DE LA RECHERCHE À L'INDUSTRIE

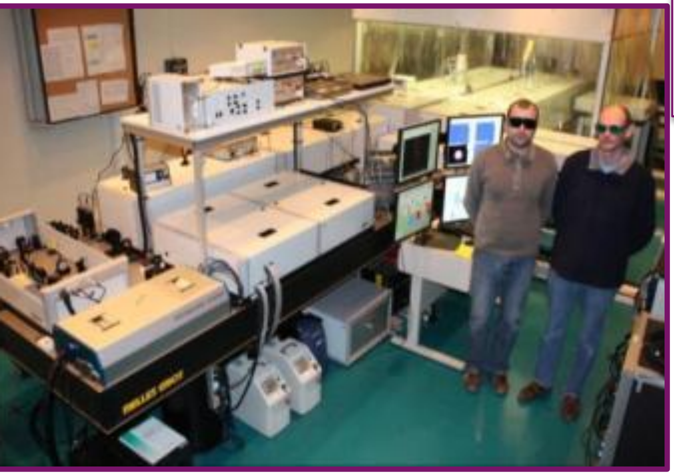
cea

MEDEA KICK OFF MEETING – BERLIN

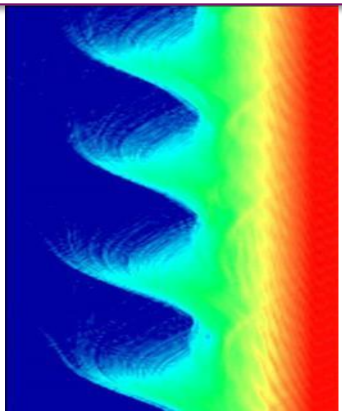
CEA-Saclay

Pascal Salières

Physics with intense lasers at CEA-Saclay/LIDyL



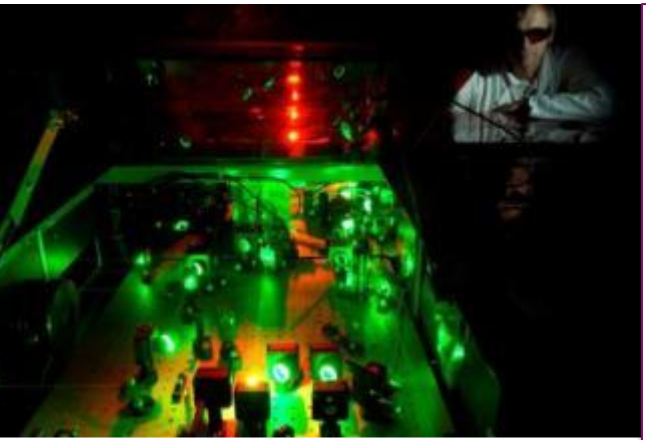
UHI
100 TW, 2 J, 20 fs, 10 Hz



Relativistic optics
=> HHG on solid targets

Electron acceleration

Ion acceleration



ATTO

PLFA: 13 mJ, 40 fs, 1 kHz → **HHS, PI**

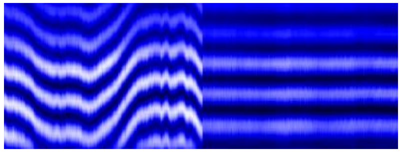
SOFOCKLE: < 1 mJ, 40 fs, 3 kHz (postcomp) → **LIED**

LUCA: 60 mJ, 40 fs, 20 Hz → **Coherent diffraction Imaging**
↘ **HHS, PI**

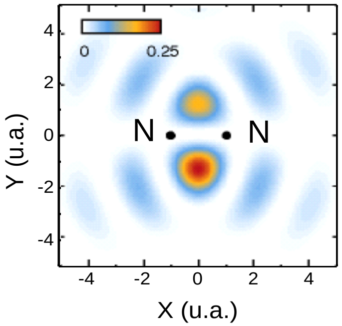
ATTOLAB : CROSS-DISCIPLINARY PLATFORM FOR ULTRAFAST DYNAMICS

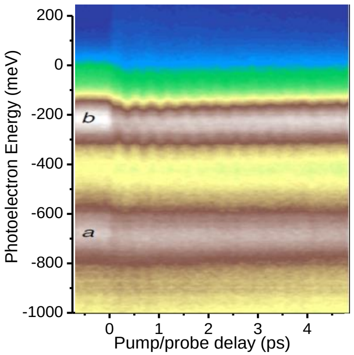
Electronic and Nuclear Dynamics at Ultimate Time & Space Scales

