Two-photon double ionisation of helium

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Outline

- Motivation
- The applied method
- Results for photoionisation
- Above-threshold double ionisation (ATDI)
- Summary and Outlook

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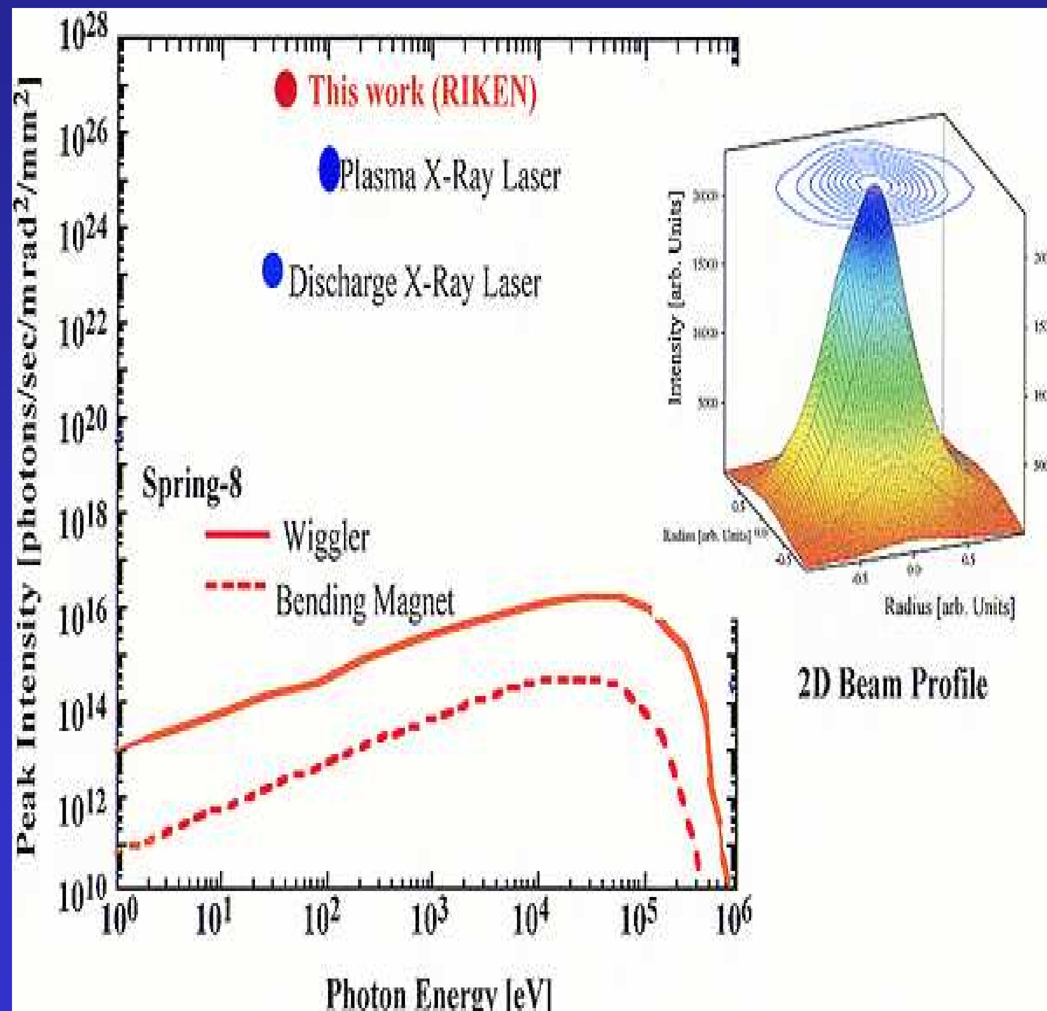
Motivation

it is experimentally possible to create XUV laser pulses with HHG

⟶ two-photon double ionisation can be studied

⟶ electron-electron correlation can be investigated

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



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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

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The coupled-channel equation

Ansatz:

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

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:

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

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The wavefunction

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

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

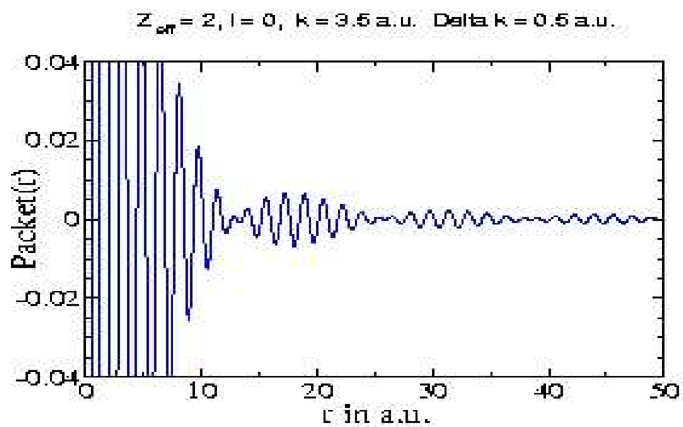
where $f_\mu(\vec{r}_1, \vec{r}_2)$ are symmetric (S=0) products of
1. Slater-type orbitals:

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

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



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Angular Electron Distribution

we use the density operator to calculate the electron density after the pulse:

$$\rho(\vec{r}) = \left\langle \Psi(\vec{r}_1, \vec{r}_2, t \to \infty) \left| \sum_{i=1,2} \hat{\delta}(\vec{r} - \vec{r}_i) \right| \Psi(\vec{r}_1, \vec{r}_2, t \to \infty) \right\rangle$$

1.) we apply the Feshbach projection to extract the singly ionised contribution from the wavefunction

$$|\Psi_{ion}\rangle = (1 - \hat{P}_b - \hat{P}_{di})|\Psi(\vec{r}_1, \vec{r}_2, t \to \infty)\rangle$$

2.) integrate the radial and azymuthal angle to get the polar distribution of the ionised electron

$$P(\theta) = \frac{1}{2\pi} \int_0^\infty \int_0^{2\pi} \langle \Psi_{ion}| \sum_{i=1,2} \hat{\delta}(\vec{r} - \vec{r}_i) |\Psi_{ion}\rangle r^2 dr d\varphi =$$

$$\frac{1}{\pi} \int_0^\infty \int_0^{2\pi} \int_{\vec{r}_1} |\Psi_{ion}(r, \theta, \varphi, \vec{r}_1)|^2 d^3 r_1 r^2 dr d\varphi$$

the angular dependence of $P(\theta)$ is given by products of associated Legendre polynomials

