Electron dynamics in strong field trajectory models

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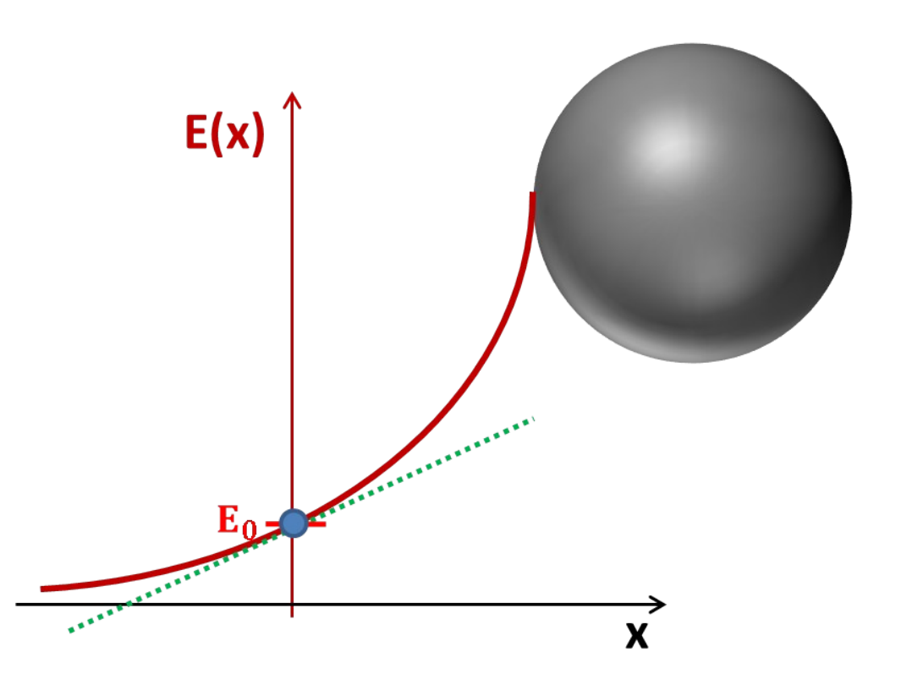
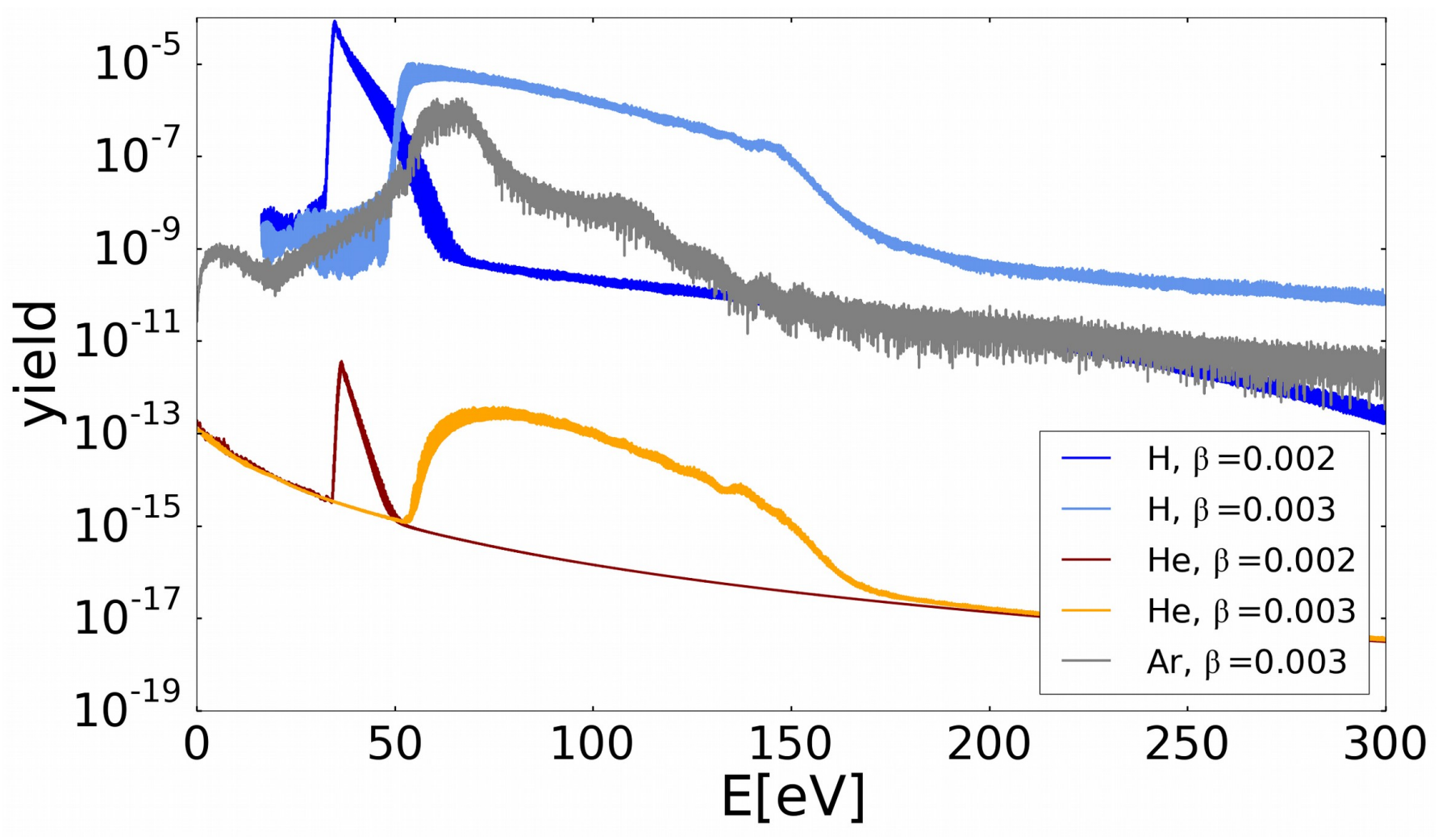
Emergence of a higher energy structure (HES) In inhomogeneous strong fields [H1,H2]

Setting:



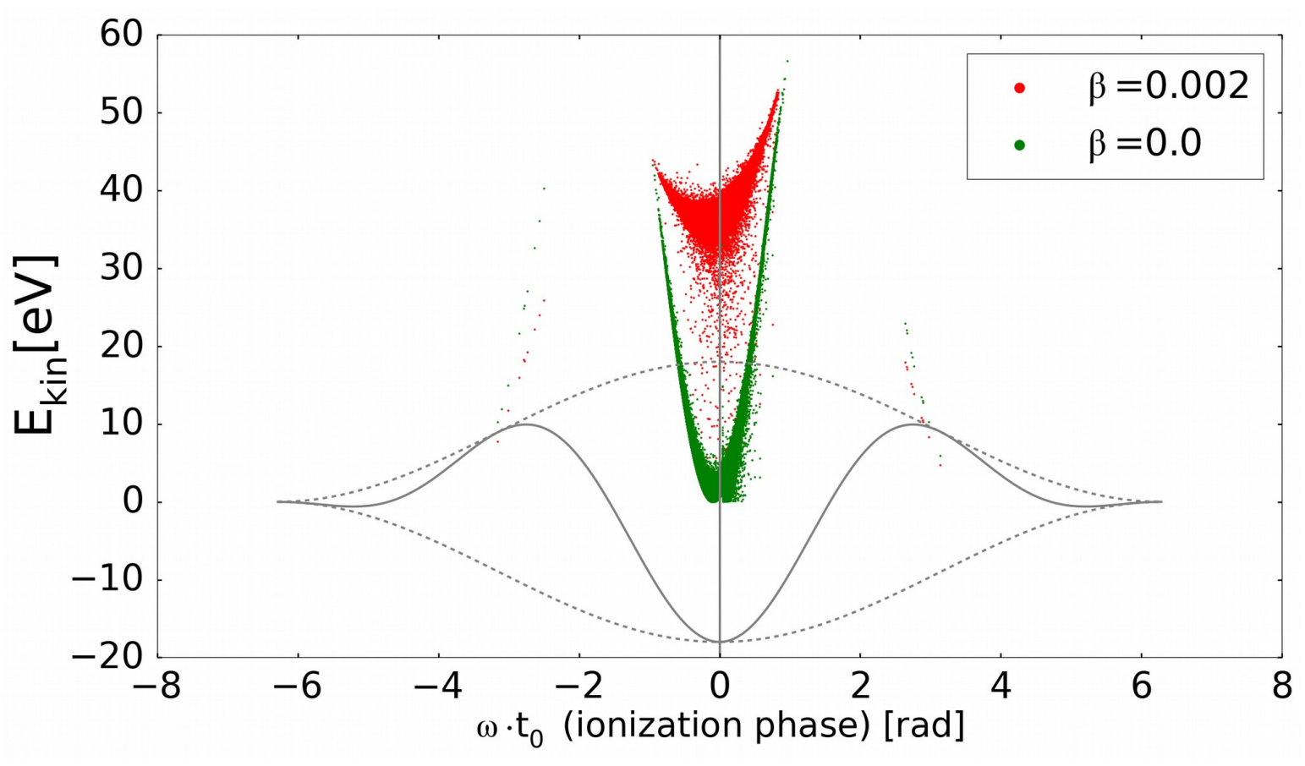
Ionization of gas in the inhomogeneous field in the vicinity of a nanostructure (linear approximation of field decay).

Photoelectron spectrum:

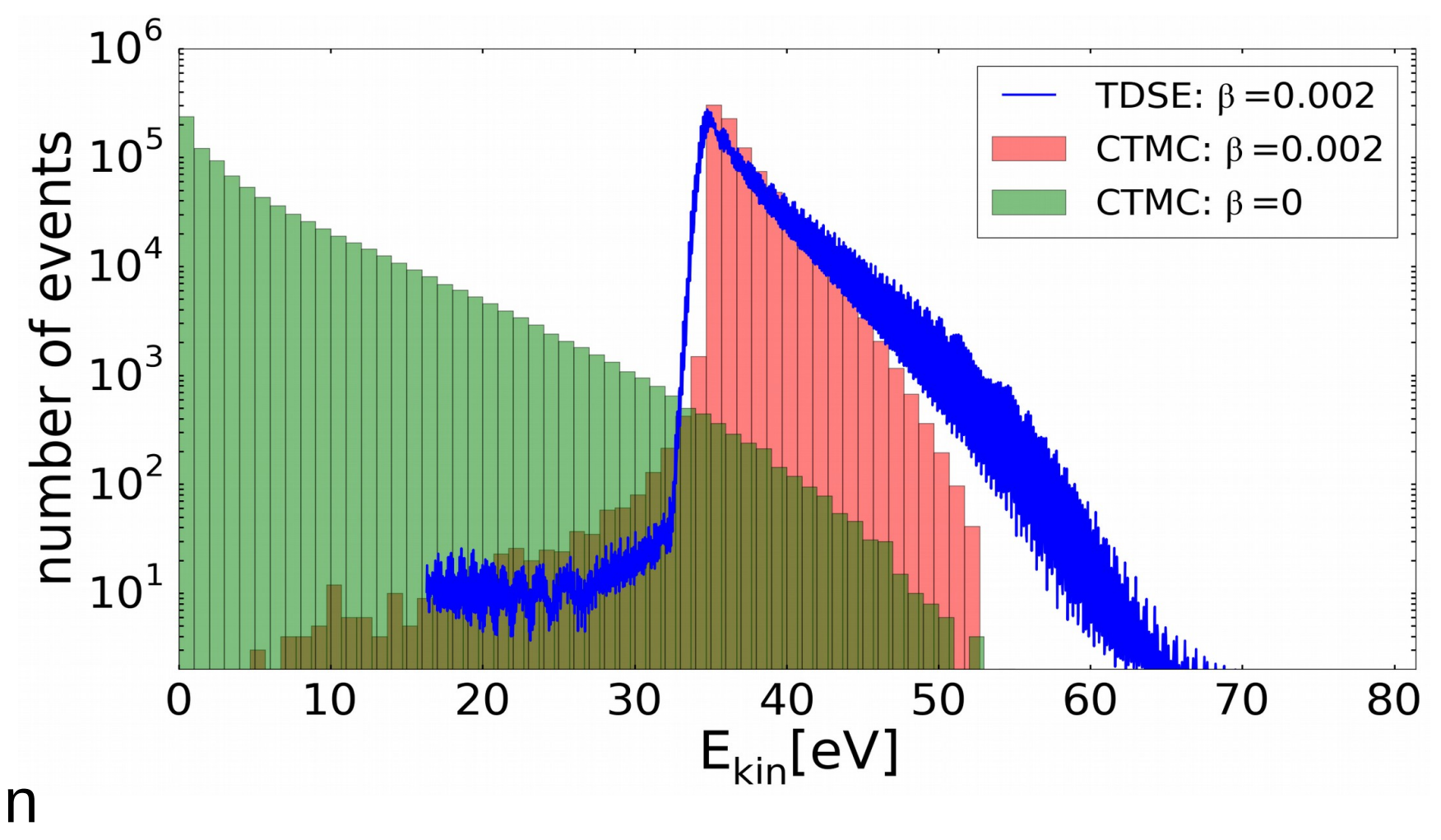


TDSE spectrum: Peaks emerge at a higher energy. The peak's width and position depend on the inhomogeneity parameter β [H1,H2].

Trajectory analysis:

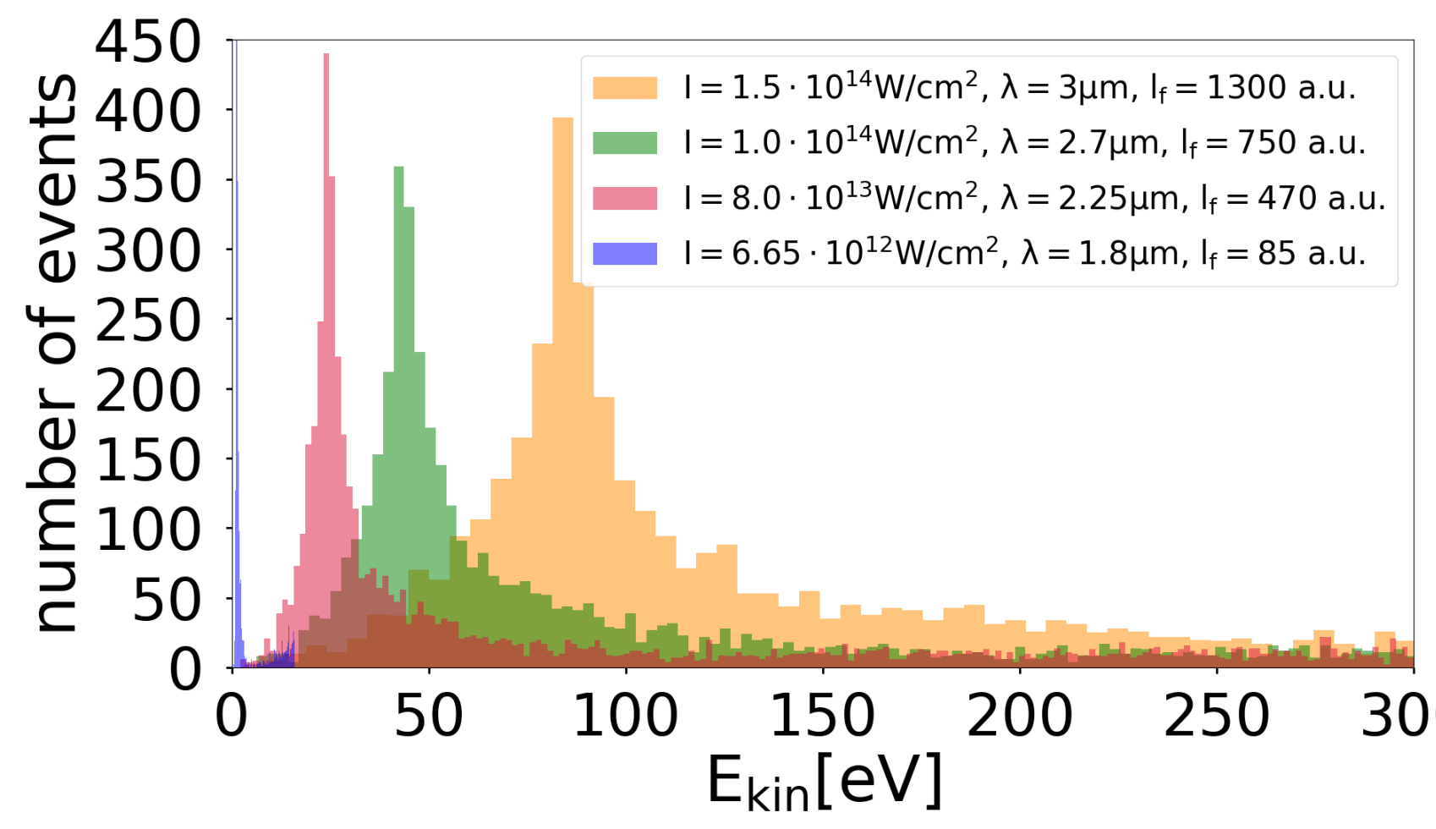


The electrons that form the HES are born within a narrow time window → creation of almost monoenergetic electron beams with femtosecond duration.



The effect is captured by CTMC simulations.

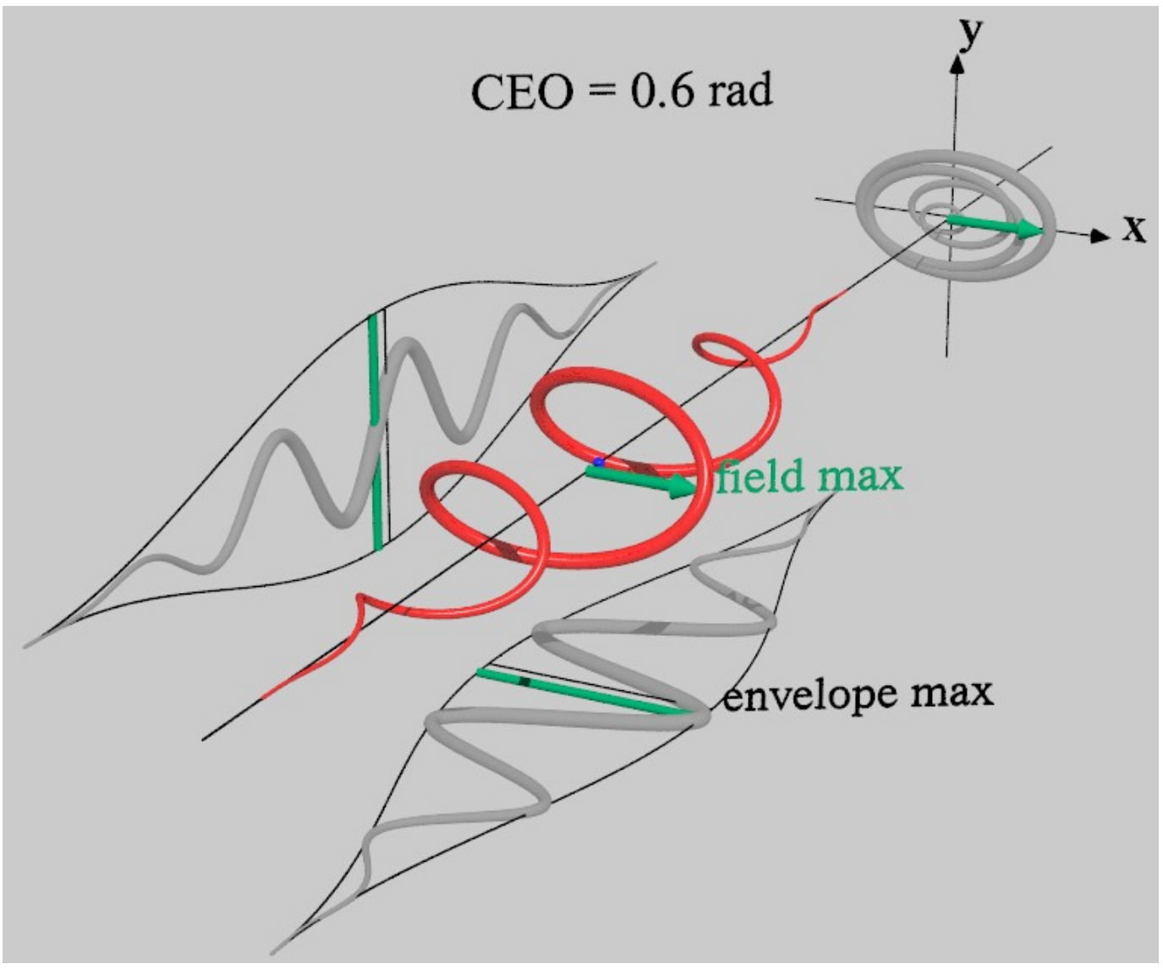
Generalization:

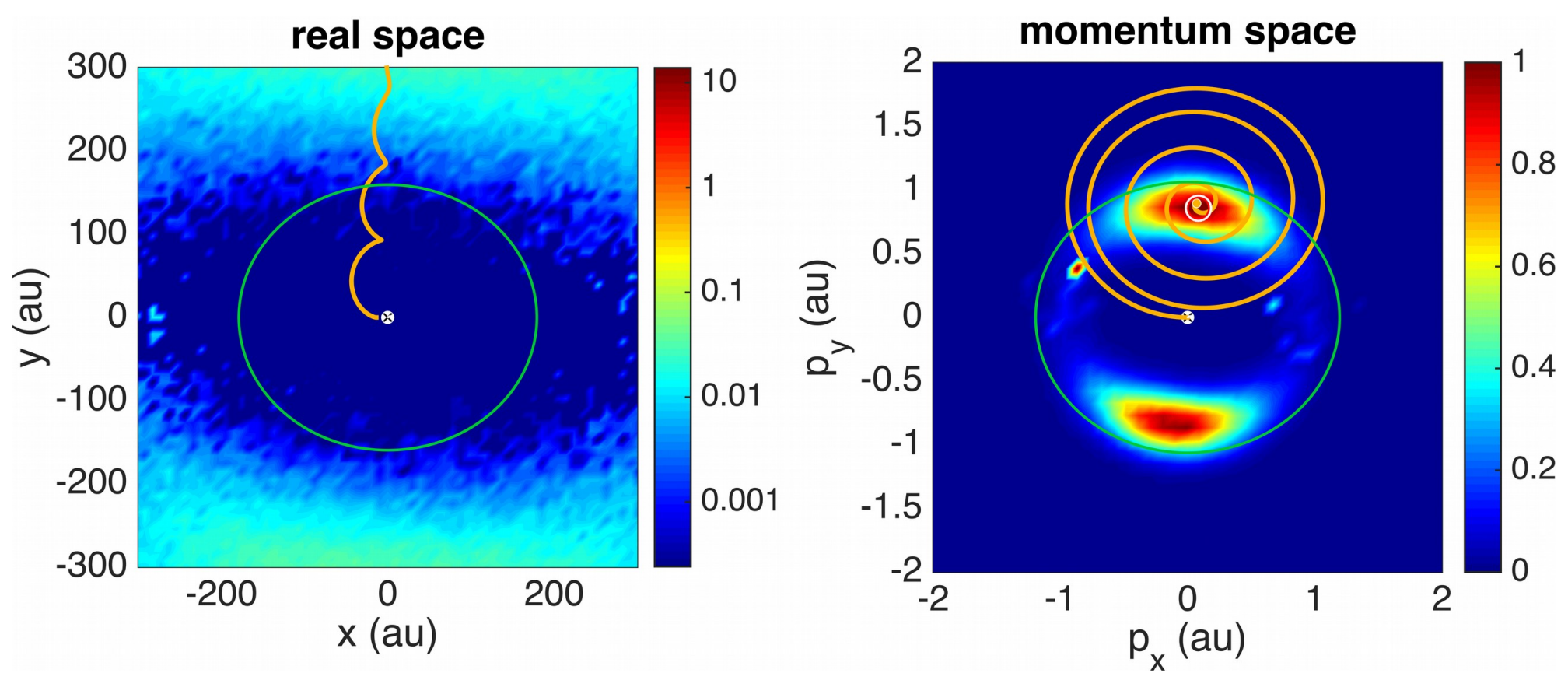


The in principle same energy upshift can be observed at a large variety of laser and nanostructure parameters – even when the electrons are ionized directly from the nanostructure.

The purple peak, around 1 eV, reproduces the experimentally detected peak, which was named 'lower-energy peak [H3]'.

Attoclock revisited on electron tunnelling time [A1]





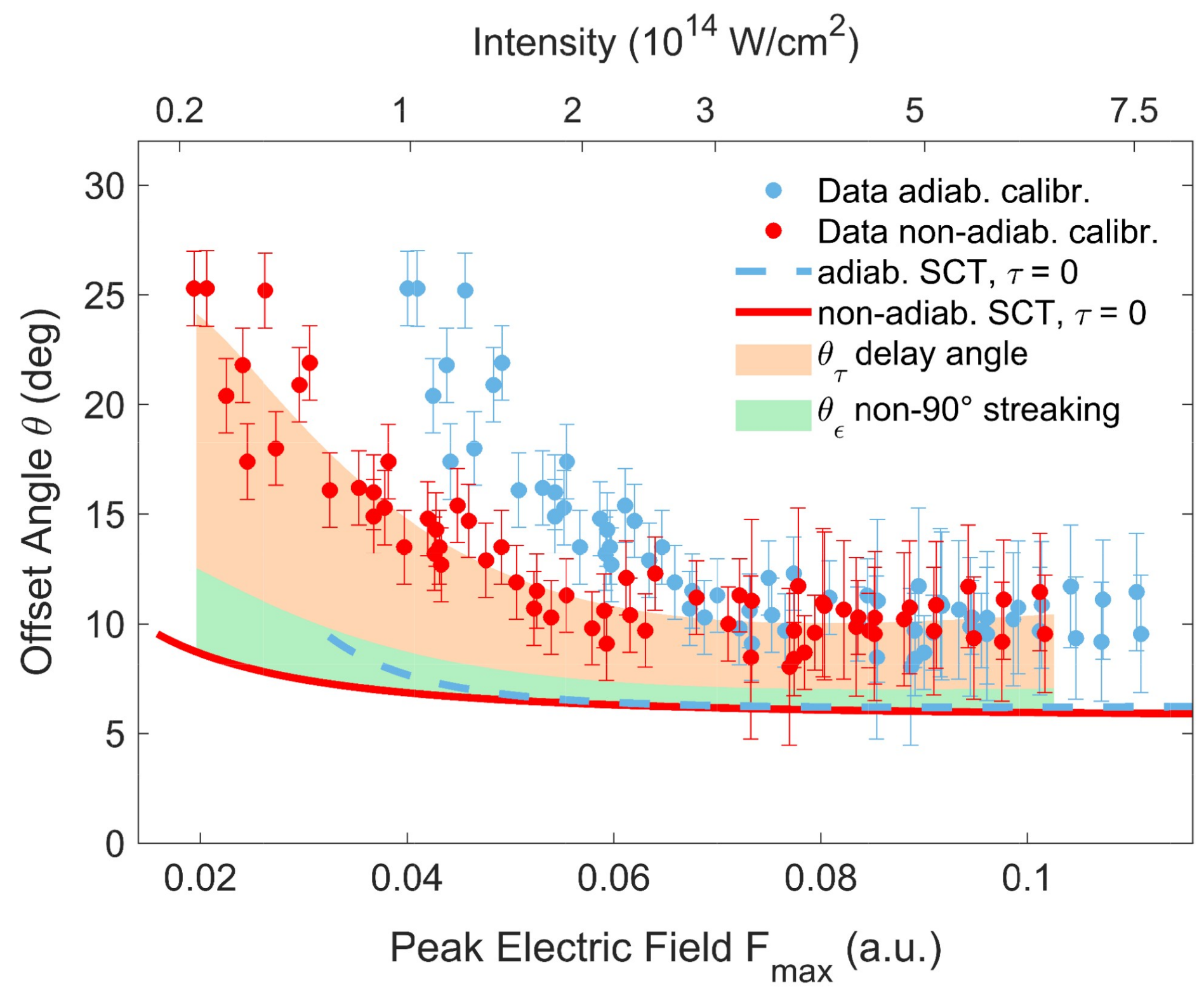
Principle [A1-A3]:

The final photoelectron momentum encodes the moment t_i when electron first entered the laser field dominated continuum: $\mathrm{p} = \mathrm{p}_i - \mathbf{A}(t_i)$

Time Reconstruction:

- Single Classical Trajectory (SCT) simulation assuming instantaneous tunnelling at field maximum
- offset angle = ellipticity correction + delay

$$\theta - \theta_{\mathrm{SCT}} = \frac{(1-\epsilon^2)\omega t_i}{\epsilon} + \epsilon\omega t_i$$