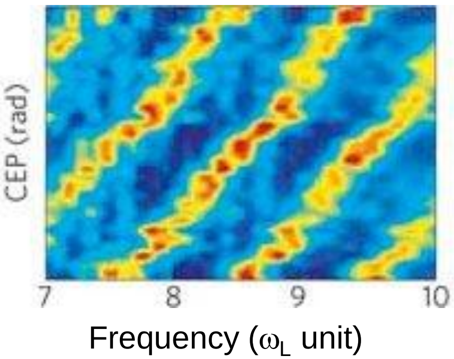
- **Controlled Ultra-short Light Pulses**



- **Imaging Electronic & Nuclear Motion**
  - ✓ **in Molecules**
  - ✓ **In Solids**
  - ✓ **In Plasmas**







EQUIPEX ATTOLAB (2013-2019) - ANR / INVESTMENTS FOR THE FUTURE

CROSS-DISCIPLINARY PLATFORM FOR ULTRAFAST DYNAMICS

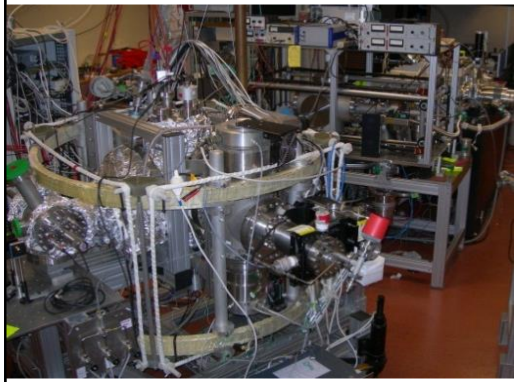
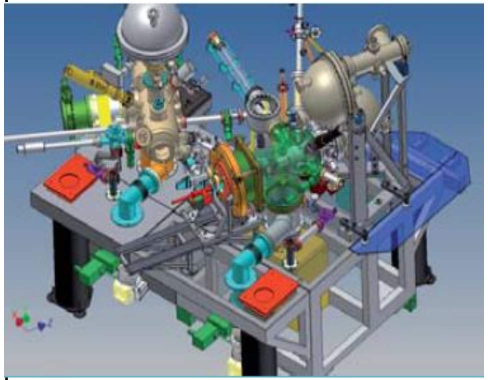
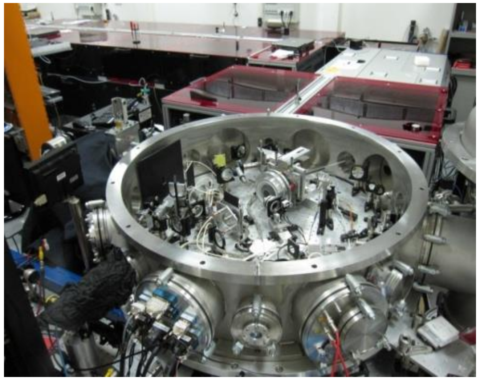
Ultrafast dynamics in (future) Paris-Saclay University : ~15 labs, ~ 80 researchers (perm)

9 partner labs ~ 50 chercheurs (perm)	**8 partner Institutions**
Laboratory Interactions, Dynamics, lasers (LIDyL, B. Carré coordinator)	CEA
Institut des Sciences Moléculaires d'Orsay	CNRS, Université Paris-Sud
Laboratoire Charles Fabry	Institut d'Optique GS, CNRS
Laboratoire Francis Perrin	CEA, CNRS
Laboratoire d'Optique Appliquée	CNRS, ENSTA, Ecole Polytechnique
Laboratoire de Physique des Solides	CNRS, Université Paris-Sud
Irradiated Solids Laboratory	CEA, CNRS, Ecole Polytechnique
Laboratory of Condensed Matter Physics	CEA, Université Cergy-Pontoise
SOLEIL Synchrotron	SOLEIL

- Operate 3 femto/atto beamlines + experimental endstations for studies in gas phase, condensed phase, plasma
- Give access to local, national and European users
- Promote « ultrafast technology » in collaboration with SMEs

