Laser-induced tunnel ionization: tunneling time and relativistic effects

Nicolas Teeny*, Enderalp Yakaboylu, Michael Kaliber,
Heiko Bauke, Karen Z. Hatsagortsyan and Christoph H. Keitel

Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

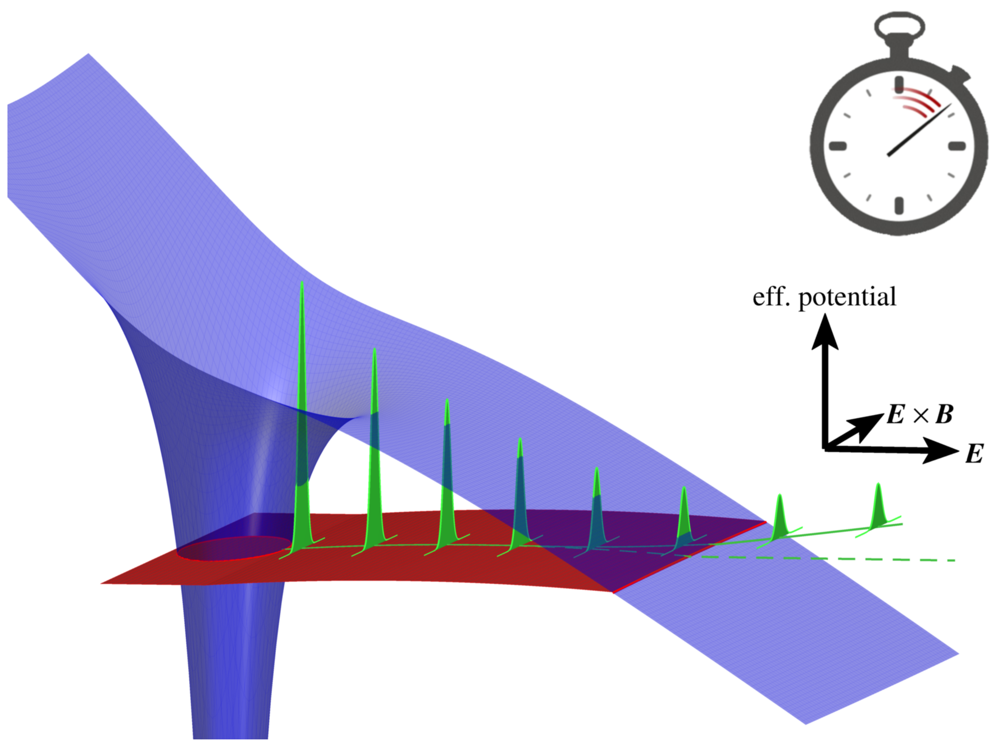

Figure 1: Wave packet tunneling through a coulomb potential bent by a laser potential.

Relativistic tunneling

Non relativistic tunneling picture:

$$\frac{\hat{P}_x^2}{2} + V(x,y,z) - xE_0 = -I_p - \left(\frac{\hat{P}_y^2}{2} + \frac{\hat{P}_z^2}{2}\right)$$

Constant total energy $E = -I_p$.

Relativistic tunneling picture:

$$\frac{\hat{P}_x^2}{2} + V(x,y,z) - xE_0 = -I_p - \left(\frac{\hat{P}_y^2}{2} + \frac{(\hat{P}_z + xE_0/c)^2}{2}\right)$$

Position dependent total energy:

$$E(x) = -I_p - \left(\frac{\hat{P}_y^2}{2} + \frac{(\hat{P}_z + xE_0/c)^2}{2}\right)$$

