Non-linear XUV processes @ intense, sub-fs radiation sources

D. Charalambidis

FO.R.T.H. - I.E.S.L./ Univ. of Crete

chara@iesl.forth.gr

P. Tzallas
E. Benis
C. Kalpouzos

Post-doc
A. Peralta Conde

Ph.D
J. Kruse
E. Skatzakis

Technician
G. Maravelias

In collaboration with

G. Tsakiris
Y. Nomura
R. Hörleine
S. G. Rykovanov
F. Krausz

L. Nikolopoulos
B. Dromey
M. Zepf

O. Faucher

M. Vrakking AMOLF

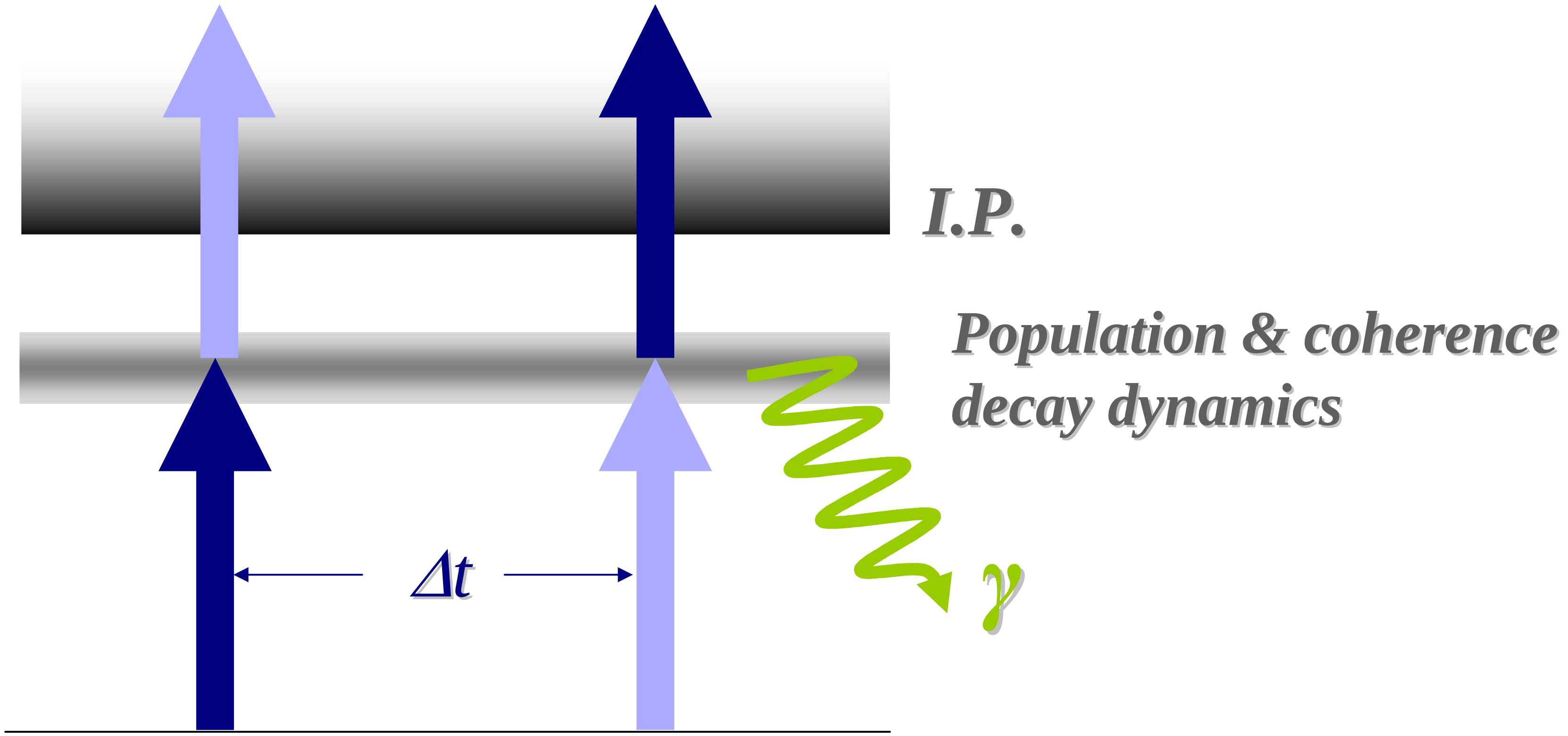
FASTQUAST Kick-off meeting

Cargese, Corsica
20 August, 2008

ULF LaserLab Europe, ELI-RI PP, X-HOMES (TOK), FASTQUAST (RTN)

Non-linear XUV processes

Metrology of ultra-short pulses & ultra-fast dynamics



FO.R.T.H. - I.E.S.L.

Current & foreseen sources of short XUV/x-ray pulses

Source	$\hbar\omega$	τ	***E* (@ the source)**	**I_{max} (@ the target)**
Gas HOHG single pulse	20 -100eV	~ 100as	≤1nJ	<10^{11}W/cm^2
Gas HOHG pulse trains	10 -100eV	≥ 300as ≥ 10fs envelope	≤1μJ	<10^{14}W/cm^2
Surface HOHG (current)	10s of eV - few keV	~ 900 fs ~40fs envelope	≤1μJ	<10^{12}W/cm^2
Surface HOHG (future)	10s of eV - few keV	≥ 5as	≤ 100mJ**	~10^{25} W/cm^2 **
XFEL (current)	≤ few 100eV*	~ 30fs (?)*	≤10mJ*	10^{16}W/cm^2*
XFEL (future)	≤ 12.4 keV	?	≤ 100mJ*	10^{18}W/cm^2 (?)

*****Source: Technical Design Report & recent publications

** Prediction and/or Vision

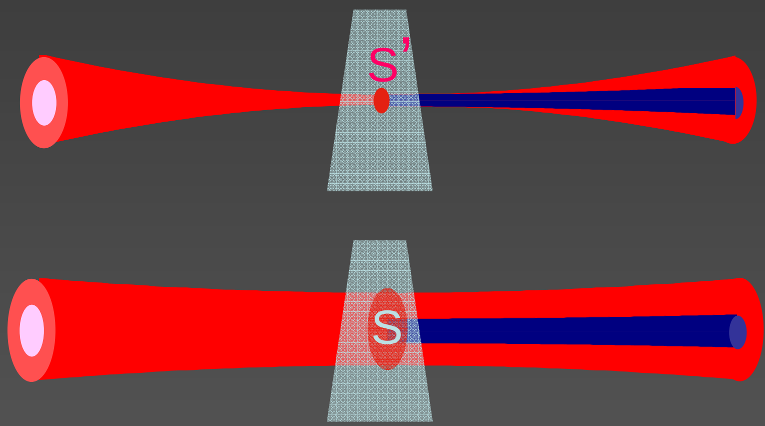
FO.R.T.H. - I.E.S.L.

Generation of intense attosecond pulse trains & pulses

How to do it

- High peak power (many cycle or new generation few cycle) driving pulses

- High conversion efficiency processes



- For depleting targets (e.g. atoms) avoid depletion through:

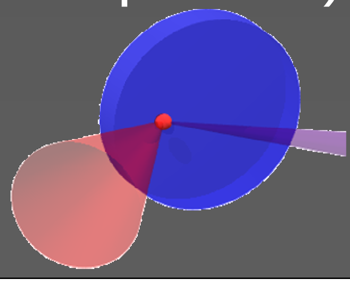
  i) Loose focusing

  ii) Short pulse duration

$$P_{med} \cdot L_{med} = \text{const}$$

$$P_{XUV} \propto N_{at}^2 \propto S^2$$

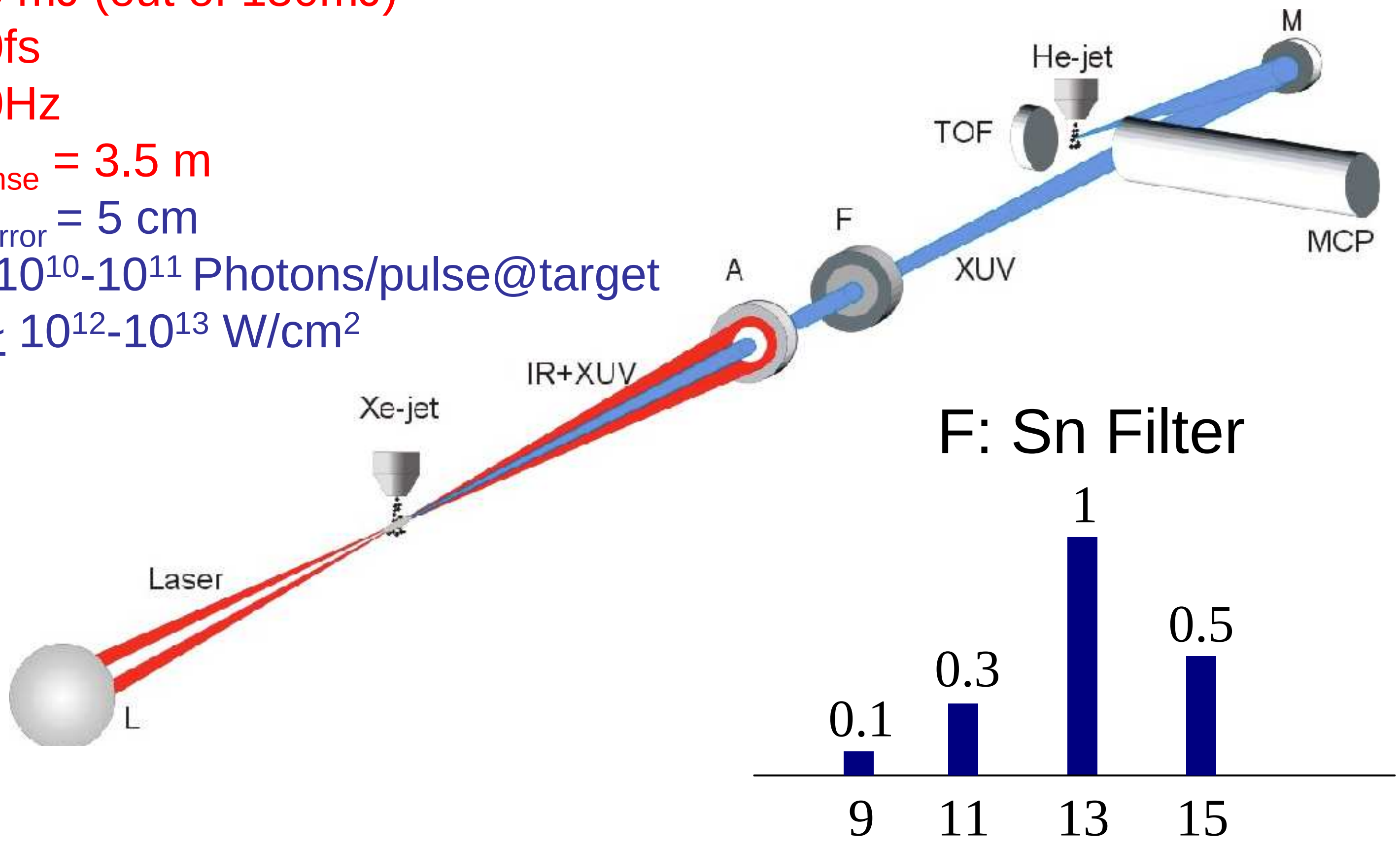
- For not depleting targets (e.g. surface plasma) use of highest possible intensity through tight focusing



