Two-Photon Ionization of He through a Superposition of Higher Harmonics

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Outline

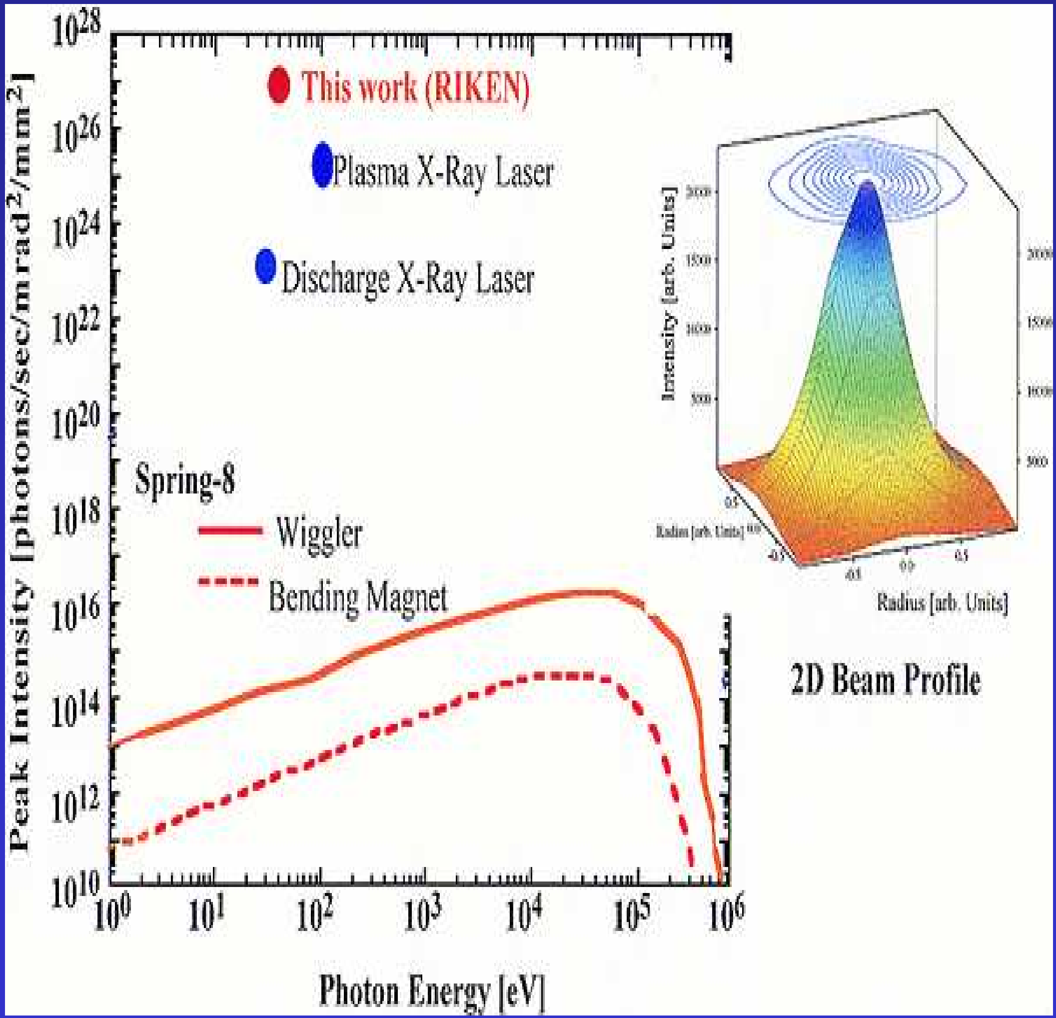
- Motivation
- The applied Coupled-Channel Method
- Results for Photoionization
- Two-Photon Single-Ionization
- Summary