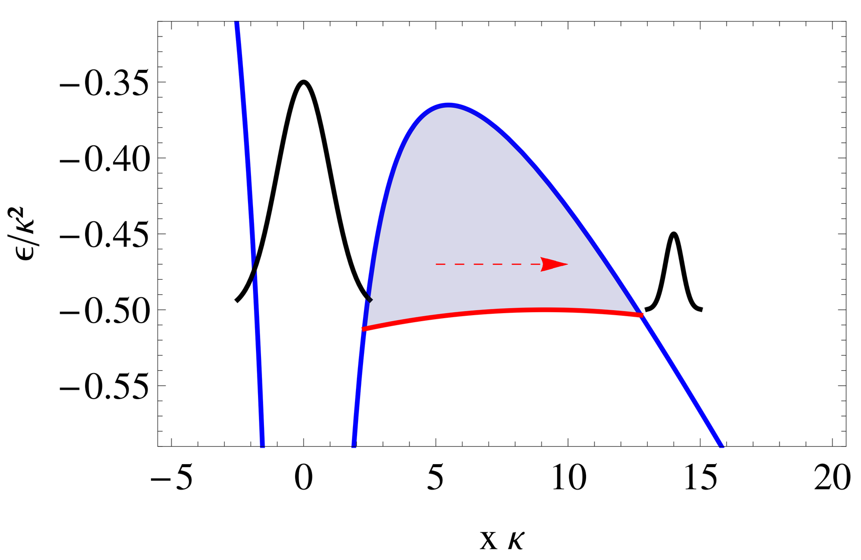

Figure 2: Schematic relativistic tunneling picture. The position dependent total energy $E(x)$ is plotted (red-line), crossing the total potential $V(x,y,z) - xE_0$ (blue-line) [1].

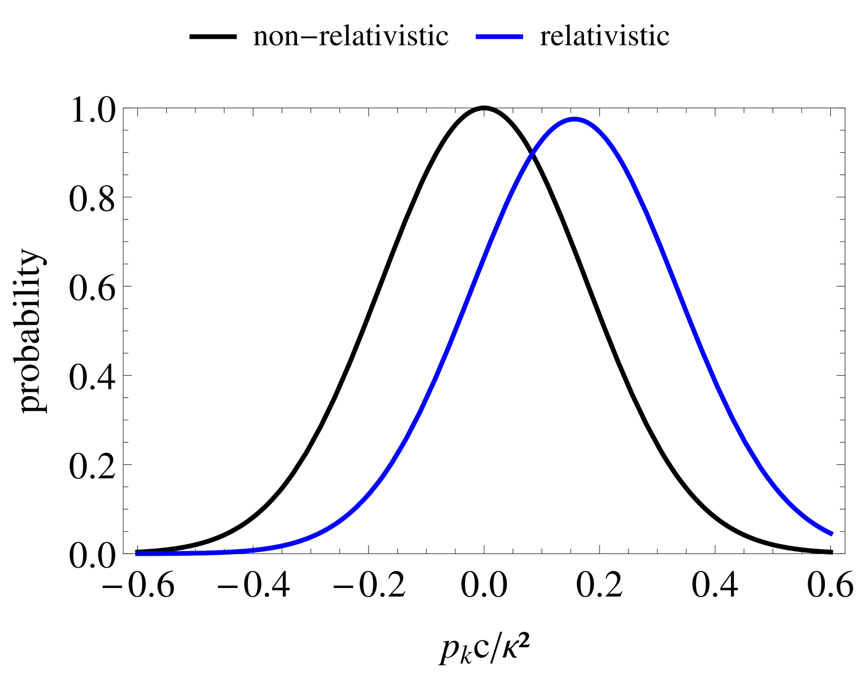

Figure 3: The momentum probability distribution of the tunneled electron at the barrier exit in the relativistic case is compared to the non-relativistic case [1].

