New experiments with dense clouds of positronium

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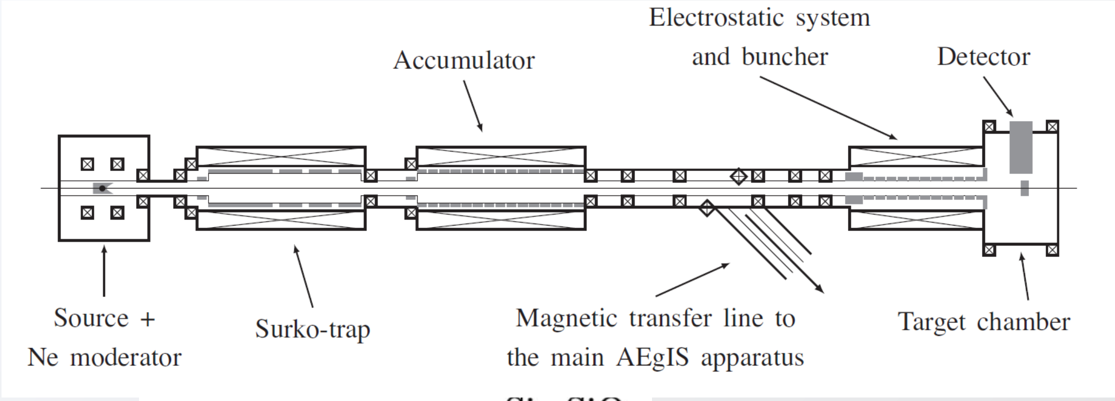
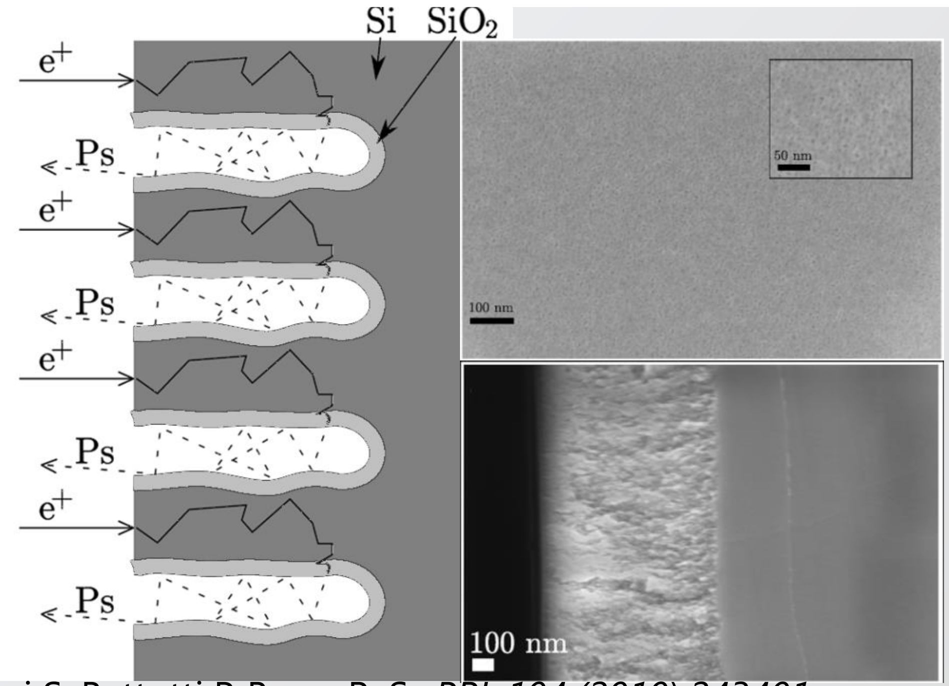
University of Oslo, Norway

Member of the AEgIS collaboration

Positronium production

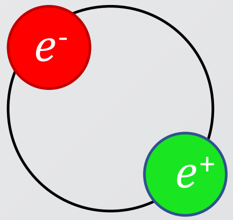
Aghion S. et al (AEgIS collaboration), *NIM B 362 (2015) 86-92*

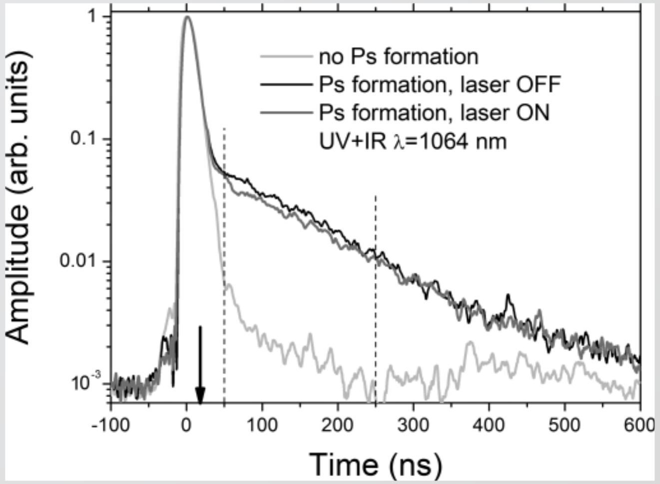




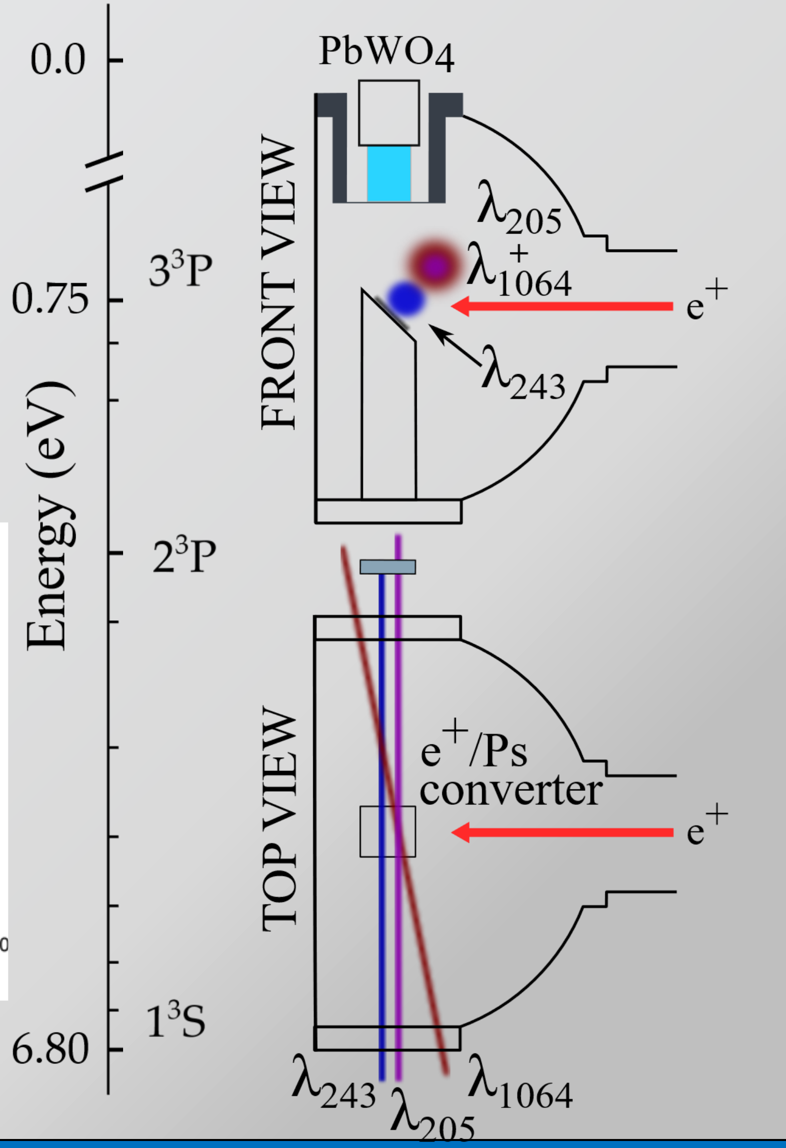
Mariazzi S. Bettotti P. Brusa R. S., *PRL 104 (2010) 243401*

