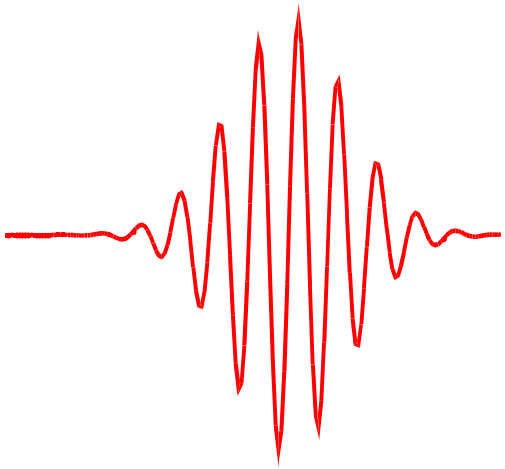
The Dawn of Attophysics

- First Steps Towards A Tabletop Attosecond X-Ray Source -

Cosmin Blaga

Motivation



Single Attosecond X-Ray Pulse

Structure

< 1 nm ⇨ few keV photons

(1 nm ~ 1.2 keV)

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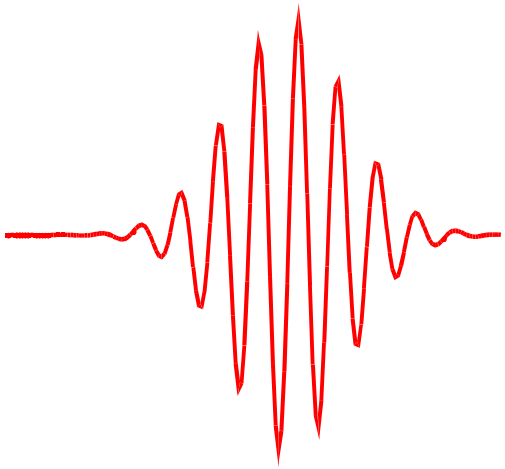

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Structure

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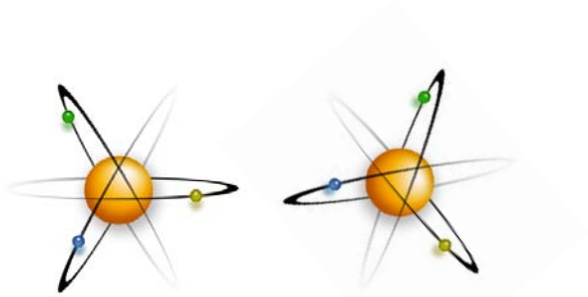
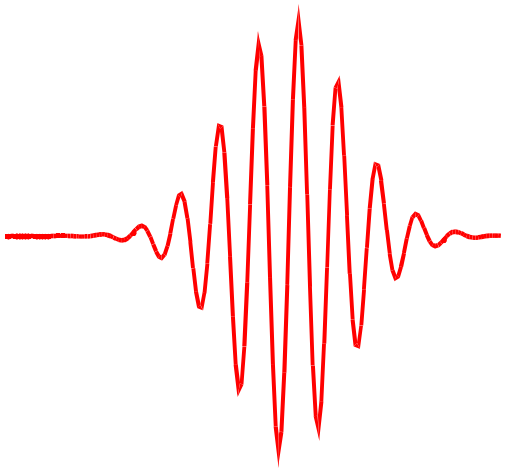
Dynamics



⇨ huge bandwidth (100 eV for 25 as)

1 atomic unit of time is 25 as

Attosecond approaches



Single Attosecond X-Ray Pulse

- coherent or cascade stimulated Raman scattering

  Kaplan, Harris, Sokolov….

- solid target interactions, non-relativistic and relativistic

  Kaplan, Mourou, Naumova….

- 4^{th} generation light sources: XFELs

  LCLS

- high harmonic generation from gases

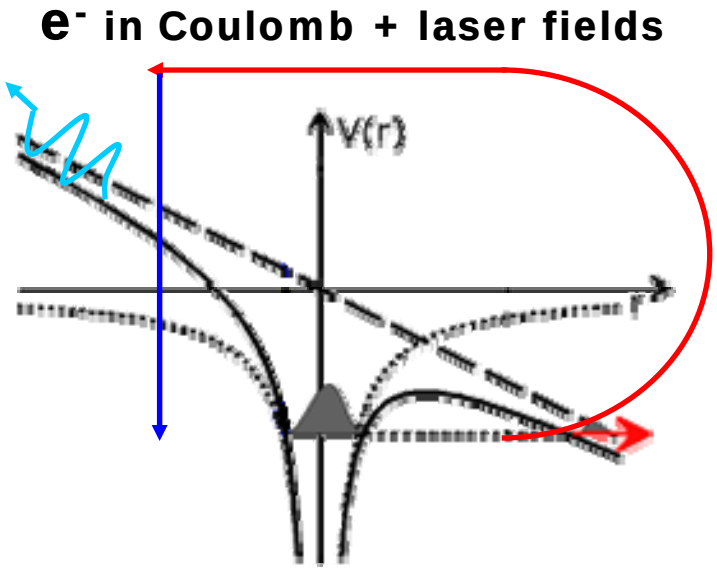
  Farkas, Toth, L'Huillier….

