

Electron beams from laser-cooled atoms

Latest developments on the Eindhoven UltraCold Electron Source

Julius Huijts



Phase26 – Orsay – 22 Sep 2026

Context:

minimizing transverse T / MTE / intrinsic emittance

$$\varepsilon_x = \frac{\sigma_x \sigma_{p_x}}{mc}$$

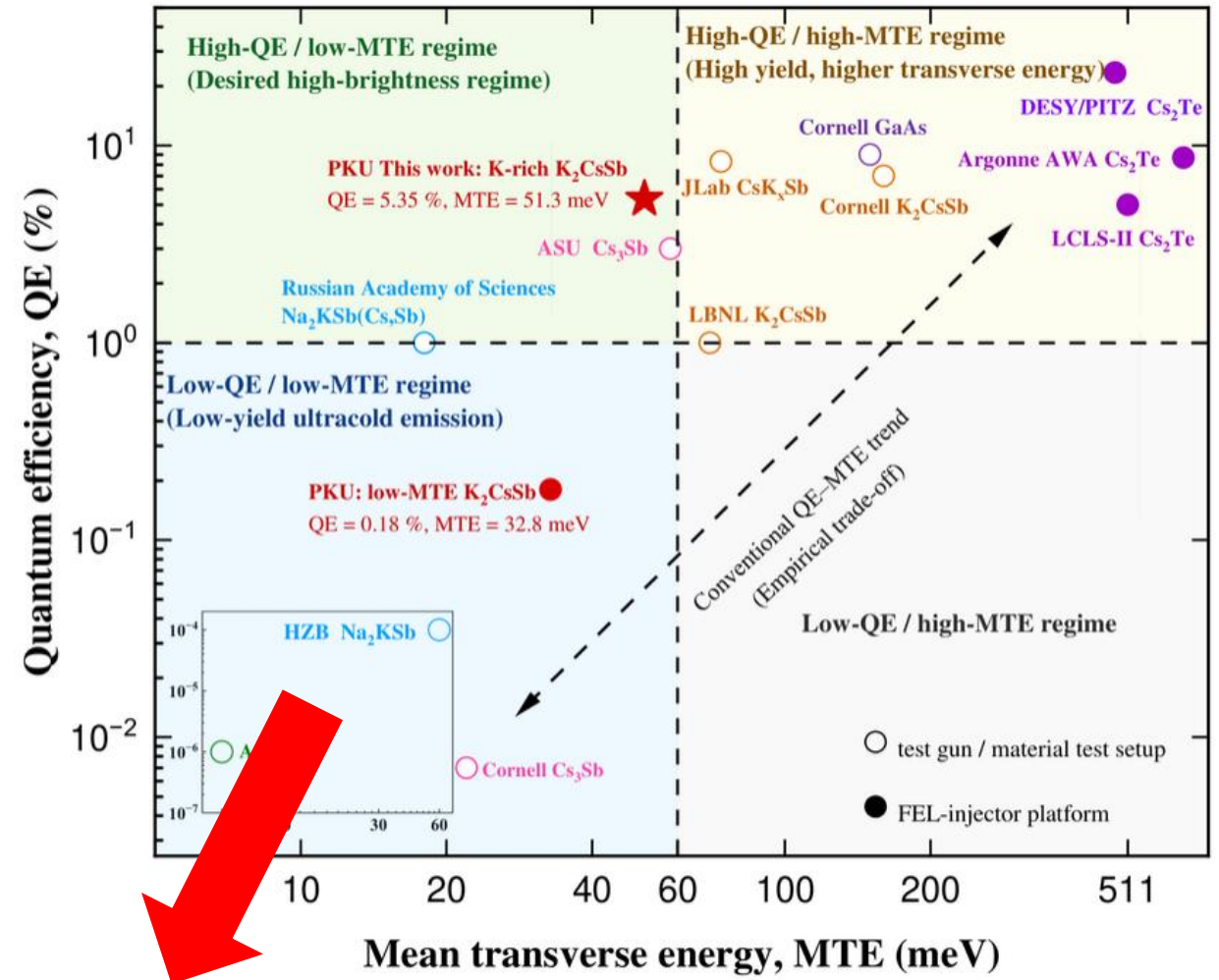
normalized emittance
at source (or focus)

$$= \sigma_x \sqrt{\frac{k_B T_x}{mc^2}}$$

Transverse
temperature

$$= \sigma_x \sqrt{\frac{2 MTE}{mc^2}}$$

Transverse energy

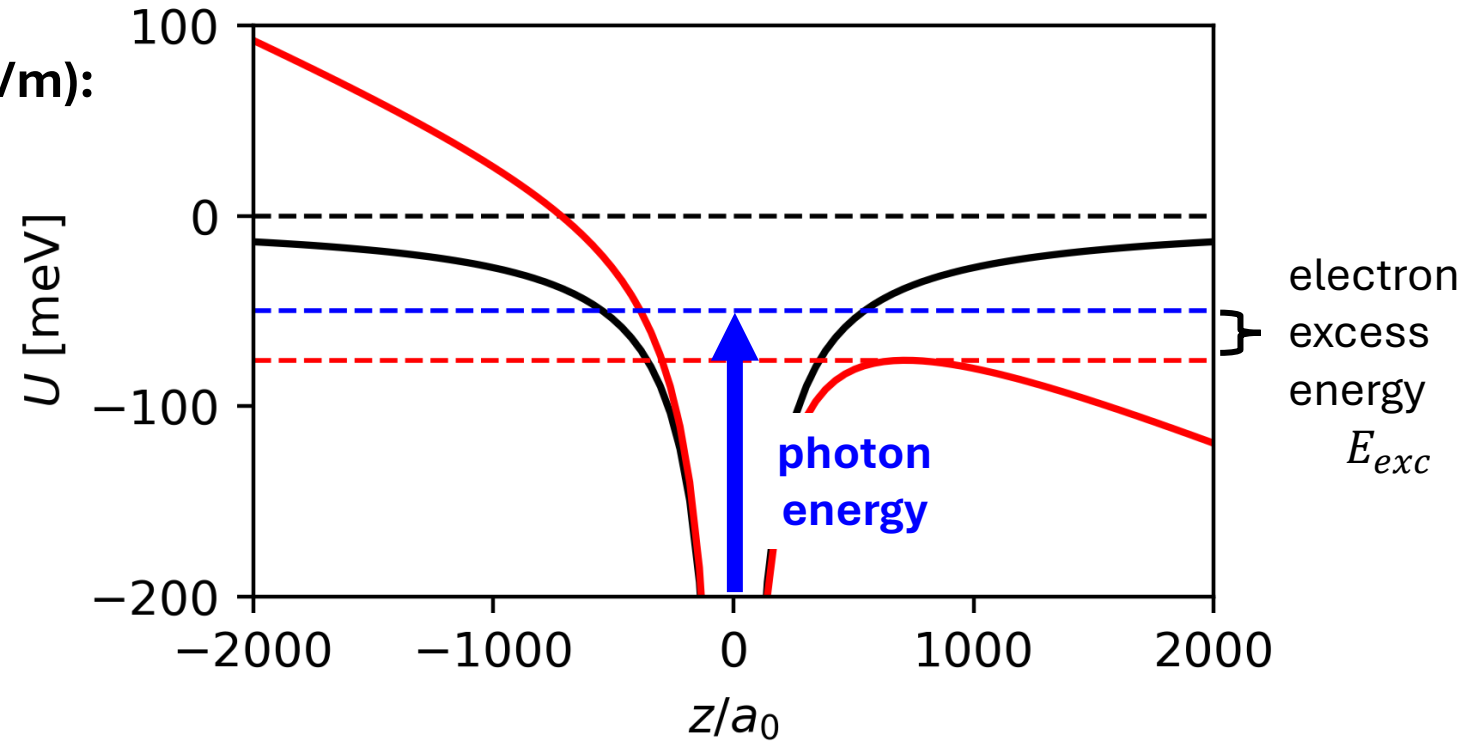


Electron emission from single atom

With Stark shift from accelerating field (1MV/m):