Positronium (Ps)





Aghion et al. (AEgIS collaboration)
PRA **94**, 012507 (2016)



Muon antimuon pair formation

PHYSICAL REVIEW A **78**, 033408 (2008)

Muon pair creation from positronium in a linearly polarized laser field

Carsten Müller, Karen Z. Hatsagortsyan, and Christoph H. Keitel
Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

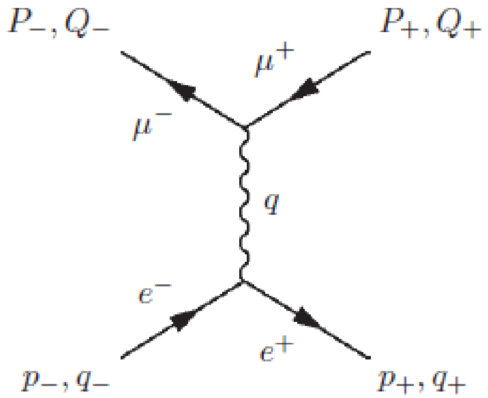


FIG. 1. Feynman graph for muon pair creation from electron-positron annihilation in a background laser field. The arrows are labeled by the particle's free momenta ($p_\pm, P_\pm$) outside and the effective momenta ($q_\pm, Q_\pm$) inside the laser field. The virtual photon has four-momentum q. The electron and positron are assumed to form a Ps atom initially.

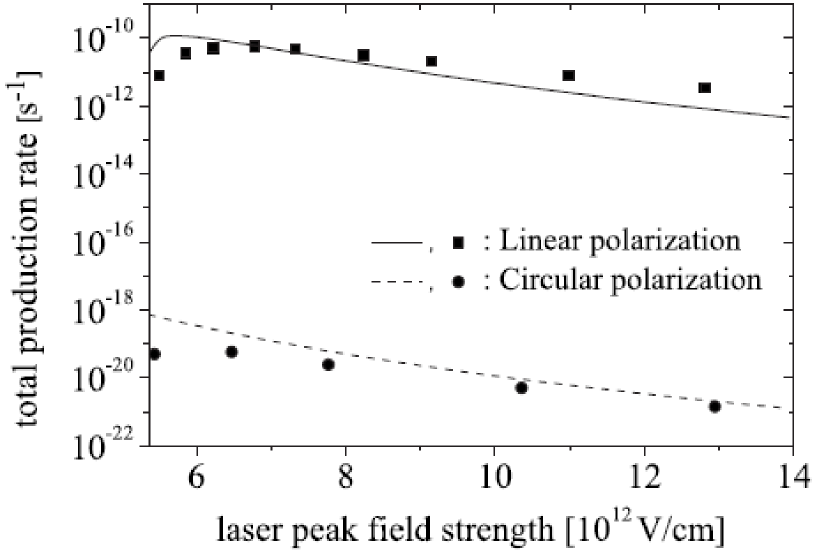
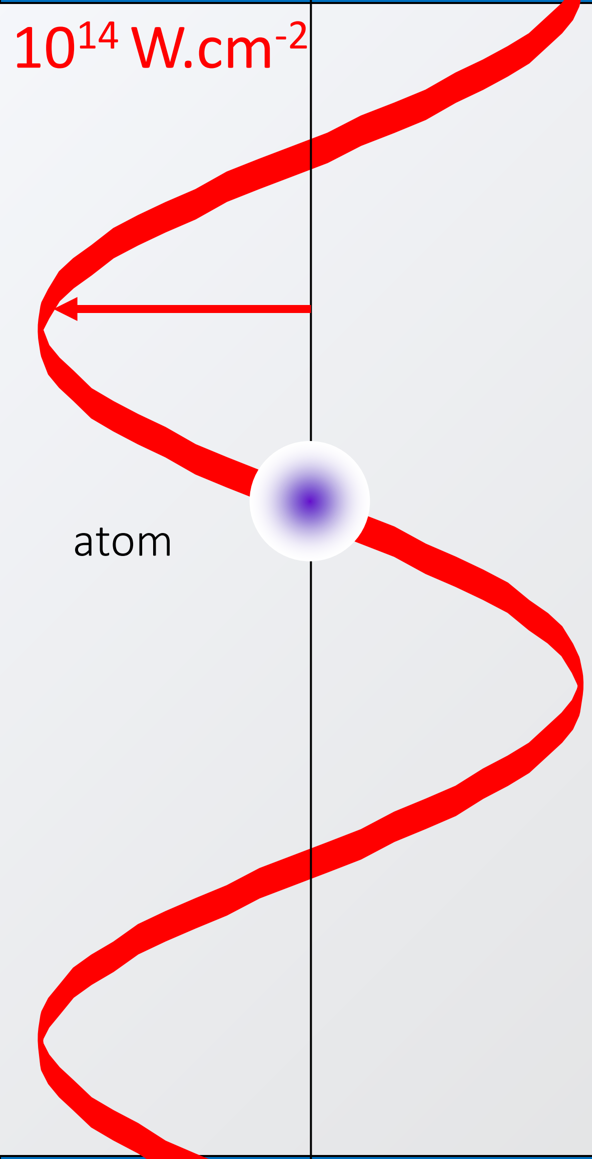


FIG. 2. Total rates for the process Ps$\rightarrow\mu^+\mu^-$ induced by an intense near-infrared laser field (ω=1 eV), as a function of the laser peak field strength. The black squares and the solid line refer to a linearly polarized laser field and show the results of numerical calculations based on Eq. (22) and the analytical estimate in Eq. (54), respectively. The black circles and the dashed line show the corresponding results for a laser field of circular polarization.