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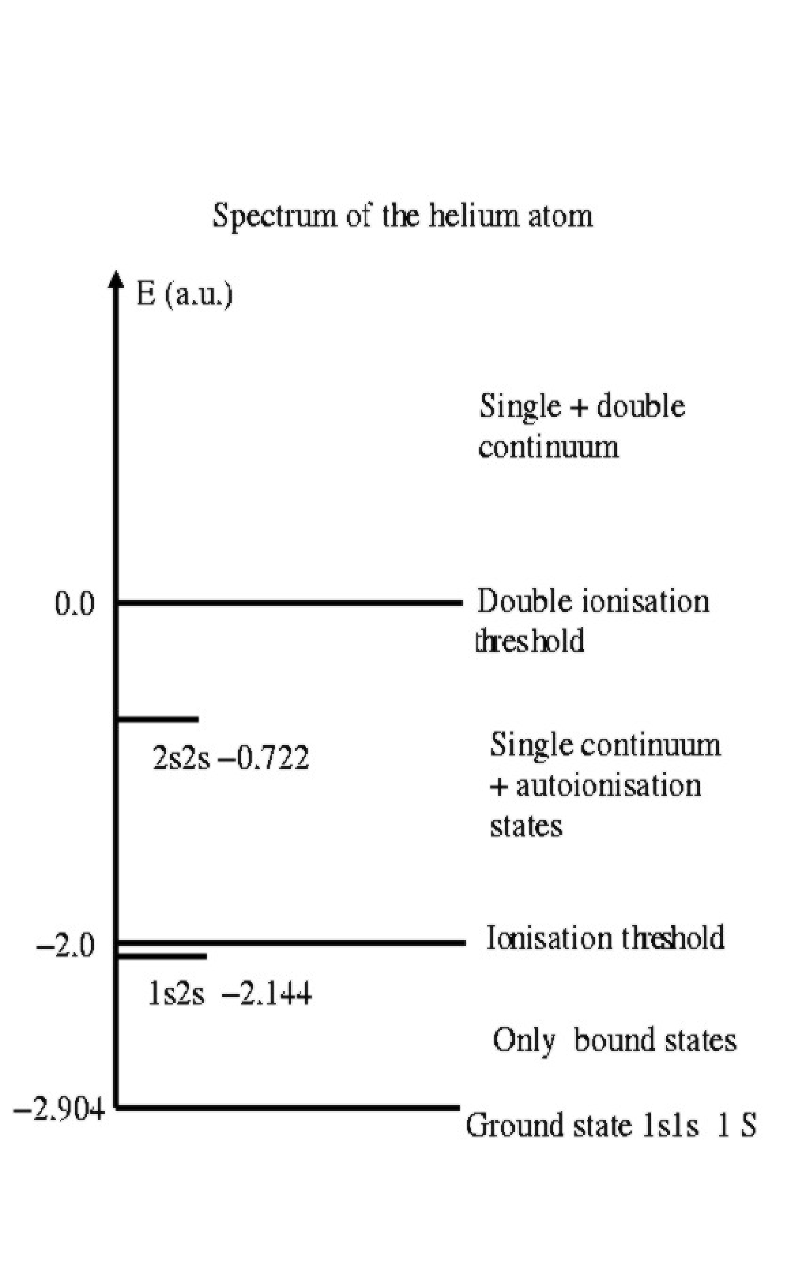
