Attosecond pulse trains at seeded free-electron laser FERMI

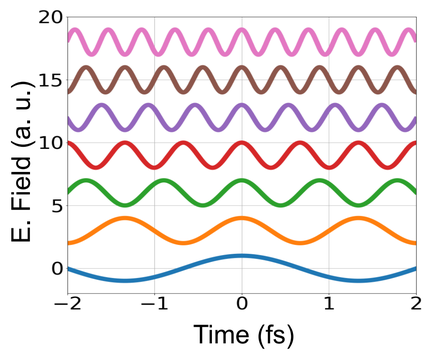
Praveen Kumar M[1] , C. Grazioli[2] , M. Di Fraia[3], M. Moioli[1], D. Ertel[1], H. Ahmadi[1], O. Plekan[3], P. Finetti[3], E. Allaria[3], L. Giannessi[3,4], G. De Ninno[3,5], C. Spezzani[3], G. Penco[3], A. Demidovich[3], M. Danailov[3], R. Borghes[3], G. Kourousias[3], C.E.S.D. Reis[3], F. Bille[3], A.A. Lutman[6] , R.J. Squibb[7], R. Feifel[7], P. Carpeggiani[8], M. Reduzzi[9], T. Mazza[10], M. Meyer[10], S. Bengstsson[11], N. Ibrakovic[11], Emma. R. Simpson[11], J. Mauritsson[11], T. Csizmadia[12], M. Dumergue[12], S. Kühn[12], Harshitha N.G. [12], D. You[13], K. Ueda[13], M. Labeye[14], K.J. Schafer[14]Elena V. Gryzlova[15], Alexei.G.Grizhmailo[15], K.C. Prince[3], C. Callegari[3], G. Sansone[1]

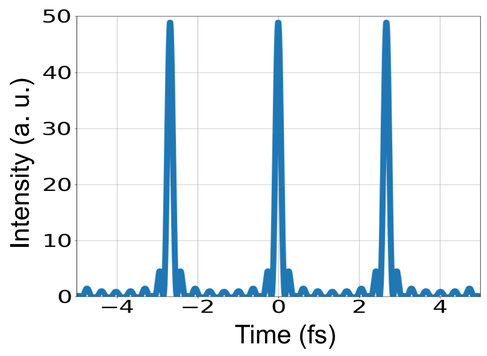
[1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg Hermann-Herder-Straße 3, 79104 Freiburg, Germany.
[2]ISM-CNR, Trieste LD2 Unit, Basovizza AREA Science Park, Trieste, I-34149, Italy.
[3]Elettra-Sincrotrone Trieste, 34149 Basovizza, Trieste, Italy.
[4]ENEA C. R. Frascati, Via E. Fermi 45, 00044 Frascati (Roma).
[5]Laboratory of Quantum Optics, University of Nova Gorica, 5001 Nova Gorica, Slovenia.
[6]SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA.
[7]Department of Physics, University of Gothenburg, Origovägen 6B, 412 96 Gothenburg, Sweden.
[8]Technische Üniversität Wien, Austria.
[9]Dipartimento Fisica Politecnico, Piazza Leonardo da Vinci 32, 20133 Milano, Italy.
[10]European XFEL, Albert-Einstein-Ring 19, 22761 Hamburg, Germany.
[11]Department of Physics, Lund University, PO Box 118, SE-221 00 Lund, Sweden.
[12]ELI-ALPS, ELI-Hu Kft., Dugonics tér 13, H-6720 Szeged Hungary.
[13]Institute of Multidisciplinary Research for Advanced Materials, Tohoku, University, Sendai 980-8577, Japan.
[14]Department of Physics and Astronomy Louisiana State University Baton Rouge, Louisiana 70803-4001, USA.
[15]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State, University, Moscow, 119991 Russia.