Non-linear XUV processes @ sub-fs scale

Source and diagnostics

800 nm
15 mJ (out of 150mJ)
50fs
10Hz
f_{lense} = 3.5 m
f_{mirror} = 5 cm
~ 10^{10}-10^{11} Photons/pulse@target
I $\simeq$ 10^{12}-10^{13} W/cm^2

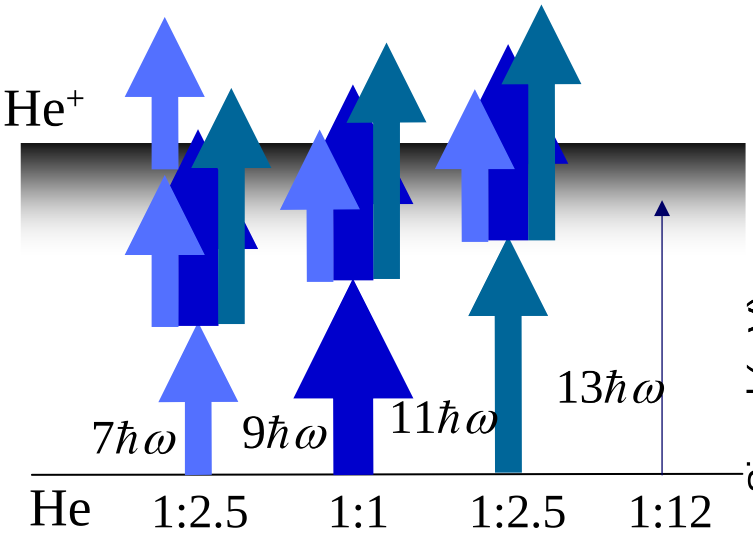


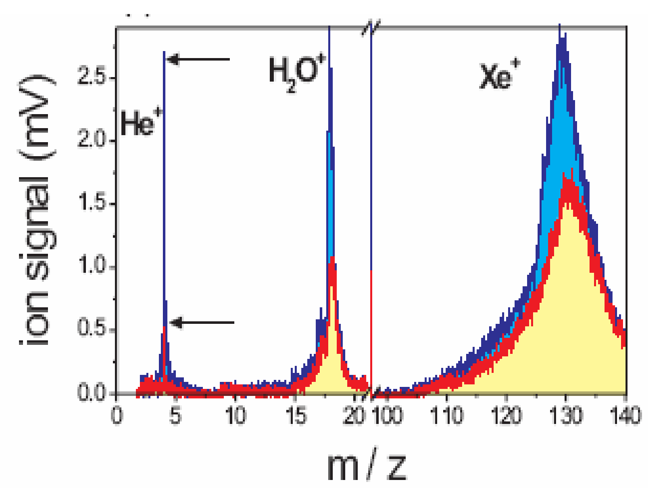
Harmonic intensity distribution

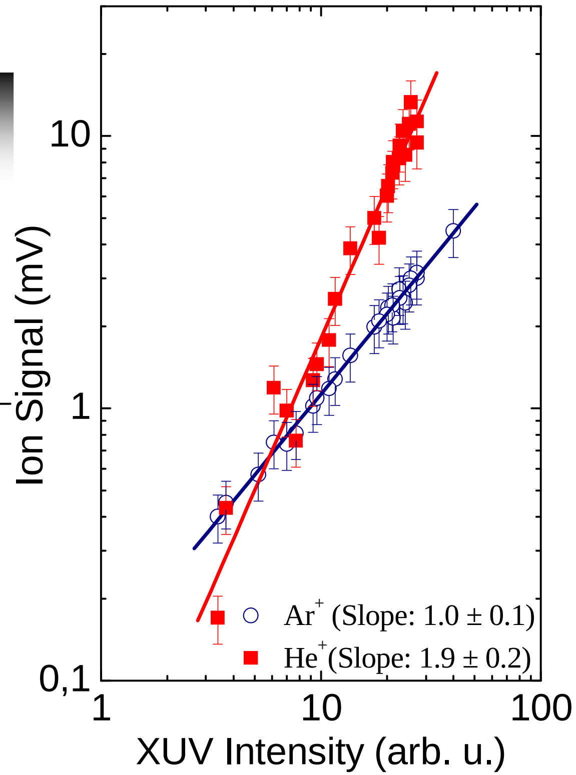
FO.R.T.H. - I.E.S.L.

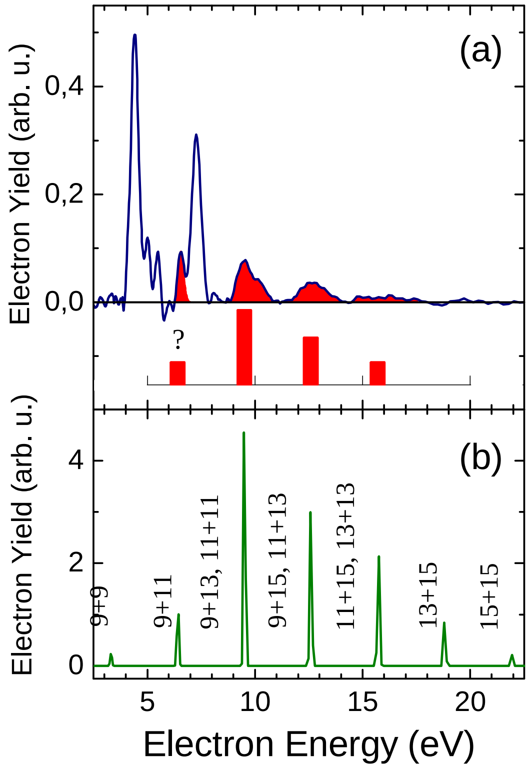
Non-linear XUV processes @ sub-fs scale

Two-XUV-photon He ionization by a superposition of HOH









E. Benis *et al.* New J. of Phys. **8** 92 (2006)

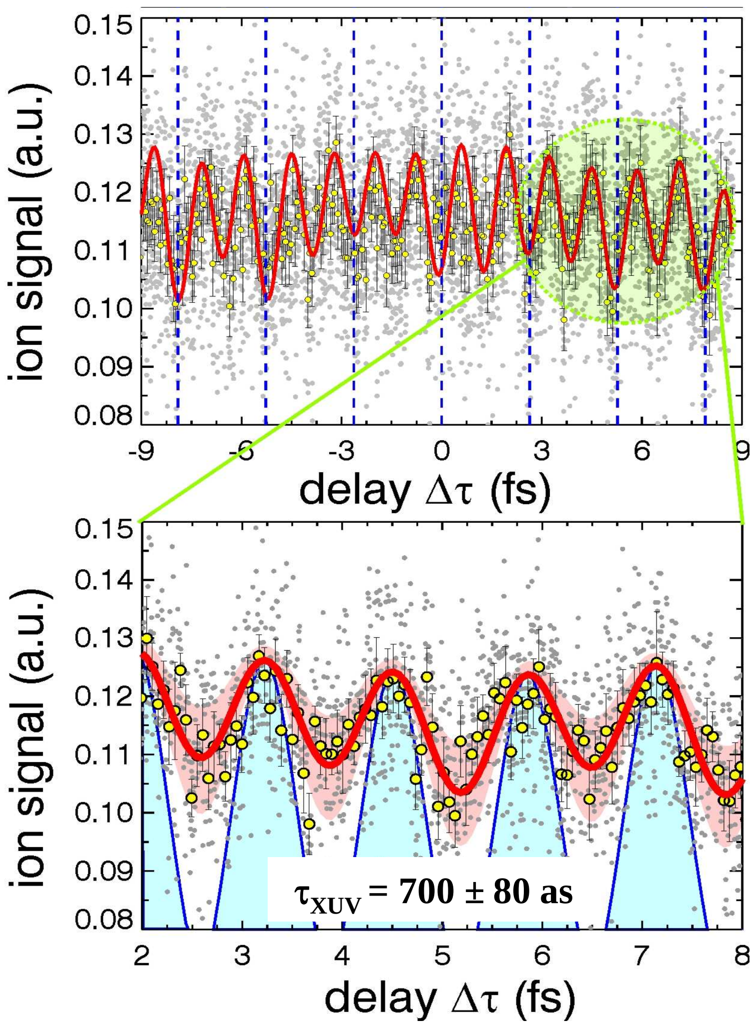
N. A. Papadogiannis *et al. Phys. Rev. Lett.* **90**, 133902 (2003)

N. A. Papadogiannis et al. Appl. Phys. B**76**, 721 (2003)

FO.R.T.H. - I.E.S.L.

Non-linear XUV processes @ sub-fs scale

2nd order intensity AC of attosecond pulse trains



The first direct measurement of asec light bunching!

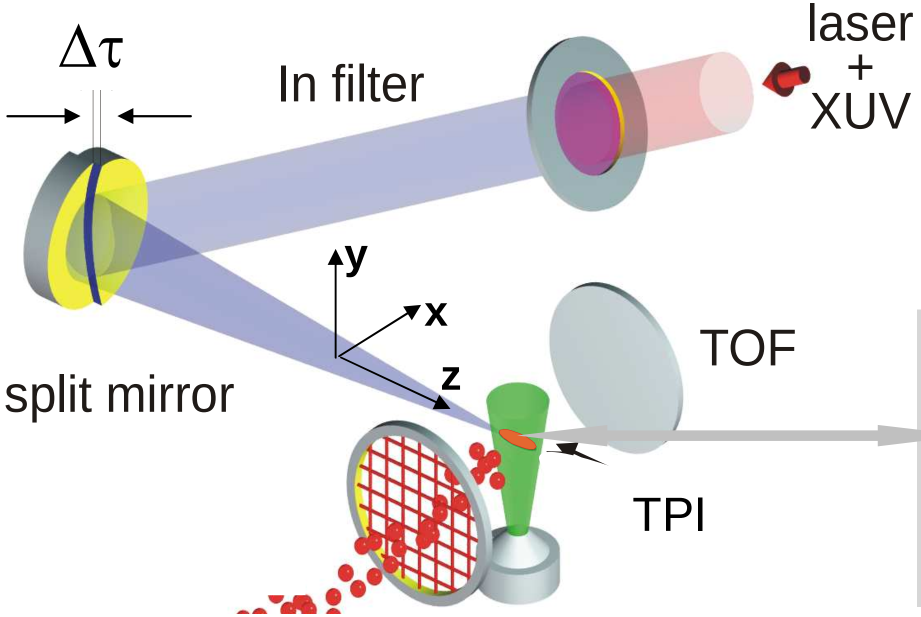
P. Tzallas *et al. Nature* **426**, 267 (2003)

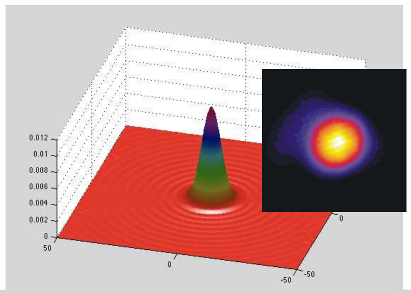
L. A. A. Nikolopoulos *et. al. Phys. Rev. Lett.* **94**, 113905 (2005)

FO.R.T.H. - I.E.S.L.