$$U = \frac{1}{R} + Fz$$

Stark shift is directional



Electron emission from single atom

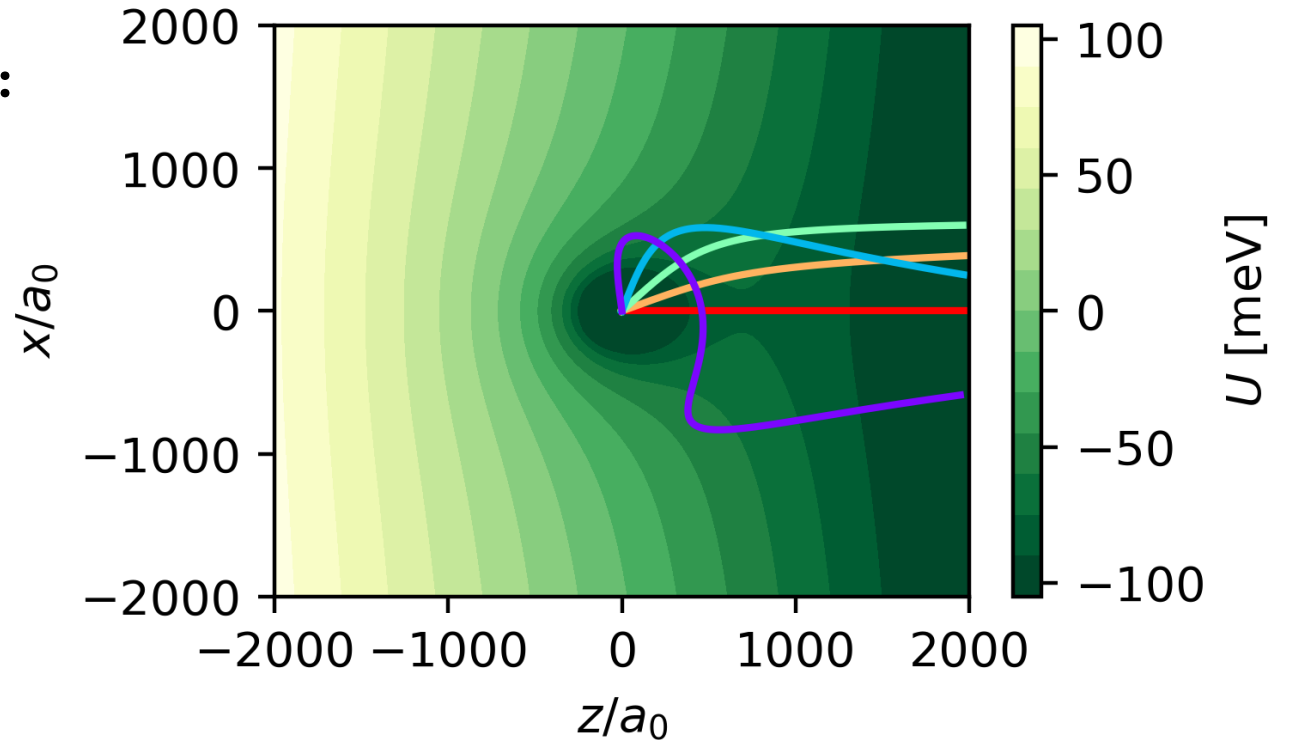
With Stark shift from accelerating field (1MV/m):

$$U = \frac{1}{R} + Fz$$

In 3D: emission cone

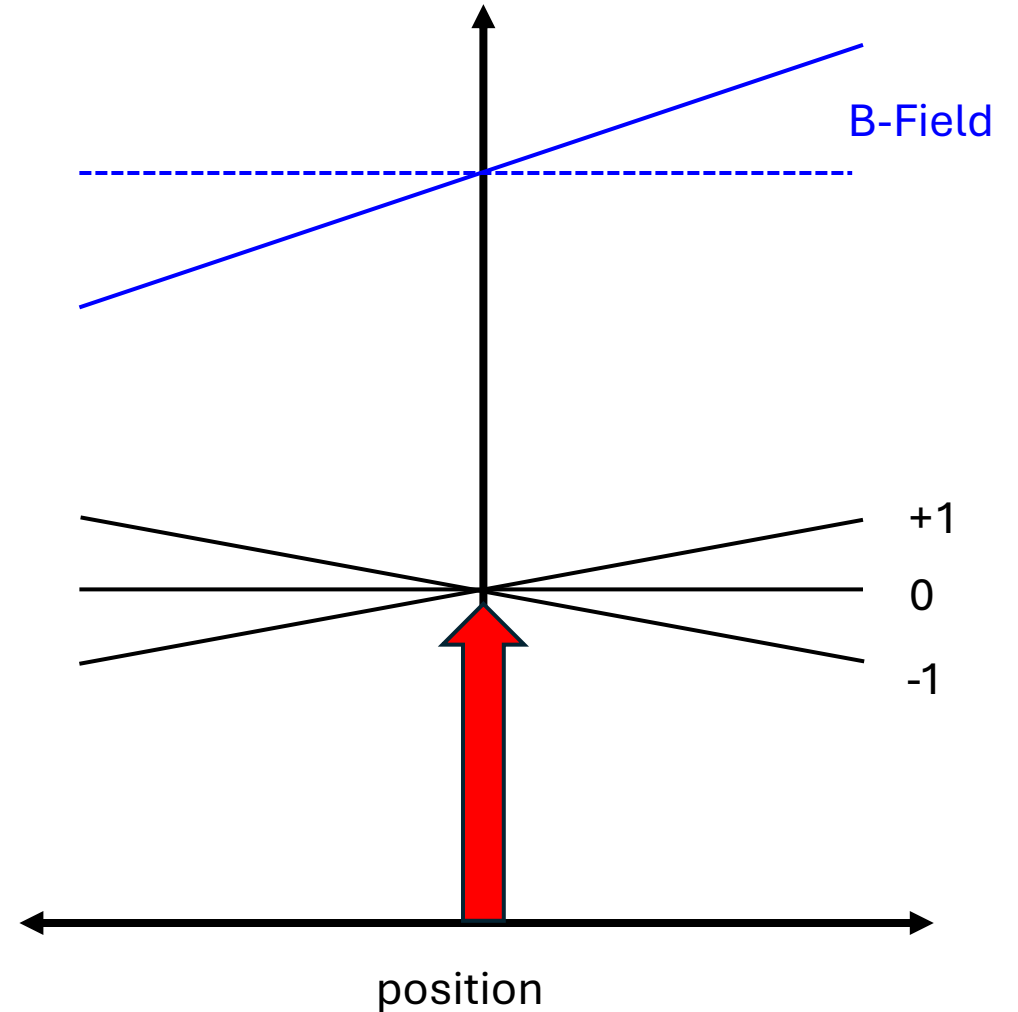
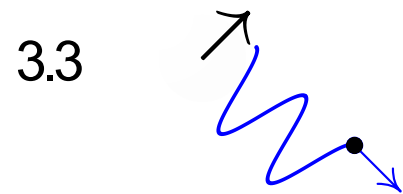
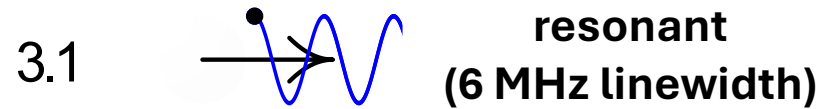
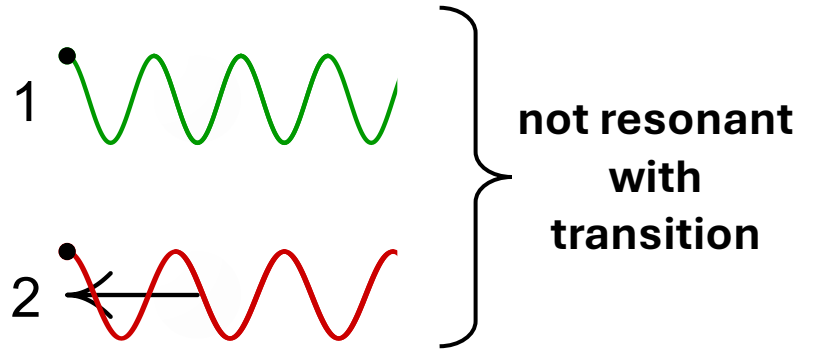
$$E_{exc} = \frac{k}{2}(T_x + T_y + T_z)$$

→ No equipartition! $E_{exc} = 10 \text{ meV}$
typical: $T_{x/y} \approx 10 \text{ K}$
 $T_z \approx 225 \text{ K}$