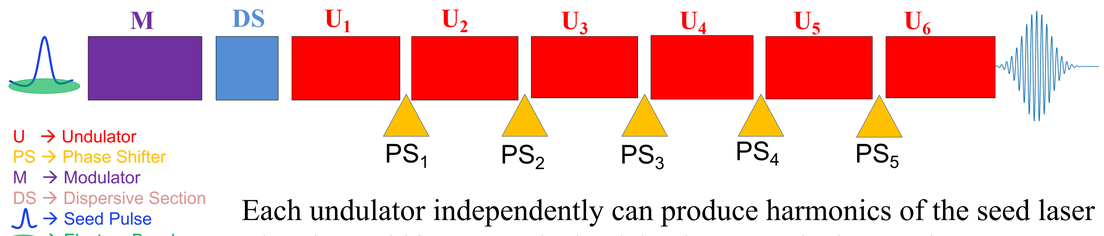
Introduction

Free-Electron Lasers (FELs), which can generate radiation in extreme ultraviolet and X-ray range along with unprecedented intensities, opened up opportunities for investigation of the valence and core electron dynamics. The temporal coherence and the high intensities have made possible the single-shot diffraction [1] imaging of non-crystalline samples. However, until recently the longitudinal coherence was not demonstrated which is essential for coherent control experiments [2]. Here in this work we present the first demonstration of generation and characterization of the Attosecond Pulse Trains (APTs) at the seeded FEL FERMI exploiting the ability to produce multiple phase locked harmonics. We also demonstrate the ability to manipulate the amplitude and phase of the generated APTs independently.

Phase-locked modes and beating

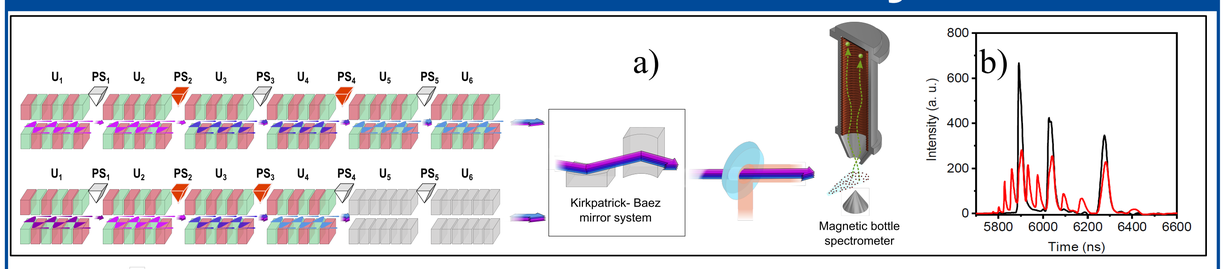


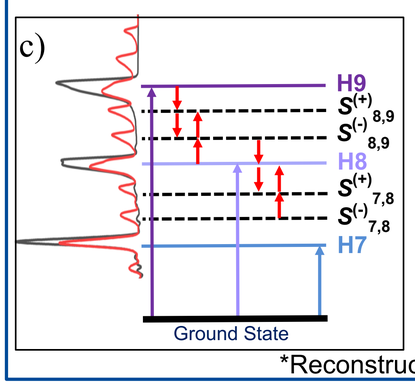


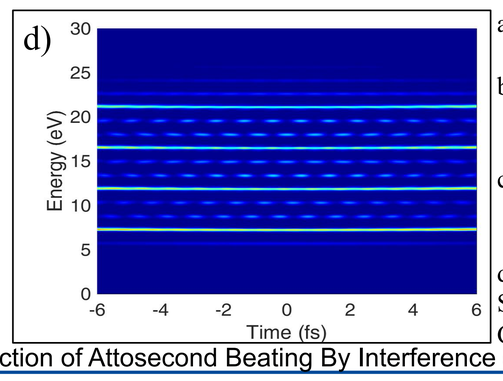


Each undulator independently can produce harmonics of the seed laser
The phase-shifter controls the delay between the harmonics