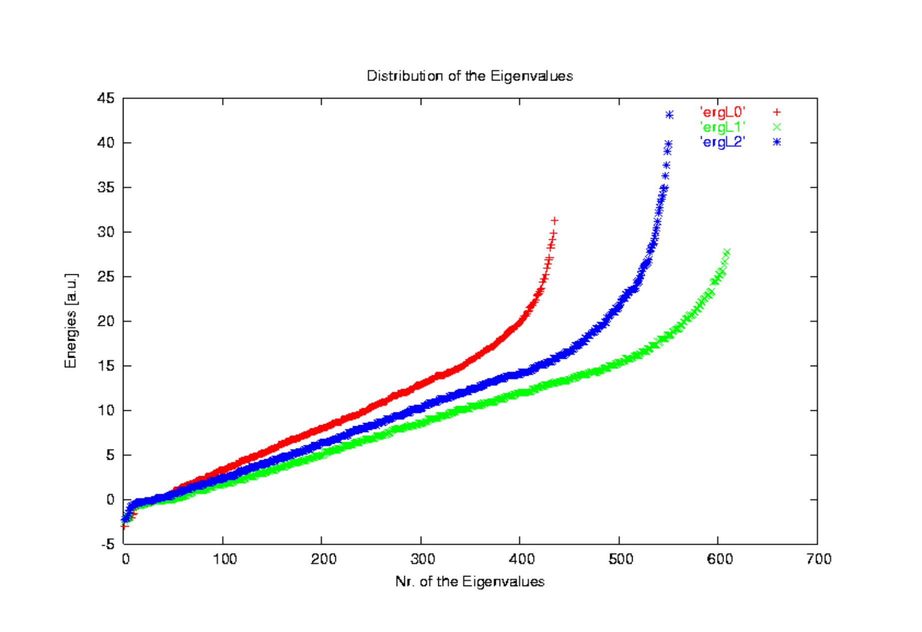
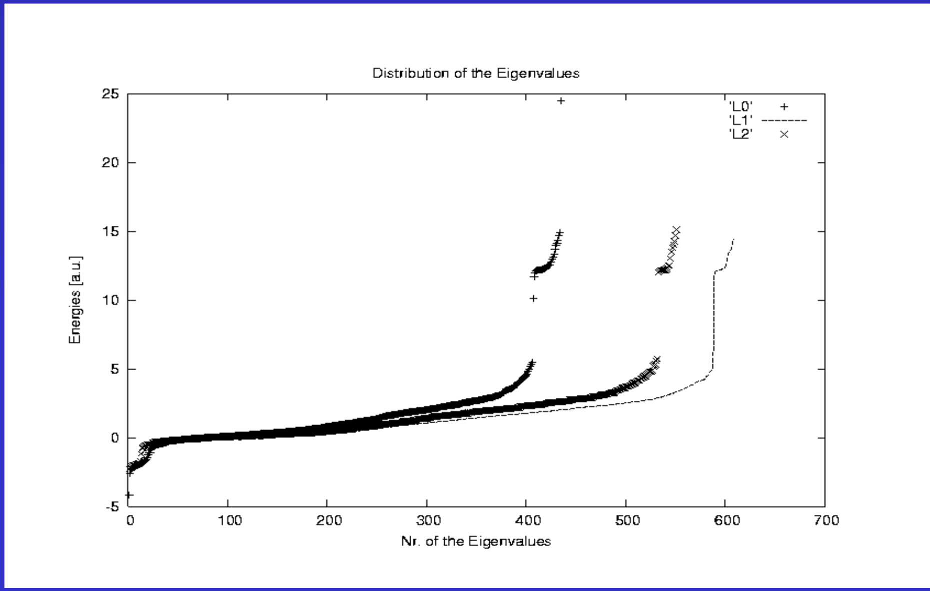
Spectrum & Continuum States