Motivation

it is experimentally possible to create XUV laser pulses with HHG

⟶ two-photon ionization can be studied

⟶ electron-electron correlation can be investigated



http://www.riken.jp/engn/rworld/research/lab/wako/laser-tech/result.htm

Our coupled-channel method

-- The applied Coupled-Channel Method was originally developed for ion-He collision (details in I.F. Barna, *Ionization of helium in relativistic heavy-ion collisions*, Doctoral Thesis, University of Giessen (2002) „Giessener Elektronische Bibliothek"

http://geb.uni-giessen.de/geb/volltexte/2003/1036

I.F. Barna, N. Grün and W. Scheid, *Eur. Phys. J. D* **25**, (2003) 239

I.F. Barna, K. Tőkési and J. Burgdörfer, *J. Phys. B* **38**, (2005) 1

-- Later modified to study photoionization and coherent control

I.F. Barna, J.M. Rost, *Eur. Phys. J. D* **27**, (2003) 287

I.F. Barna, *Eur. Phys. J. D* **33**, (2005) 307

I.F. Barna, J. Wang and J. Burgdörfer, *Phys. Rev. A* **73**, 023402 (2006)

The Hamiltonian of the system:

The time-dependent Schrödinger equation:

$$i\frac{\partial}{\partial t}\Psi(\vec{r}_1,\vec{r}_2,t) = (\hat{H}_{He} + \hat{V}(t))\Psi(\vec{r}_1,\vec{r}_2,t)$$

- $\hat{V}(t)$ laser-electron interaction
- $\Psi(\vec{r}_1,\vec{r}_2,t)$ CI. wavefunction of helium

The unperturbed helium Hamiltonian:

$$\hat{H}(\vec{r}_1,\vec{r}_2)_{He} = -\frac{\vec{\nabla}_1^2}{2} - \frac{\vec{\nabla}_2^2}{2} - \frac{2}{r_1} - \frac{2}{r_2} + \frac{1}{|\vec{r}_1 - \vec{r}_2|}$$

- spin-spin, spin-orbit, and mass polarisation terms are neglected

The coupled-channel equation

Ansatz:

$$\Psi(\vec{r}_1, \vec{r}_2, t) = \sum_{j=1}^{N} a_j(t)\Phi_j(\vec{r}_1, \vec{r}_2)e^{-iE_jt}$$

Leads to a system of first-order-differential equations for the coefficients a_j :

$$\frac{da_k(t)}{dt} = -i\sum_{j=1}^{N} V_{kj}(t)e^{-i(E_j-E_k)t}a_j(t) \quad (k = 1\ldots.N)$$

$V_{kj}(t) = \langle\Phi_k|\hat{V}(t)|\Phi_j\rangle$ coupling matrix

Initial conditions:

$$a_k(t \to -\infty) = \begin{cases} 1 & k = 1 \\ 0 & k \neq 1 \end{cases}$$

the final probability for each channel:

$$P_k(b, t \to \infty) = |\, a_k(t \to \infty)\,|^2$$

The wavefunction

Configuration interaction(CI) expansion of $\Phi_j(\vec{r}_1, \vec{r}_2)$ in terms of two-particle basis functions f_μ

$$\Phi_j(\vec{r}_1, \vec{r}_2) = \sum_\mu b^j_\mu f_\mu(\vec{r}_1, \vec{r}_2).$$

where $f_\mu(\vec{r}_1, \vec{r}_2)$ are symmetric (S=0) products of

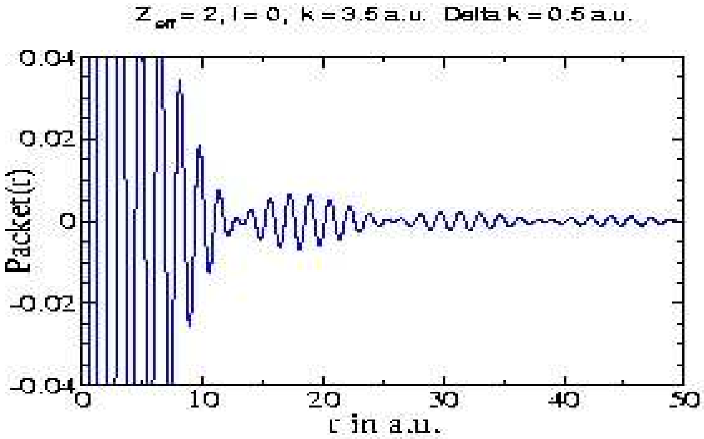
1. Slater-type orbitals:

$$\chi_{n,l,m,\kappa}(\vec{r}) = C(n, \kappa) r^{n-1} e^{-\kappa r} Y_{l,m}(\theta, \varphi)$$

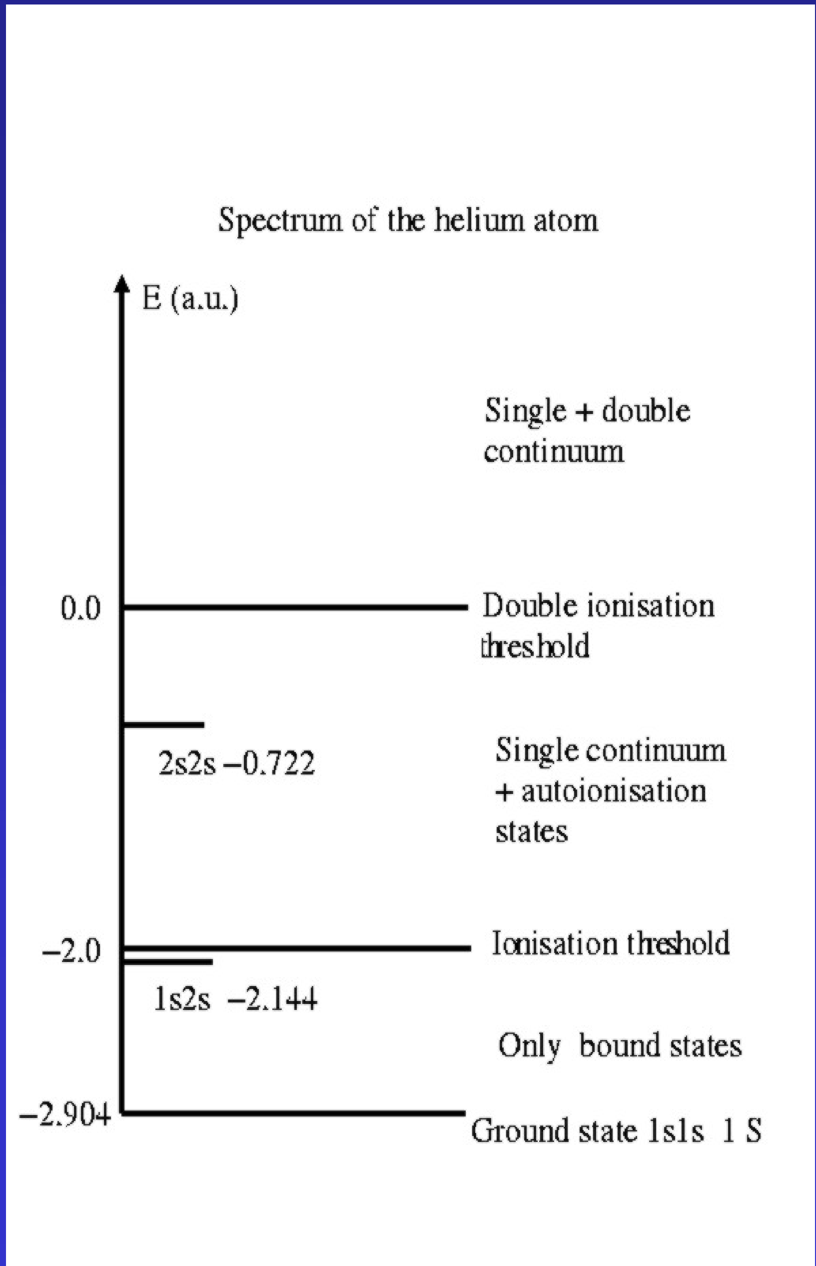
2. regular Coulomb wave packets:

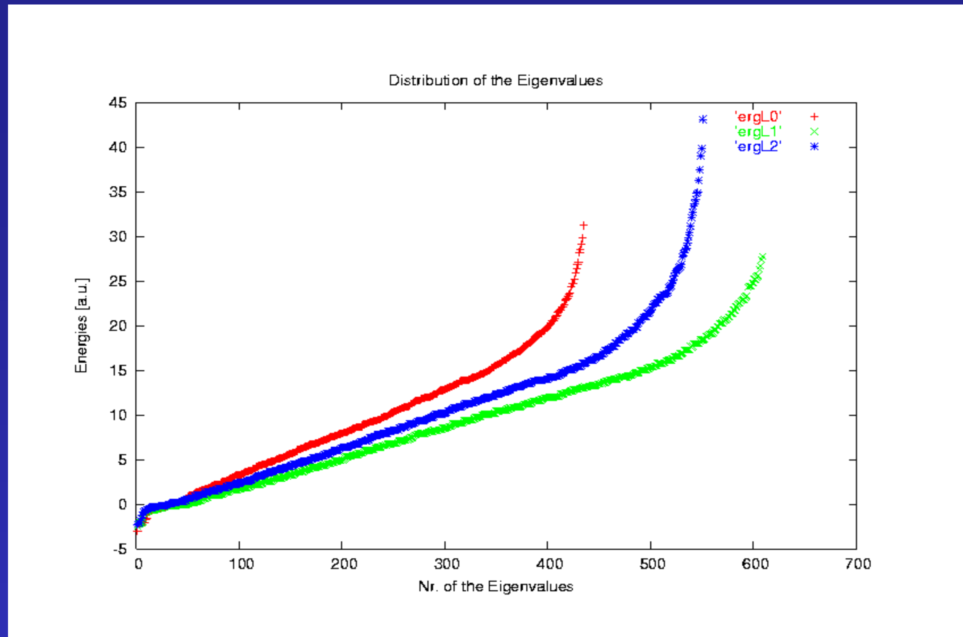
$$\varphi_{k,l,m,\tilde{Z}}(\vec{r}) = N(k, \Delta k) \int_k^{k+\Delta k} R_l(\eta, \rho) dk' Y_{l,m}(\theta, \varphi)$$

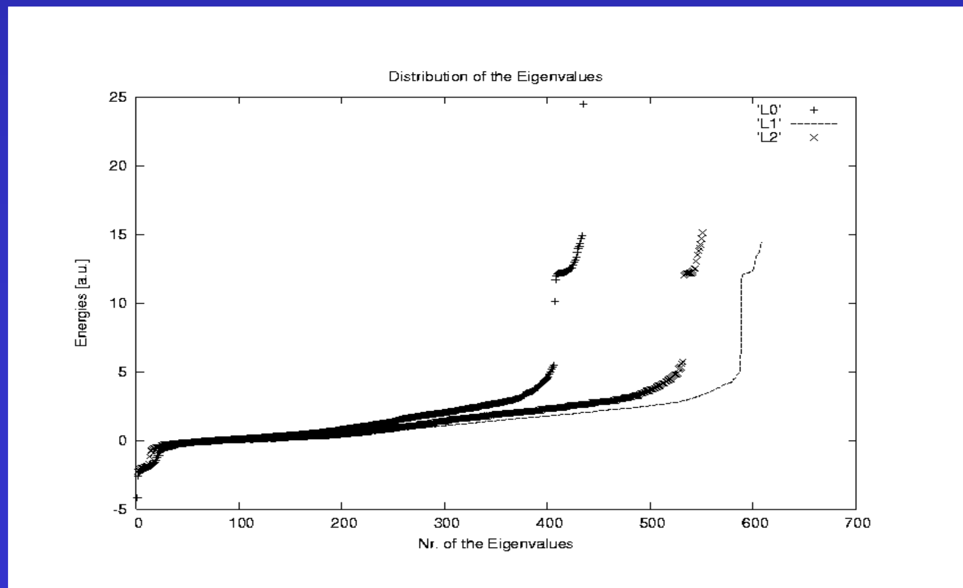
- $\eta = \tilde{Z}/k'$, $\rho = k'r$, $\tilde{Z}$ effective charge
- $N(k, \Delta k)$, $C(n, \kappa)$ normalisation constants