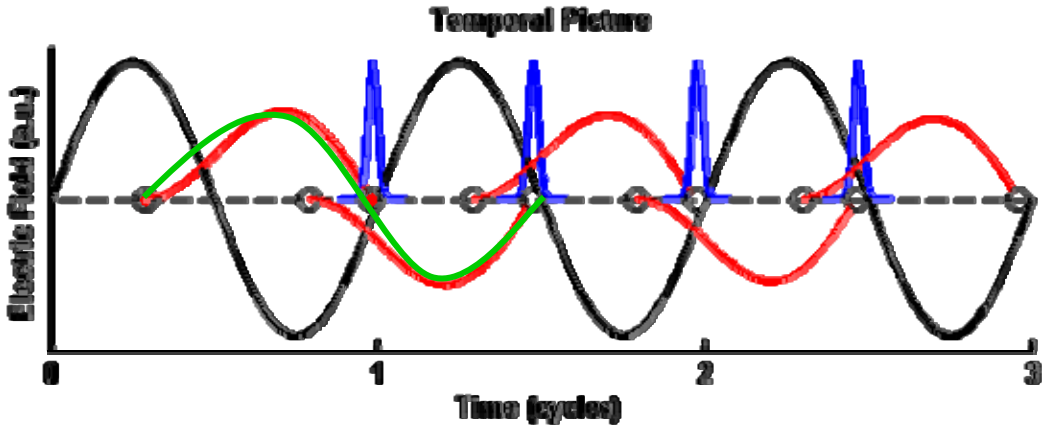
A quick HHG overview – The Three Step Model

I The electron tunnels through the distorted Coulomb barrier

II The free electron is accelerated by the field, and may return to the atomic core

III The electron recombines with the atom, emitting its energy as a photon

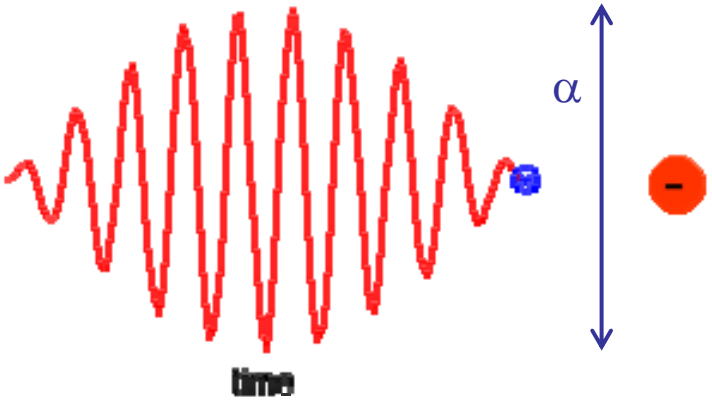




Short trajectories

Long trajectories

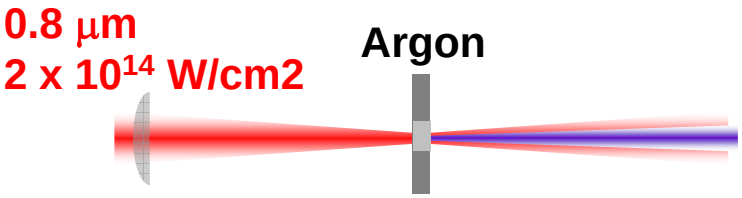
A quick HHG overview – Ponderomotive Forces

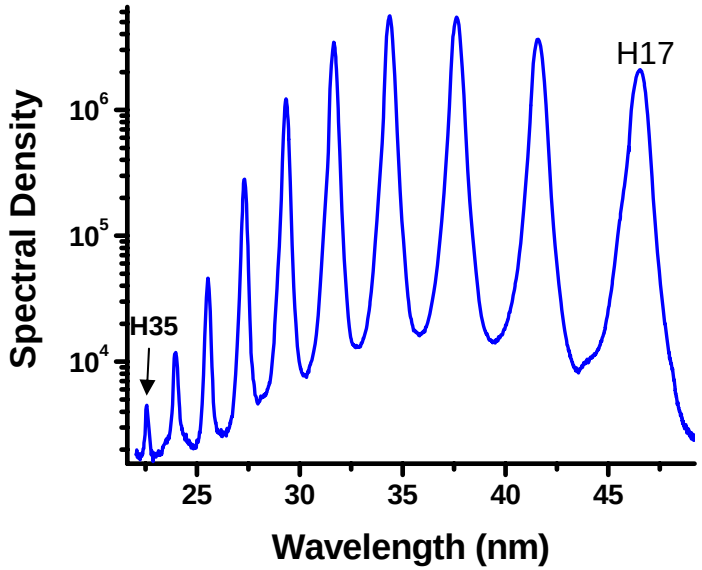


- electron ponderomotive energy (au):
  $U_p = I/4\omega^2$
- displacement:
  $\alpha = E/4\omega^2$
- PW/cm^2 titanium sapphire laser:
  $U_p \sim 60$ eV & $\alpha \sim 50$ au