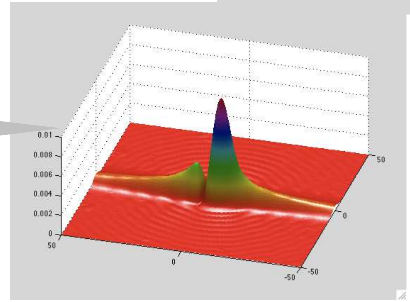
Non-linear XUV processes @ sub-fs scale

The split mirror NL volume autocorrelator

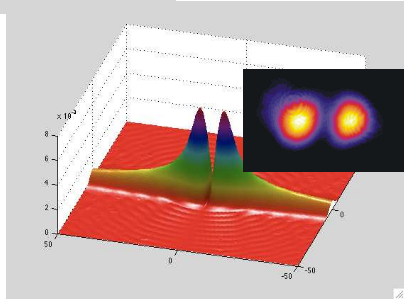




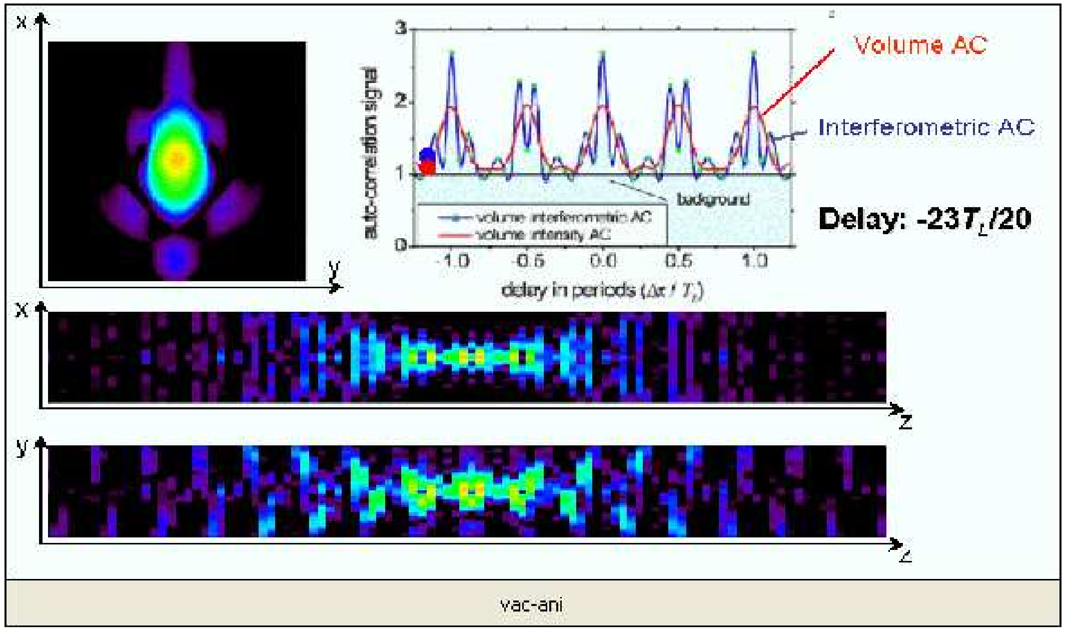
φ=0



φ=π/2



φ=π

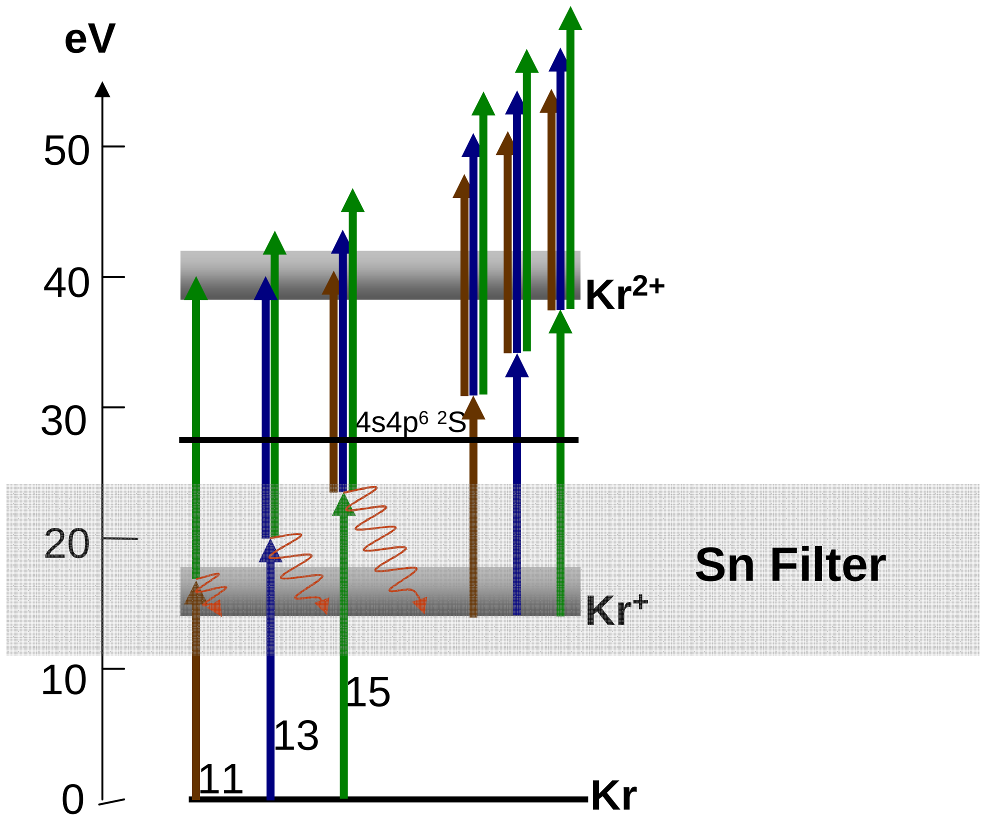


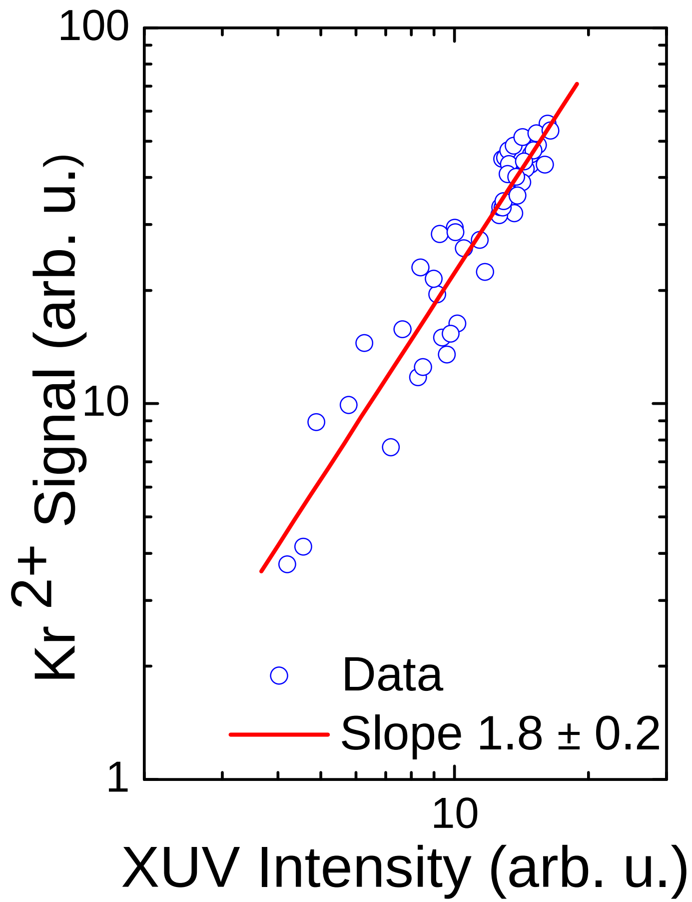
P. Tzallas *et al.*
J. Mod. Opt. **52**, 321 (2005)

FO.R.T.H. - I.E.S.L.