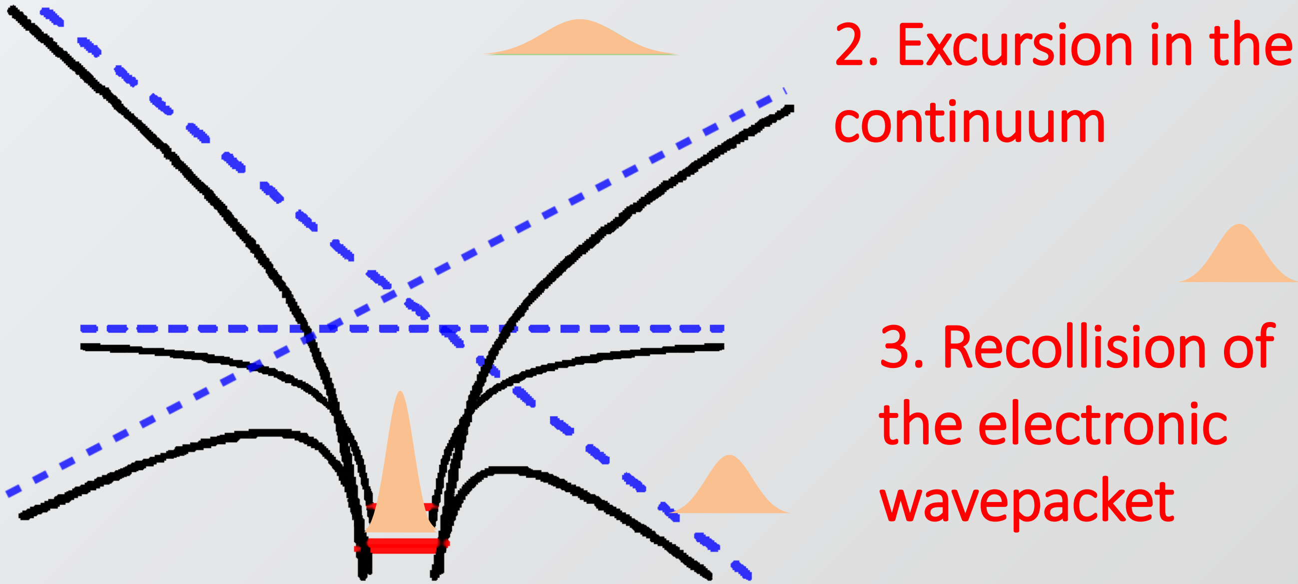
Attoscience : Laser driven electron recollision



1. Tunnel ionizaiotn

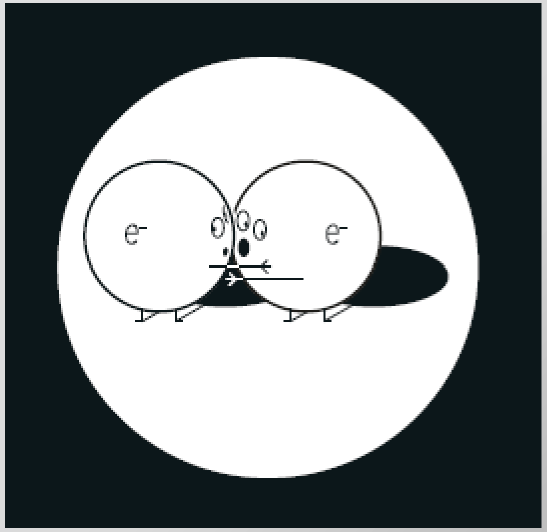
Kulander et Schafer, SILAP (1993)
Corkum, PRL (1993)

2. Excursion in the continuum



3. Recollision of the electronic wavepacket

2023 Physics Nobel prize
Agostini, L'Huillier, Krausz

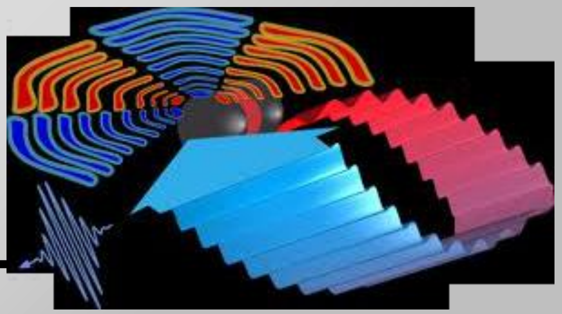


Laser Induced Electron Diffraction

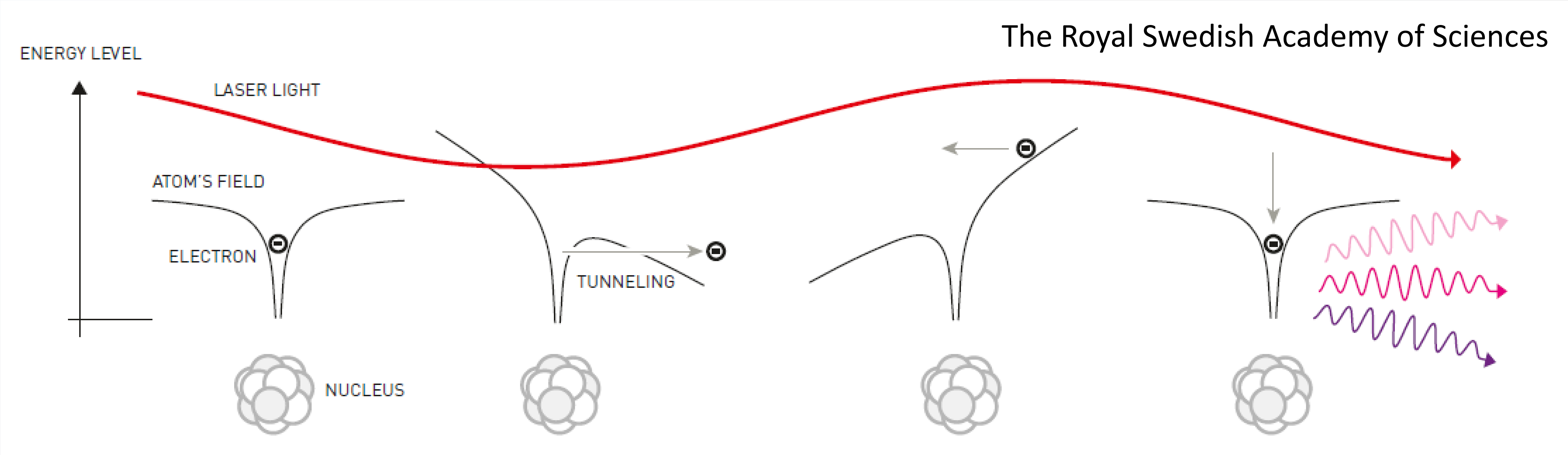
Meckel, Science (2008)
Blaga, Nature (2012)