*e-mail: nicolas.teeny@mpi-hd.mpg.de

Ionization time, exit momentum and asymptotic momentum

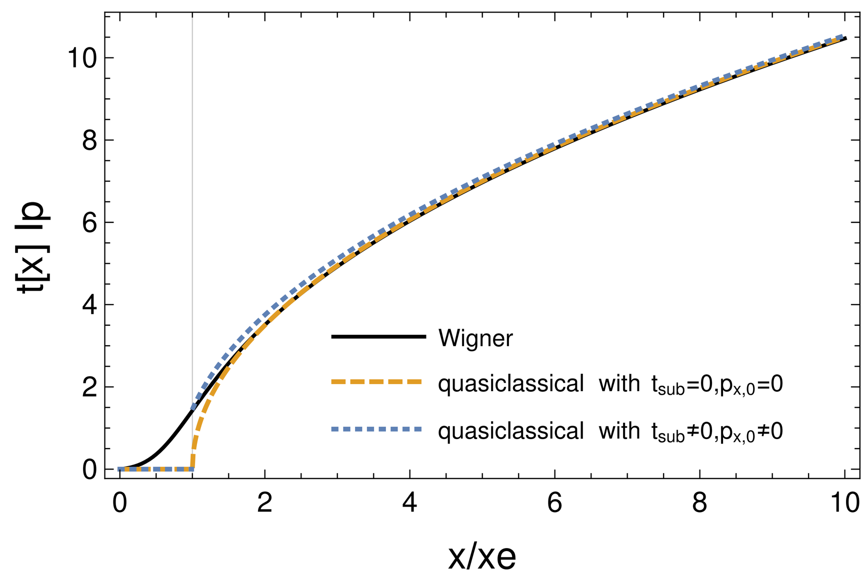

Figure 4: Wigner trajectory compared to the classical trajectory in the deep tunneling regime with the electric field strength $E_0 = Z^3/30$ [2, 3].

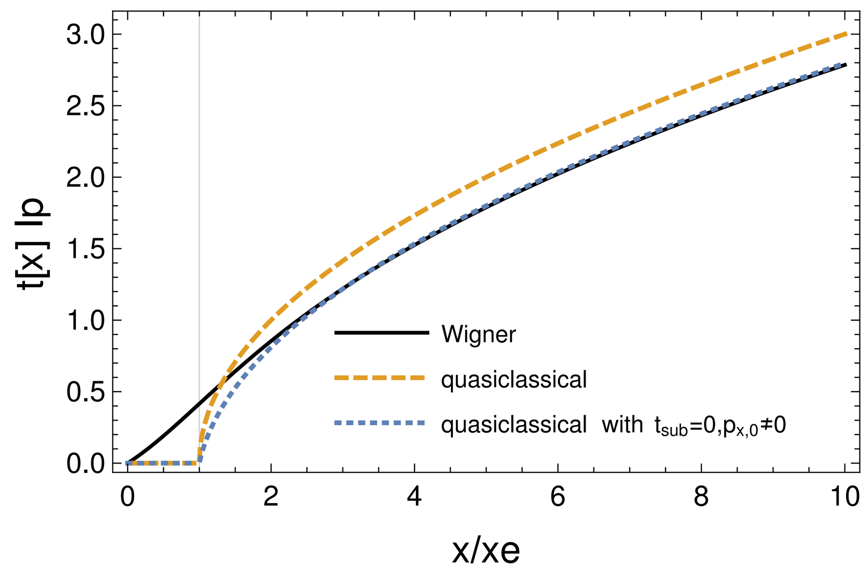

Figure 5: Wigner trajectory compared to the classical trajectory in the near-threshold-tunneling regime with the electric field strength $E_0 = Z^3/17$ [2, 3].