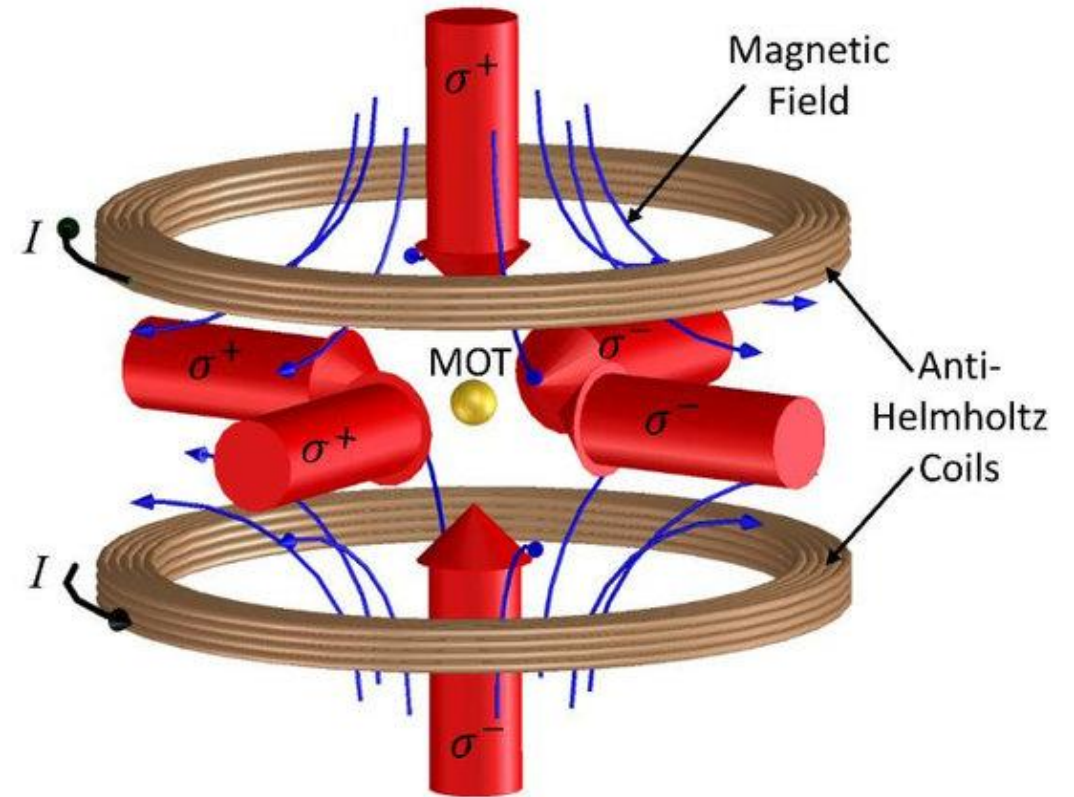
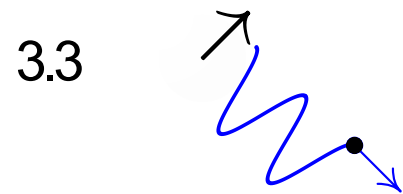
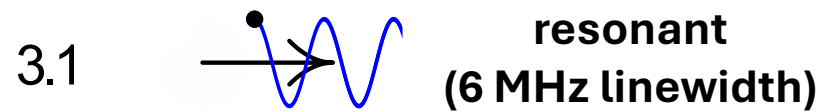
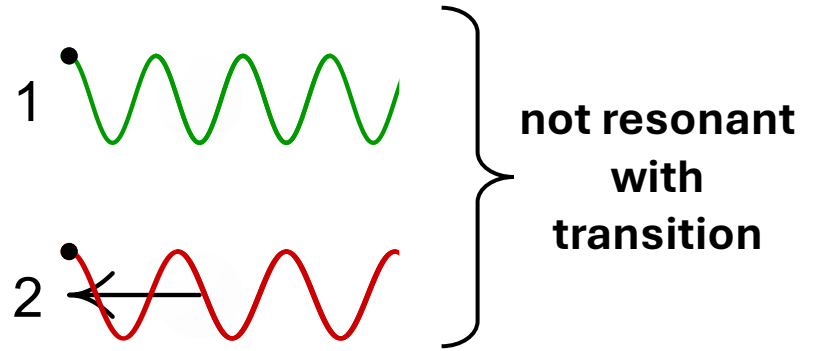
Principle of a Magneto-Optical Trap (MOT)

Laser Doppler Cooling:



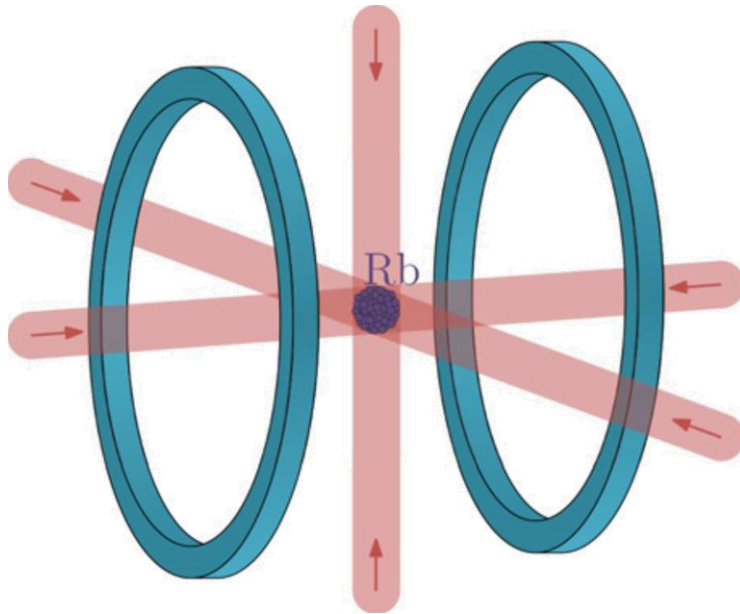
Principle of a Magneto-Optical Trap (MOT)

Laser Doppler Cooling:



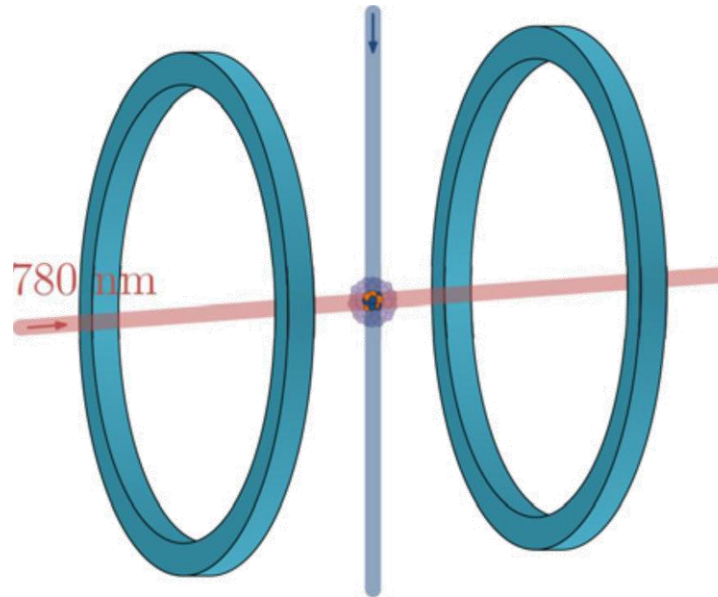
Principle of the Cold Atom Electron Source