Non-linear XUV processes @ sub-fs scale

Two-XUV-photon direct double ionization in Kr and Ar





$$\frac{IP_2}{2} \le \hbar\omega \le IP_2 - IP_1$$

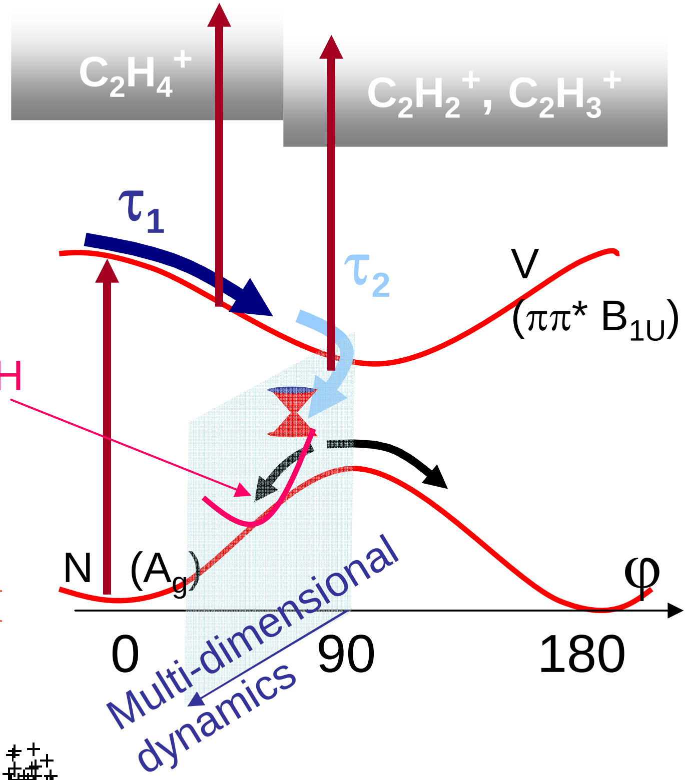
E. Benis *et al.* Phys. Rev. A **74**, 051402 (**R**) (2006)

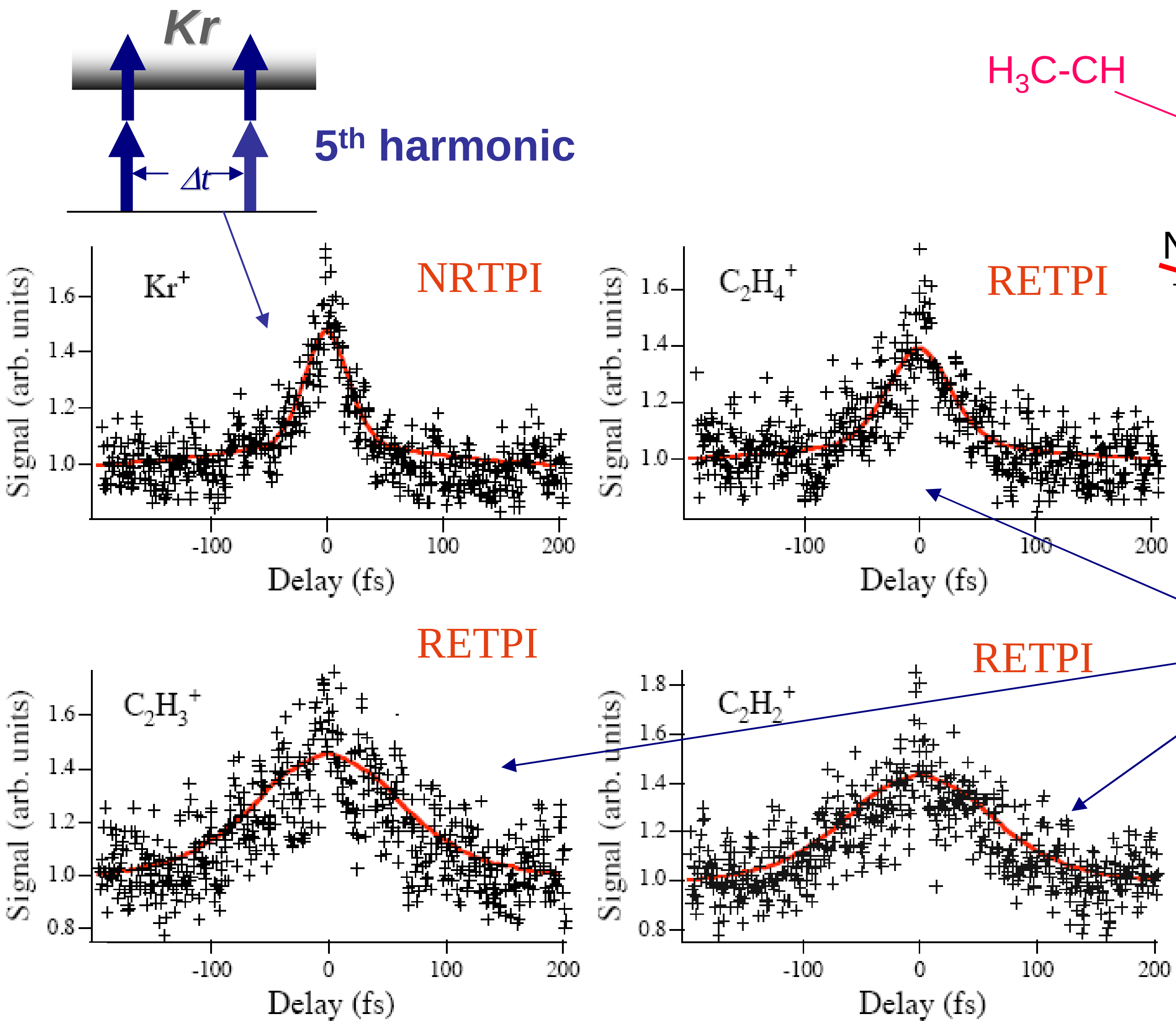
FO.R.T.H. - I.E.S.L.

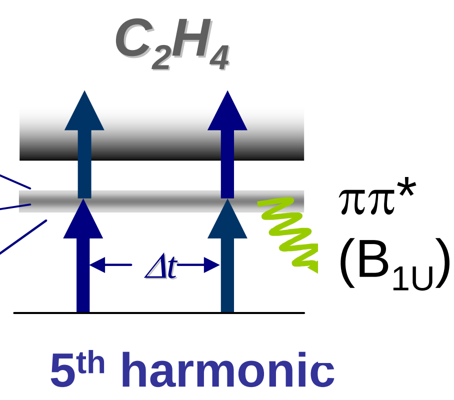
Non-linear VUV processes

Ultra fast dynamics in RETPI of C_2H_4

A. Peralta Conde et al. (under submission)





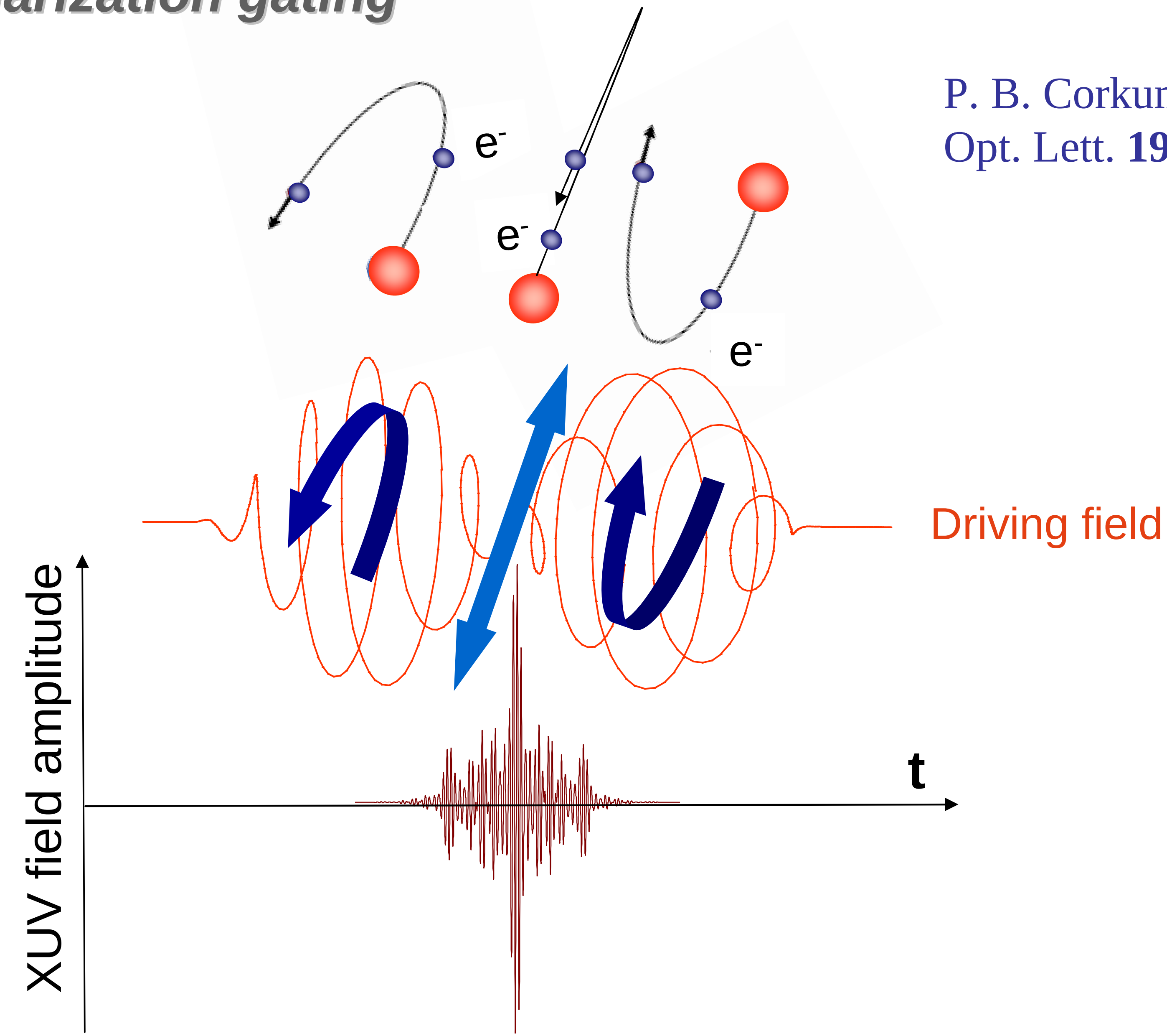


FO.R.T.H. - I.E.S.L.