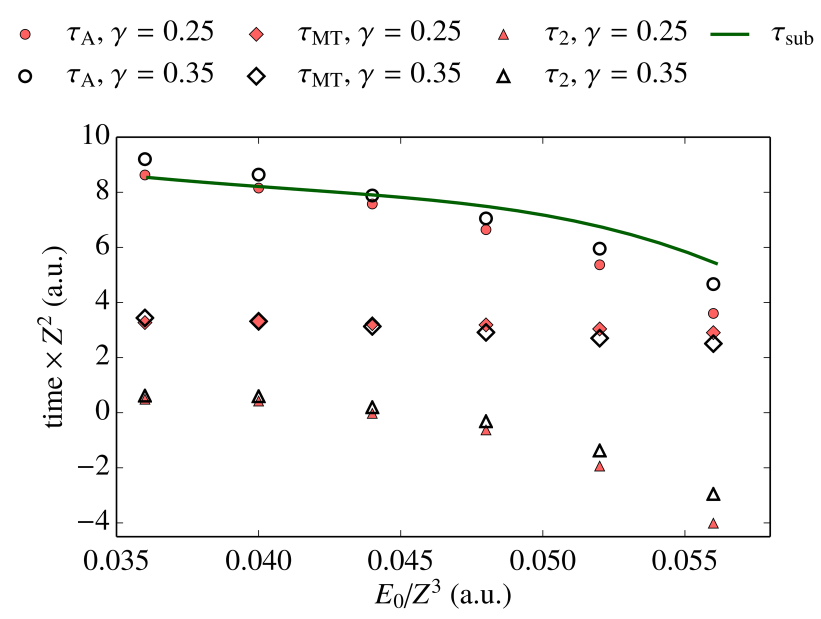

Figure 6: Various times plotted for different electric field strengths E_0 and different Keldysh parameters γ. The ionization time τ_A determined by placing a virtual detector at the tunneling exit. The Mandelstam and Tamm time τ_{TMT} measured at the instant of electric field maximum. The ionization time τ_2 calculated from the asymptotic momentum using the two-step model. The time spent under the barrier using Wigner formalism τ_{sub} is a good estimate for τ_A [4].

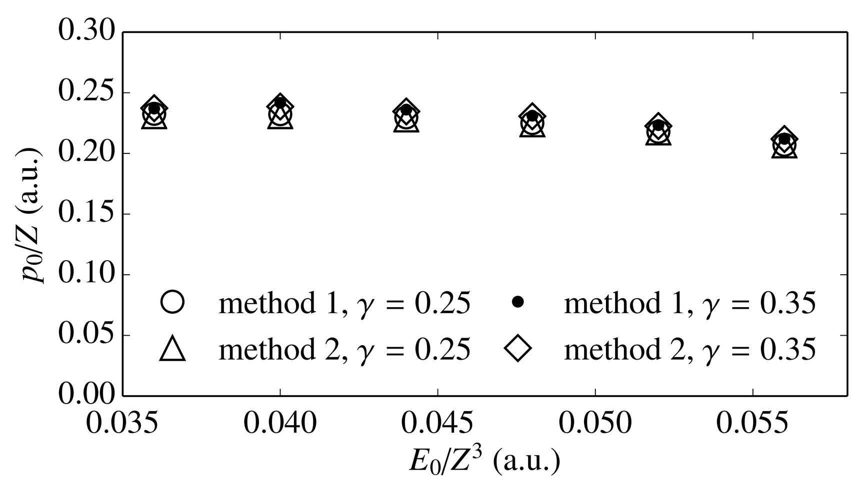

Figure 7: The exit momentum at the instant of ionization at the tunnel exit for different electric field strengths E_0 and different Keldysh parameters γ determined by two different methods. Method 1 is based on the space resolved momentum distribution, while method 2 utilizes the velocity of the probability flow [4].

References

[1] M. Klaiber, E. Yakaboylu, H. Bauke, K. Z. Hatsagortsyan and C. H. Keitel *Phys. Rev. Lett*, vol. 110, p. 153004, 2013.

[2] E. Yakaboylu, M. Klaiber, H. Bauke, K. Z. Hatsagortsyan and C. H. Keitel *Phys. Rev. A*, vol. 90, p. 012116, 2014.

[3] E. Yakaboylu, M. Klaiber, H. Bauke, K. Z. Hatsagortsyan and C. H. Keitel *Phys. Rev. A*, vol. 88, p. 063421, 2013.

[4] N. Teeny, E. Yakaboylu, H. Bauke and C. H. Keitel *arXiv*:1502.05917