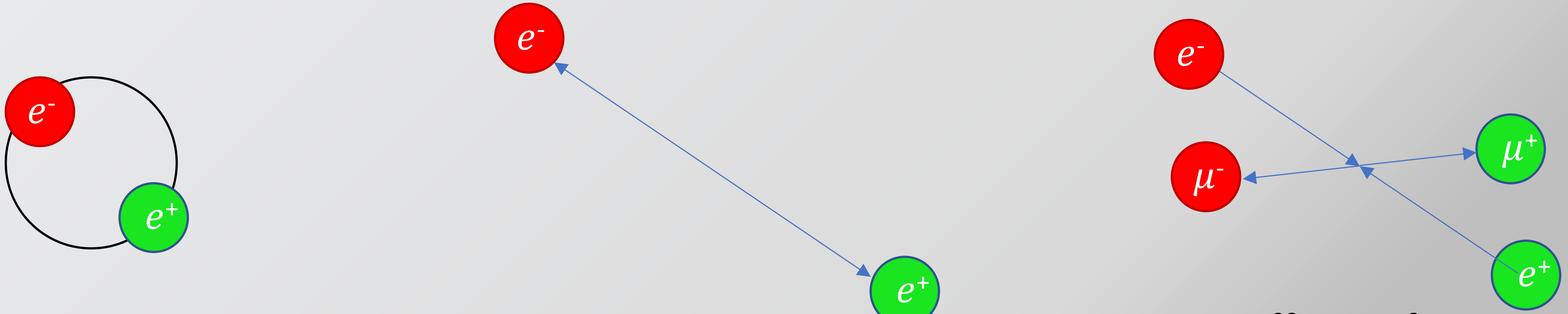
High-order Harmonic Generation

Ferray et al. , J. Phys. B (1988)
McPherson et al., J. Opt. Soc. A. (1987)

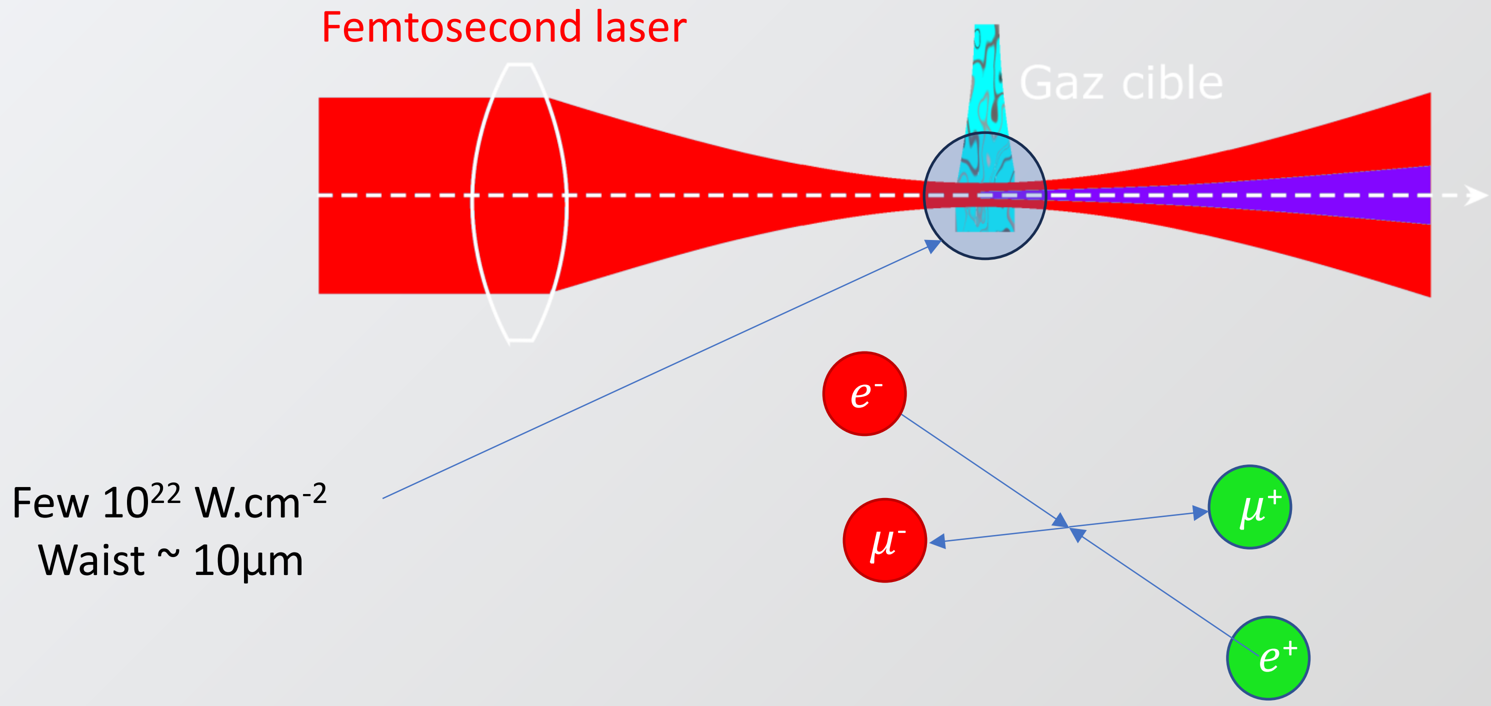


Electron-positron laser-driven recollision





Few 10^{22} W.cm^{-2}

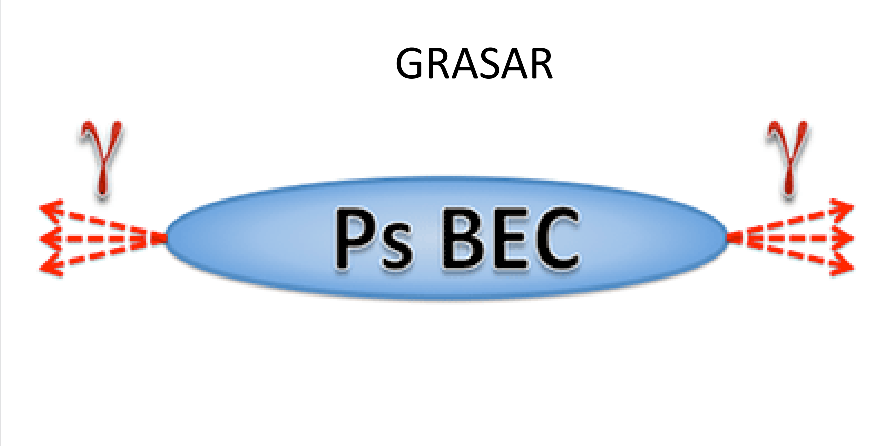


Requires dense Ps clouds!