Cooling & Trapping

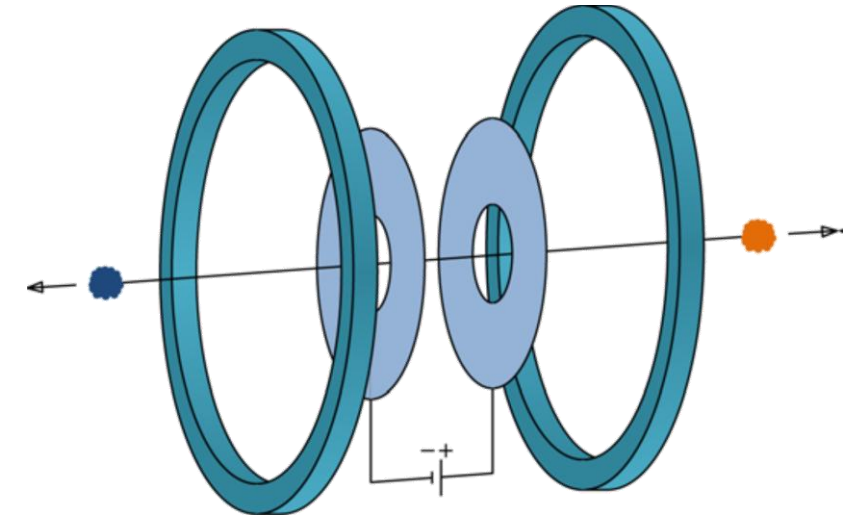


Atom temperature: ~ 0.1 mK
Atom density: $\sim 10^{10}$ cm $^{-3}$
atoms: $\sim 10^7$

Ionization



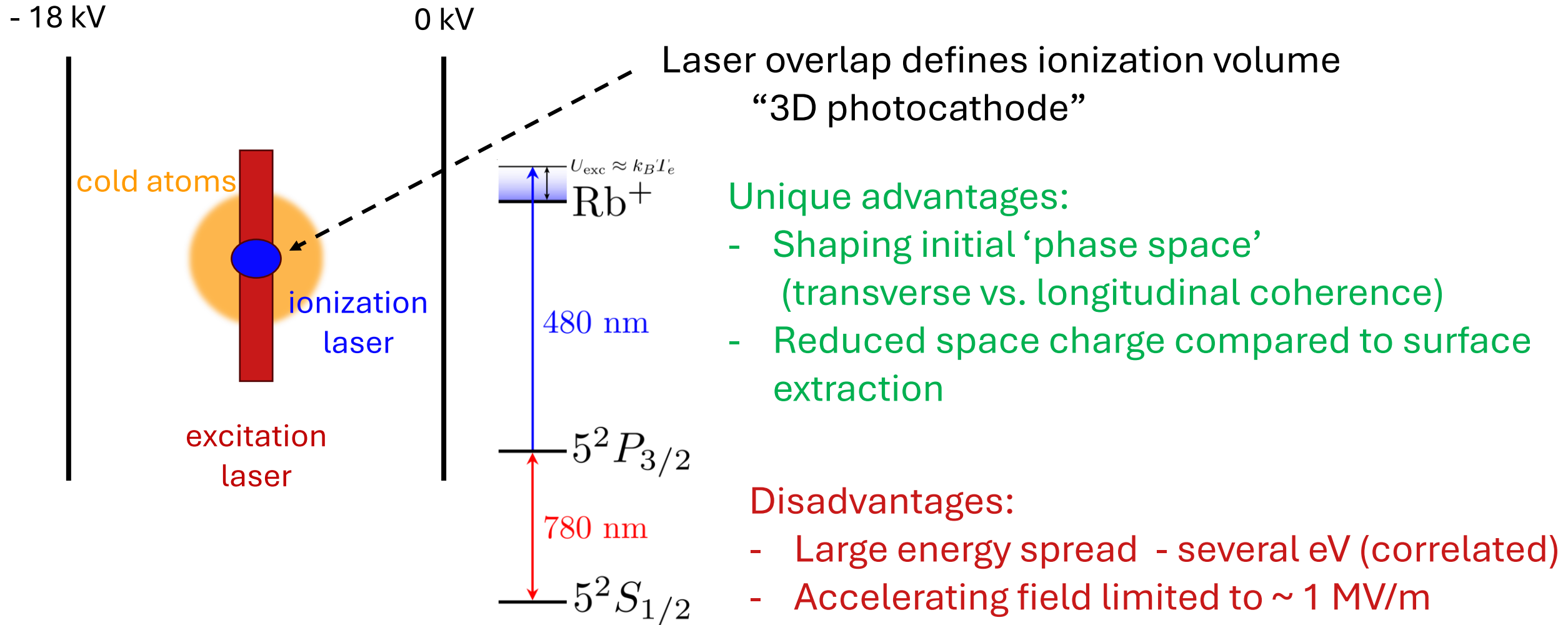
Acceleration



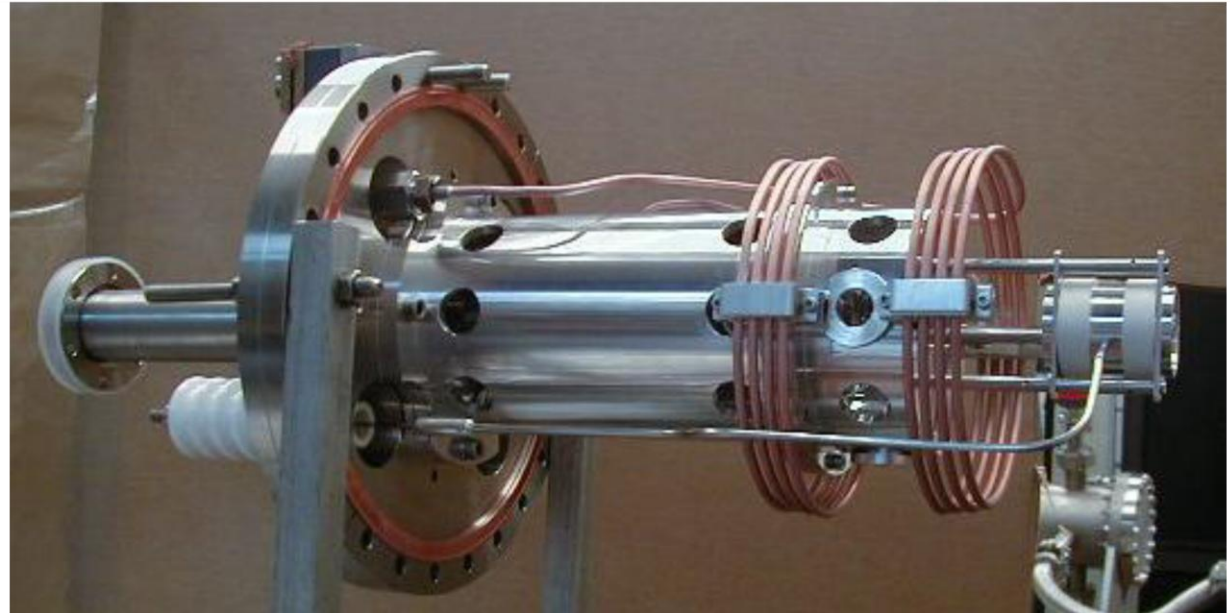
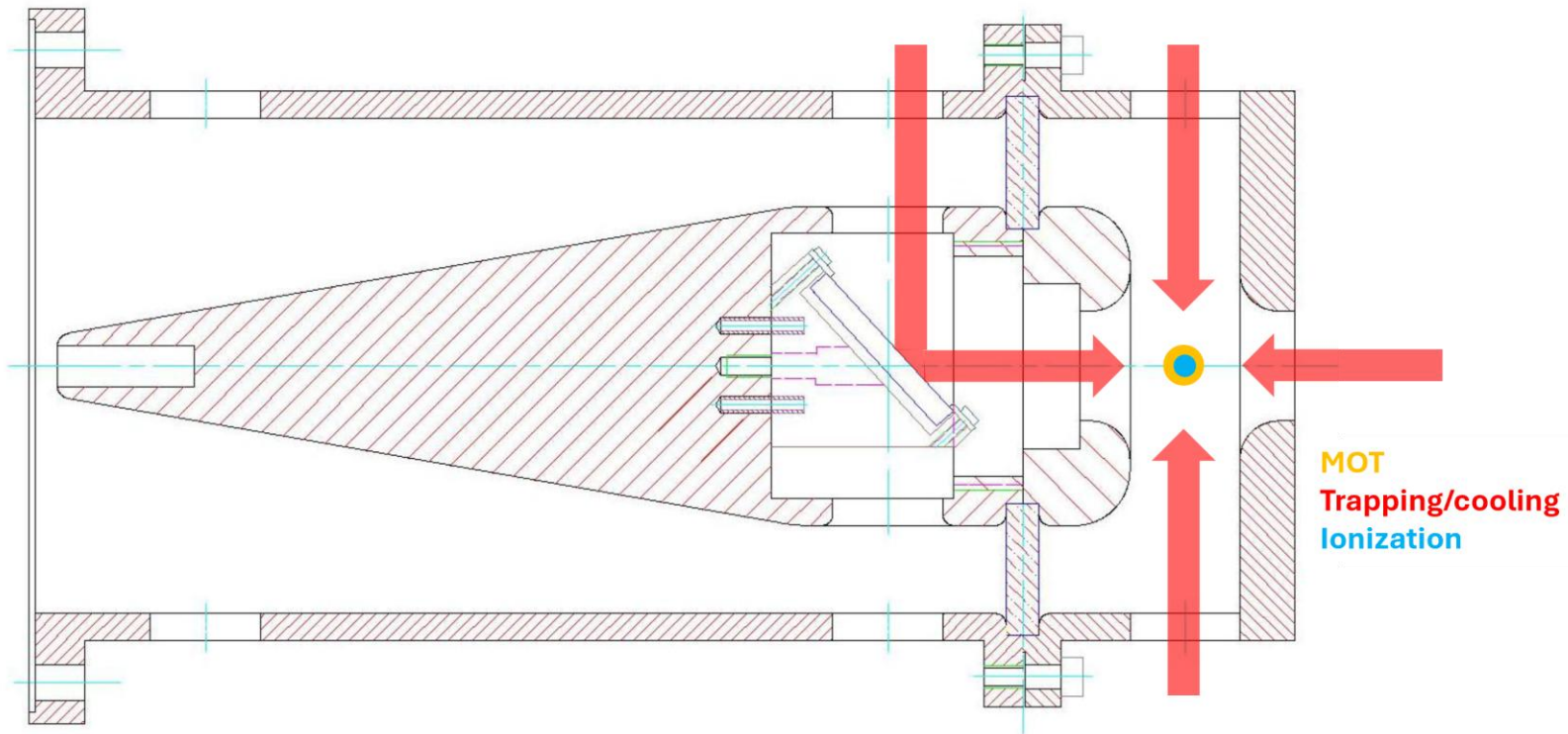
REPEAT