Towards NL XUV processes with isolated asec pulses

Polarization gating

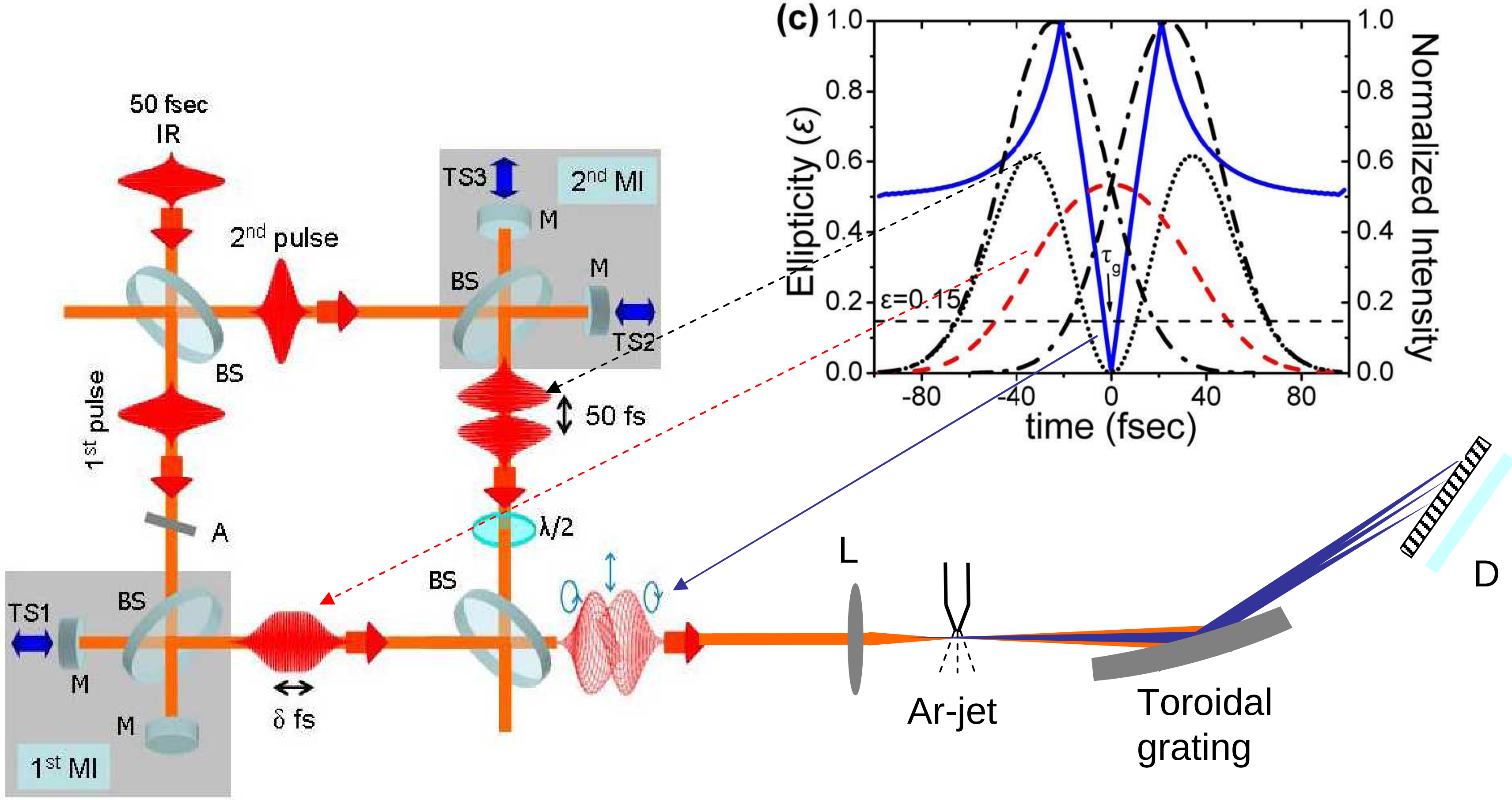
P. B. Corkum et al.
Opt. Lett. **19,** 1870 (1994)



FO.R.T.H. - I.E.S.L.

Towards NL XUV processes with isolated as pulses

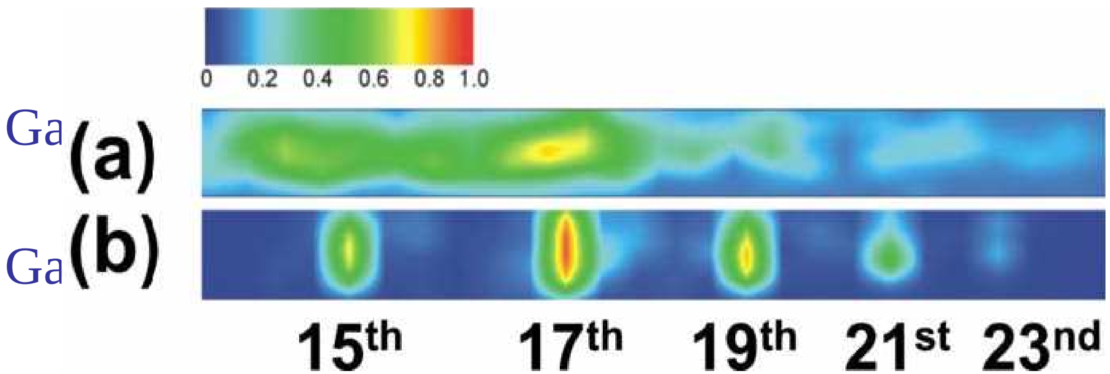
Interferometric polarization gating (IPG)

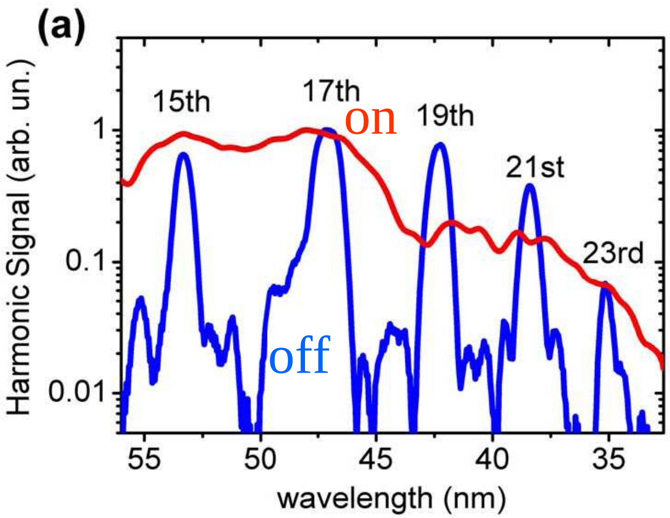


See also: Y. Silberberg, D.M. Villeneuve et al.PRA **72**, 063816 (2006)

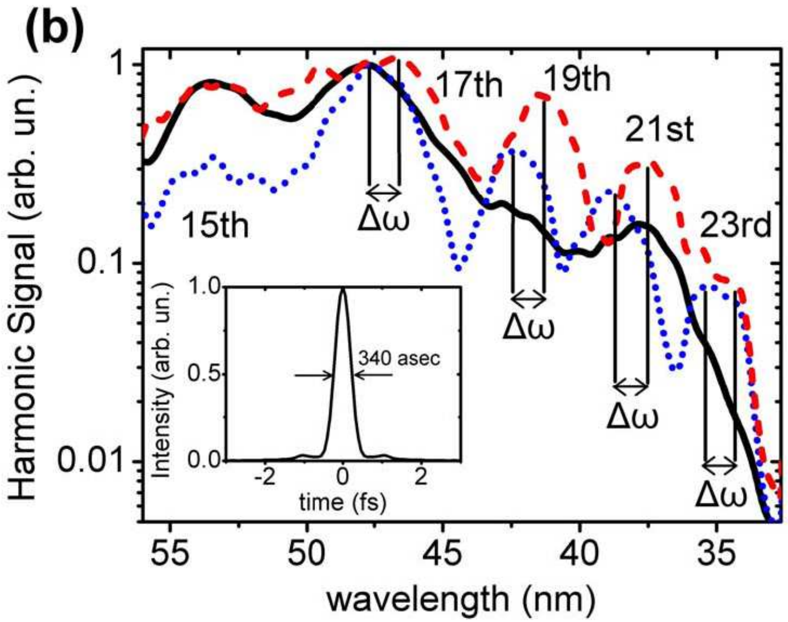
Towards NL XUV processes with isolated as pulses

IPG results





Averaged



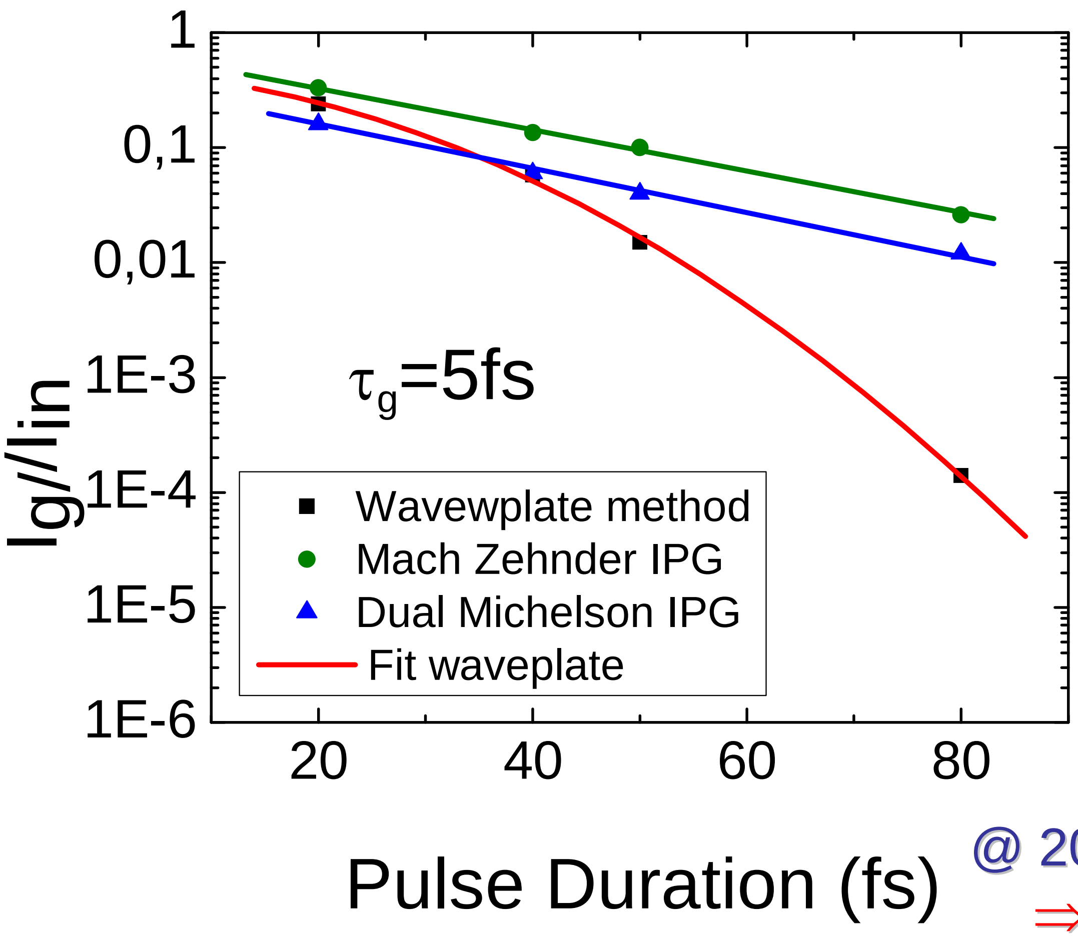
Single shot

P. Tzallas *et al. Nature Phys.* **3**, 846 (2007)

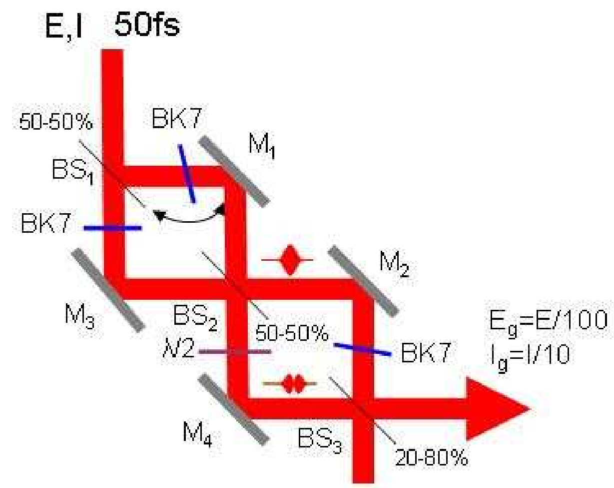
FO.R.T.H. - I.E.S.L.