THREE FEMTO-ATTO BEAMLINES + ENDSTATIONS

Equipment (10/2012 – 09/2015) : 3 M€ - Operation (04/2014-12/2019) : 2 M€

Gas Phase LIDyL, ISMO, LFP, SOLEIL	Solid-state SPEC, LSI, LPS	Plasmas LOA, LIDyL	XUV Optics LCF
CEA / l'Orme-les-merisiers (1,2,3,4)		LOA (5)	Institut d'Optique (6)
FAB1 : laser IR (15W, ~16fs, CEP, 1kHz) + XUV-as high energy OPA (1.2-2 µm) FAB10: laser IR (20W, ~16fs, CEP, 10kHz) + XUV-as		FABP (5mJ, 5fs, CEP, 1kHz) laser IR HE + XUV-as	Atto-CeMOX Platform
Experimental Endstations			
e^-/ion spectrometers (VMIS, MBES, COLTRIMS)	e^- spectrometers (PEEM, TOF-Spin, ARTOF)	Plasma target	Clean room
			

THREE NEARBY SITES

Condensed phase

Gas phase

XUV Optics

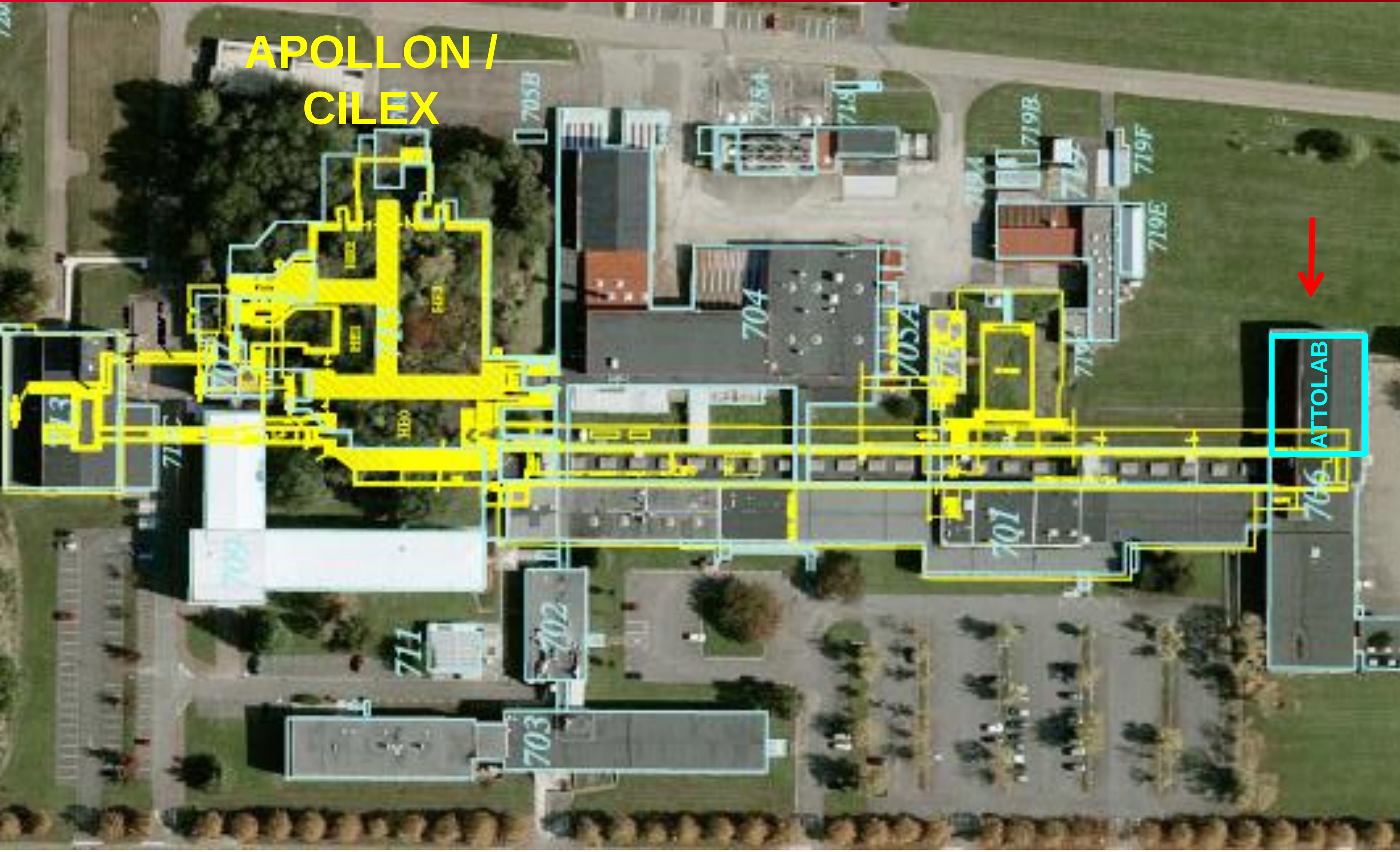
Plasmas

http://attolab.fr/

- CEA/l'Orme-les-merisiers (2015) : APOLLON – CILEX – ATTOLAB

Laser Centre of Paris–Saclay University

ATTOLAB AT CEA-L'ORME-DES-MERISIERS



SOLEIL

WP1: ATTOSECOND XUV-IR SPECTROSCOPY