Data collection and Analysis



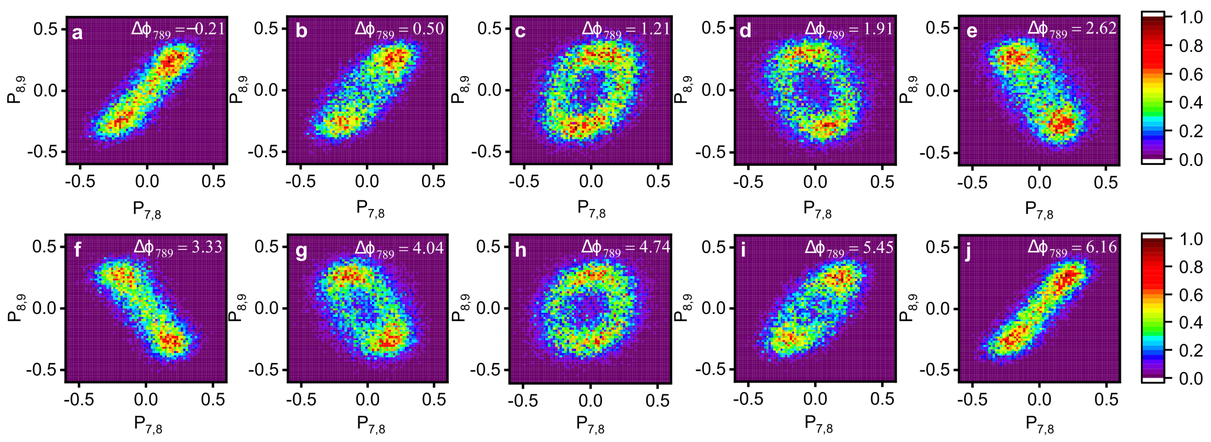


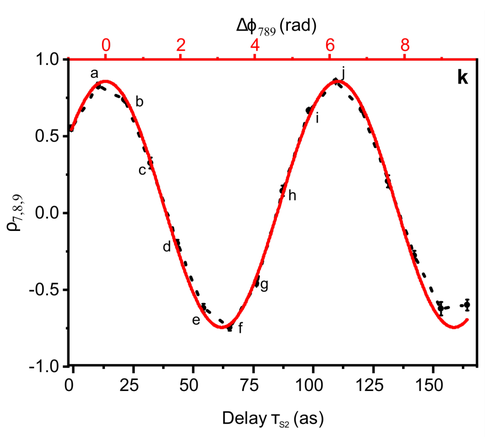


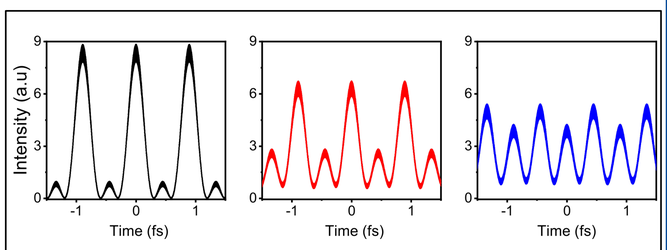
a) FEL configuration and experimental scheme
b) Acquired Photoelectron Time of Flight (TOF) spectrum
c) Energy level scheme and the Interfering quantum paths
d) RABBITT* Spectrum with Sub-femtosecond delay Control (Simulation).

