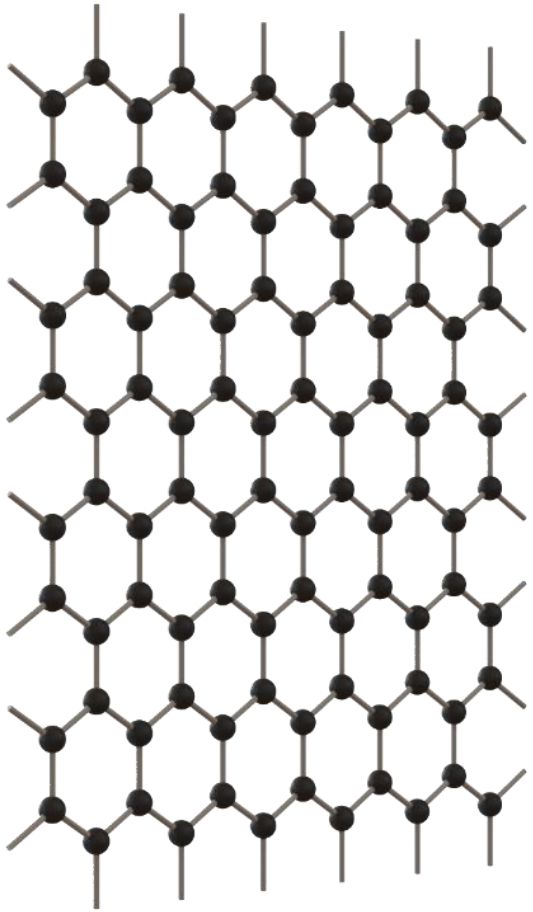

Plano-em.de, Trentino *et al.*, Nano Lett. **21** 5179 (2021)

# Detection

- Multi-Channel-Plate detector stacked onto Phosphor screen
- CMOS camera recording events
- Single event detection for background-free reconstruction of diffraction pattern
- Count rate of up to $5 \times 10^4 \frac{\text{atoms}}{\text{s}}$ expected



# Summary



- Transmission of neutral atoms through 2D materials
- Complimentary microscopy approach at low energies without ionizing radiation
- Detailed analysis of the coupling between atoms and 2D materials