Towards NL XUV processes with isolated as pulses

Throughput comparison



Mach Zehnder IPG set up



@ 20TW (e.g. 1J, 40fs) driving power

⇒ >2TW (10mJ, 5fs) in the gate

@ low B integral values!

D. Charalambidis *et al.* New J. Phys. **10**, 025018 (17pp), (2008)

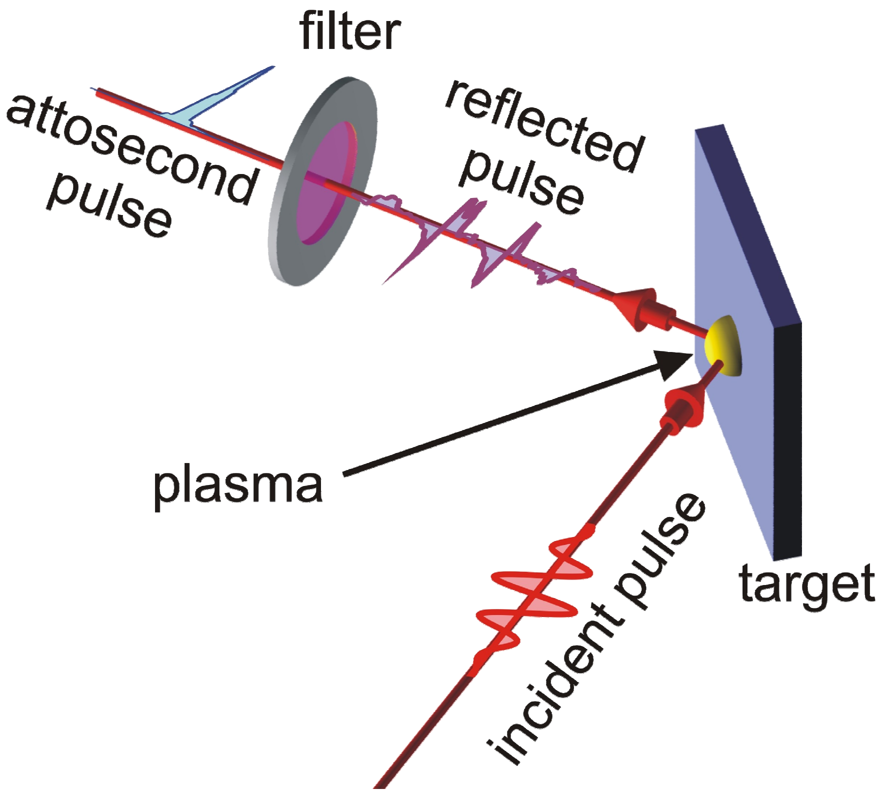
FO.R.T.H. - I.E.S.L.

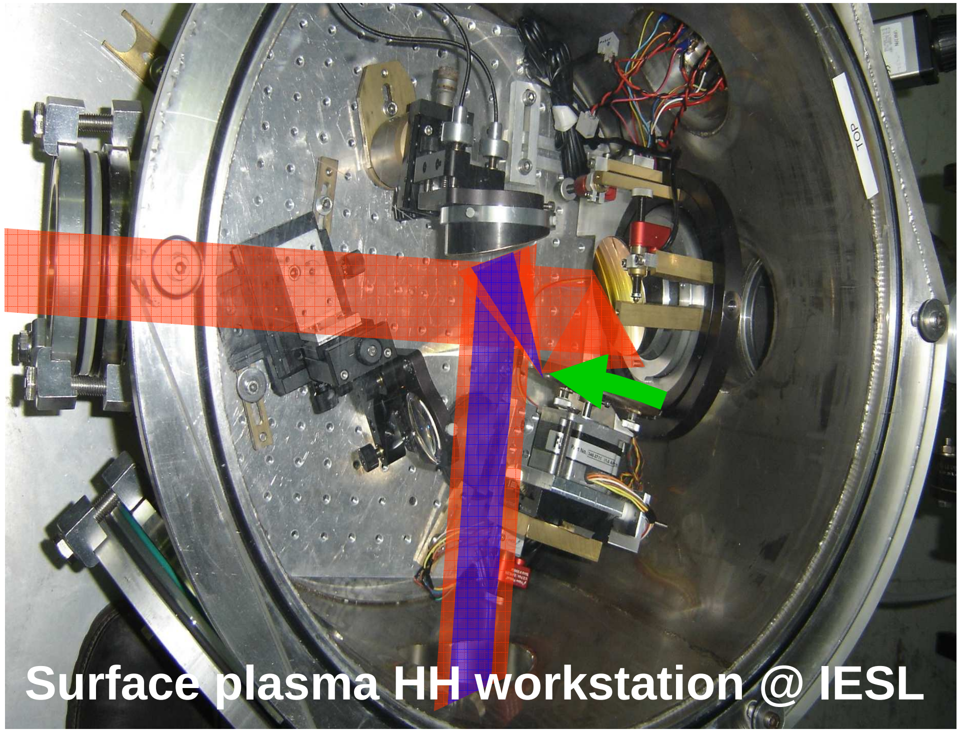
A new promising attosecond XUV/x-ray source

Surface plasma harmonic emission

$$a_L = |e|A_L / mc = \sqrt{I_L \lambda_L^2 (1.37 \cdot 10^{18} W\mu m^2 / cm^2}$$

$$a_L \approx 1$$





by G. D. Tsakiris

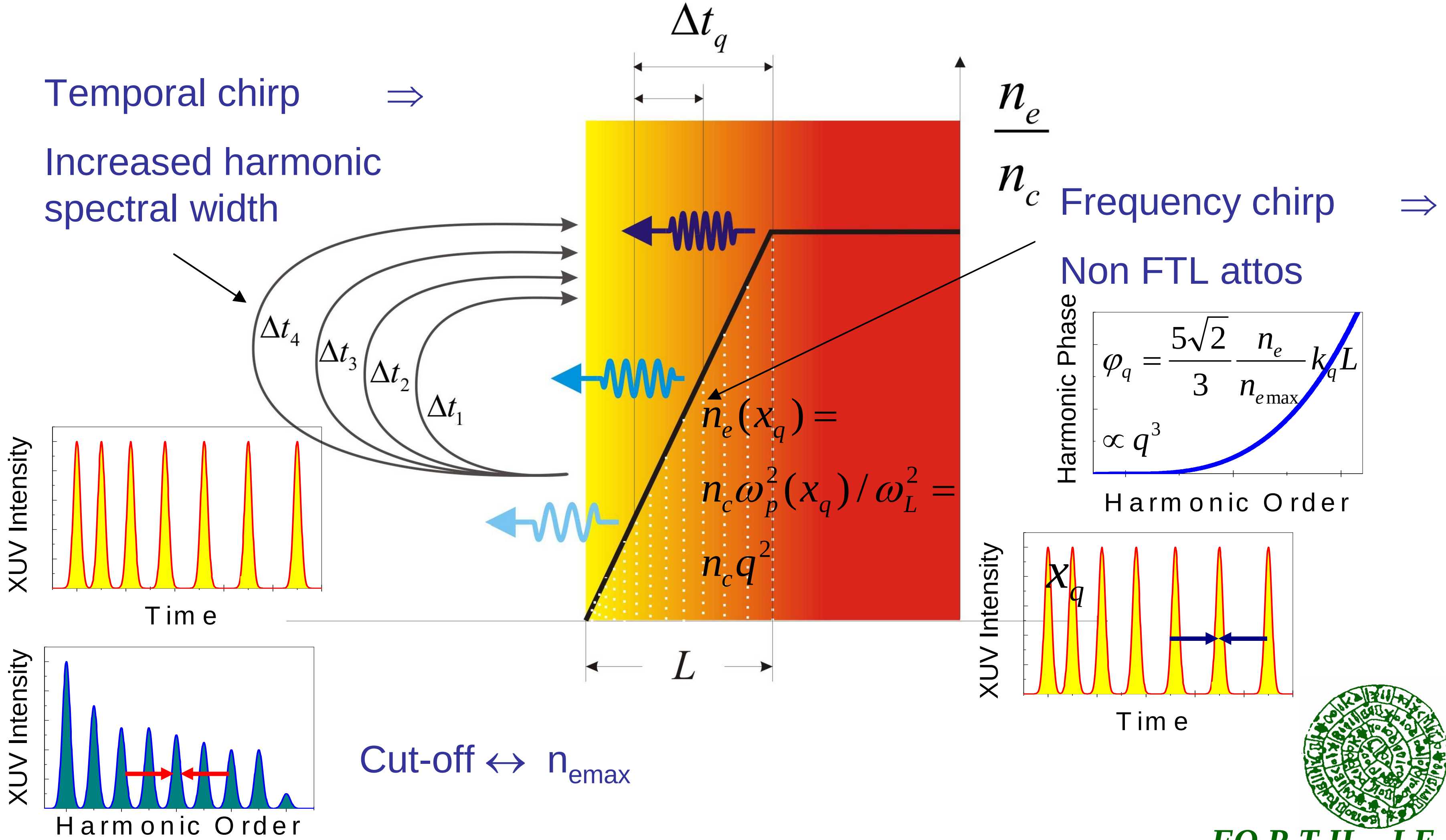
FO.R.T.H. - I.E.S.L.