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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

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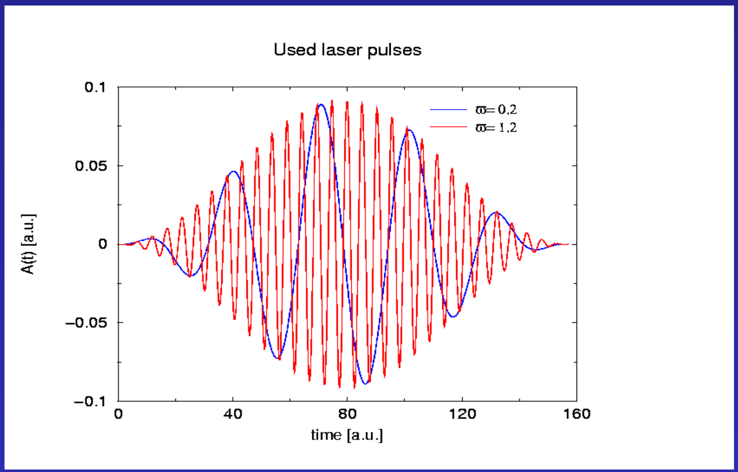
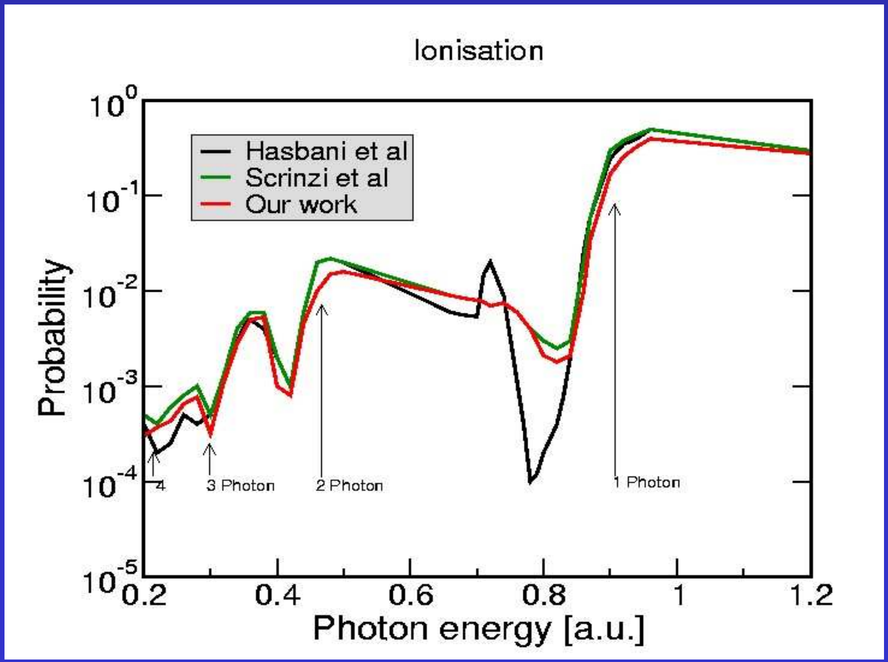
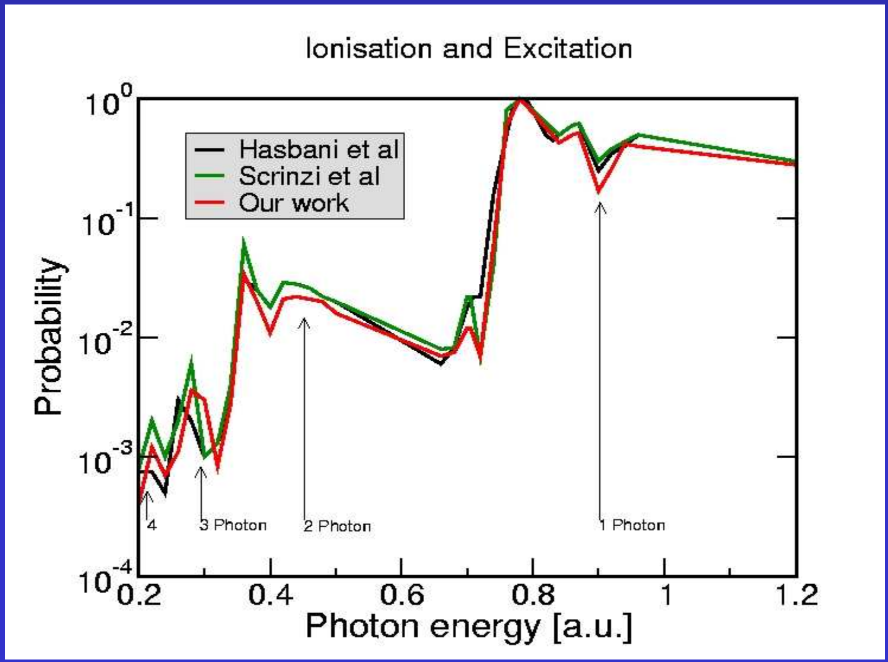
Laser pulse & Photoionisation Results 1