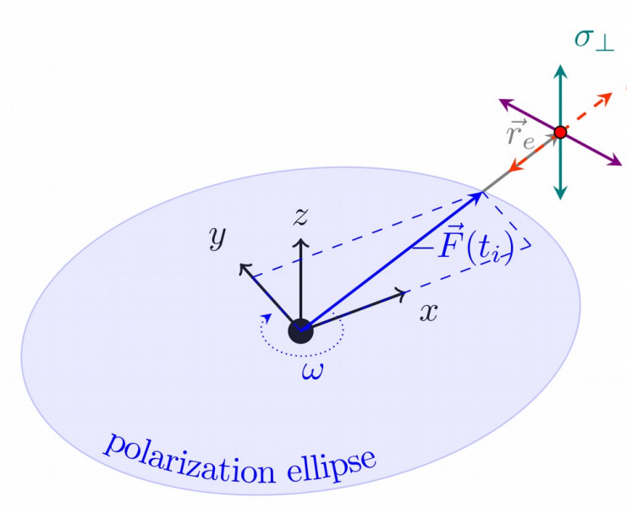


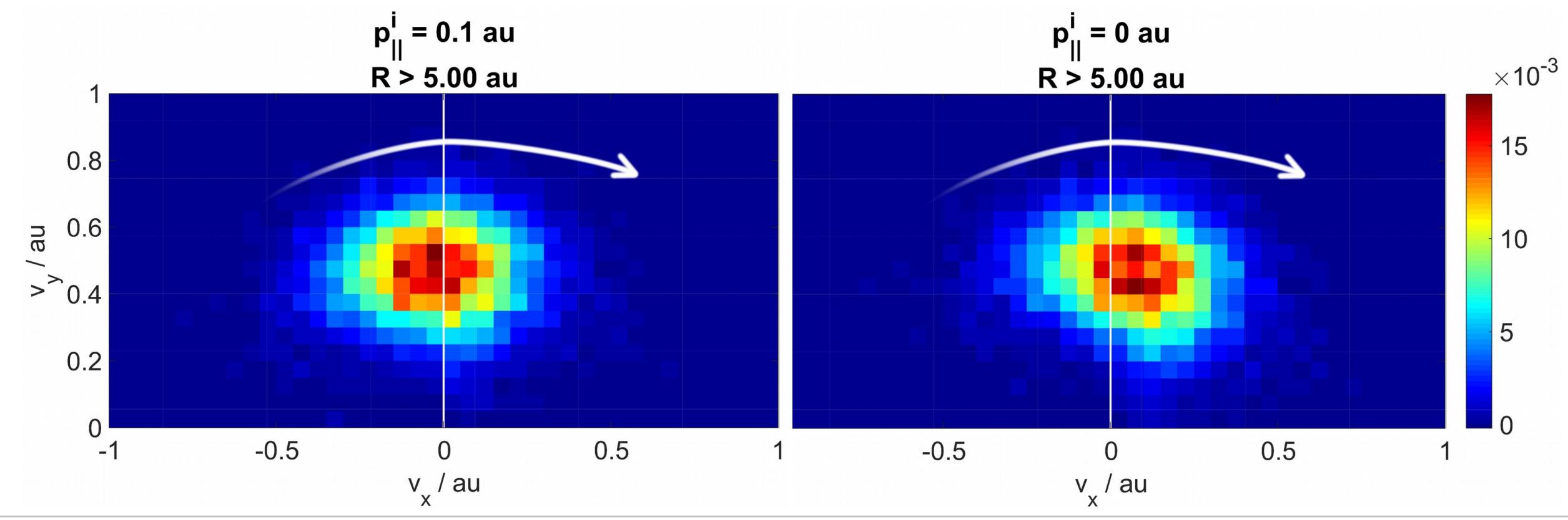
Nonadiabatic effects [A4]:

- initial transverse momentum
→ lower field strength calibration for same data [A5]
- energy gain
→ shorter exit radius

Initial condition dependence in classical trajectories

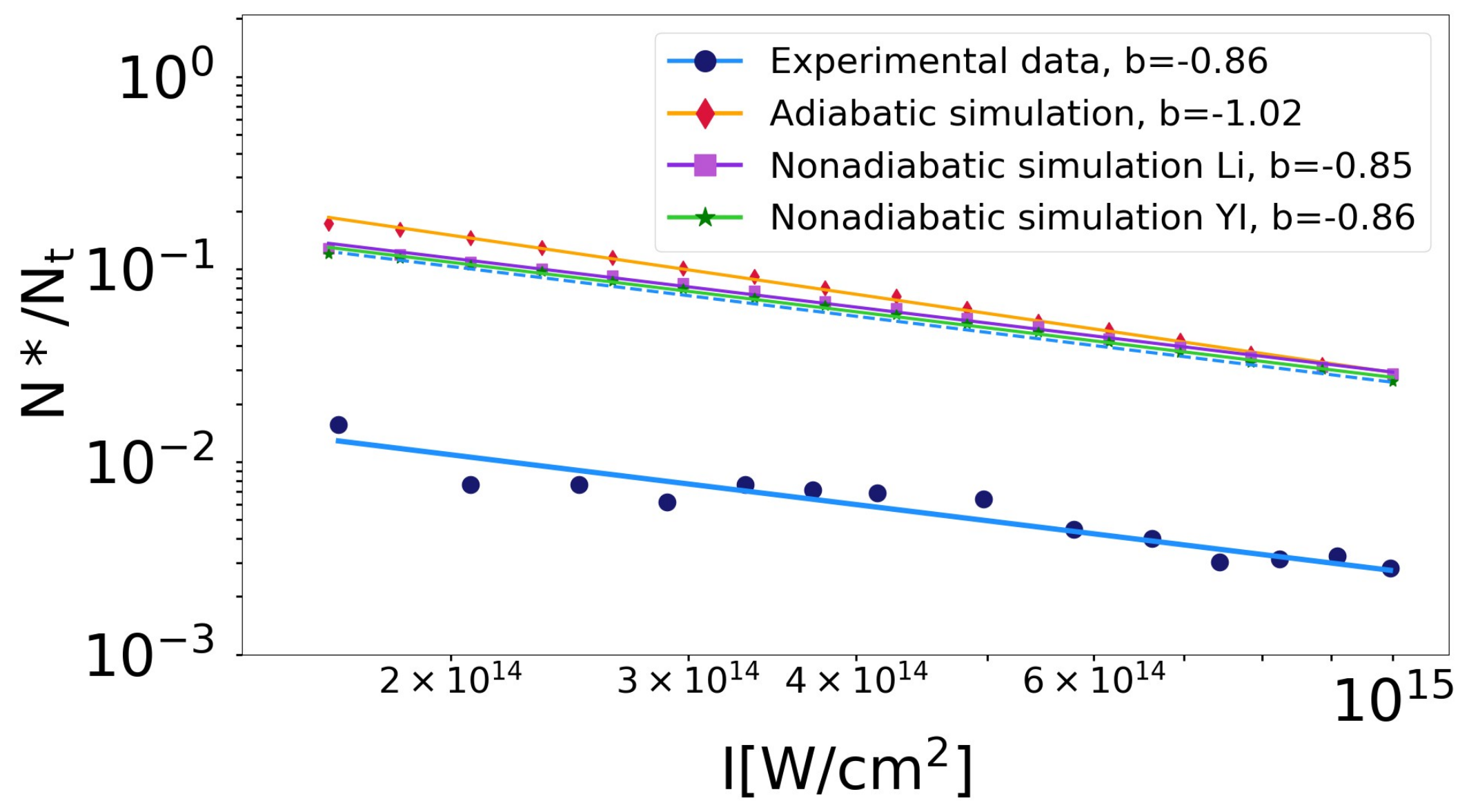
An initial momentum distribution centered around finite longitudinal momentum $\mathbf{p}^i_{||}$ [A6,A7,R5] reduces θ_{SCT} → $\theta - \theta_{\mathrm{SCT}}$ even larger.