WP 1.1 Development of high-repetition rate lasers for electronic correlation and electron-nuclear coupling in small systems

⇒ In collaboration with Amplitude Technologies, development of a 10-kHz, 2-mJ, 16-fs, CEP-stable laser system (joint laboratory IMPULSE)

⇒ Attosecond XUV-IR photoionization spectroscopy

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COHERENT MULTIPHOTON MULTICOLOR IONIZATION (I)

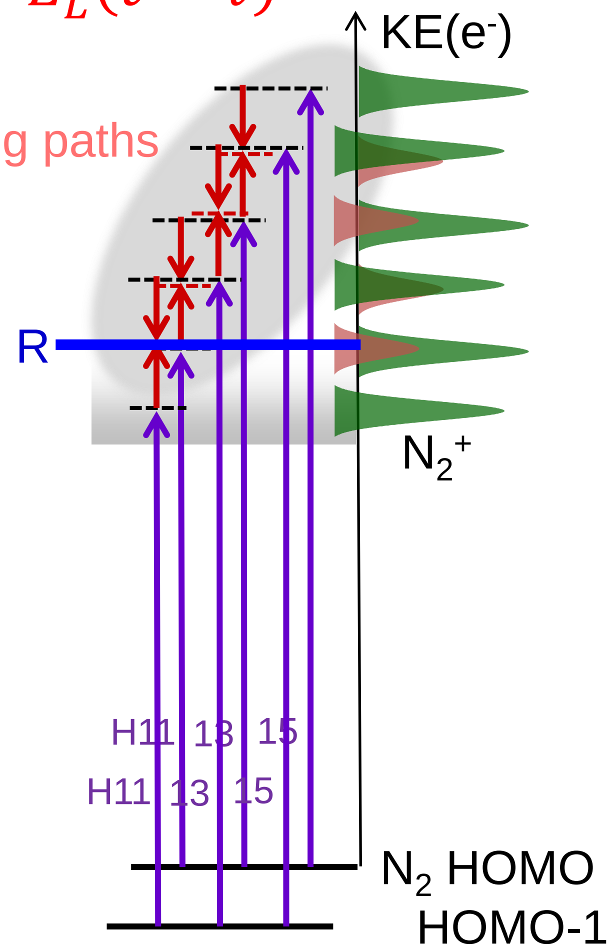
1) XUV + weak IR (~ 10^{11} W/cm^2)

$$E_{XUV}(t) \; + \; E_L(t-\tau)$$

Sideband intensity:

$$S_{q+1} \sim \cos(2\omega_L t + \varphi_q - \varphi_{q+2} + \Delta\varphi^{target})$$

Interfering paths



=> Access to the XUV group delay: $\dfrac{\partial \varphi^{XUV}}{\partial \omega}(\omega_{q+1})$

RABBIT technique

=> Access to target-specific PI delays: $\dfrac{\partial \varphi^{target}}{\partial \omega}(\omega_{q+1})$

- Wigner time delay difference between PI channels
- Time delay introduced by an intermediate resonance R