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)





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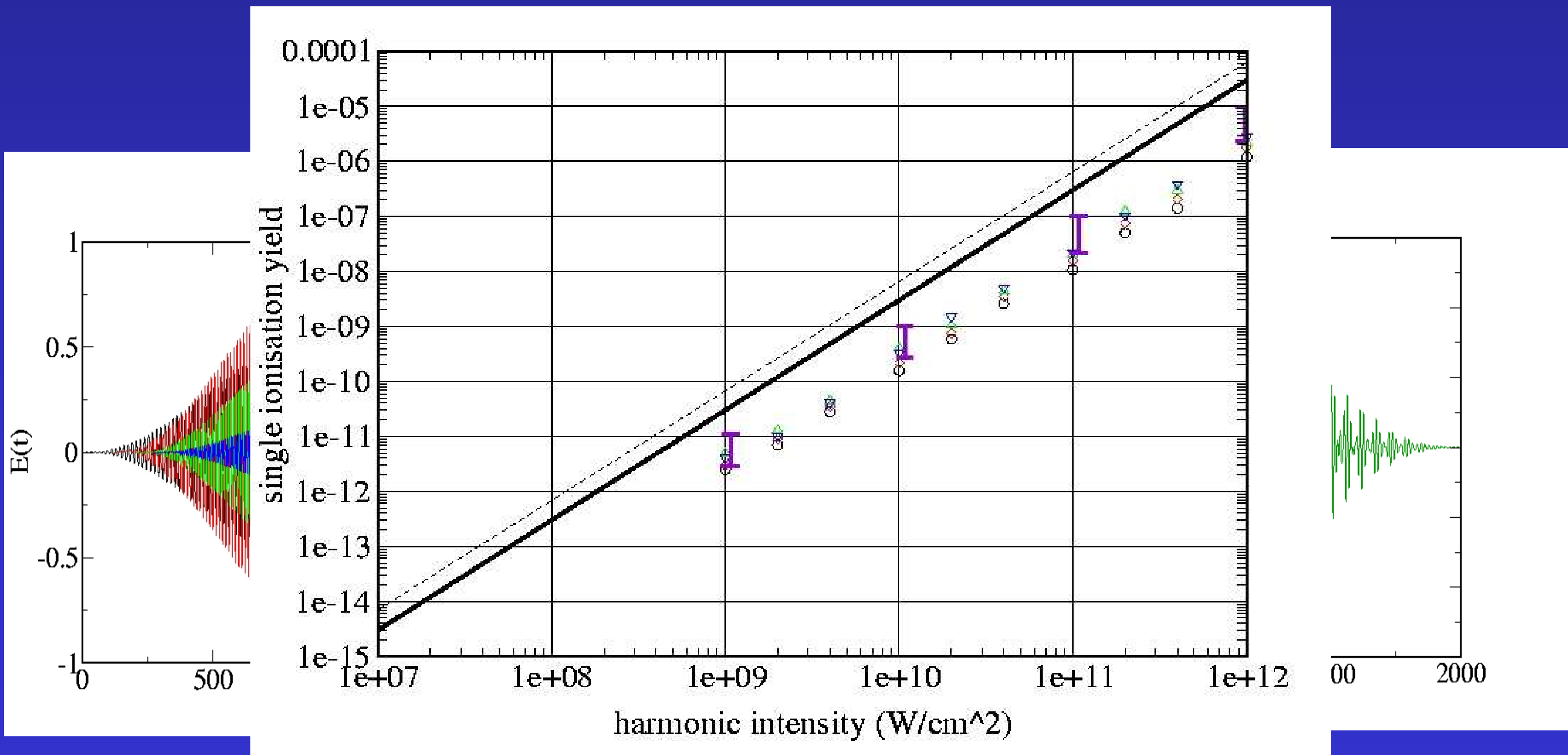
Photoionisation Results 2