Spectrum & Continuum States







Laser field

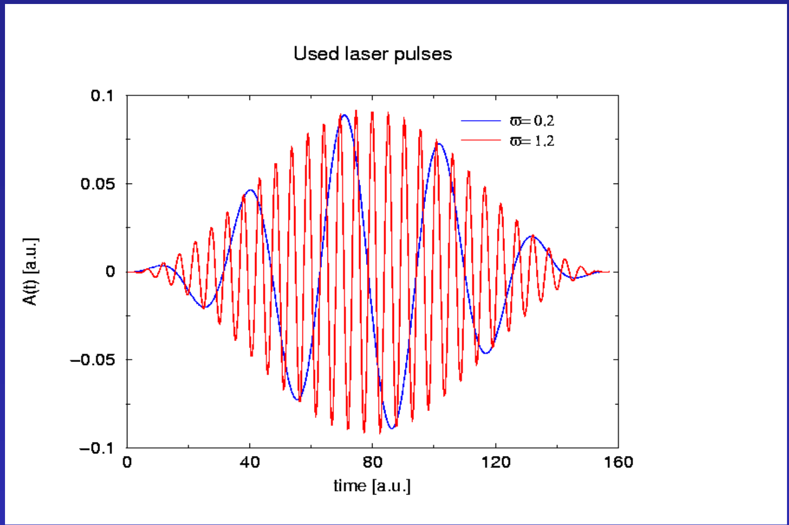
minimal coupling for the electromagnetic field to $\hat{H}_{He}$

$$\hat{H}(\vec{r}_1,\vec{r}_2,t) = \frac{(\vec{p}_1 - \vec{A}(\vec{r}_1,t)/c)^2}{2} + \frac{(\vec{p}_2 - \vec{A}(\vec{r}_2,t)/c)^2}{2}$$

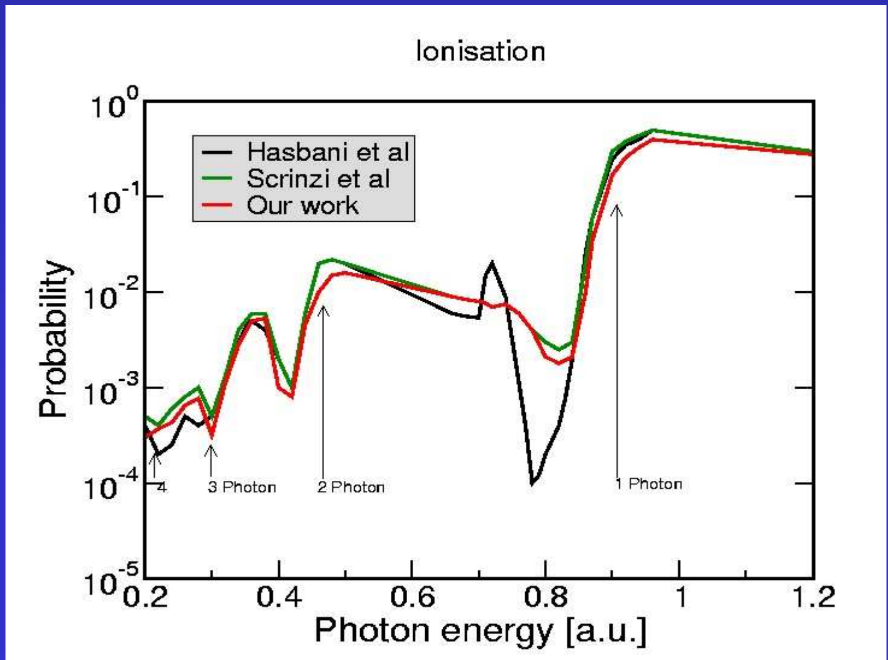
$$-\frac{2}{r_1} - \frac{2}{r_2} + \frac{1}{r_{12}} - \phi(\vec{r}_1,t) - \phi(\vec{r}_2,t) = \hat{H}_{He} + \hat{V}(t)$$