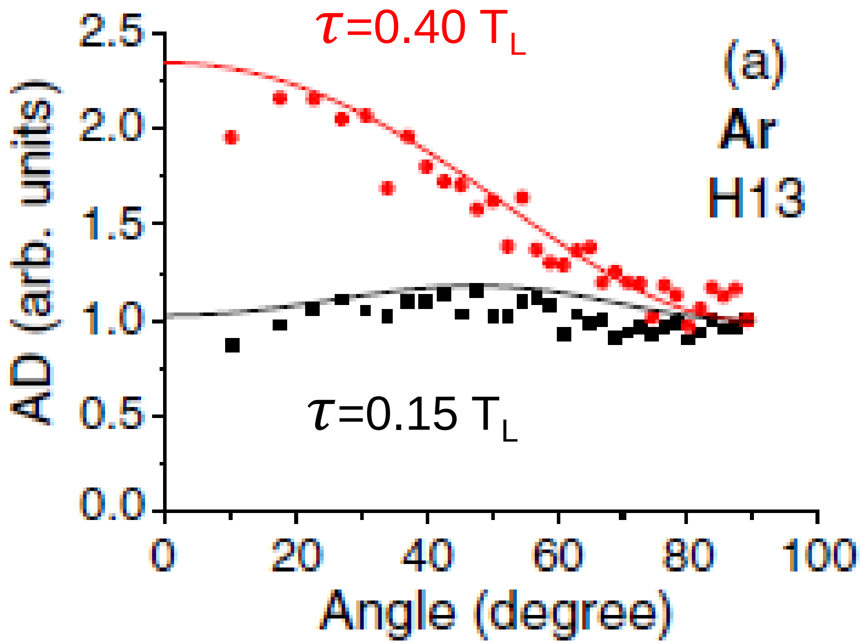
(Collab. CELIA, LCPMR)

S. Haessler et al. PRA (2009)

J. Caillat et al. PRL (2011)

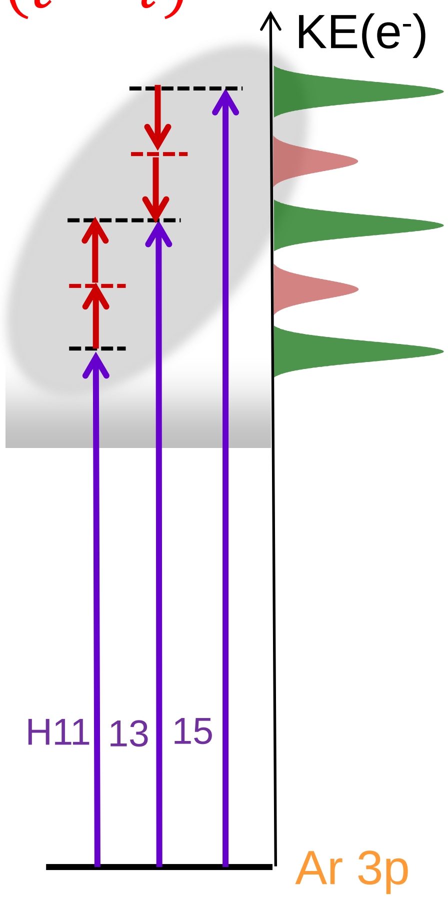
2) XUV + moderate IR (~ 10^{12} W/cm^2) $E_{XUV}(t) + E_L(t-\tau)$