Surface plasma harmonic emission

The coherent wake emission (CWE) regime

F. Quéré, *et al.* PRL. **96**, 125004 (2006);
Nature Phys. **3**, 424 (2007)

CWE (a_L<1⇒ I_L< 10^{18} W/cm^2 @ 800nm)



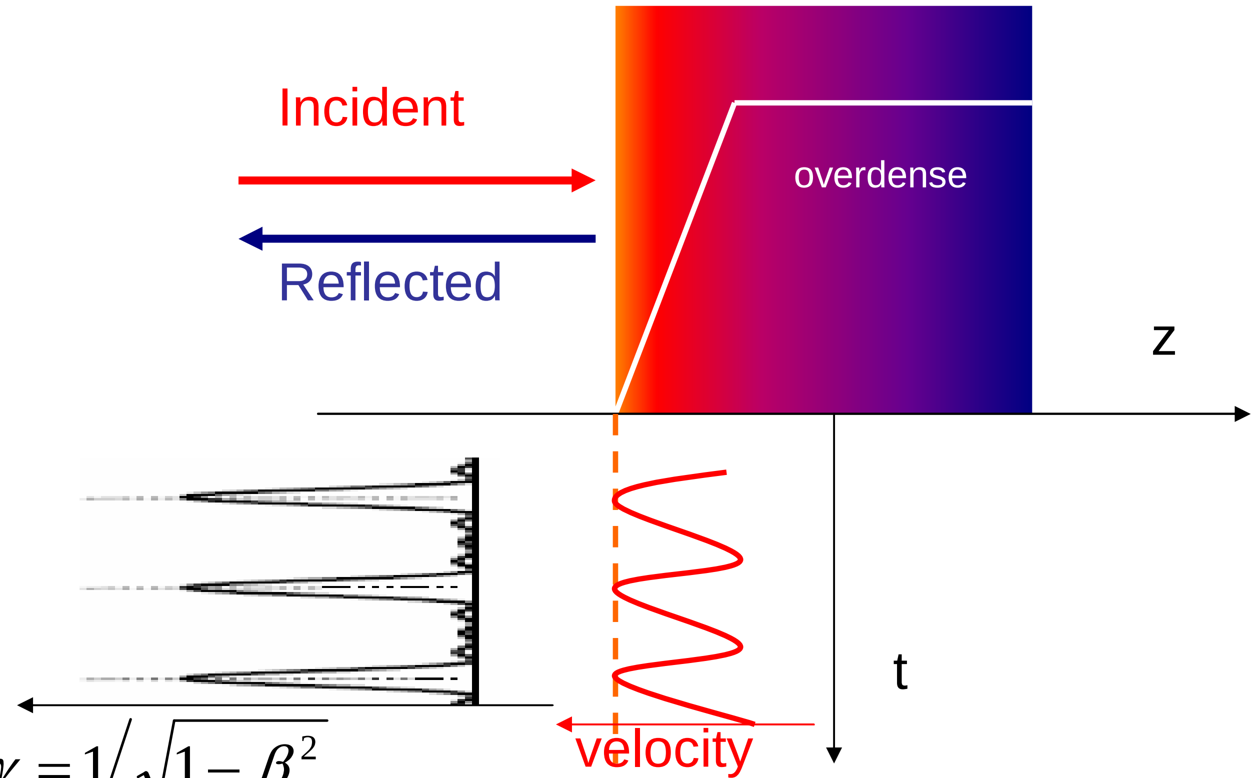
FO.R.T.H. - I.E.S.L.

Surface plasma harmonic emission

The relativistic oscillating mirror (ROM) regime

T. Baeva, PRE **74**, 046404 (2006)

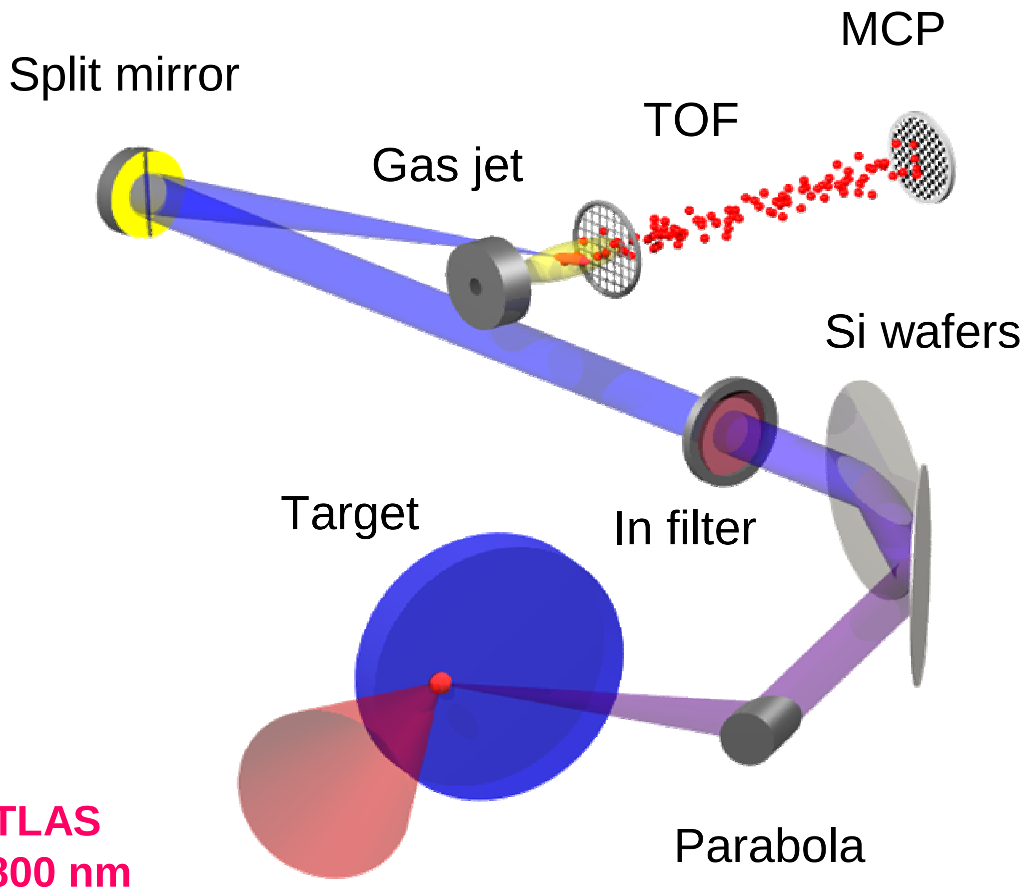
ROM (a_L>1⇒ I_L< 10^{18} W/cm^2 @ 800nm)



$$\gamma = 1/\sqrt{1-\beta^2}$$

Surface plasma harmonic emission experiments

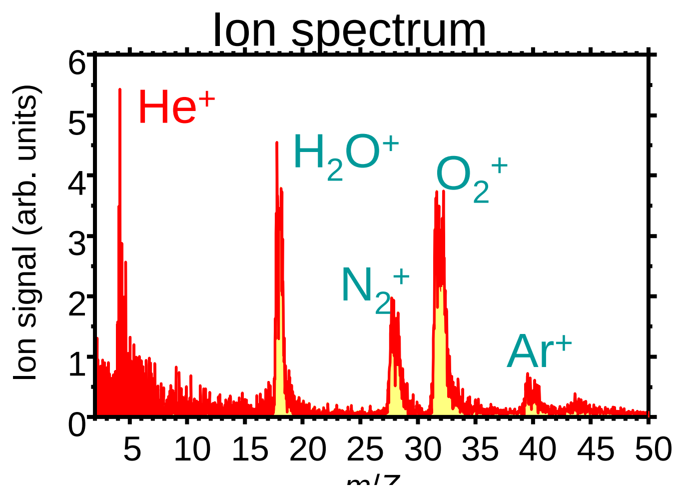
Set up and spectra

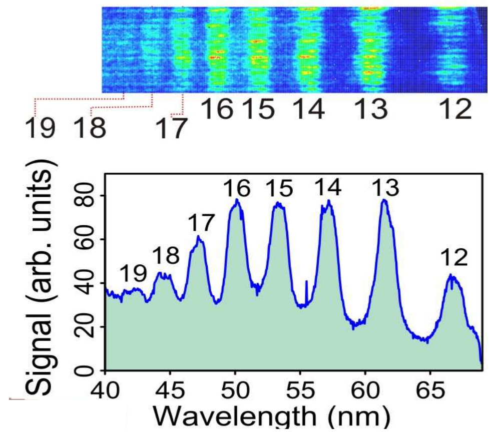


ATLAS
~800 nm
~45 fs
~0.7 J (I≃ $4 \cdot 10^{18}$ W/cm^2)

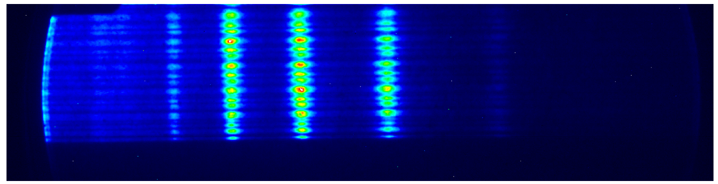
~ $2 \cdot 10^{13}$ XUV photons/pulse @ source

~ $5 \cdot 10^{10}$ XUV photons/pulse @ target (I≃10^{11} W/cm^2)





Plexiglas: No harmonic above 15th



Surface plasma harmonic emission experiments

Observation of a two-XUV-photon ionization process

Y. Nomura et al. (submitted)

Surface plasma harmonic emission experiments

2^{nd} order AC measurements

The harmonics from the plasma medium are phase-locked !

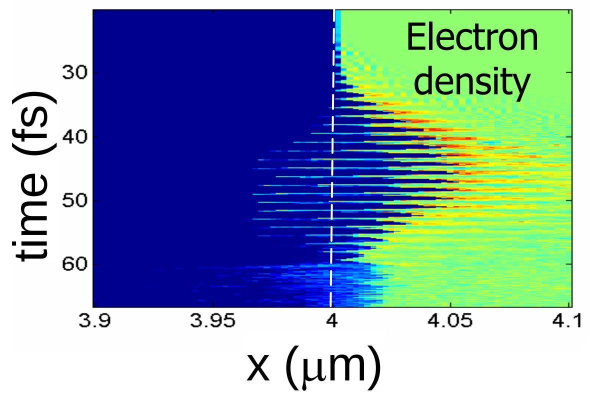
Y. Nomura et al. (submitted)

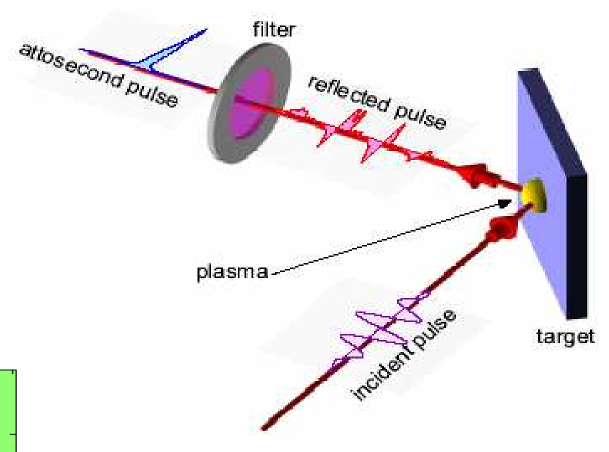
Relativistic plasma attosecond pulse generation