Polyelectron systems

- Ps, Ps^-, Ps^+, Ps_2 , Ps_2^+, Ps_2^- … Ps BEC
- Analogous to H, H^-, H_2, H_2^- … H BEC

- Never observed : Ps^+, Ps_2^+, Ps_2^-, Ps BEC



PRL **113,** 023904 (2014) PHYSICAL REVIEW LETTERS week ending 11 JULY 2014

Self-Amplified Gamma-Ray Laser on Positronium Atoms from a Bose-Einstein Condensate

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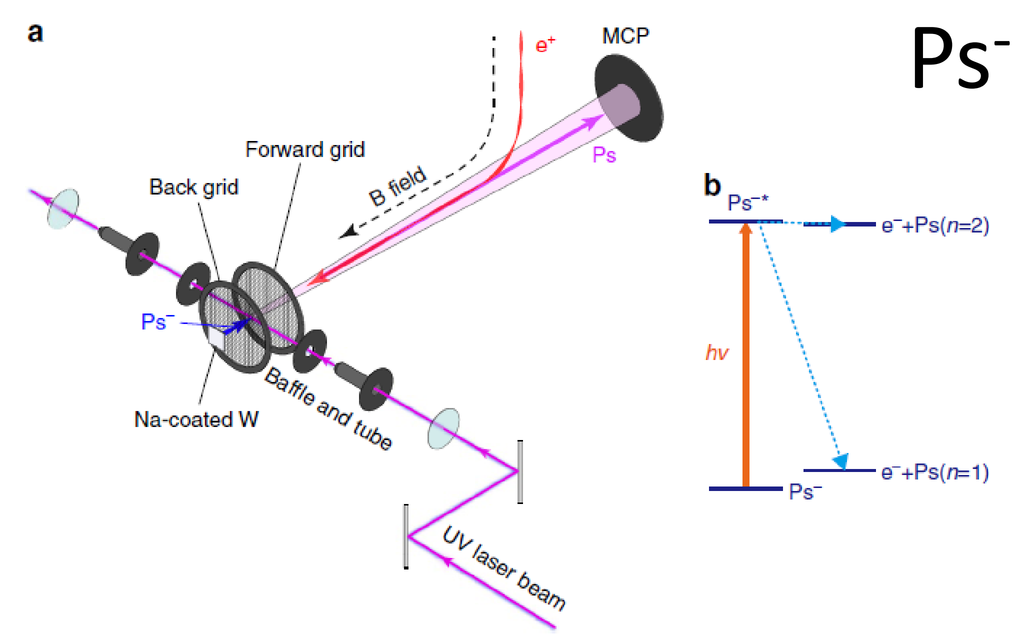
DOI: 10.1038/ncomms11060

Observation of a shape resonance of the positronium negative ion

Ps^-



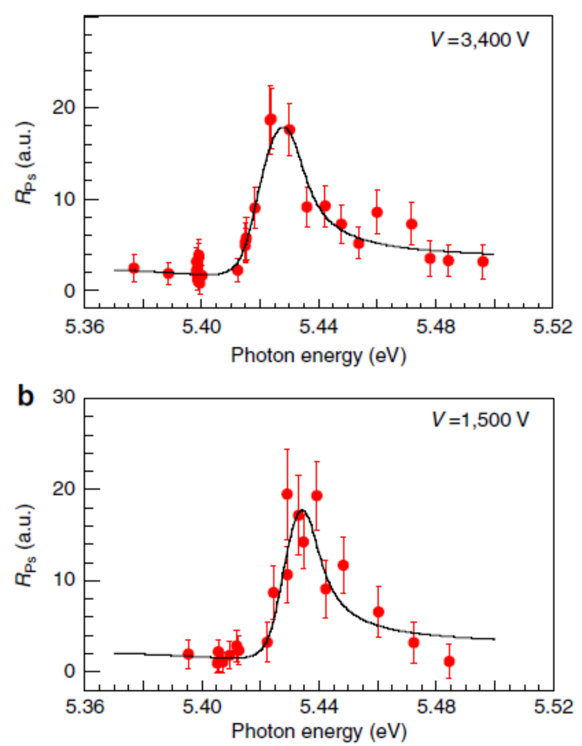


Figure 3 | Resonance profiles of Ps^- ions in the vicinity of the $n=2$ threshold. R_{Ps} plotted against photon energy for acceleration voltages of 3,400 V (**a**) and 1,500 V (**b**). The best fit results using a Fano profile convoluted with a Gaussian profile which represents the angular distribution of Ps^- are indicated by the solid lines, where the fitting parameters, except for the resonance energy, were constrained to be the same for both sets of data ($\chi^2/\nu = 0.66$). Error bars show the standard deviation of the mean R_{Ps} values including the error of normalization factors.

PRL **108,** 133402 (2012) PHYSICAL REVIEW LETTERS week ending 30 MARCH 2012

Optical Spectroscopy of Molecular Positronium

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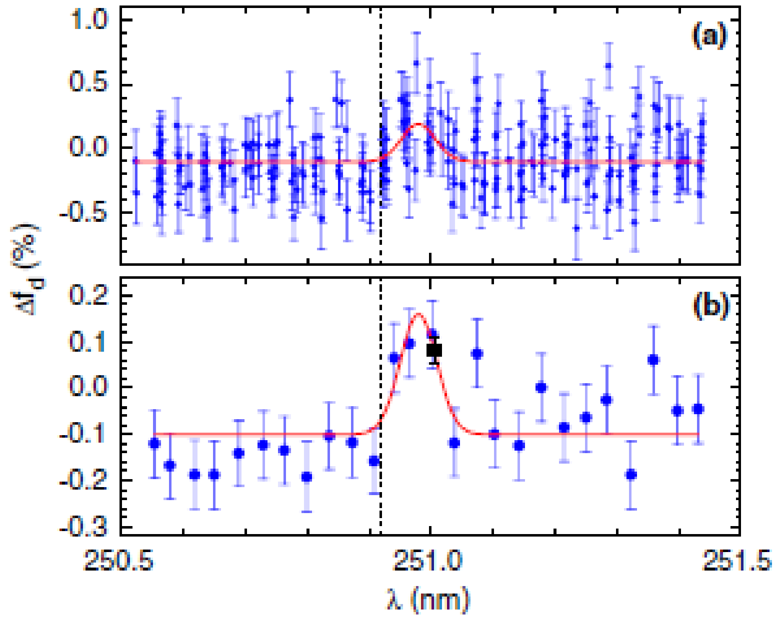

FIG. 1 (color online). Ps_2 resonance measured inside a porous silica film. All data recorded in four separate runs as a function of the laser (vacuum) wavelength (a) and rebinned data (b) The vertical scale is the change in the delayed fraction in percent. The measurement for the single square point in (b) was obtained as described in the text. The solid lines are simple Gaussian fits to the data from which we determine a line center of $\lambda_0 = (250.979 \pm 0.006)$ nm, amplitude $(0.027 \pm 0.008)\%$, and a full width at half maximum (FWHM) of (0.069 ± 0.026) nm. The dashed vertical line indicates the theoretical resonant wavelength for the Ps_2 excitation in vacuum.