→ fresh 'cathode' at each shot!

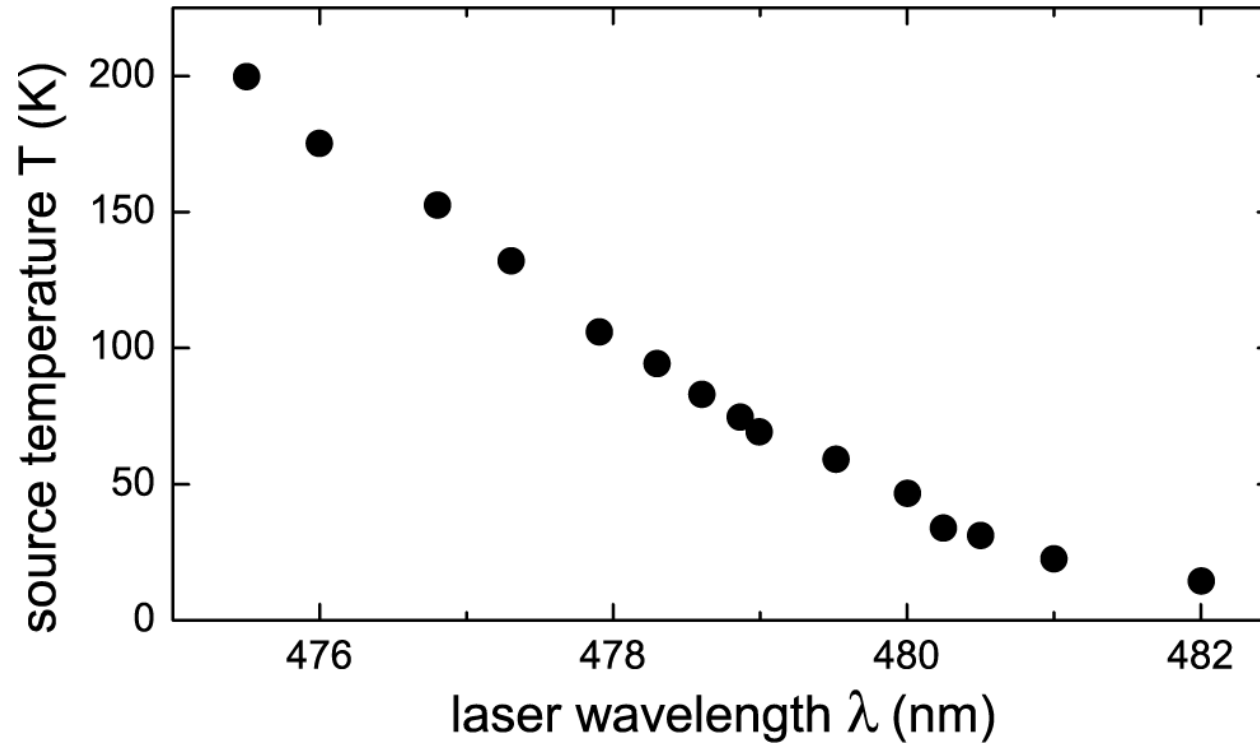
Principle of the Cold Atom Electron Source



Early days:

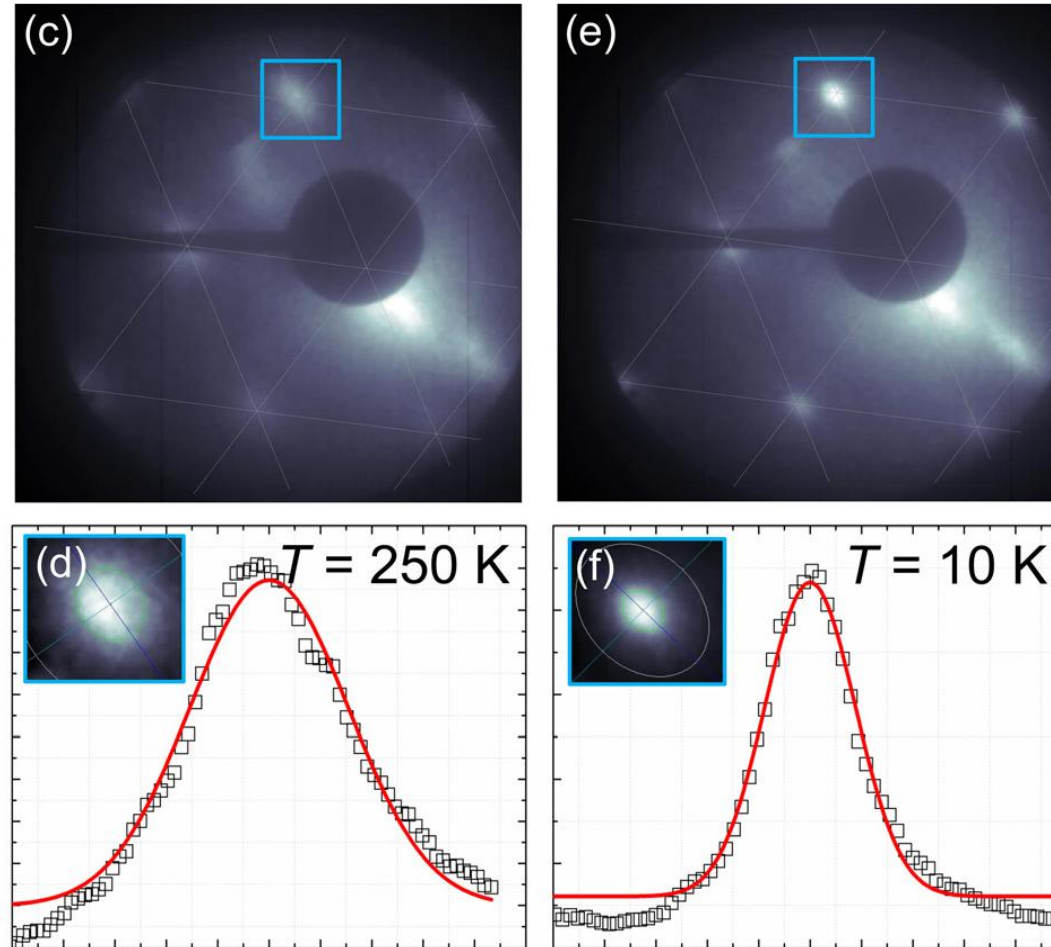


Early days:

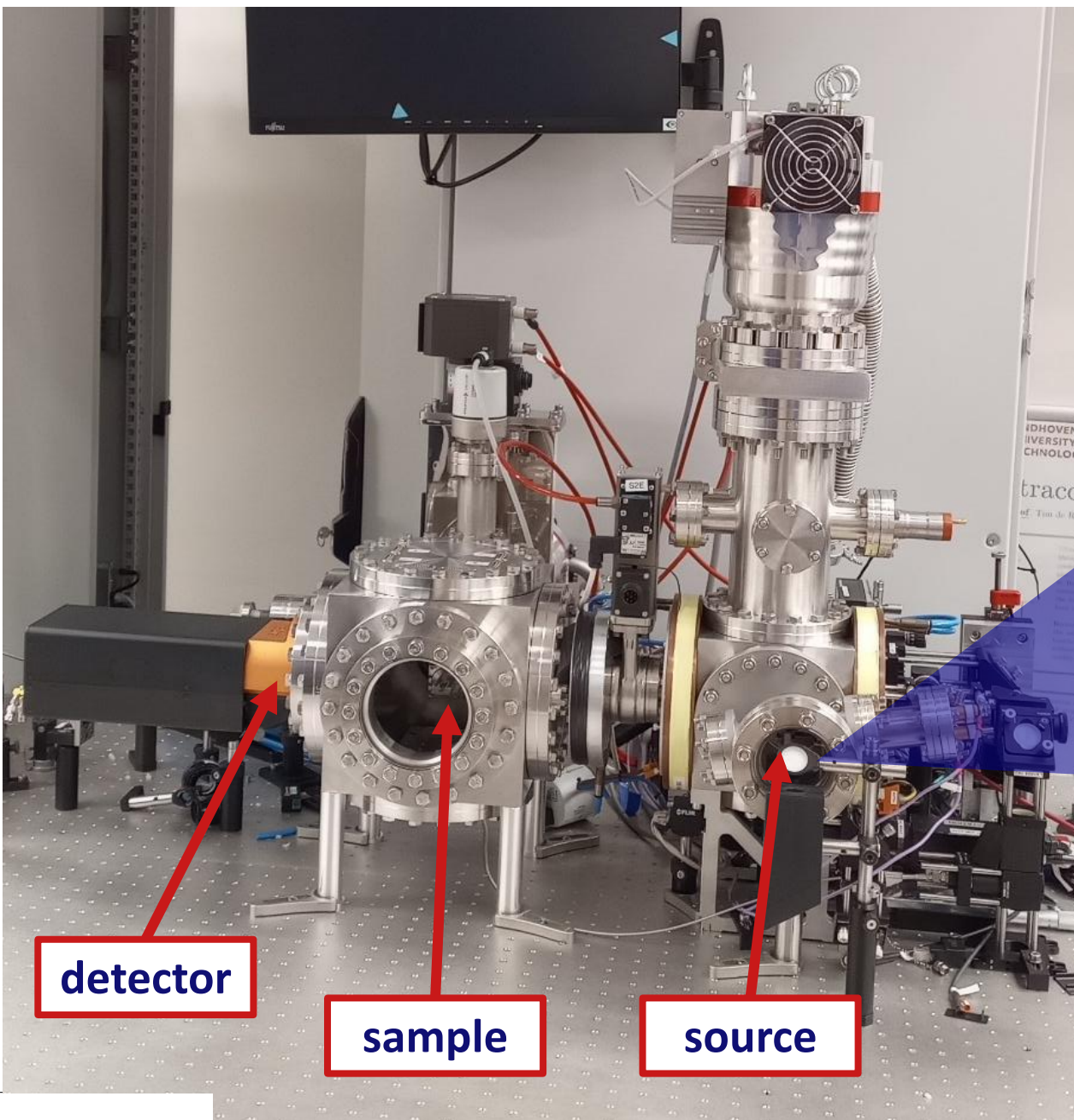


Already around 10 K!
(nanosecond ionization)

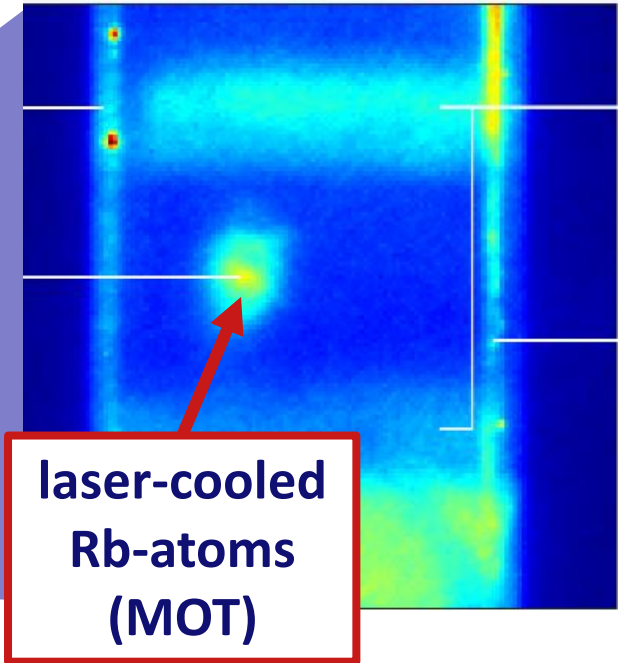
Early days: graphite diffraction experiment