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

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



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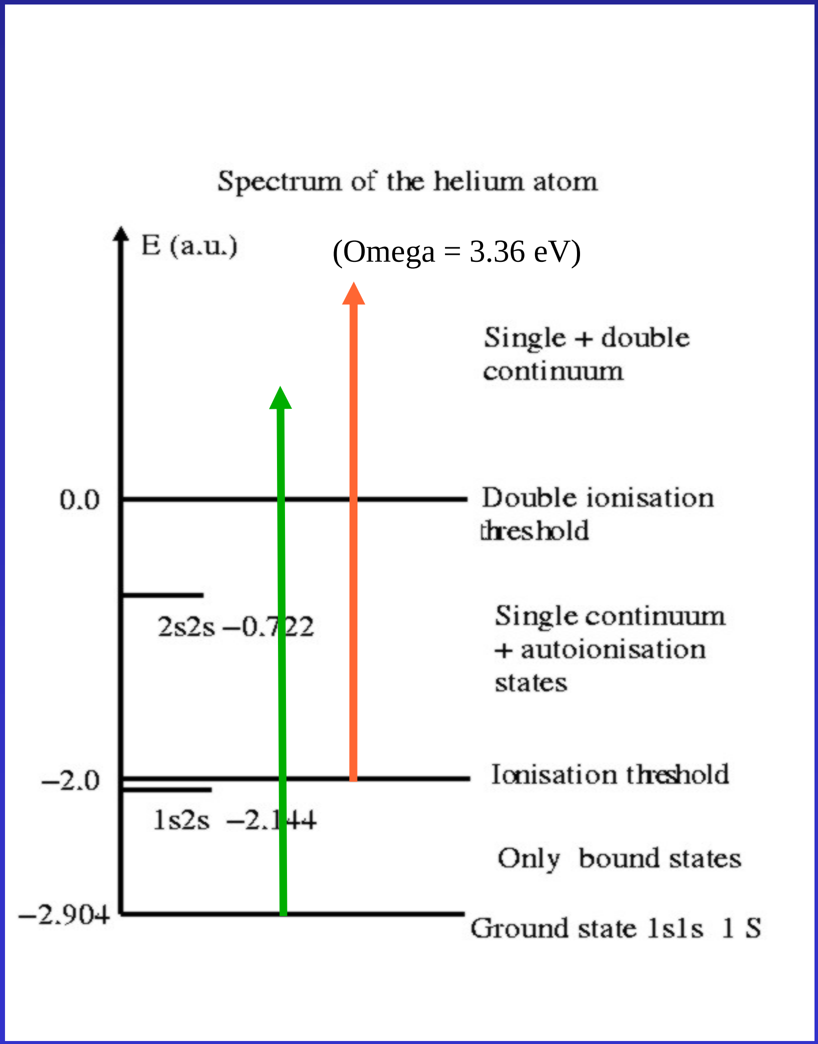
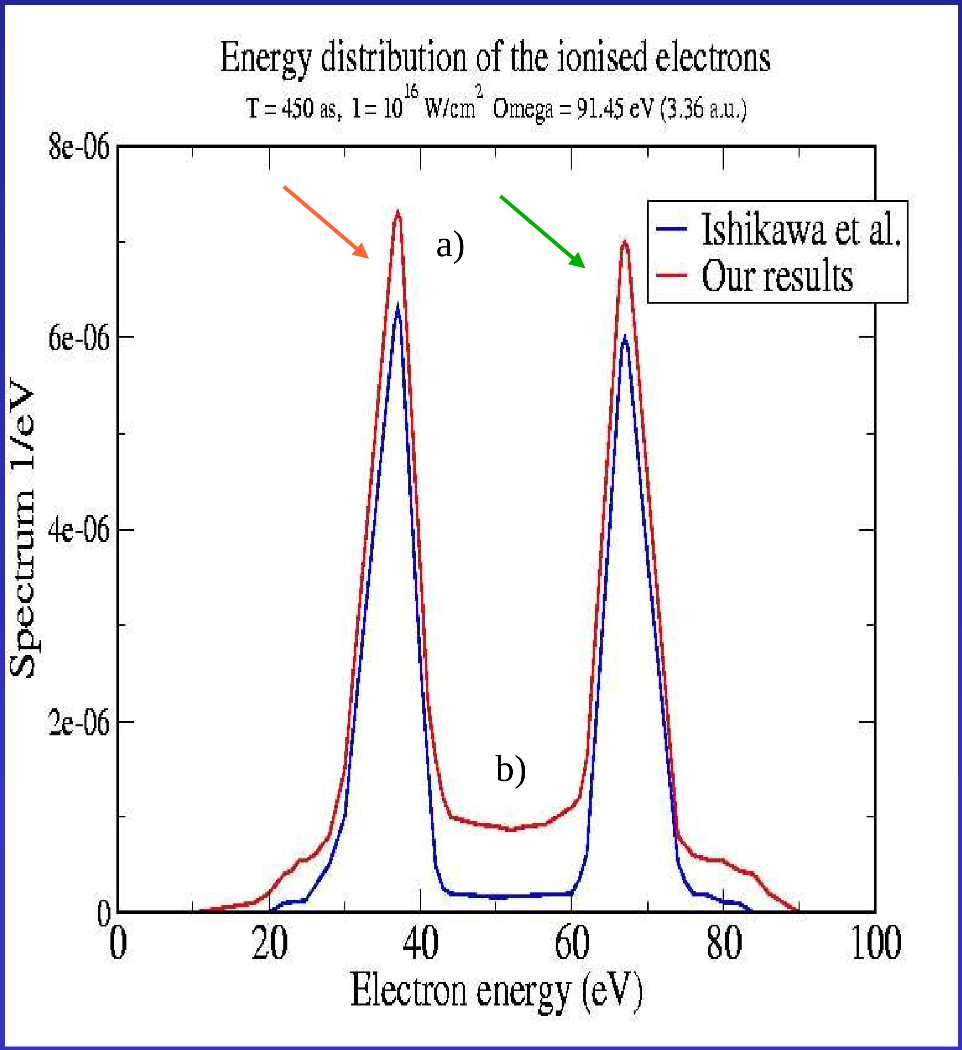
Above-threshold double ionisation (ATDI)