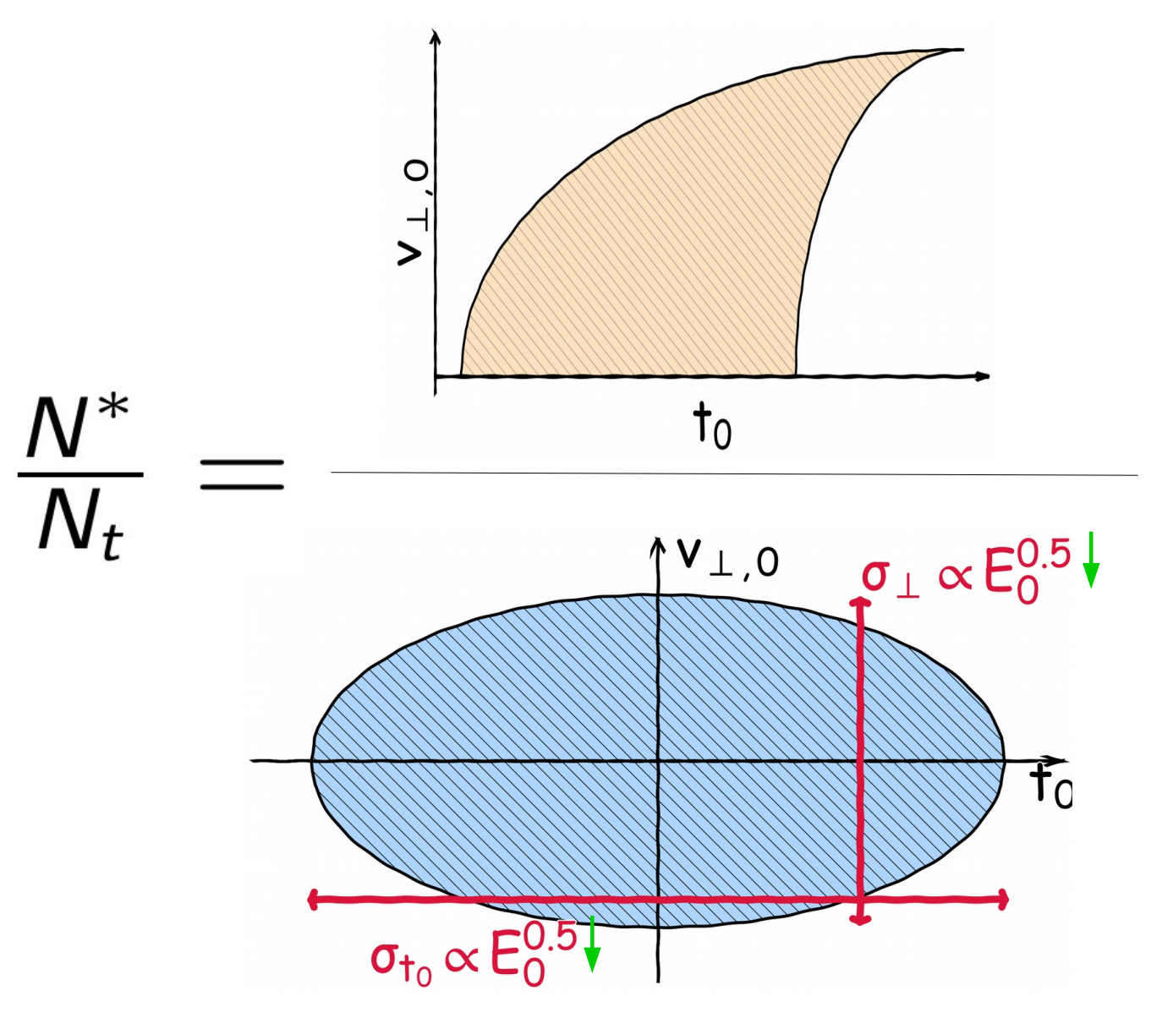


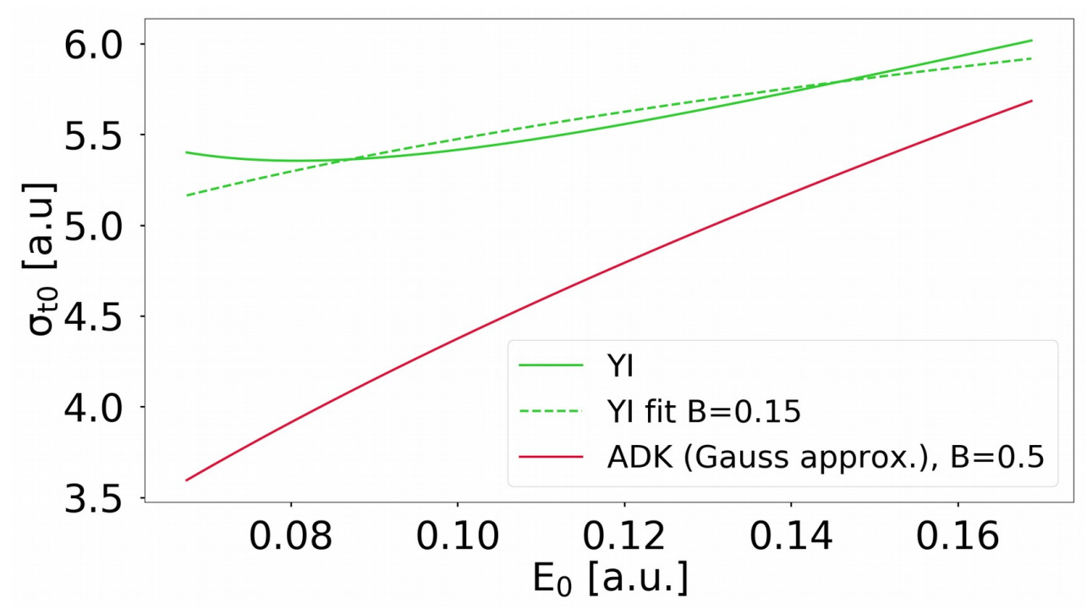
Rydberg states

Intensity dependence [R2]:



Experimental data extracted from [R1], the adiabatic and nonadiabatic data were obtained in CTMC simulations [R2] using [R3], [R4] and [R5] for the theories labelled ADK, YI, and Li respectively.



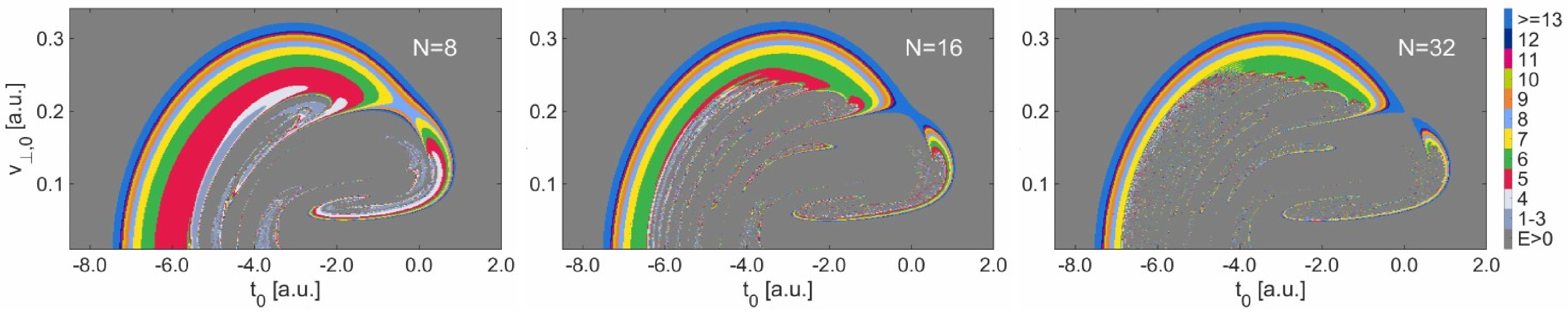


Left panel: Scheme to estimate the Rydberg yield, adapated from [R6].
Right panel: Field strength dependence of the ionization time spread in the adiabatic [R3] and nonadiabatic case [R4].