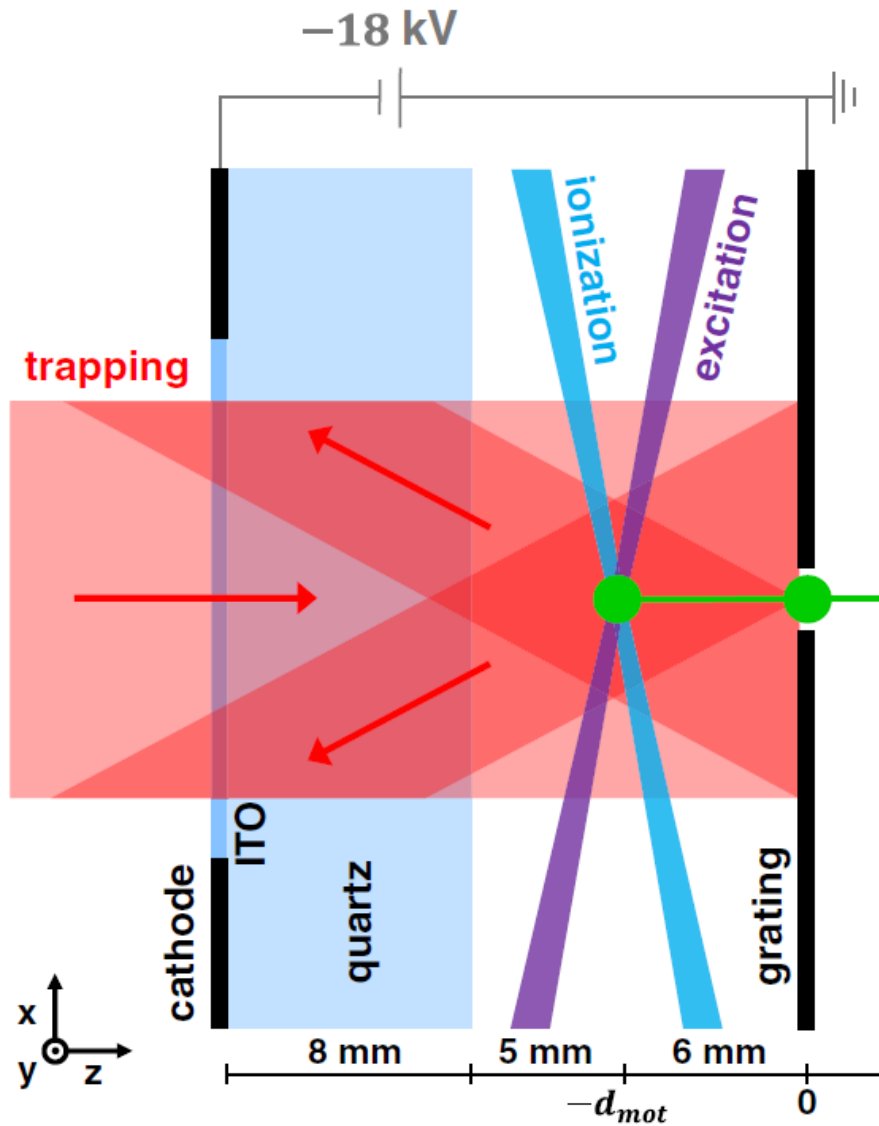
Current setup



Fluorescence image



Current setup: grating MOT

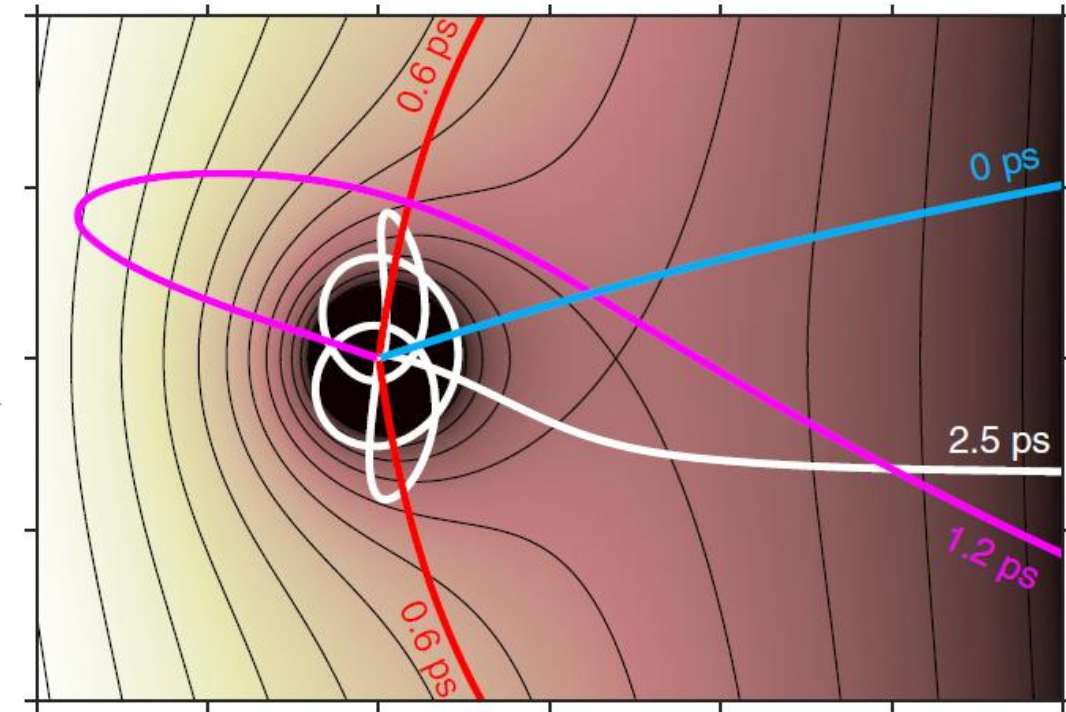
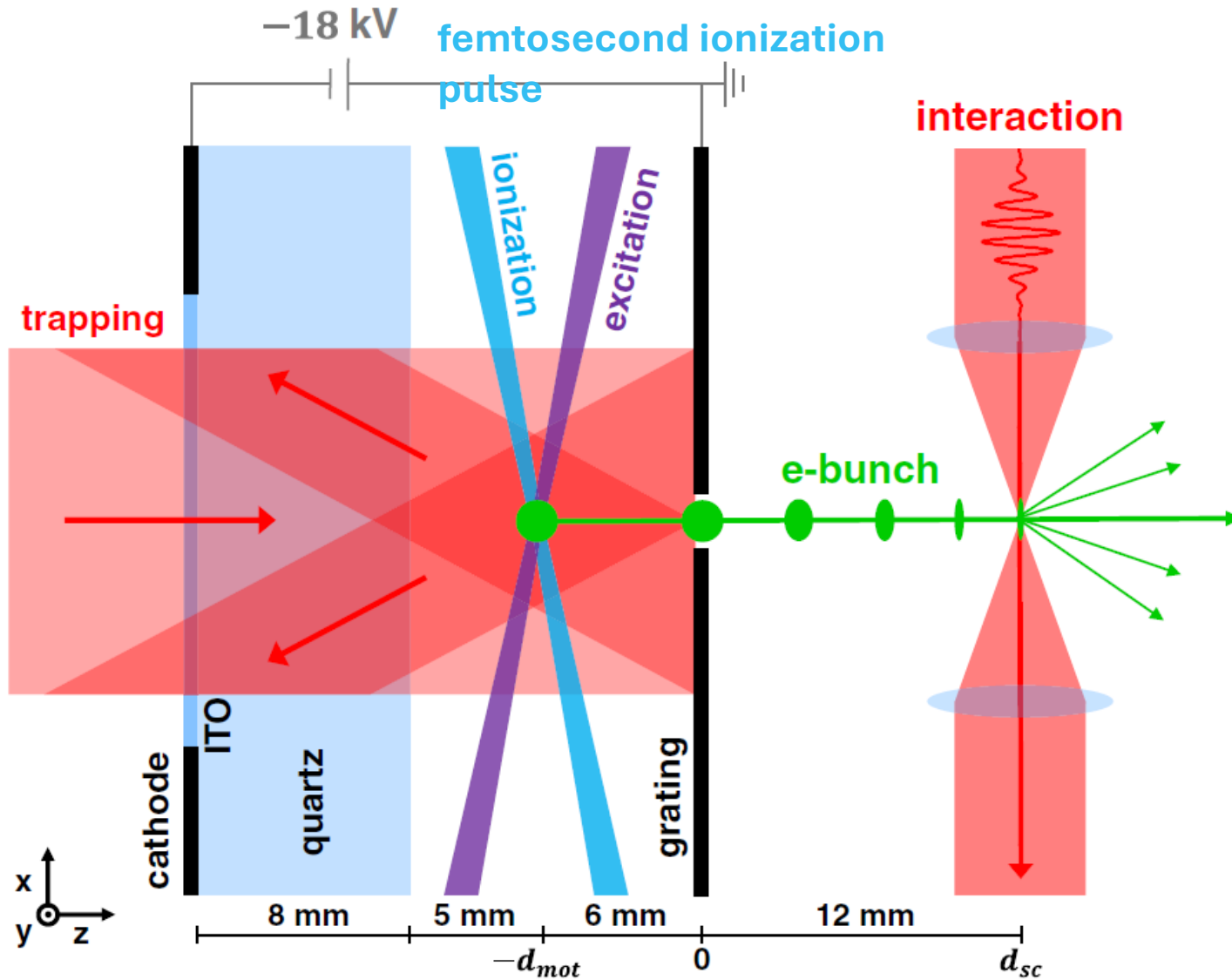


grating chip:

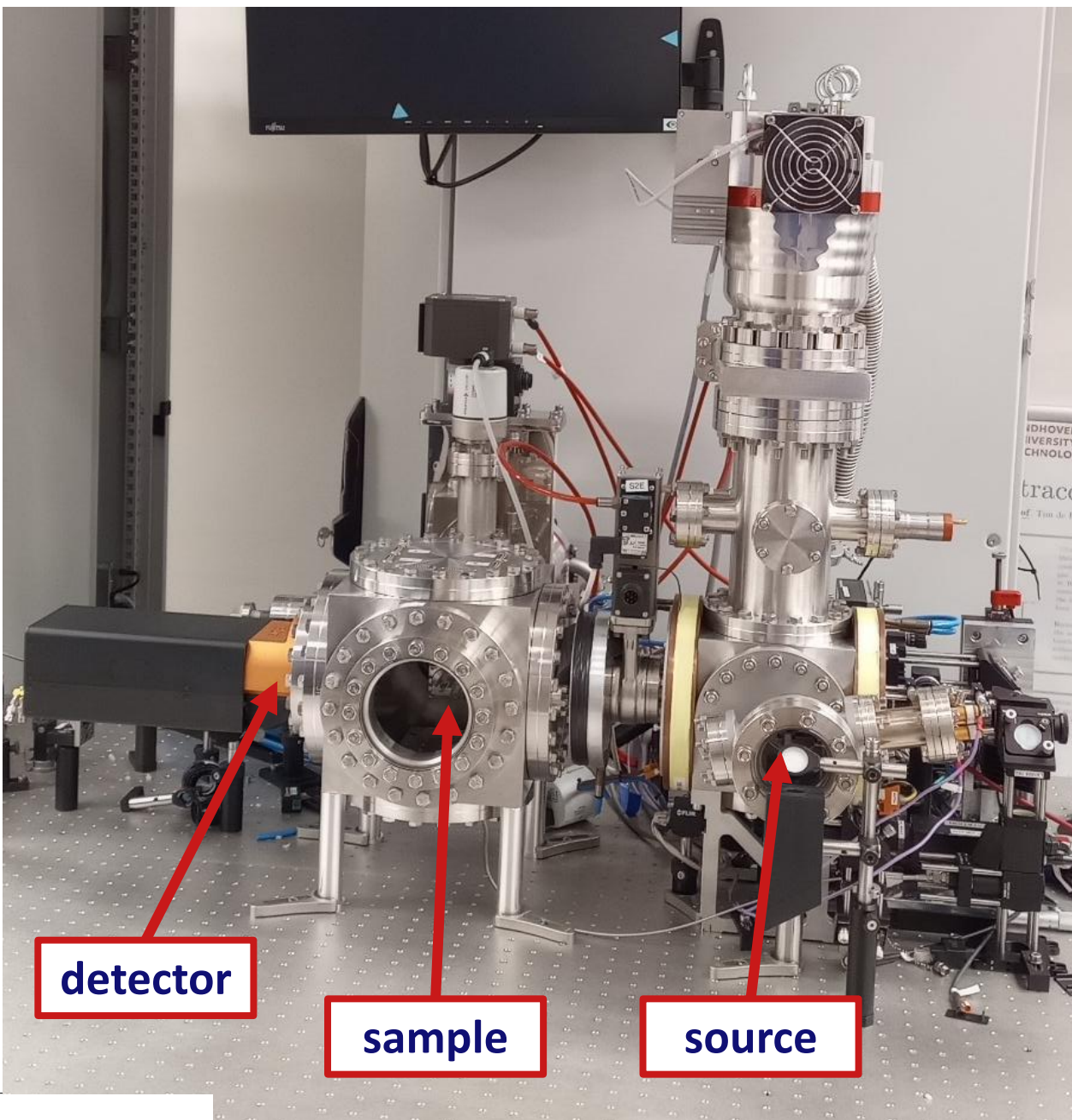


[Nshii, *Nat. Nanotechnol.* **8** (2013);
Franssen, *PRAB* **22** (2019)]

Current setup: picosecond electron bunches



Current setup: performance



# electrons per pulse	$10^3 - 10^4$ ($\sim$ fC)
Energy	8 keV
Energy spread	~ 35 eV
Pulse length	~ 2 ps
Transv. Emittance	1 –2 nm.rad
Transverse T	~ 10 K (< 1 meV)

Transverse temperature determined by:

- Bandwidth femtosecond ionization
- Disorder-induced heating

Physics > Accelerator Physics

[Submitted on 10 Oct 2025 (v1), last revised 17 Oct 2025 (this version, v2)]

The Coming of Age of the Ultracold Electron Source: A Review

Julius Huijts, Jom Luiten

The ultracold electron source is a unique approach to the generation of high-brightness electron beams. We give an overview of its development over the past 20 years, including the underlying physical principles, technical details and recent experiments, and give a flavor of the exciting prospects that the future may hold.

Subjects: **Accelerator Physics** (physics.acc-ph); Atomic Physics (physics.atom-ph)

Cite as: [arXiv:2510.09889](#) [physics.acc-ph]

(or [arXiv:2510.09889v2](#) [physics.acc-ph] for this version)

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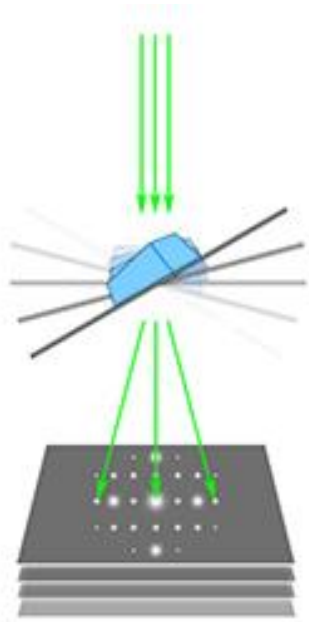
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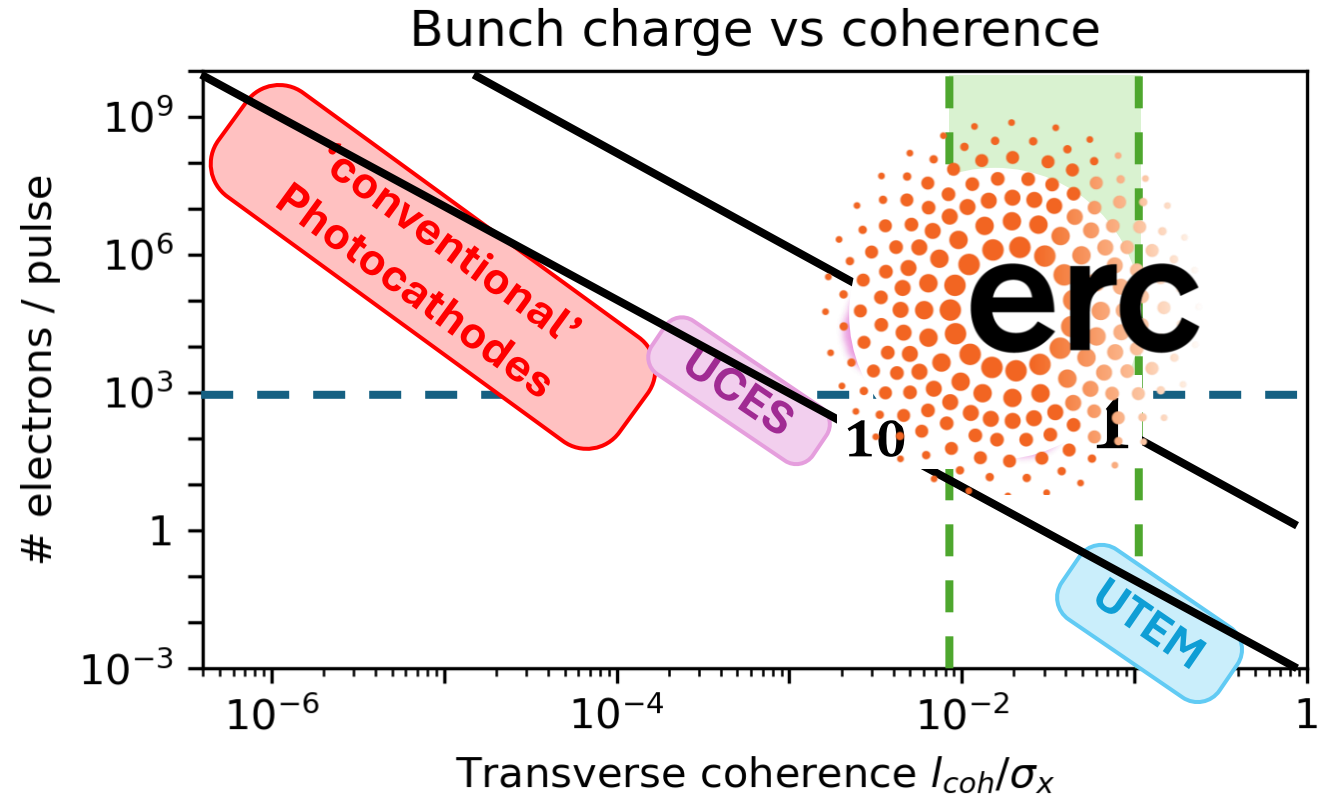
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Up next: towards nanosecond protein crystallography

microED:
protein structure determination from
submicron-sized crystals

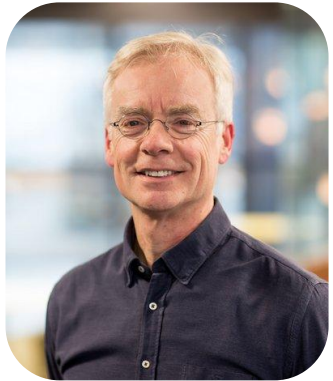


Do this time-resolved?



[Nannenga Nat. Methods 16 (2019)]

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