ponderomotive potential is everything at long wavelengths

A quick HHG overview

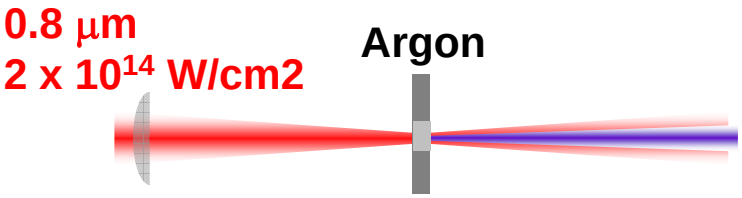


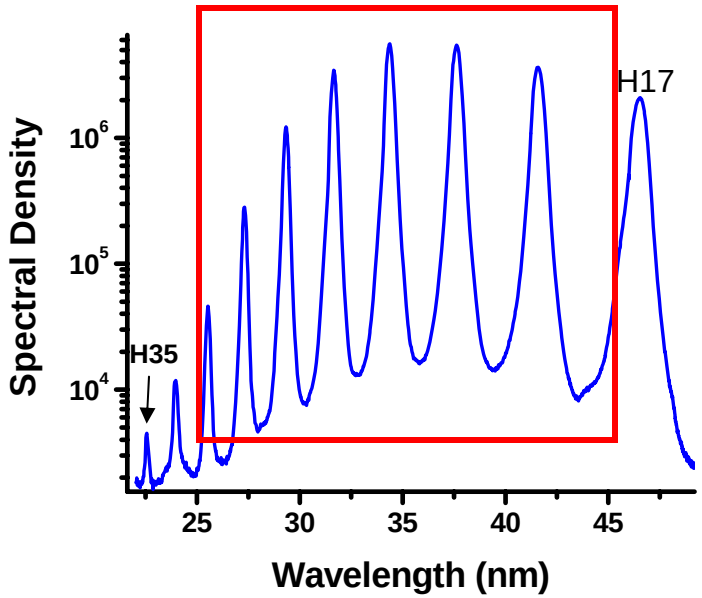


- harmonics result from the physics of a field-driven electron
- intense laser-atom interaction produces a comb of odd harmonic
- macroscopic physics (phase-matching) is important