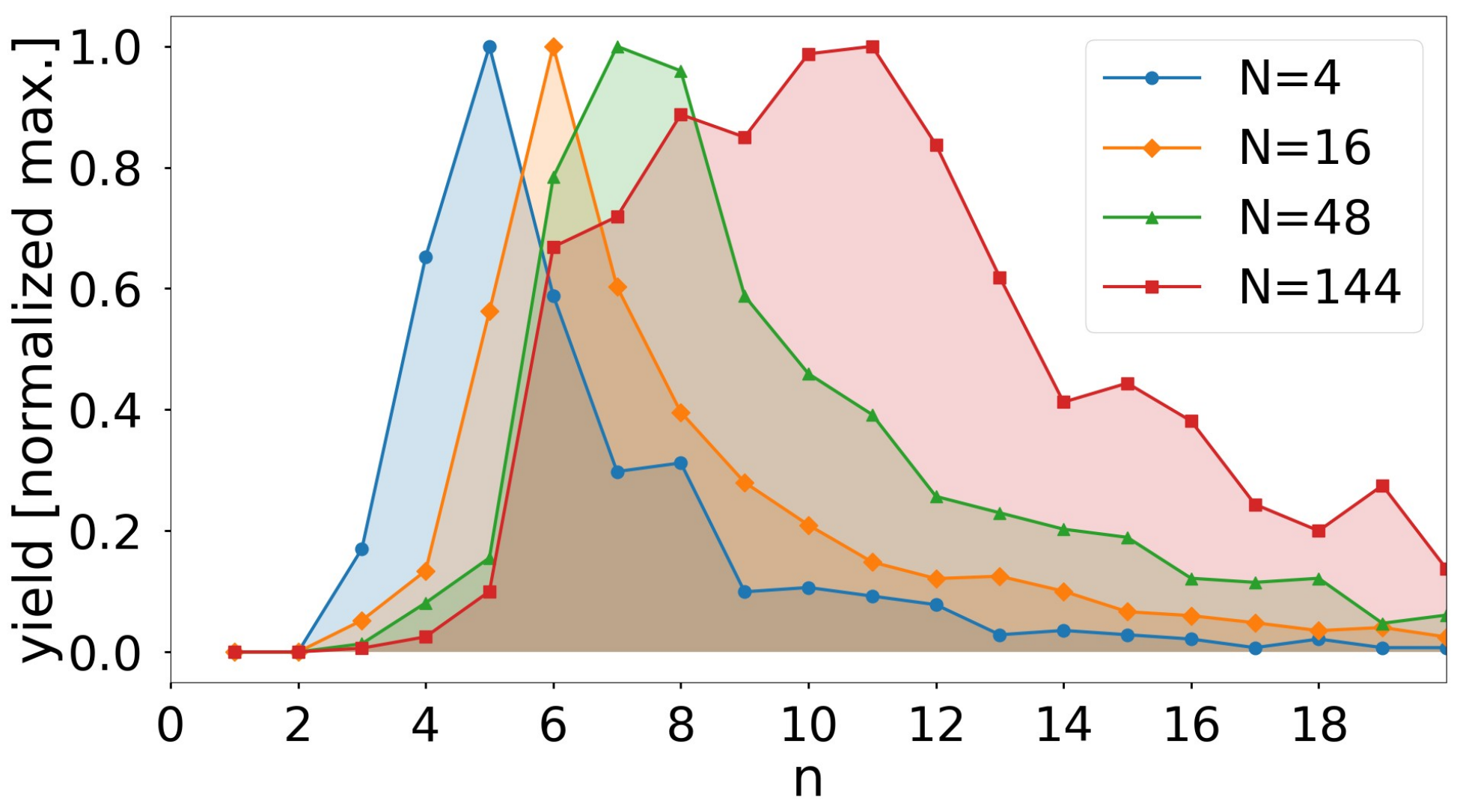
Nonadiabatic Rydberg yield decreases more slowly with increasing intensity, mainly because the time spread grows more slowly with increasing intensity in the nonadiabatic theory (due to nonadiabatic broadening at smaller intensities).

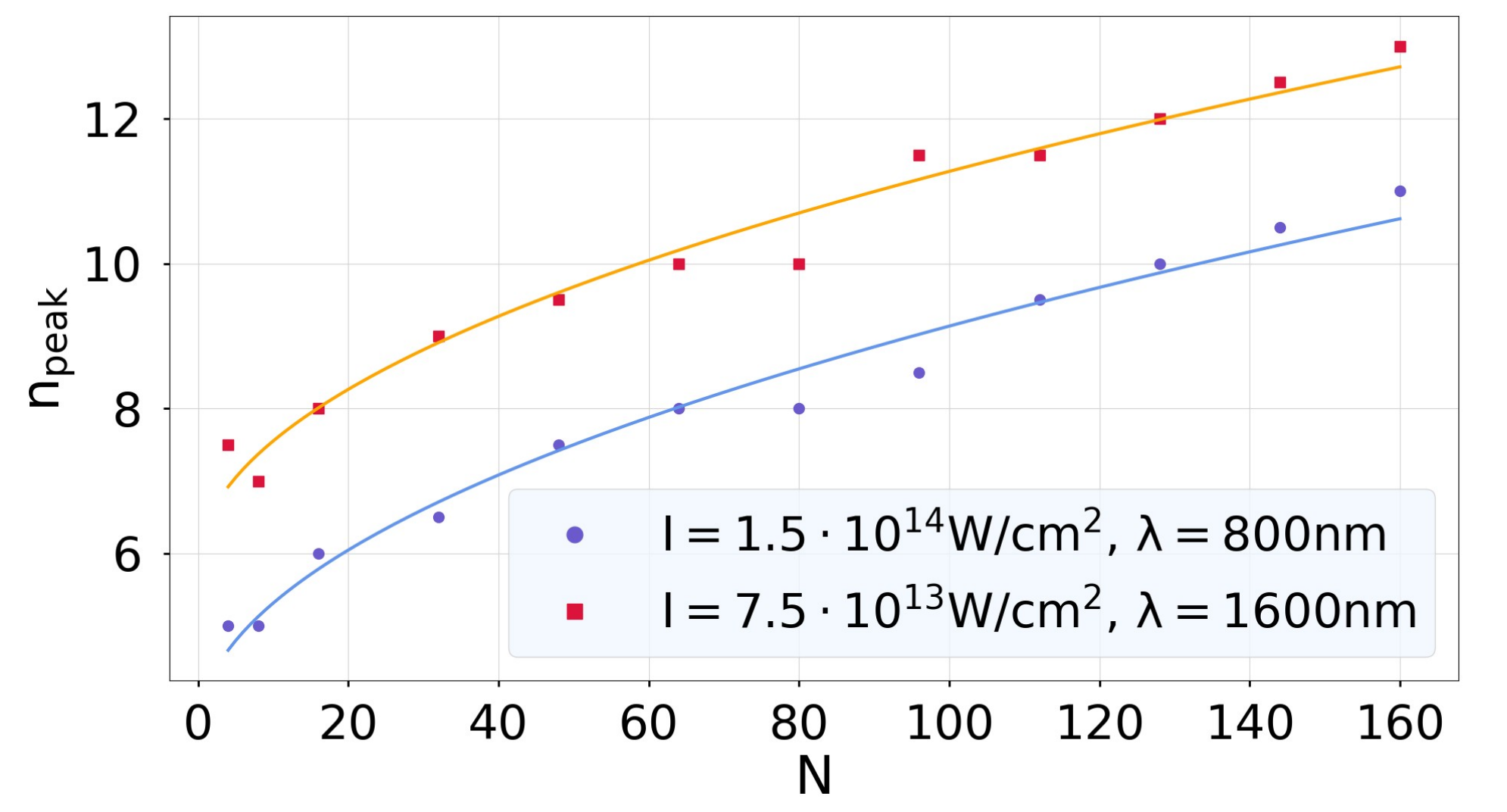
→ New nonadiabaticity test without calibration of absolute intensity