Ellipticity dependence & Polarization gating

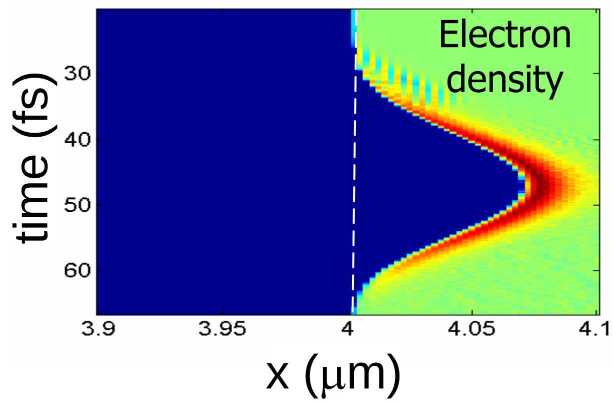
T. Baeva *et al*., *Phys. Rev*. E**74**, R065401(2006)

Linear polarization

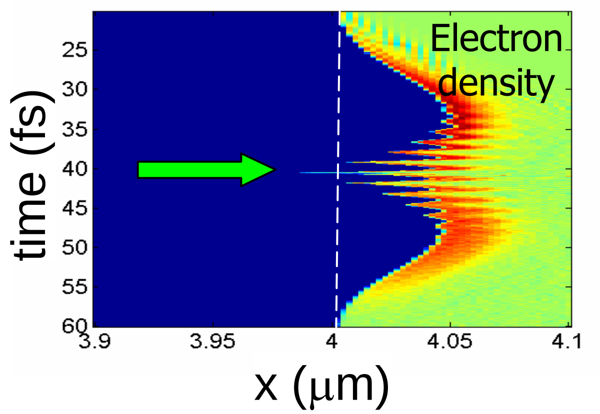




Circular polarization



With polarization gating



S. G. Rykovanov et al.
New J. Phys. **10**, 025025 (2008)

A new promising asec XUV/x-ray source

PIC simulations of the XUV specs

Driving field parameters

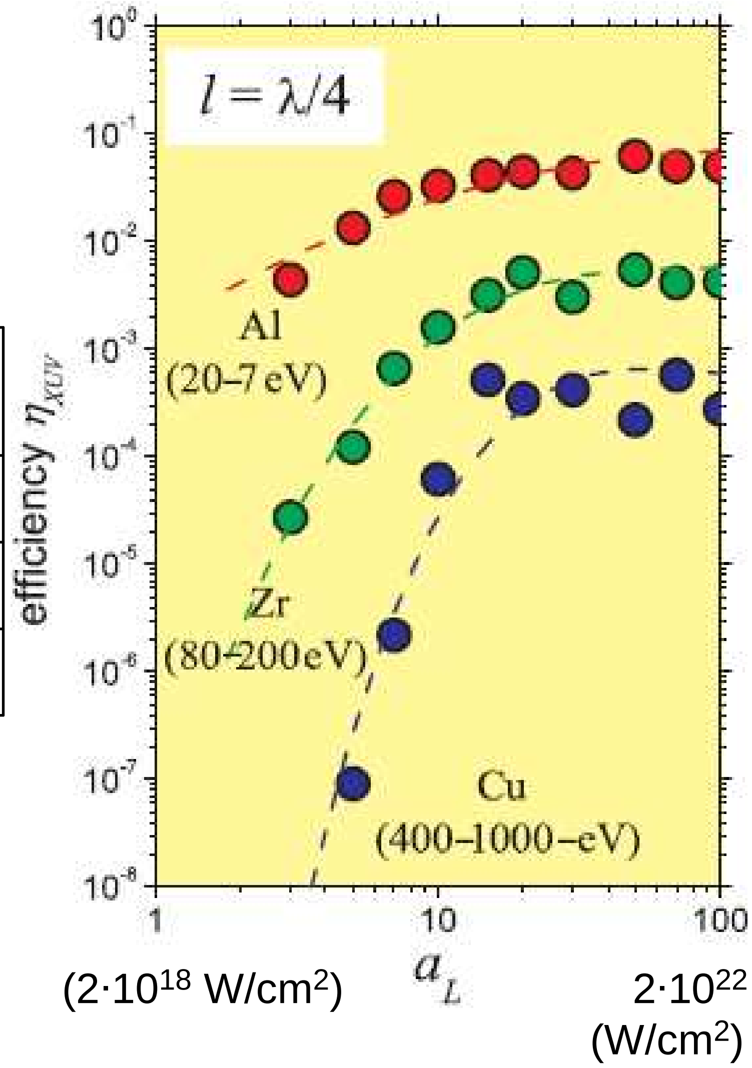
phase stabilized, λ_L = 0.8μm, τ_L ~ 5 fs, E=1J, 10μm spot.

XUV Source Specs

Spectral range	Number of photons	Pulse duration
20-70 eV	~10^{16}	~80 as
80-200 eV	~$3*10^{14}$	~40 as
400-1000 eV	~$5*10^{12}$	~5 as

G. Tsakiris *et al.* New J. Phys. **8**, 19 (2006)

ELI front end (1PW) or PFS is expected to do even better !!

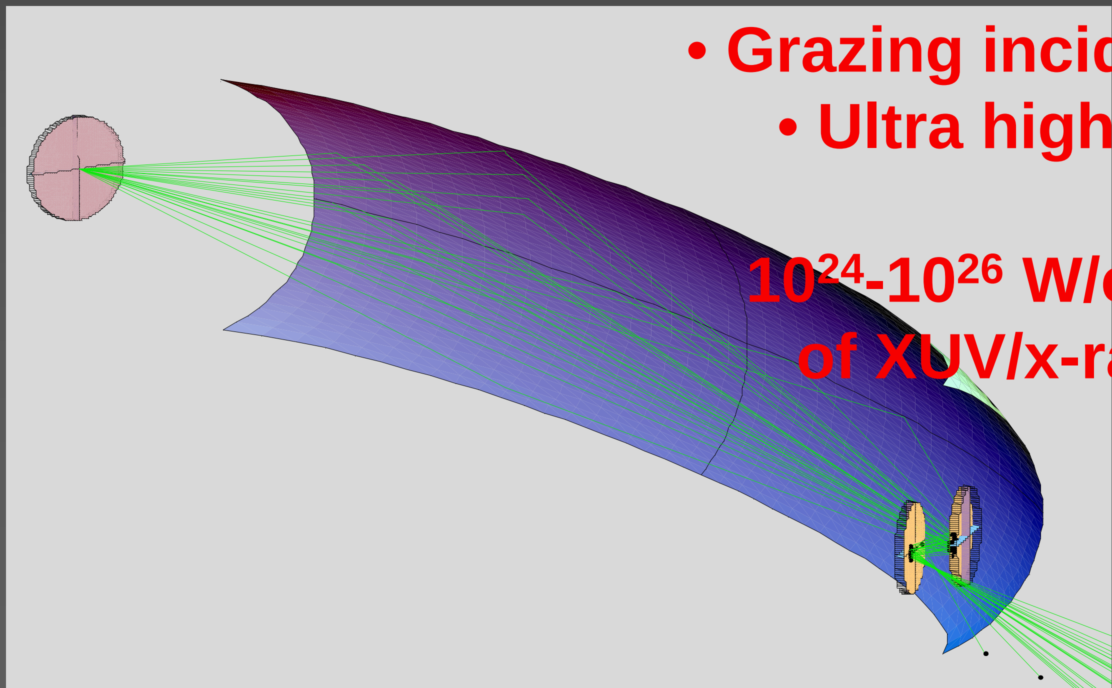


The Extreme Light Infrastructure European Project

eli

@ ELI front end
(5 J, 5 fs , 1 kHz)

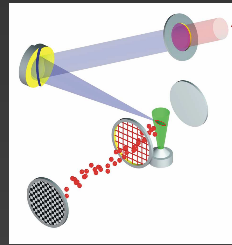
The Attosecond Light Source (ALS) @ ELI will be a PW XUV/x-ray source !



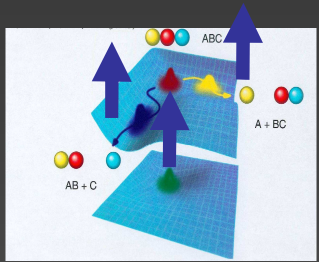
- **Grazing incidence geometries**
- **Ultra high quality optics**

10^{24}-10^{26} W/cm^2, 5 - 80 asec of XUV/x-rays @ target!!

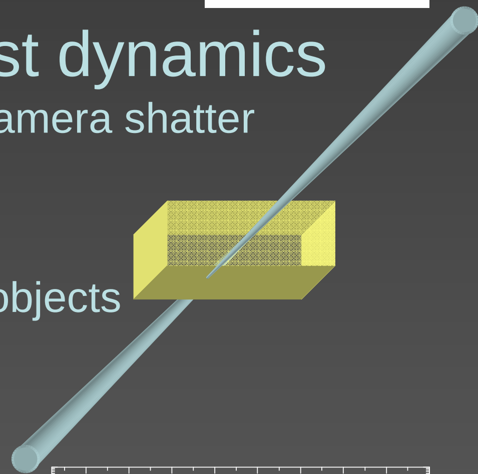
High XUV/x-ray intensity applications & ELI
NL & high field science @ highest temporal resolution



- Advanced ultra-short pulse metrology
  (NL AC based approaches for sub-fs pulses)

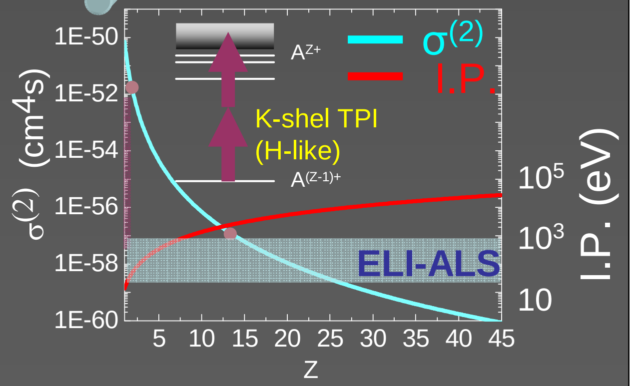


- Pump-probe studies of ultra-fast dynamics
  (XUV opening and closing of the attosecond camera shatter



- Spatially resolved applications
  (nm spatial selectivity, 4D diagnostics), time resolved imaging of nano-objects

- Inner shell non-linear interactions
  (Inner shell MPP- MP beyond the electric dipole approximation - relativistic intensity regime-Non-perturbative Inner Shell effects - Ultra-fast dynamics of hollow atoms - Ground state stabilization?)



- High XUV/x-ray field science
  (NLQED, Fundamental physics, Exotic physics, Nuclear Physics Transmutation induced by laser)

TABLE TOP!