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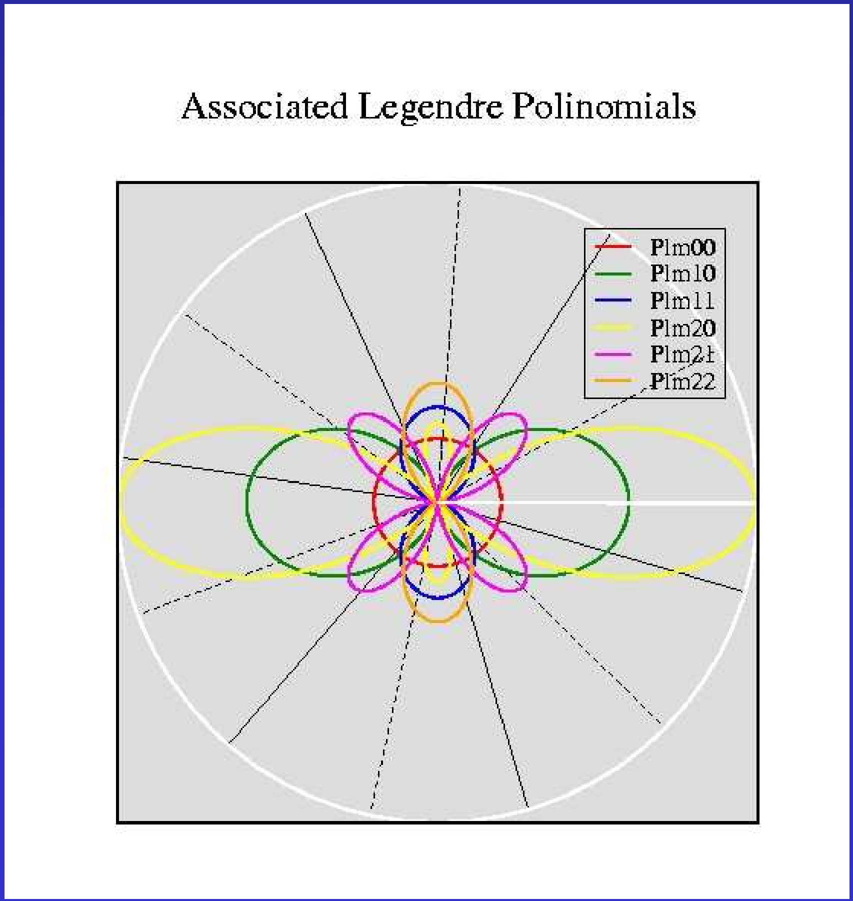
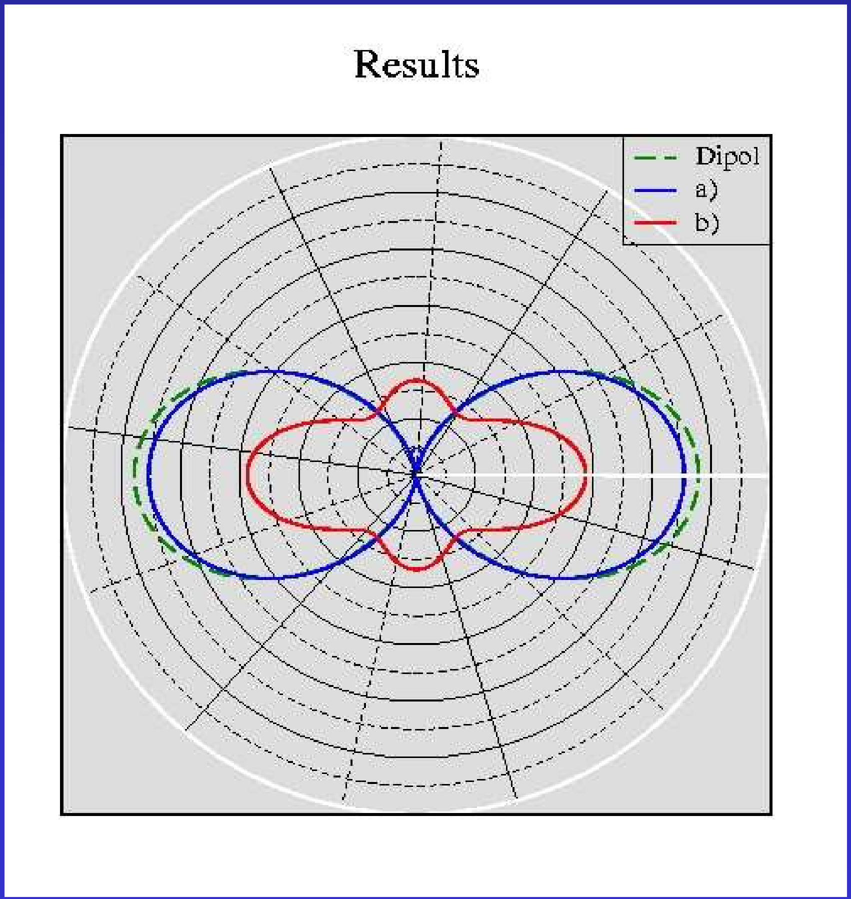
Angular distribution of the ejected electrons

L = 0 ss+pp+dd, L = 1 sp+pd, L = 2 sd+pp+dd





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Summary and Outlook

we presented our CC method for photoionisation

showed some results for photoionisation

presented the angular distribution of the ejected
electrons in above-threshold double ionisation

further work is in progress to clear out the dark points

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