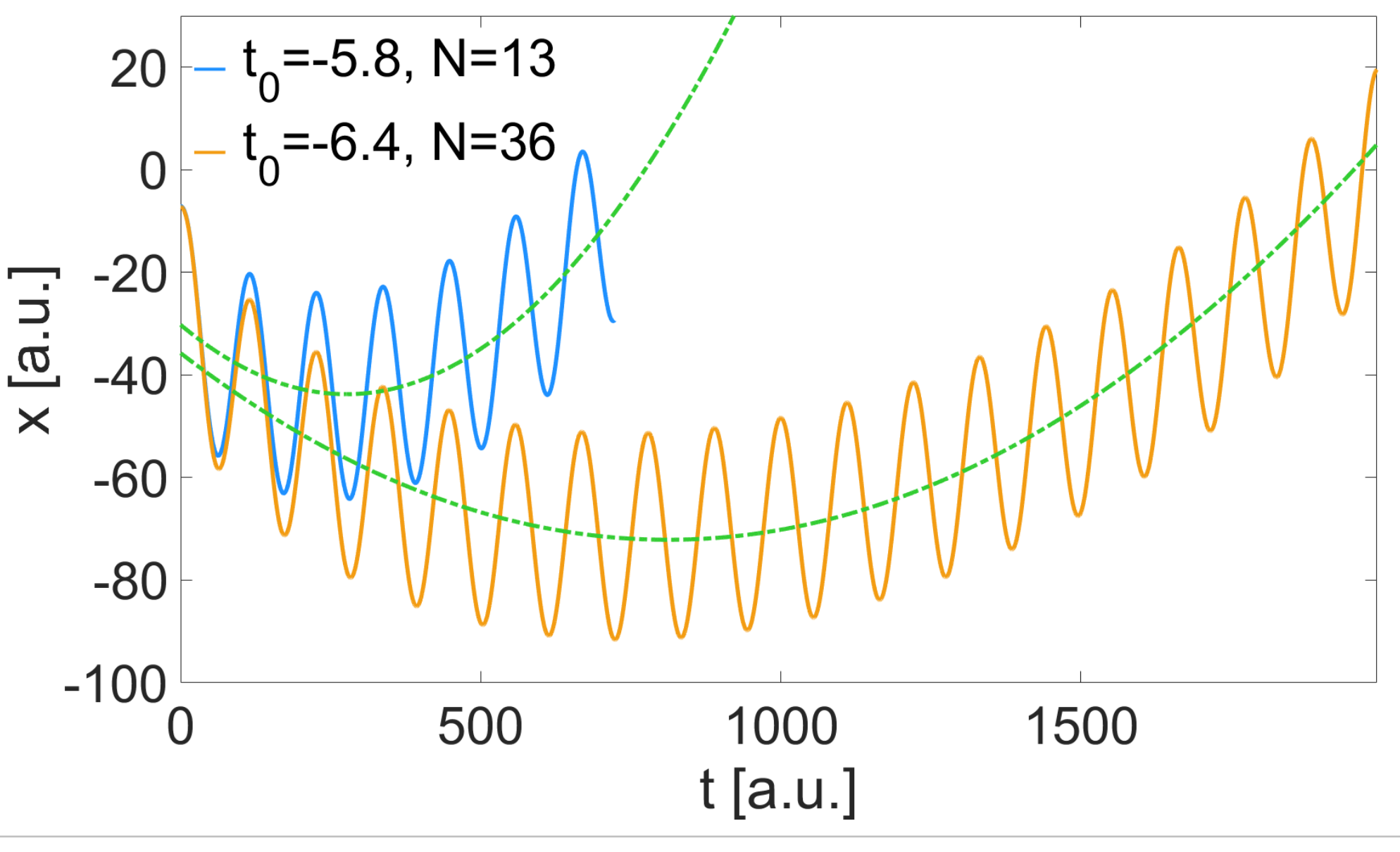
Pulse duration dependence [R7]:



Initial conditions for classical trajectories ending up in Rydberg states, colour coded by principal quantum number n, become fewer with increasing pulse duration.







Principal quantum number distribution shifting to larger values for longer pulses because:

Smaller principal quantum number n
→ born closer to the field maximum (t_0=0)
→ driven back to the parent ion in fewer optical cycles
→ only 'survives' short pulse as Rydberg state

The same mechanism also explains Rydberg yield decreasing with increasing pulse duration.

References

[H1] Ortmann, *et al*. and Landsman, Phys. Rev. Lett. **119**, 053204 (2017)
[H2] Ortmann and Landsman, Phys. Rev. A **119**, 023420 (2018)
[H3] Schötz, *et al*., Phys. Rev. A **119**, 013413 (2018)

[A1] Hofmann, Landsman, Keller, J. Mod. Opt. **66**, 1052-1070 (2019)
[A2] Eckle, *et al.*, Science, **322**, 1525-1529 (2008)
[A3] Landsman, *et al.,* Optica **1**, 343 (2014)
[A4] Mur, *et al.,* JETP 92, 777/788 (2001)
[A5] Hofmann, *et al.* and Landsman, New J. Phys. **18**, 043011 (2016)
[A6] Teeny, *et al.*, Phys. Rev. Lett. **116**, 063003 (2016)
[A7] Camus, *et al*., Phys. Rev. Lett. **119**, 023201 (2017)

[R1] Nubbemeyer, *et al.*, Phys. Rev. Lett. **101**, 063003 (2008)
[R2] Ortmann, Hofmann and Landsman, Phys. Rev. A **101**, 033415 (2018)
[R3] Ammosov, *et al.*, Sov. Phys. JETP **64**, 1191 (1986)
[R4] Yudin and Ivanov, *et al.*, Phys. Rev. A **64**, 013409 (2011)
[R5] Li, *et al.*, Phys. Rev. A **93**, 013402 (2016)
[R6] Shvetsov-Shilovski, *et al.*, Laser Phsyics **19**, 1550 (2009)
[R7] Ortmann, Hofmann and Landsman, arxiv:1810.07164 (2018)