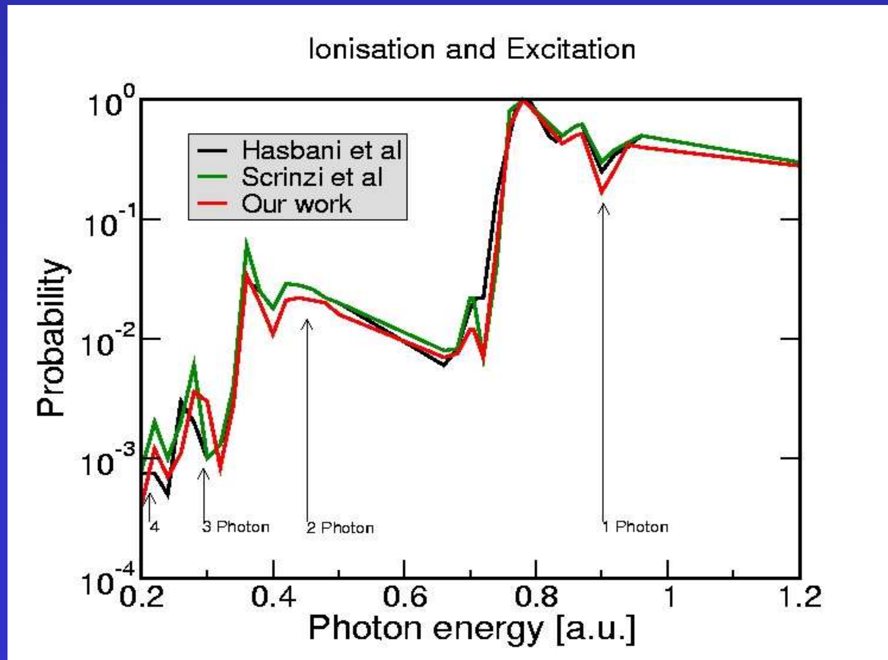
- dipole approximation: $\lambda_{laser} >> r_{atom}$
- velocity gauge: $\hat{V}(\vec{r},t) = \sum_{i=1,2} \vec{A}(t)\cdot\vec{p}_i$
- length gauge:
  $\hat{V}(\vec{r},t) = -\sum_{i=1,2} \vec{E}(t)\cdot\vec{r}_i, \qquad \vec{E}(t) = -\frac{1}{c}\frac{\partial}{\partial t}\vec{A}(t)$
- $\vec{E}(t) = E_0 \cdot F(t)\cdot \sin(\omega t)\cdot \vec{e}_z$ linearly polarised pulse
- envelope function: $F(t) = \sin^2\left(\frac{\pi t}{T}\right)$ T is the pulse duration
- or $F(t) = \exp\left(-\frac{(2ln2)t^2}{T^2}\right)$ T is the FWHM

Laser pulse & Photoionization



A. Scrinzi *et al*. PRA **58**, 1310 (1998)
R. Hasbani *et al*. JPB **33**, 2101 (2000)
I. F. Barna *et al*. Eur. Phys. J. D **27,** 287 (2003)