=> Attosecond coherent control of PI angular distribution

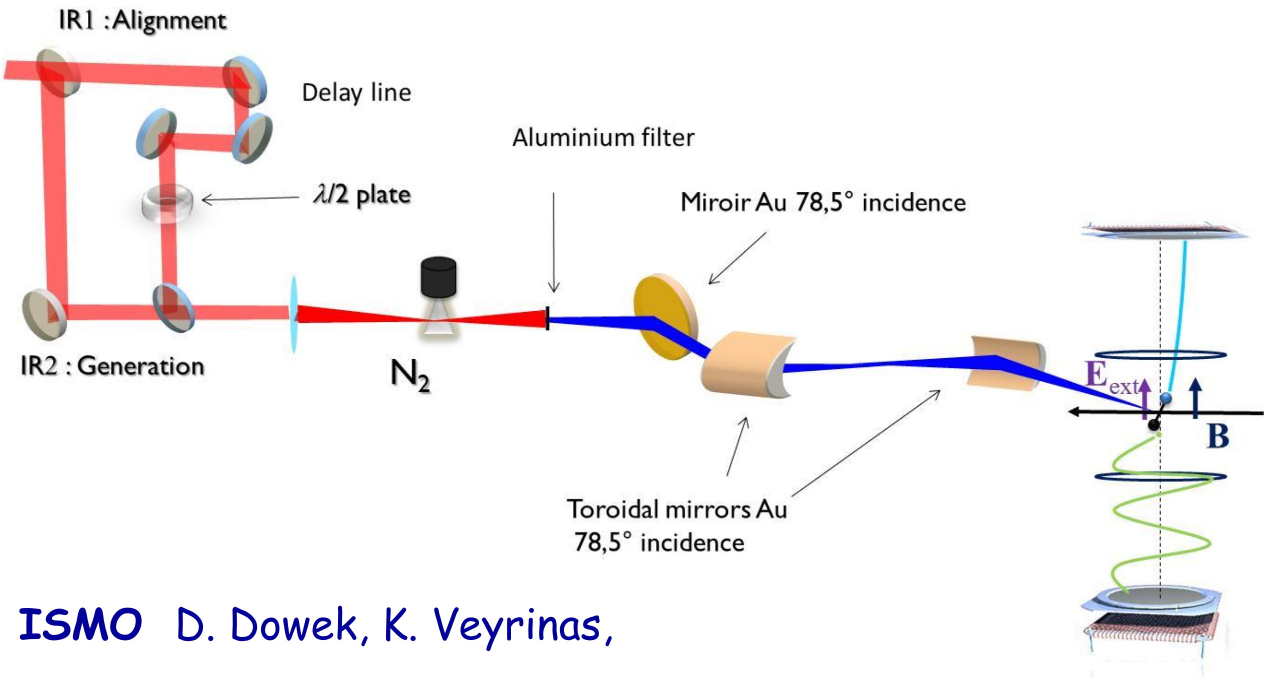


Y. Picard et al. PRA (2014)

(Collab. ISMO, LCPMR)

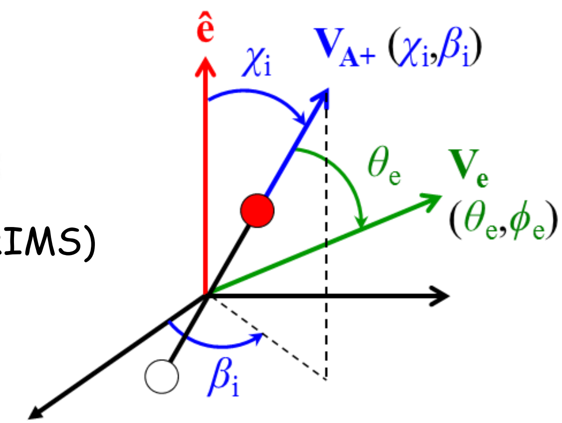


Full access to the polarization state of the harmonic radiation



CIEL (COLTRIMS)

$NO\ (X^2\Pi)$ + $HHG(N_2)$
$\rightarrow NO^+(c^3\Pi\ \mathbf{4\sigma^{-1}})$ + e
$\rightarrow N^+(^3P)+O(^3P)$ + e



ISMO D. Dowek, K. Veyrinas,

Dissociative photoionization of NO: gives access to the Stockes parameters of the XUV light

$\mathbf{I}\ (\chi, \beta, \theta_e, \phi_e\ , s_1,s_2,s_3)$

S_3: Circular dichroism in the Molecular Frame, CDAD

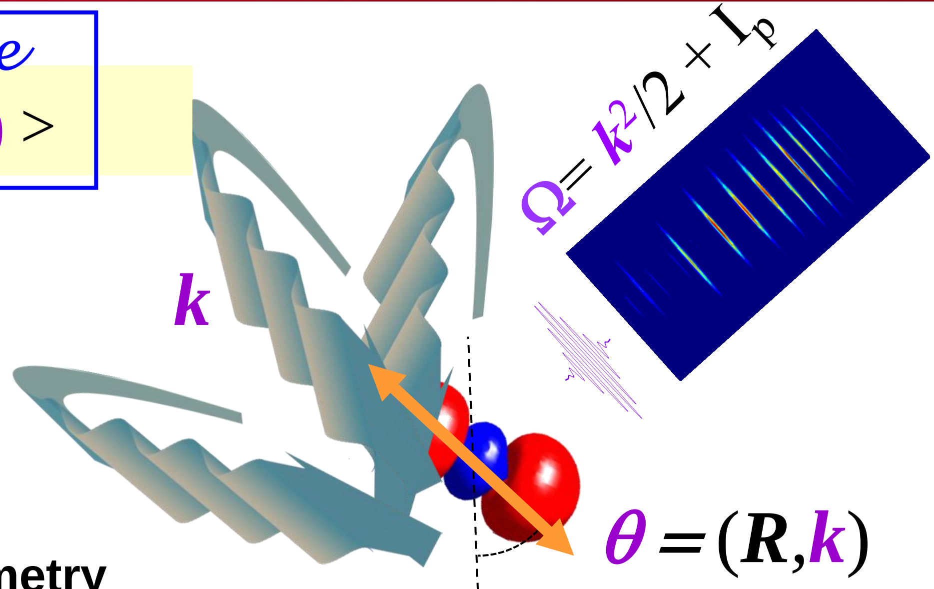
$$I_{lm\mu}^{M_iM_f} = \left\langle \psi^i_{M_i} \middle| d_\mu \middle| \phi^f_{M_f} \psi^{(-)}_{lm} \right\rangle$$