Harmonic cutoff: $3.2*U_P + IP$

A quick HHG overview



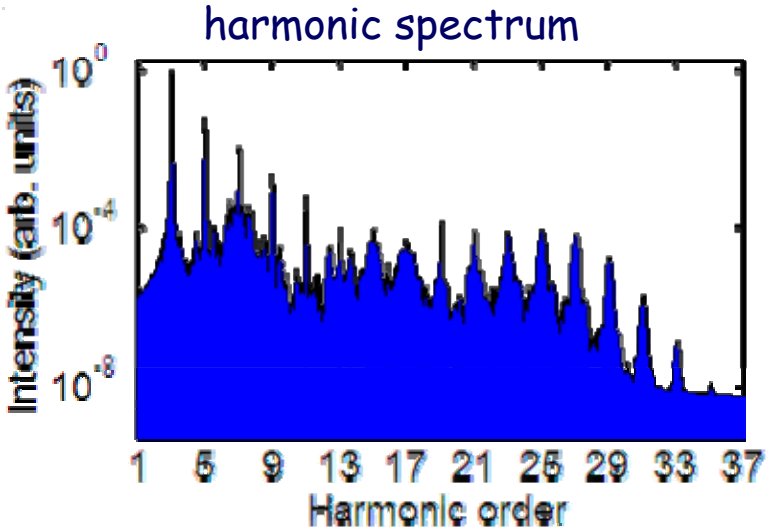


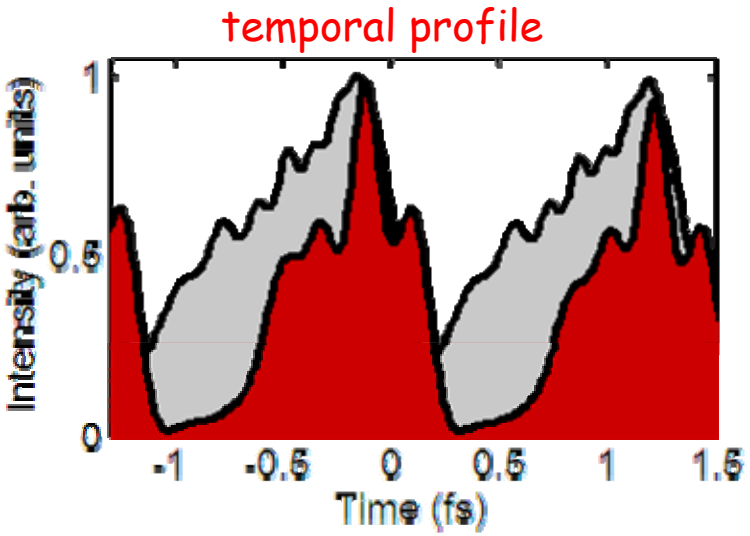
Center wavelength: 35 nm

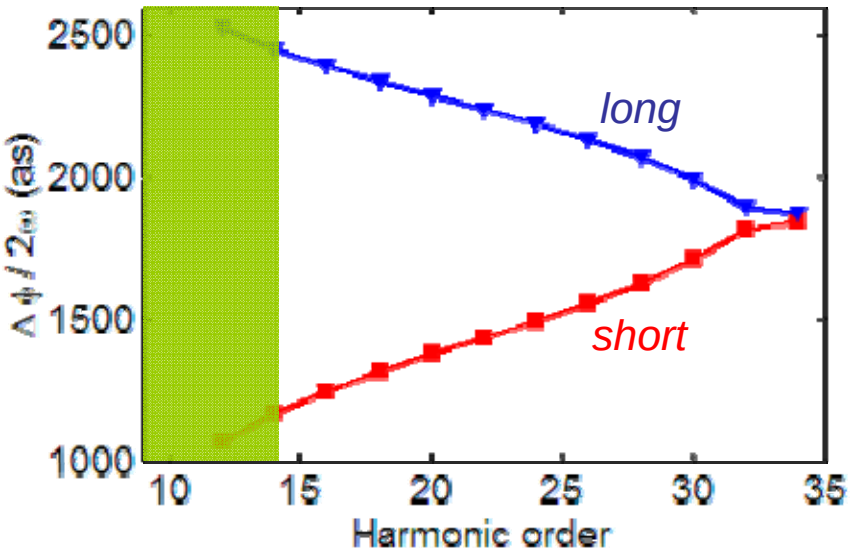
FWHM bandwidth: 7 eV

TF limit	Lund	Milano Bordeaux
100 as	170 as	170 as

Generating attoseconds – Lund Group's Recipe

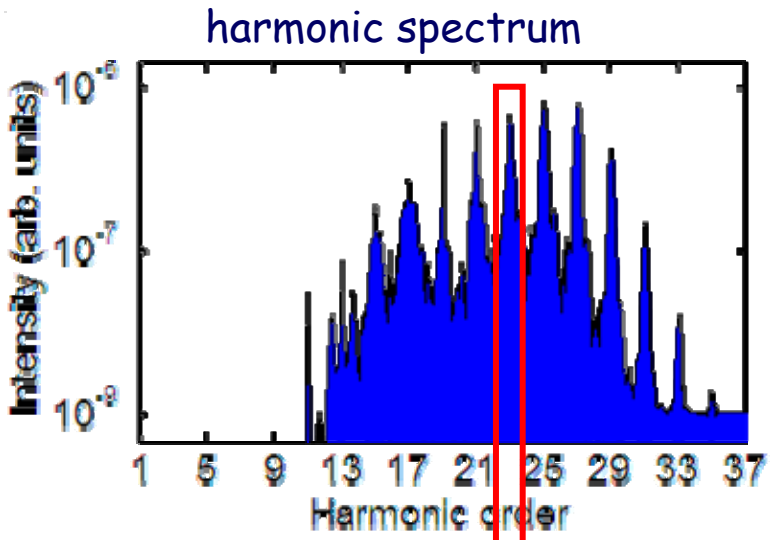


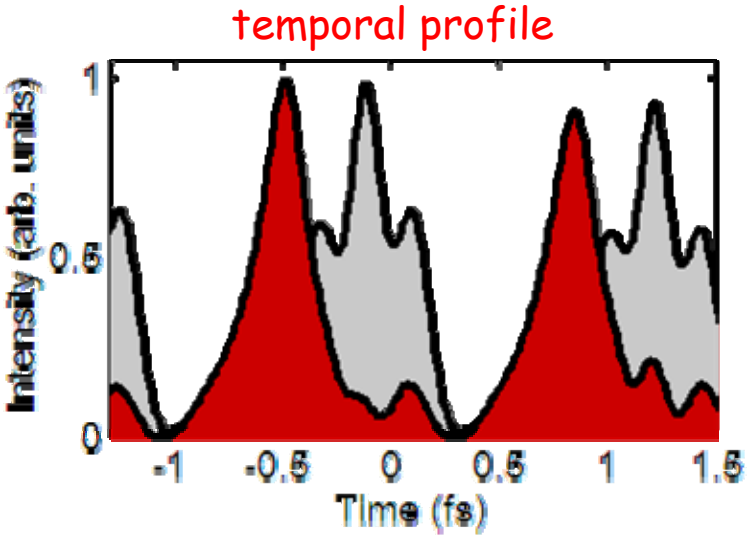




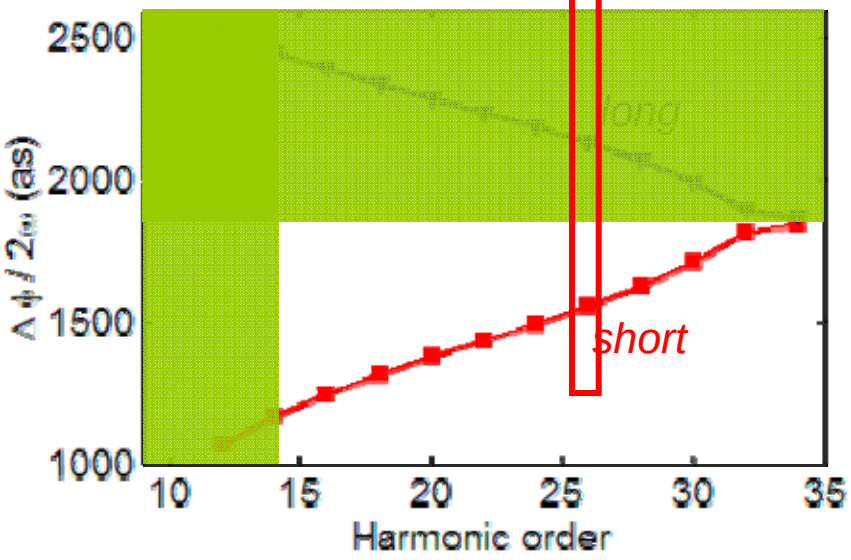
- intrinsic time-structure is dominated by the beating between the strong low-order harmonics
- select the plateau region by spectral filtering