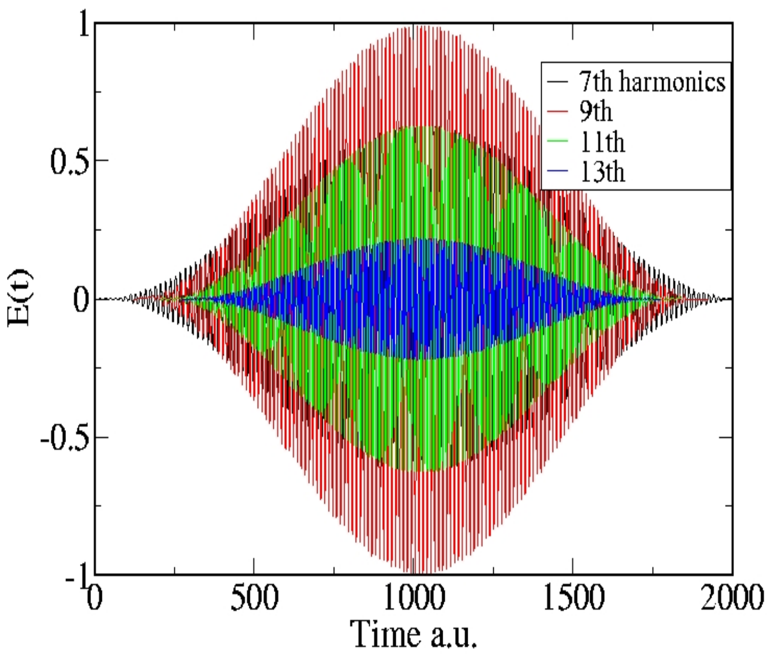


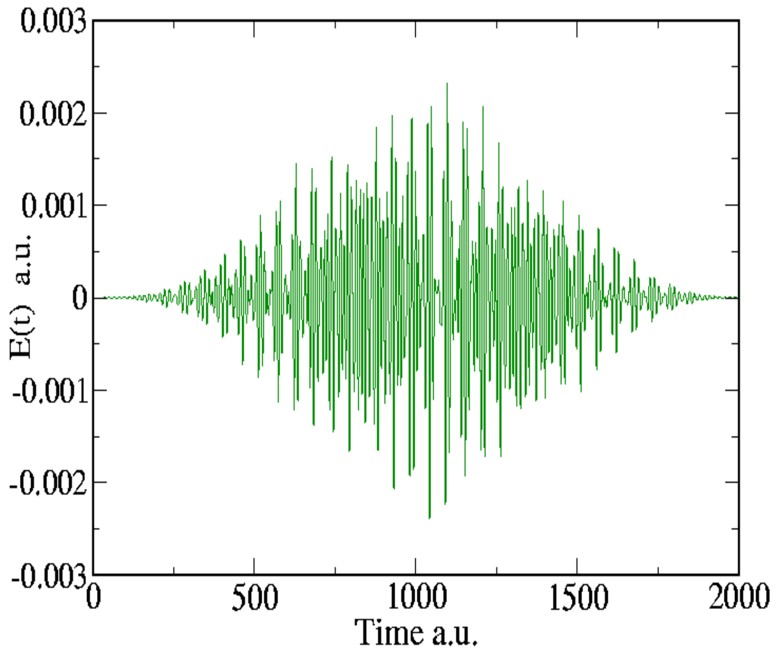


Two-Photon Ionization of He through a superposition of Higher Harmonics

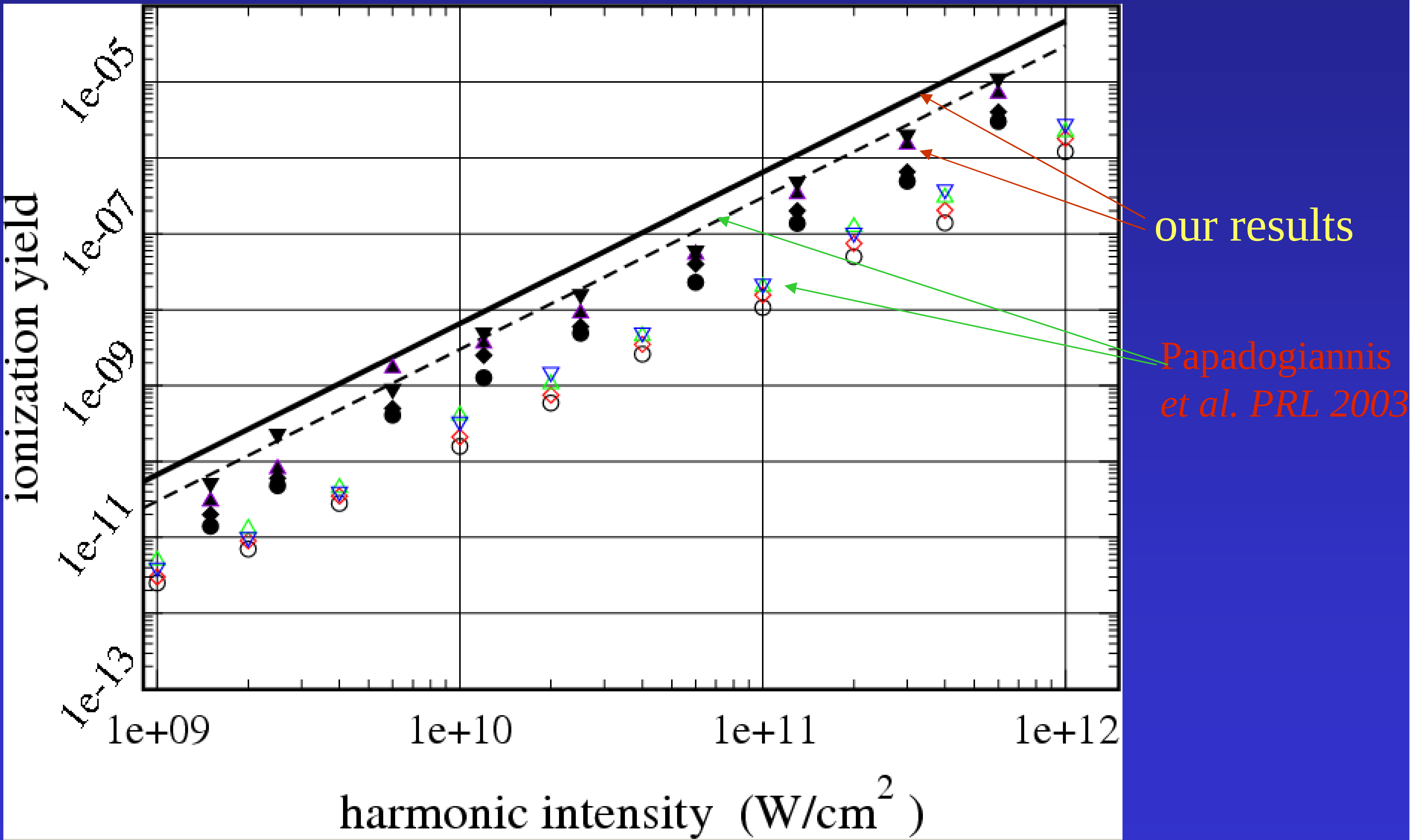
Experiment & Theory (Coupled Channel method, Spline Base)

N. A. Papadogiannis *et al.* ***PRL 90 133902-1 (2003)***





Results



ionization yield
1e-05
1e-07
1e-09
1e-11
1e-13
1e+09
1e+10
1e+11
1e+12
harmonic intensity (W/cm^2)
our results
Papadogiannis
et al. PRL 2003

Summary

we presented our ab-initio coupled-channel method

showed some results for photoionization in short XUV laser pulses

showed some results for photoionization in a superposition of short XUV laser pulses

it seems to be that:
atomic orbit bases are inferior to spline bases