(s_1,s_2,s_3)

WP 3.1: HIGH HARMONIC SPECTROSCOPY OF ELECTRONIC STRUCTURE AND MULTI-ELECTRON DYNAMICS

Molecular dipole

$$\vec{E}_{XUV}(\Omega,\theta) \approx \langle \psi_{mol}(r,t) | \vec{r} | k(\Omega,\theta) \rangle$$



Development of advanced technologies to characterize:

- ***Phase*** (Ω) **RABBIT quantum interferometry**

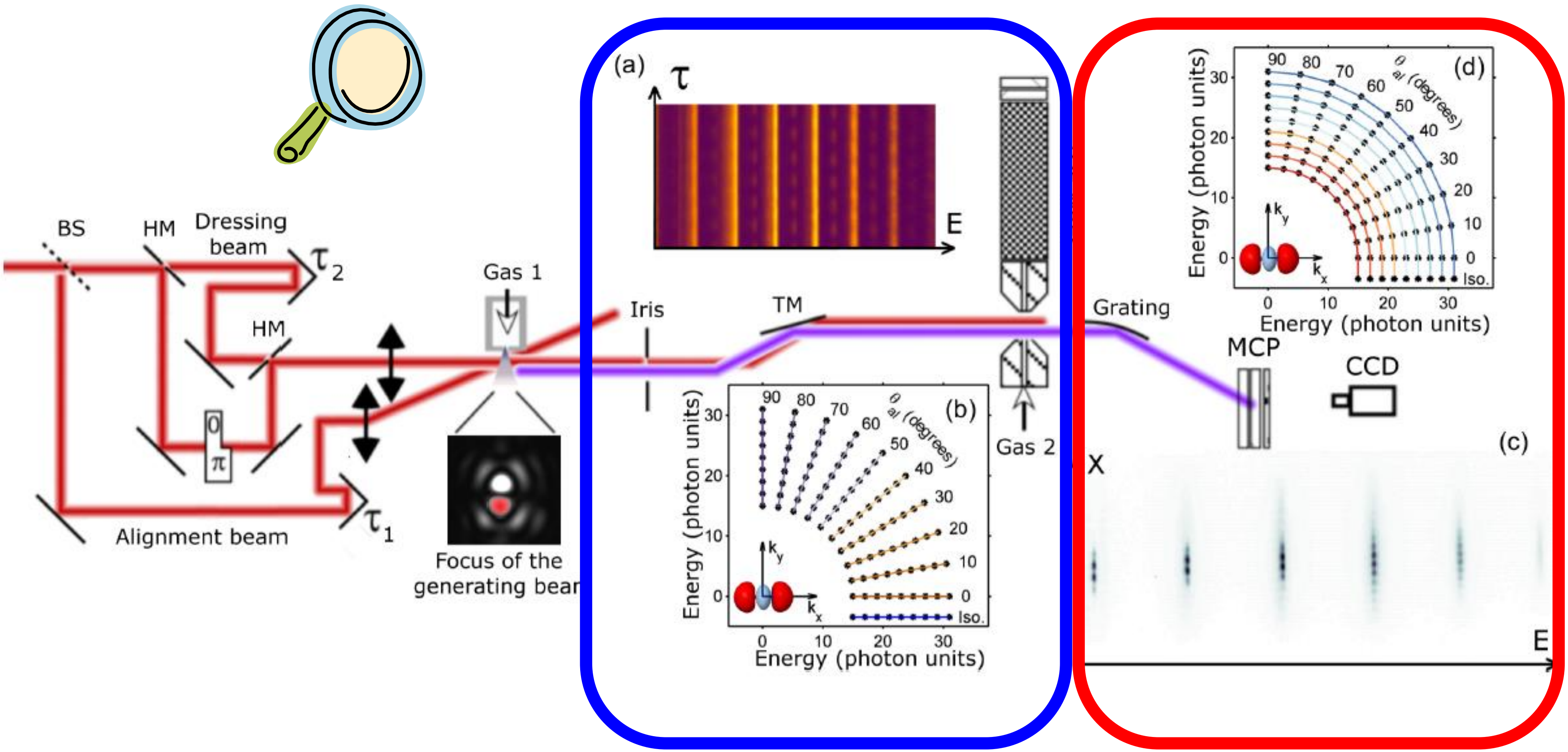
- ***Phase*** (θ) **2-souce optical interferometry**