Generating attoseconds – Lund Group's Recipe

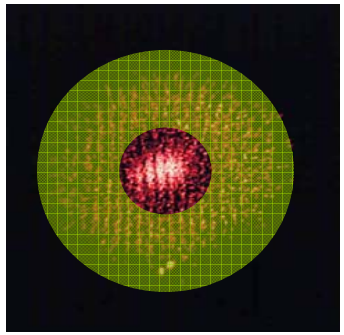




contributions from 2 dominant trajectories



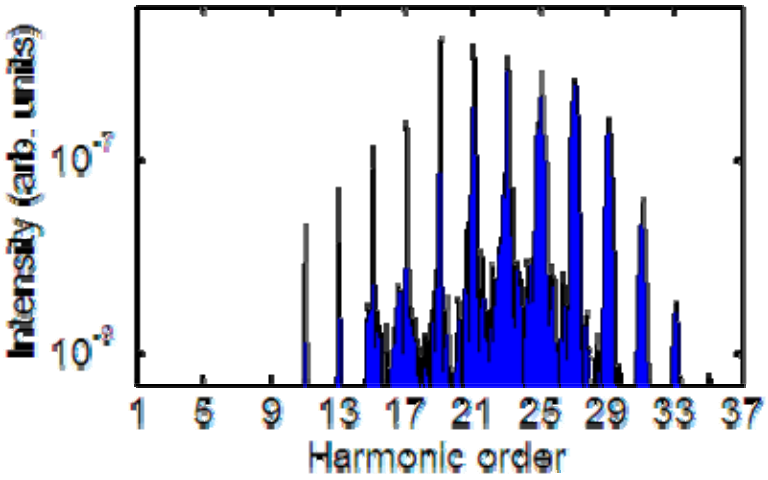
select the short trajectory by spatial filtering



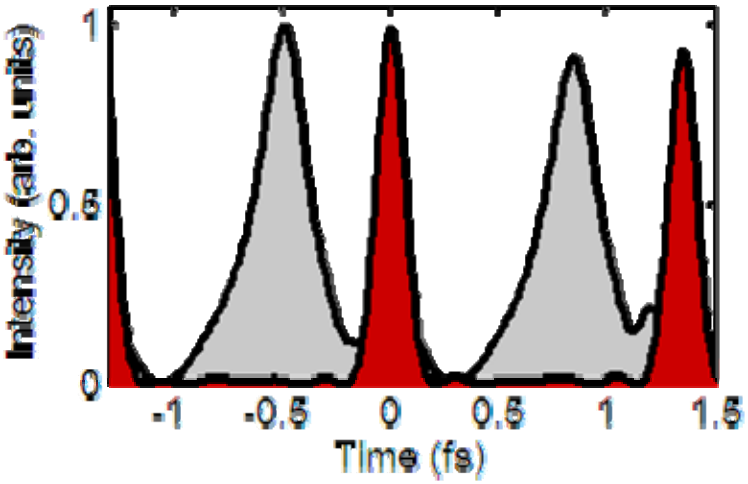
Bellini *et al.* PRL (1998)

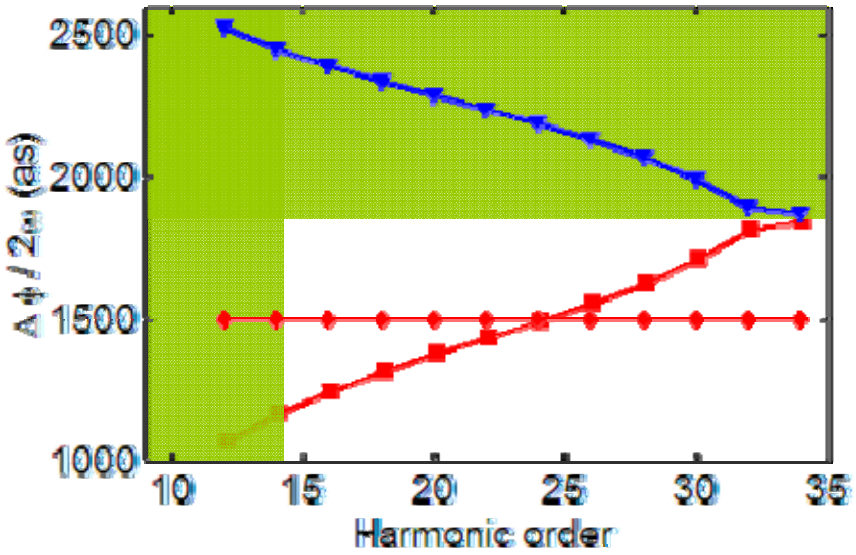
Generating attoseconds – Lund Group's Recipe

harmonic spectrum



temporal profile





the first trajectory exhibits
an intrinsic positive chirp

compress by
dispersive filtering
Lund group PRL **94**,
033001 (2005)
170 as

The case for wavelength scaling – an IR promise

Maximum classical harmonic energy: $3.2U_p + I_p$, $U_p \sim I*\lambda^2$

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Atom	Ar	He				
λ nm	800	800				
Max U_p eV	12	60				
HHG Cutoff eV(nm)	55 (22)	216 (6)				

The case for wavelength scaling – an IR promise

Maximum classical harmonic energy: $3.2U_p + I_p$, $U_P \sim I^*\lambda^2$

clamped at I_{sat} — no limitation

Atom	Ar	He	Xe	Ar	He	
λ nm	800	800	2000	2000	2000	
Max U_P eV	12	60	30	75	372	
HHG Cutoff eV(nm)	55 (22)	216 (6)	108 (11.5)	255 (5)	1200 (1)	

The case for wavelength scaling – an IR promise

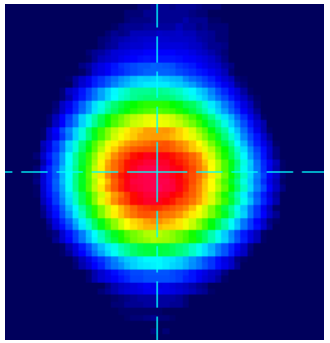
Maximum classical harmonic energy: $3.2U_p + I_p$, $U_P \sim I^*\lambda^2$