*Reconstruction of Attosecond Beating By Interference of Two-photon Transitions

Experimental results

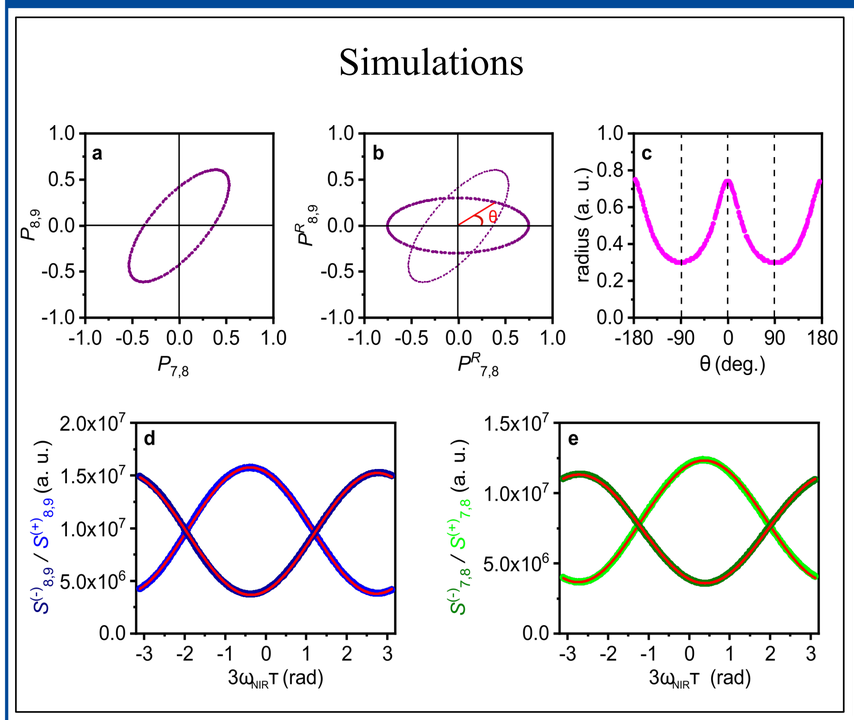




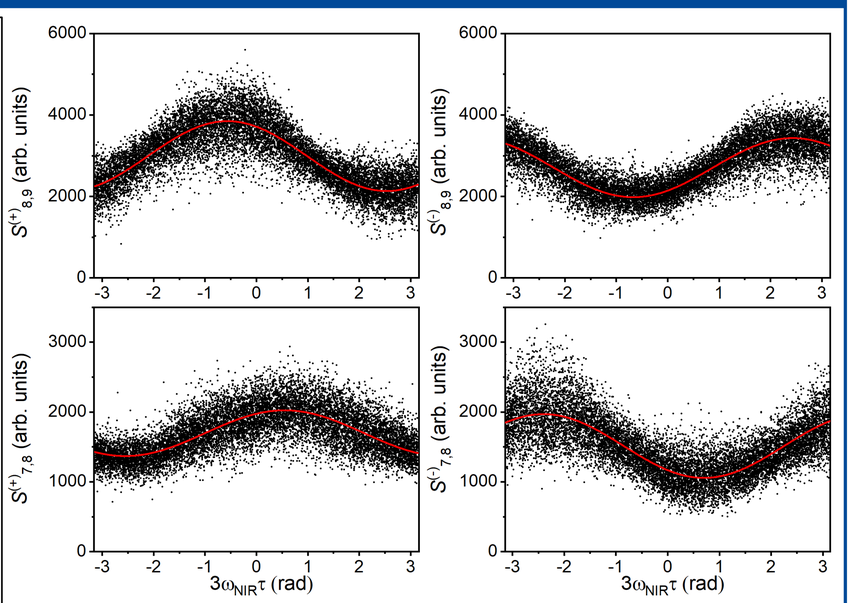


- In the experiment 7th, 8th and 9th harmonics were used
- The phase between the harmonics is changed using the phase shifters
- The critical aspects to reconstruct the attosecond pulses are the amplitudes and the phases of the individual harmonics
- Using the calibrated correlation curve over full scan, the phases are extracted
- The experiment was also performed with four harmonics
- The shortest attosecond pulse from the reconstruction is estimated to be around 280 as FWHM [3]
- We demonstrate the independent amplitude and phase control
- Pulse width can be further shortened by increasing the number of harmonics

Single-shot delay between APT and NIR



- The correlation plots can be used to extract the shot-to-shot delay jitter between XUV and the NIR field.
- As per the theory, the adjacent sidebands in between two harmonics are supposed to be out of phase.
- The oscillations of the sidebands as a function
- of the extracted shot-to-shot delay show cases
- the same results.
- In the simulations, harmonic fluctuations were
- not considered.
- The sideband oscillations for the experimental data is showed in the right. The expected behavior of the sidebands is established.
- The method can be used as a sub-femtosecond Timing tool for the experiments at FELs



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