Positron and positronium binding atoms

Binding energies of positron-atom and positronium-atom bound states
(electron volts)

0 Ps 0.3260 0.4355								
1 H X 1.0547								2 He X (X)
3 Li 0.0675 0.3366	4 Be 0.0860 (X)		5 B (0.16) X	6 C (X) 0.476	7 N X X	8 O (X) 0.785	9 F X 2.776	10 Ne X (X)
11 Na 0.0129 0.229	12 Mg 0.464 (X)		13 Al (0.54) (X)	14 Si (0.25) (0.30)	15 P (X) (0.13)	16 S (X) (0.85)	17 Cl X 2.297	18 Ar X (X)
19 K X 0.139	20 Ca 0.521 (X)	*	31 Ga (0.54) (X)	32 Ge (0.33) (0.20)	33 As (?) (0.11)	34 Se (?) (0.73)	35 Br X 1.873	36 Kr X (X)
37 Rb X (0.07)	38 Sr 0.356 (X)	*	49 In (0.26) (X)	50 Sn (0.54) (0.08)	51 Sb (0.19) (0.12)	52 Te (0.11) (0.59)	53 I (?) 1.39	54 Xe X (X)
55 Cs X (?)	56 Ba (0.03) (X)	*	81 Tl (0.57) (X)	82 Pb (0.50) (X)	83 Bi (0.56) (?)			

*	21 Sc (0.75) (X)	22 Ti (0.84) (X)	23 V (0.81) (X)	24 Cr (0.54) (0.38)	25 Mn (0.53) (X)	26 Fe (0.37) (X)	27 Co (0.36) (X)	28 Ni (0.42) (0.16)	29 Cu 0.170 0.423	30 Zn 0.103 (X)
*	39 Y (?) (X)	40 Zr (?) (X)	41 Nb (?) (0.41)	42 Mo (0.46) (0.38)	43 Tc (0.62) (X)	44 Ru (?) (0.53)	45 Rh (?) (0.58)	46 Pd X (0.85)	47 Ag 0.123 (0.64)	48 Cd 0.178 (X)

*	57 La (?) (X)	58 Ce (?) (X)	59 Pr (?) (X)	60 Nd (?) (?)	61 Pm (?) (?)	62 Sm (?) (?)	63 Eu (?) (X)	64 Gd (?) (?)	65 Tb (?) (?)	66 Dy (?) (?)	67 Ho (?) (?)	68 Er (?) (?)
*	69 Tm (?) (X)	70 Yb (?) (X)	71 Lu (?) (X)	72 Hf (?) (X)	73 Ta (?) (X)	74 W (?) (?)	75 Re (0.42) (X)	76 Os (?) (0.15)	77 Ir (?) (0.40)	78 Pt (X) (1.14)	79 Au X (1.25)	80 Hg 0.045 (X)

e+ only	23
Ps only	21
both	13

PHYSICAL REVIEW A **85**, 012503 (2012)

Binding-energy predictions of positronium-atom systems

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Theoretical and experimental challenge

Formation of Positronium Hydride

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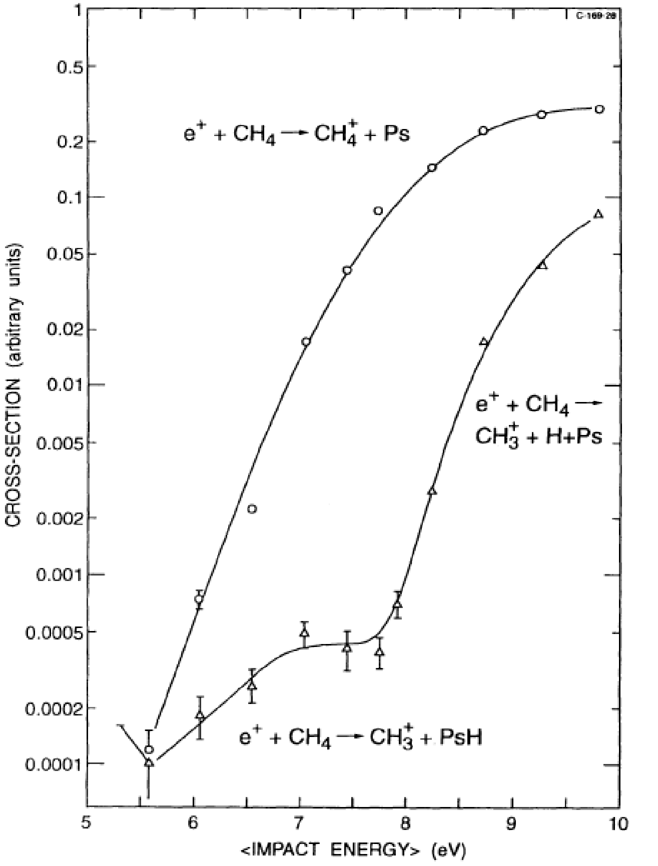

FIG. 3. Cross sections for the production of CH_4^+ and CH_3^+ ions in positron collisions with CH_4.

VOLUME 14 7 JUNE 1965 NUMBER 23

RESONANCE ANNIHILATION OF POSITRONS IN CHLORINE AND ARGON*

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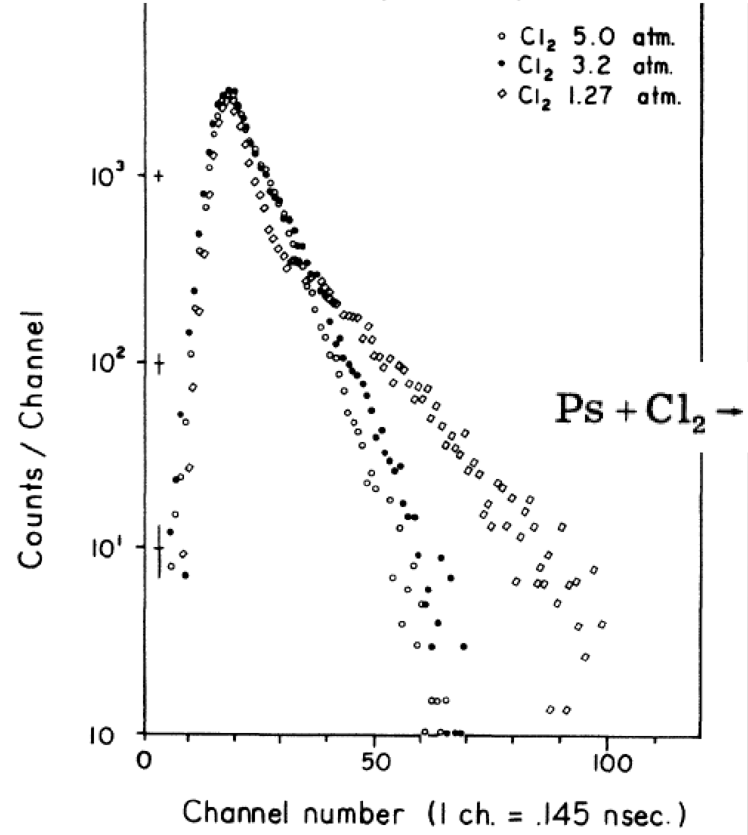