# Thank you for your attention!

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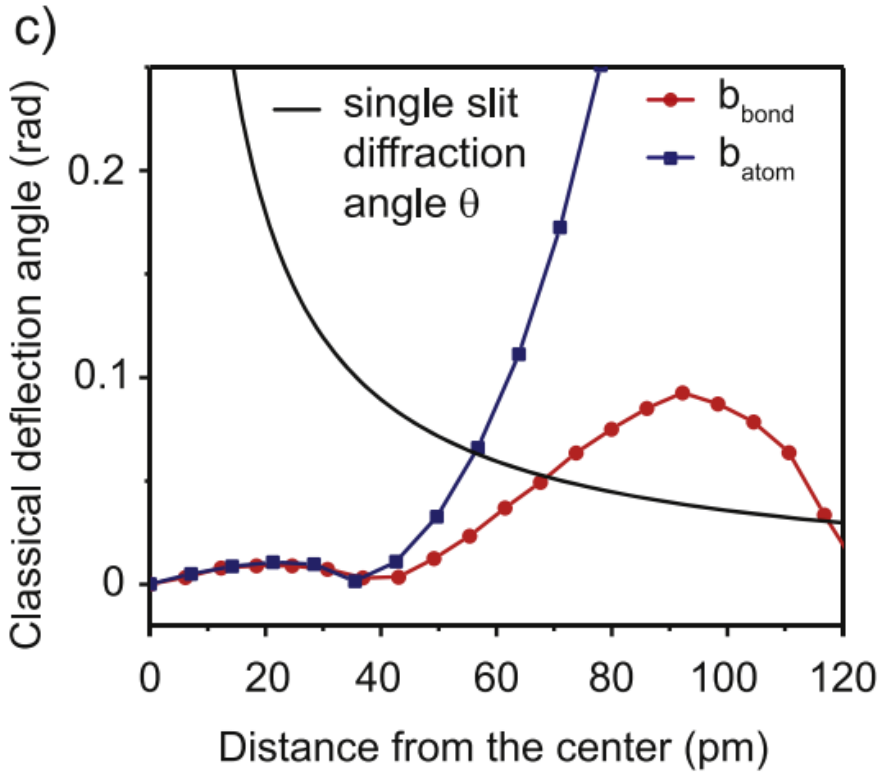
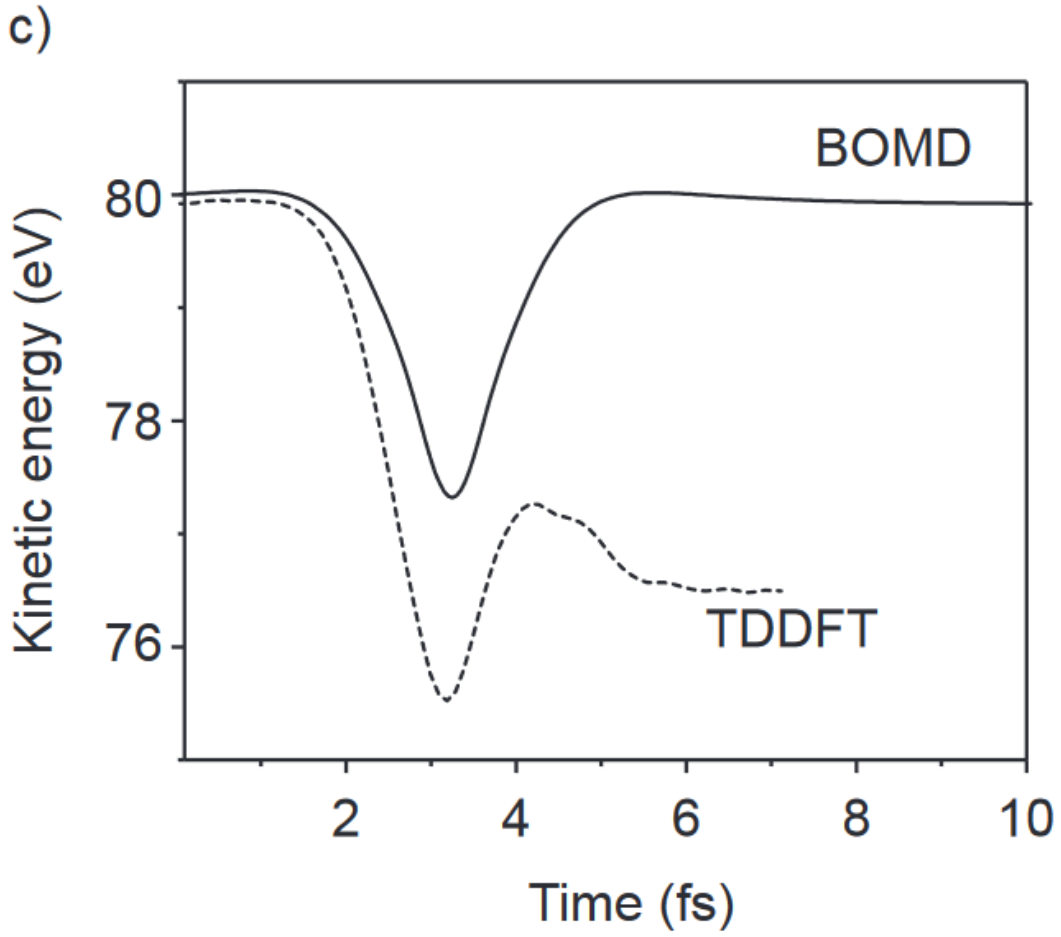
Jakob Bühler