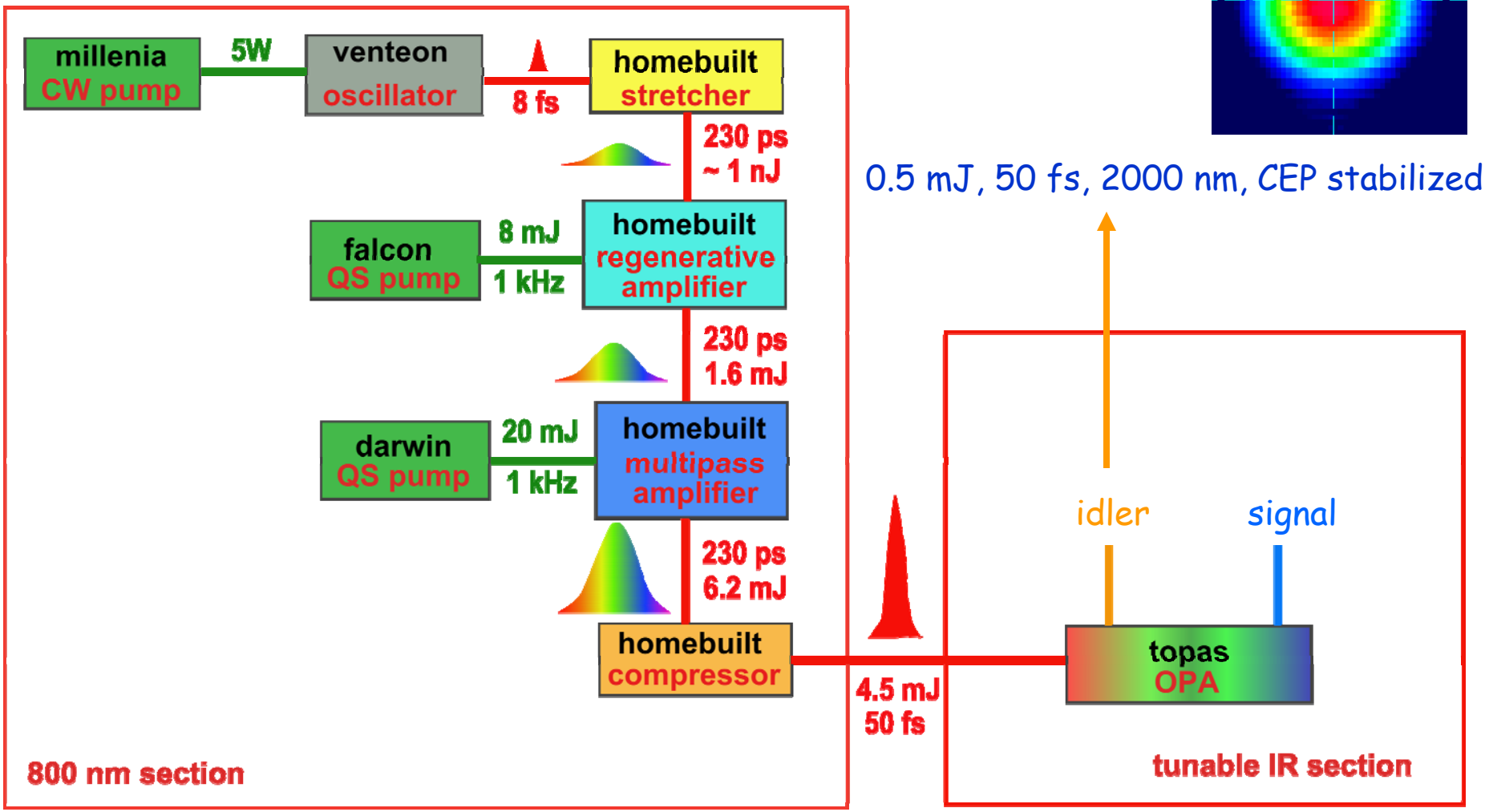
clamped at I_{sat} — no limitation

Atom	Ar	He	Xe	Ar	He	He
λ nm	800	800	2000	2000	2000	3600
Max U_P eV	12	60	30	75	372	1200
HHG Cutoff eV(nm)	55 (22)	216 (6)	108 (11.5)	255 (5)	1200 (1)	3800 (0.3)

First results at 2000 nm in Argon

The "toy":