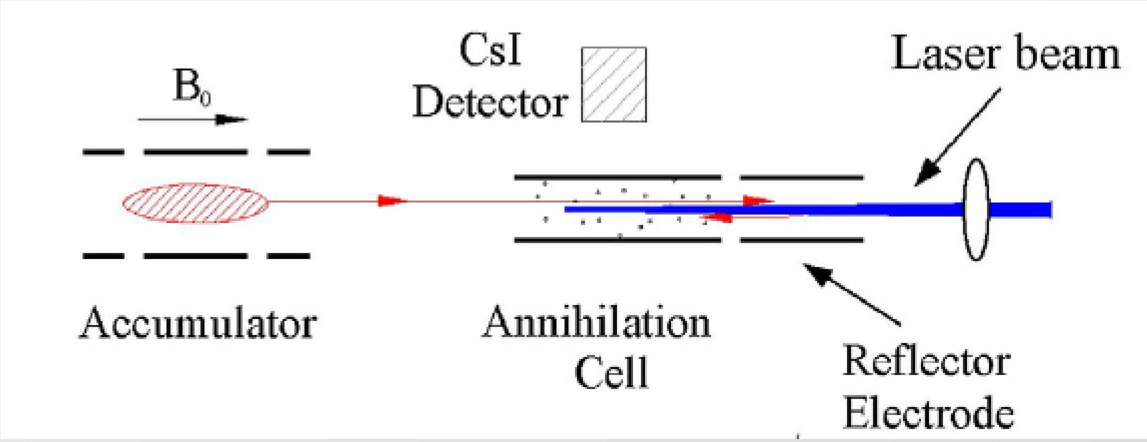
$$Ps + Cl_2 \rightarrow PsCl + Cl$$

FIG. 1. Lifetime spectra of positron annihilation in chlorine.

Laser assisted photorecombination

Measuring positron–atom binding energies through laser-assisted photorecombination

C M Surko[1,4], J R Danielson[1], G F Gribakin[2] and R E Continetti[3]

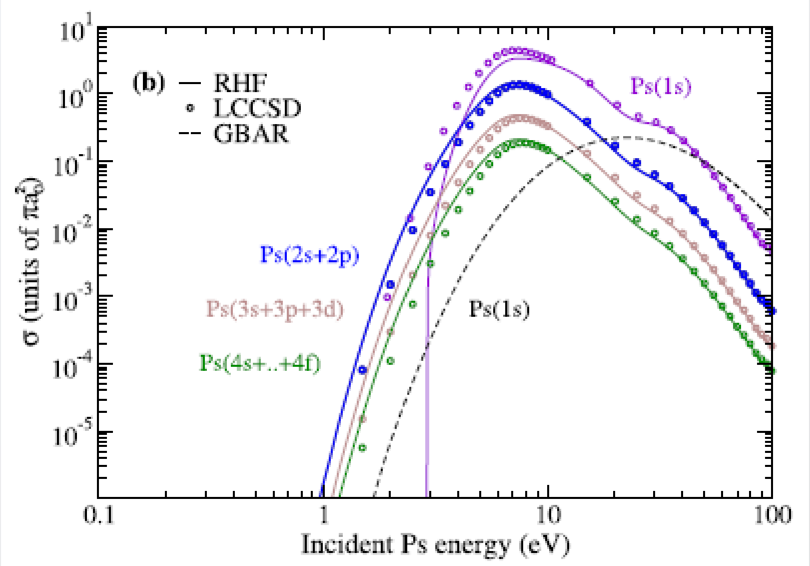


Pulsed production of PsCl

Production of positronium chloride: A study of the charge exchange reaction between Ps and Cl⁻

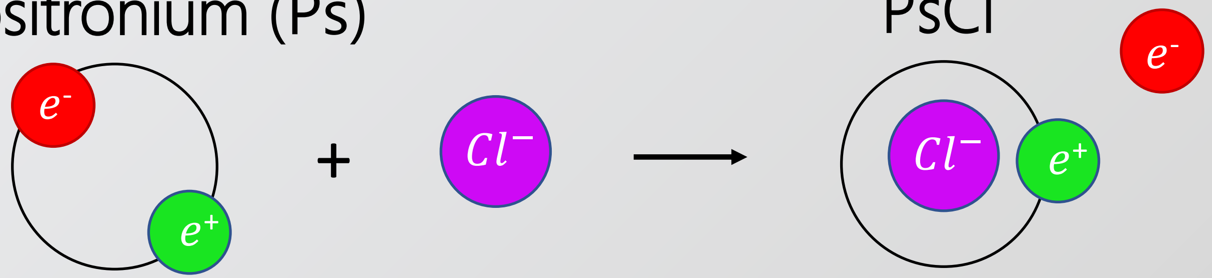
Cite as: J. Chem. Phys. 160, 104301 (2024);

K. Lévêque-Simon,[1,a)] A. Camper,[2] R. Taïeb,[1] J. Caillat,[1] C. Lévêque,[1] and E. Giner[3]

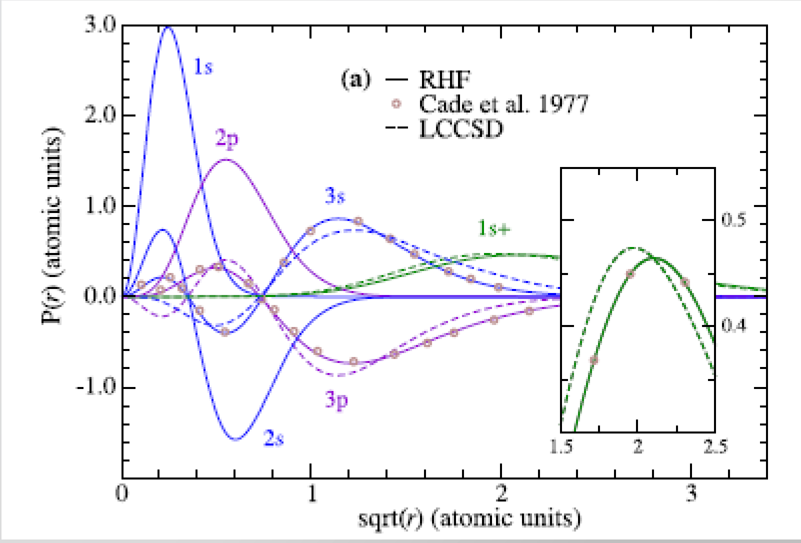


Positronium (Ps)

PsCl



Pulsed production of antihydrogen
Amsler et al. (AEgIS)
Comm Phys 4:19 (2021)



Pulsed production enables laser spectroscopy
High flux allows to probe rare events
Including ultrafast antimatter spectroscopy

Ultrafast dynamics in e^+ binding systems

PHYSICAL REVIEW LETTERS **121**, 133001 (2018)