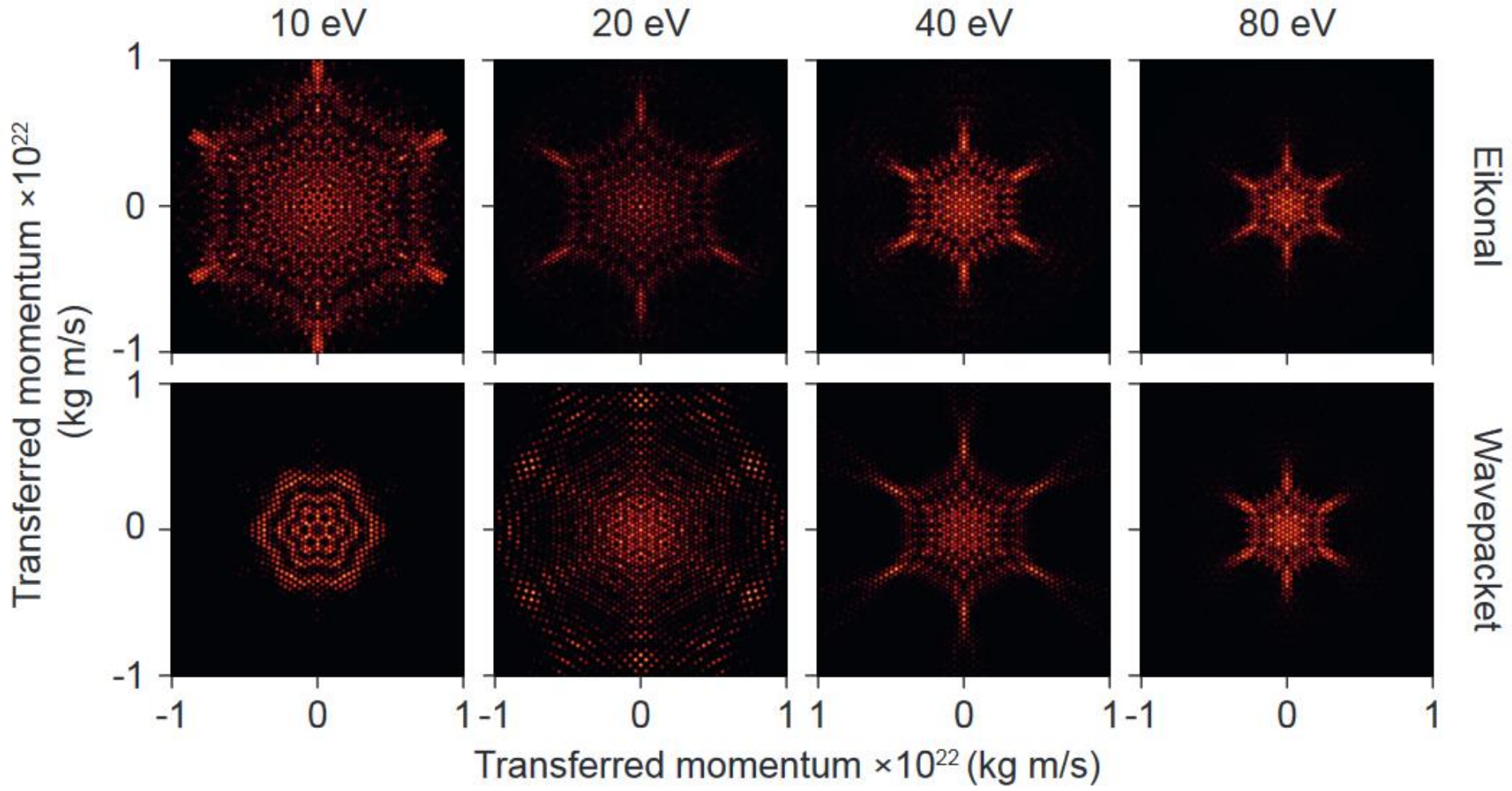
# Scattering of hydrogen atoms



# Excitation of electronic system

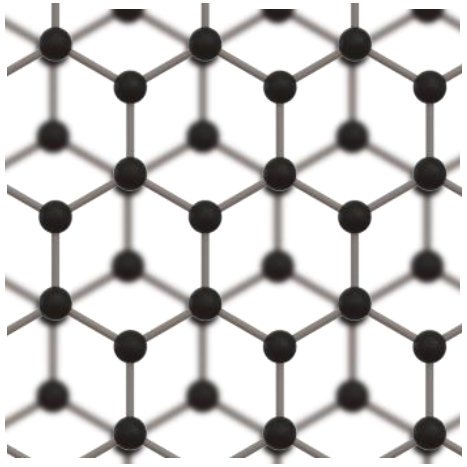


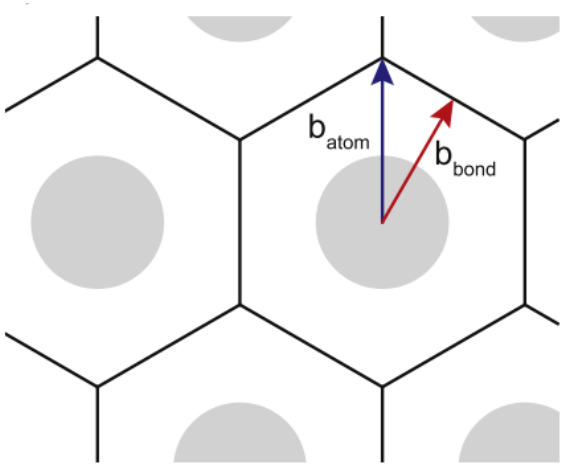
# Energy dependent diffraction pattern



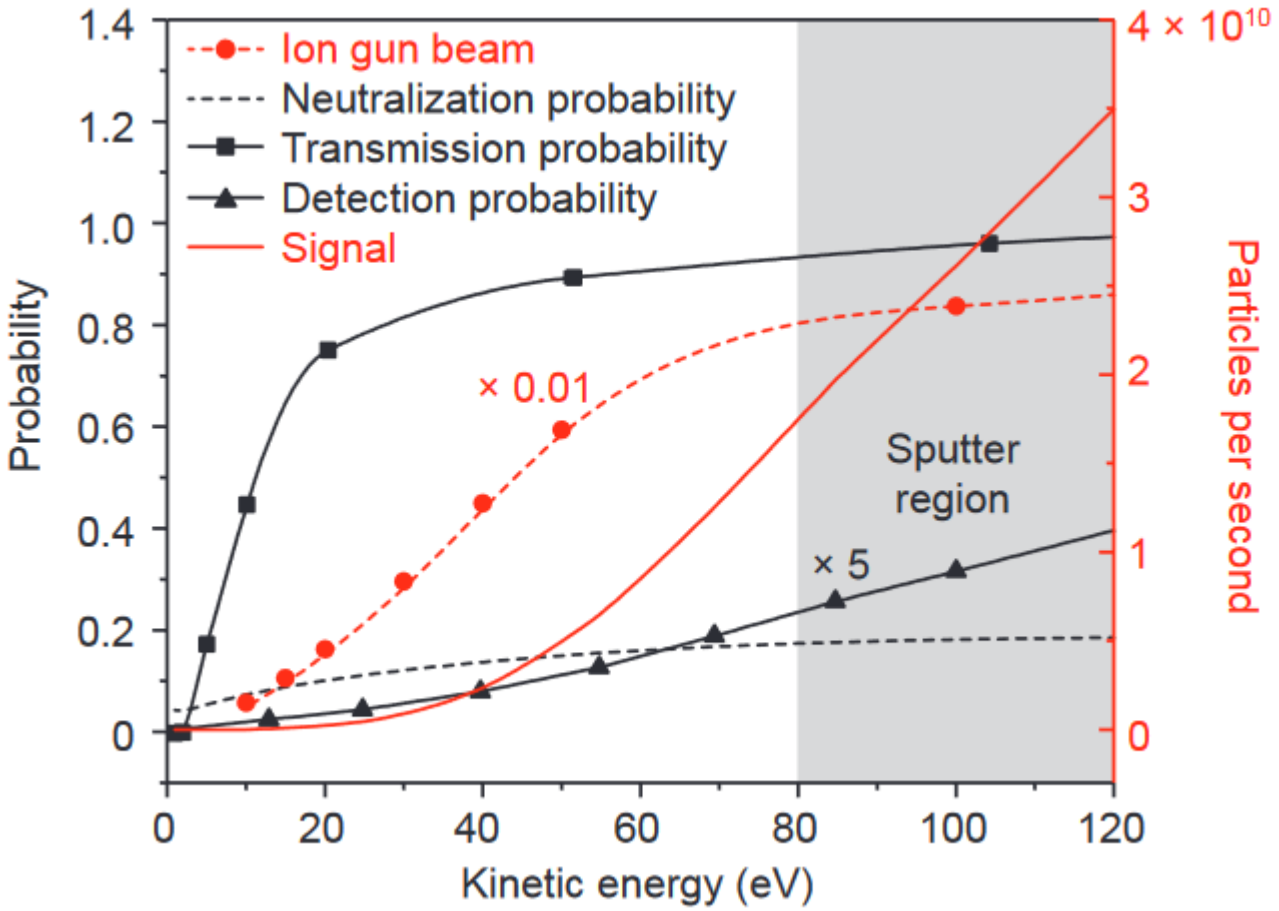
# Bulk materials

2 layers of graphene:





# Ion Flux


Ion gun beam
Neutralization probability
Transmission probability
Detection probability
Signal
× 0.01
× 5
Sputter region
Probability
Particles per second
Kinetic energy (eV)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
0
1
2
3
4 × 10^10
0
20
40
60
80
100
120