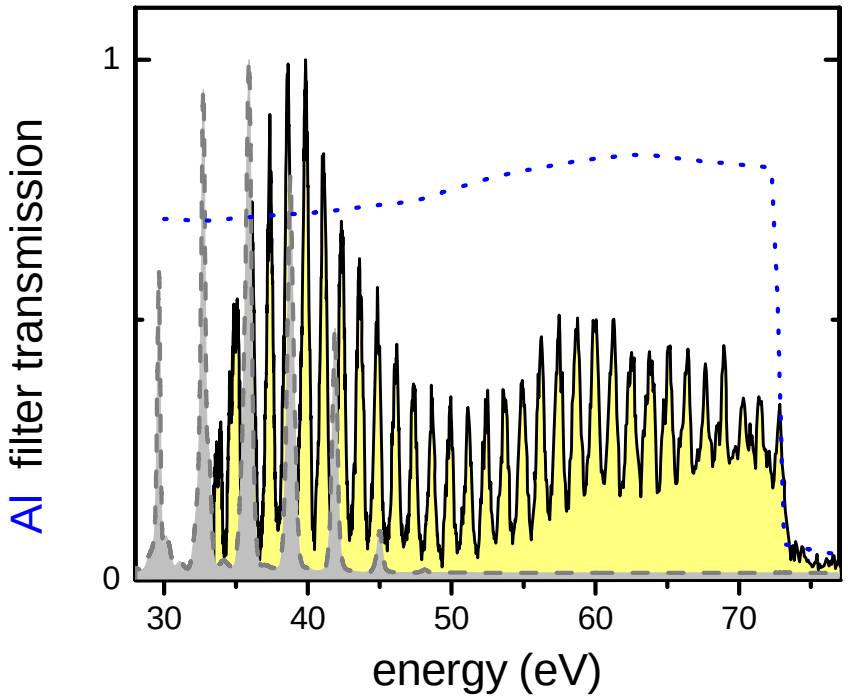


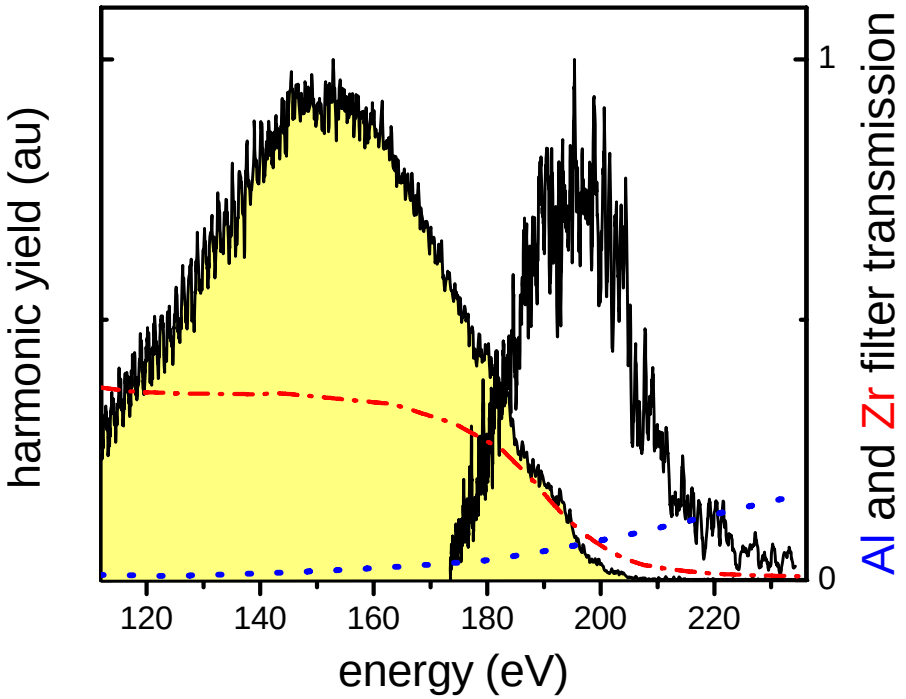


0.5 mJ, 50 fs, 2000 nm, CEP stabilized

First results at 2000 nm in Argon

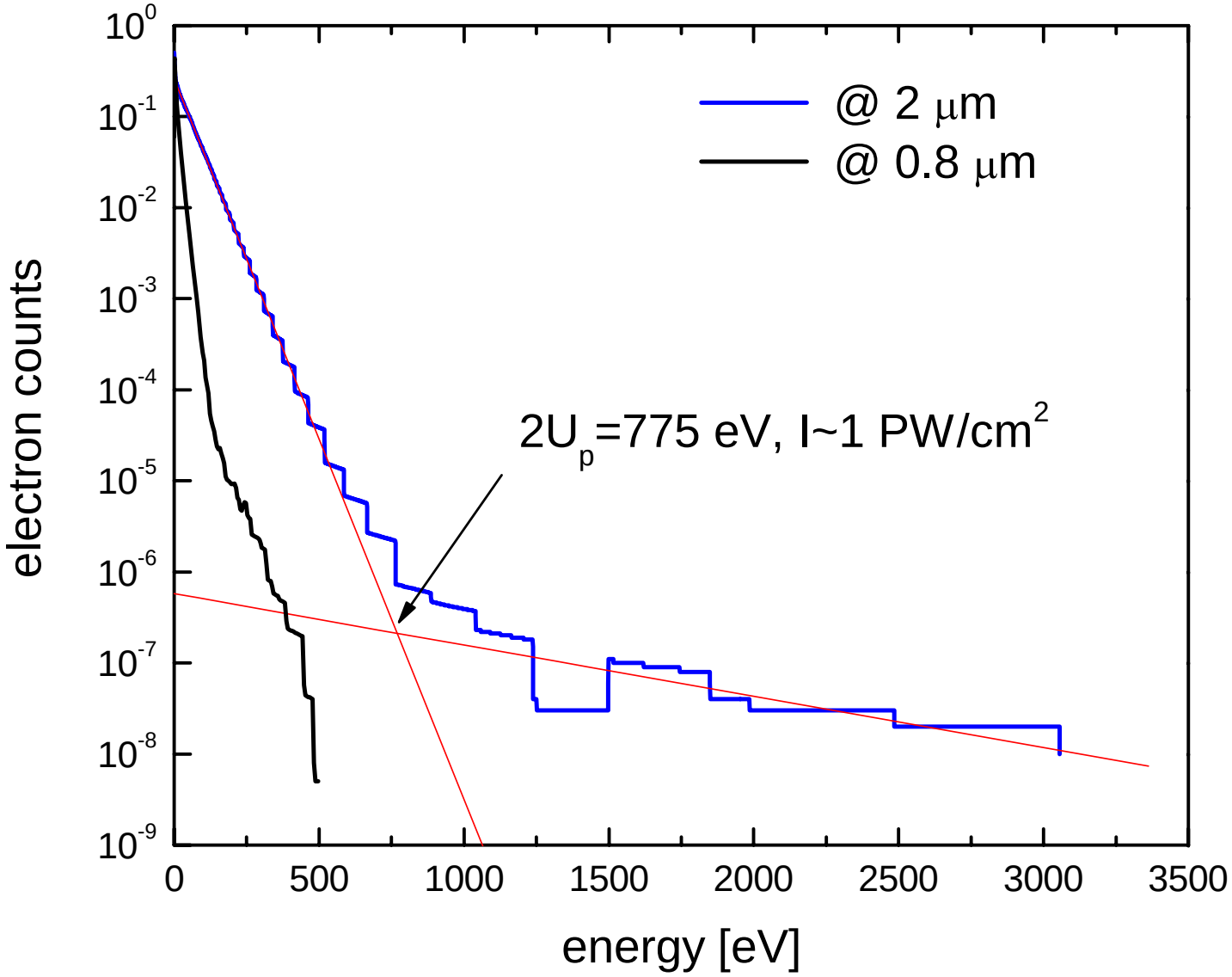
HHG Spectrum:



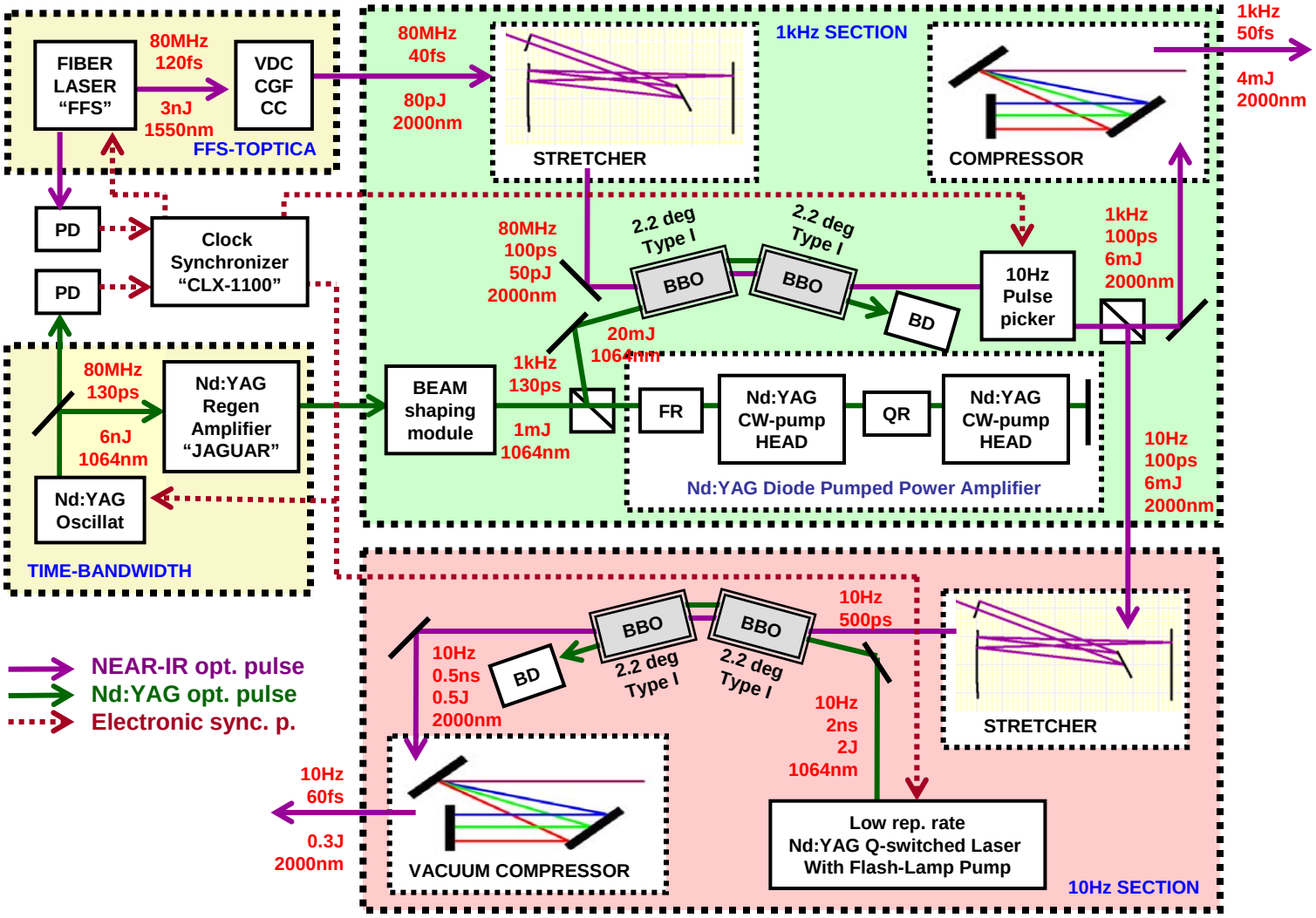


- cutoff corresponds ~351th-order harmonic
- for constant conditions and bandwidth; (35-50 eV), $I_2 \cong I_{0.8}/1000$
- varying density alone; $I_2 \cong I_{0.8}/20$

Helium Photoelectron Spectrum at 2000 nm



OPCPA for Helium HHG at 2000 nm



The DiMauro - Agostini Group

post-docs
Gilles Doumy
Fabrice Catoire
Ilya Lachko
Anthony DiChiara

graduate students
Phil Colosimo (2007)
Anne Marie March
Cosmin Blaga
Jonathan Wheeler
Razvan Chirla
Emily Sistrunk
Christoph Roedig

collaborators: H. Muller, T. Auguste, P. Salieres, G. Paulus, K. Kulander, C. Hauri