Time-Dependent Multicomponent Density Functional Theory for Coupled Electron-Positron Dynamics

Yasumitsu Suzuki,* Satoshi Hagiwara,† and Kazuyuki Watanabe
Department of Physics, Tokyo University of Science, 1-3 Kagurazaka, Shinjuku-ku, Tokyo 162-8601, Japan

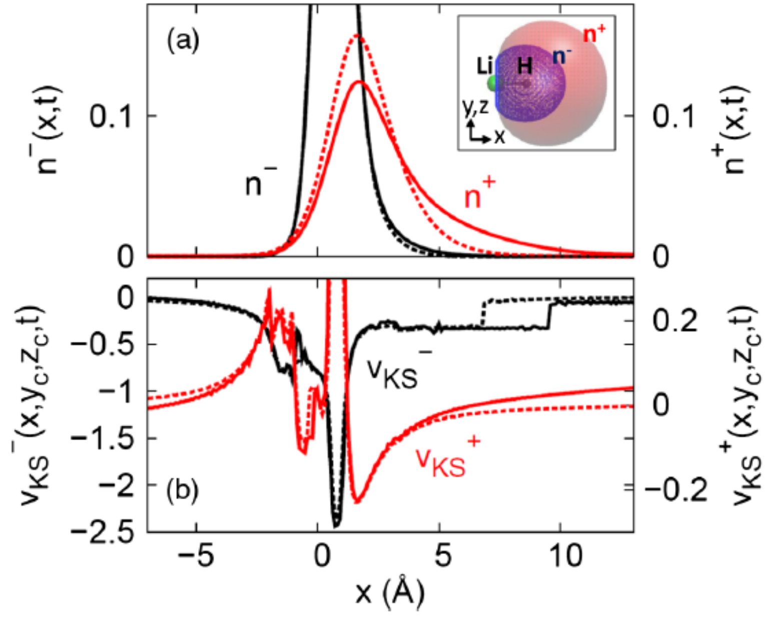


FIG. 1. (a) Snapshots of $n^-(x,t)$ (black) and $n^+(x,t)$ (red) at $t = 0$ (dotted) and $t = 4.36$ fs (solid) in the dynamics of e^+-LiH under a laser field ($\omega = 1.5$ eV), and (b) corresponding $v^{\mp}_{KS}(x, y_c, z_c, t)$. The inset shows the isosurfaces of the ground-state densities (see text).

$LiHe^+$

Pulsed production enables laser spectroscopy
High flux allows to probe rare events
Including ultrafast antimatter spectroscopy

Chemical bounds formed with positrons

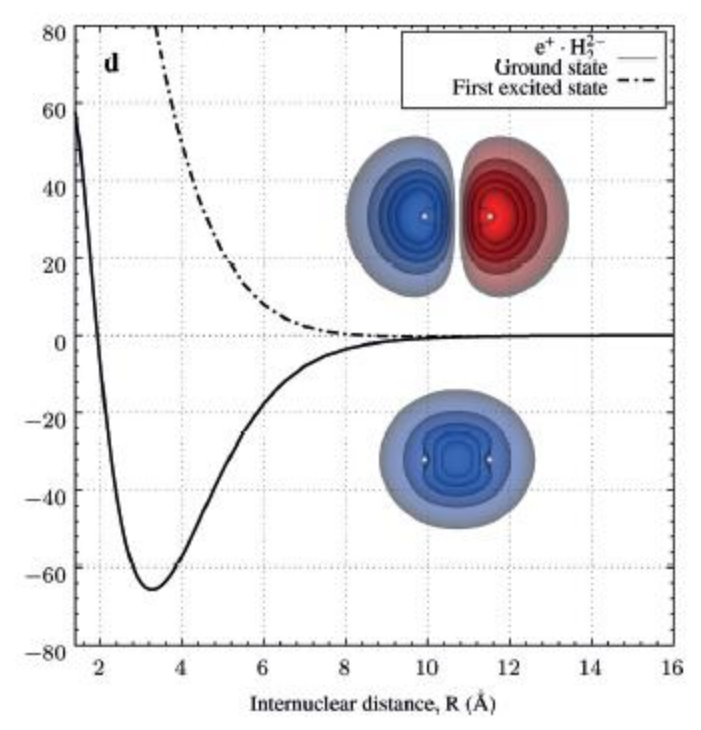
Quantum Chemistry

Angewandte Chemie International Edition

International Edition: DOI: 10.1002/anie.201800914
German Edition: DOI: 10.1002/ange.201800914

Binding Matter with Antimatter: The Covalent Positron Bond

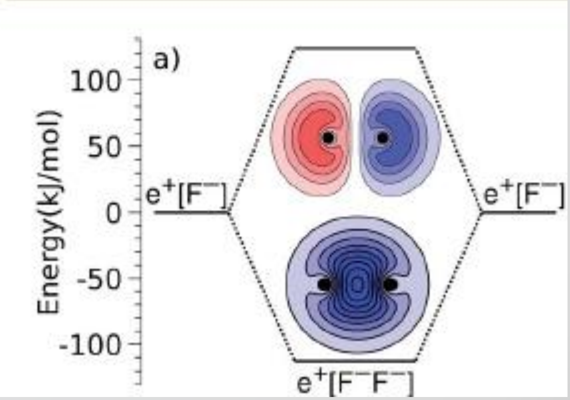
Jorge Charry, Márcio T. do N. Varella, and Andrés Reyes**

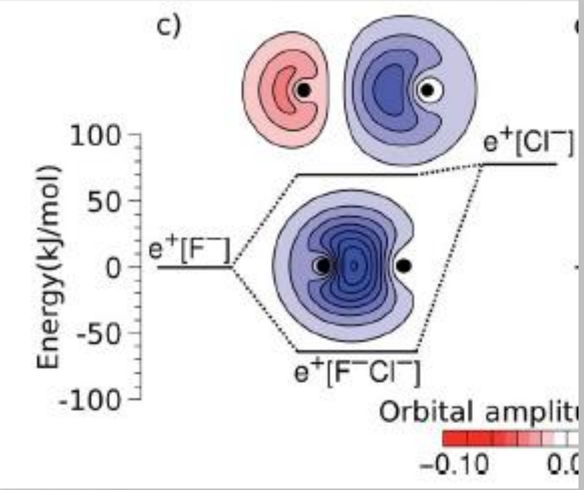


Covalent bonds in positron dihalides†

Félix Moncada, ‡[a] Laura Pedraza-González,‡[a] Jorge Charry, [a] Márcio T. do N. Varella [b] and Andrés Reyes *[a]

Cite this: *Chem. Sci.*, 2020, **11**, 44





Conclusion

- Some experiments require high density (small laser beam waist like in the muon-antimuon pair production or density requirements like in Ps BEC)
- Some experiments require high flux (rare events like in ultrafast antimatter spectroscopy)

Thanks for your attention!