- ***Polarization*** (Ω,θ) **optical polarimetry and photo-electron spectroscopy (CDAD)**

Combine these techniques in the SAME generation conditions

=> « full » dipole characterization

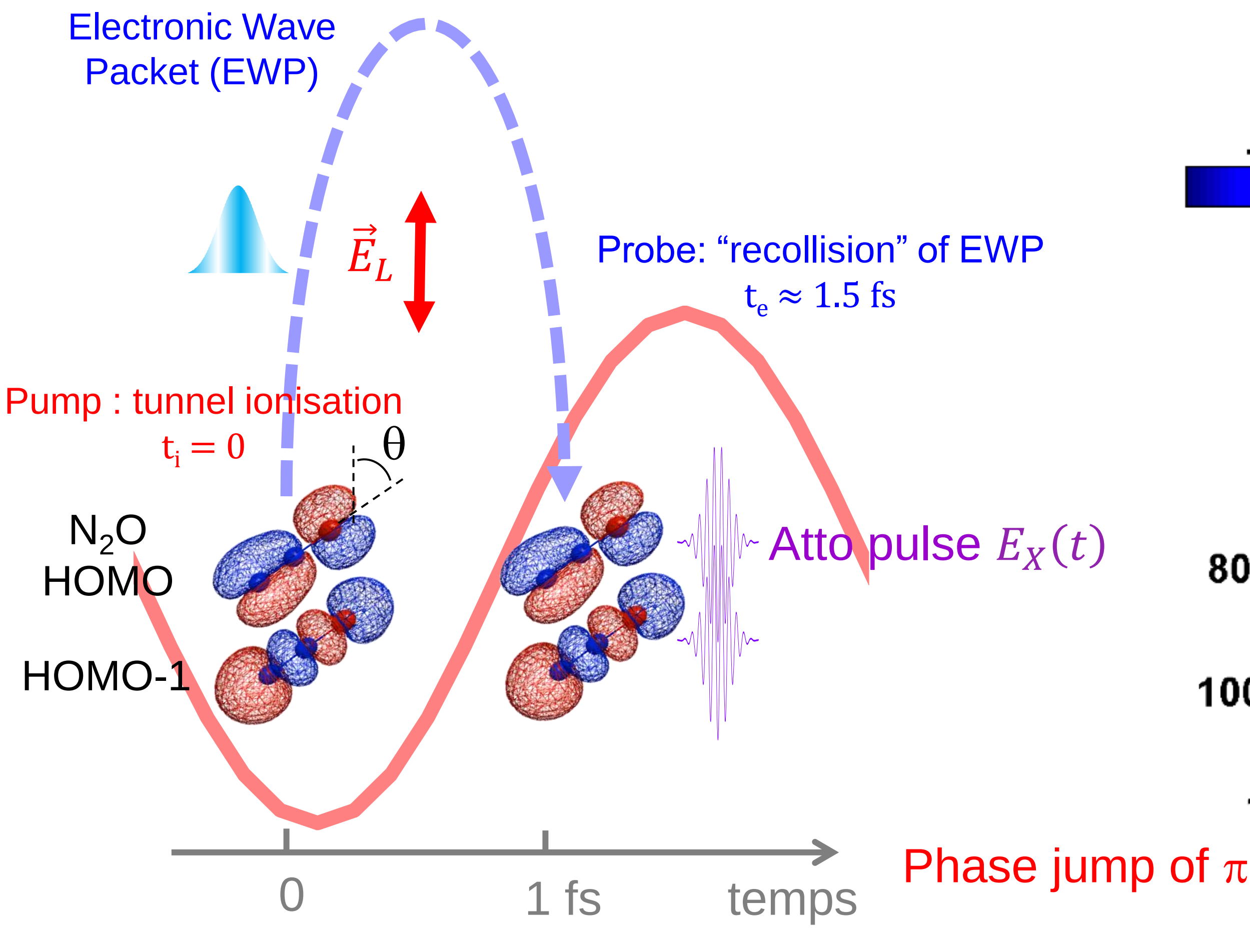
Experimental setup for measuring the 1st 2D-phase map



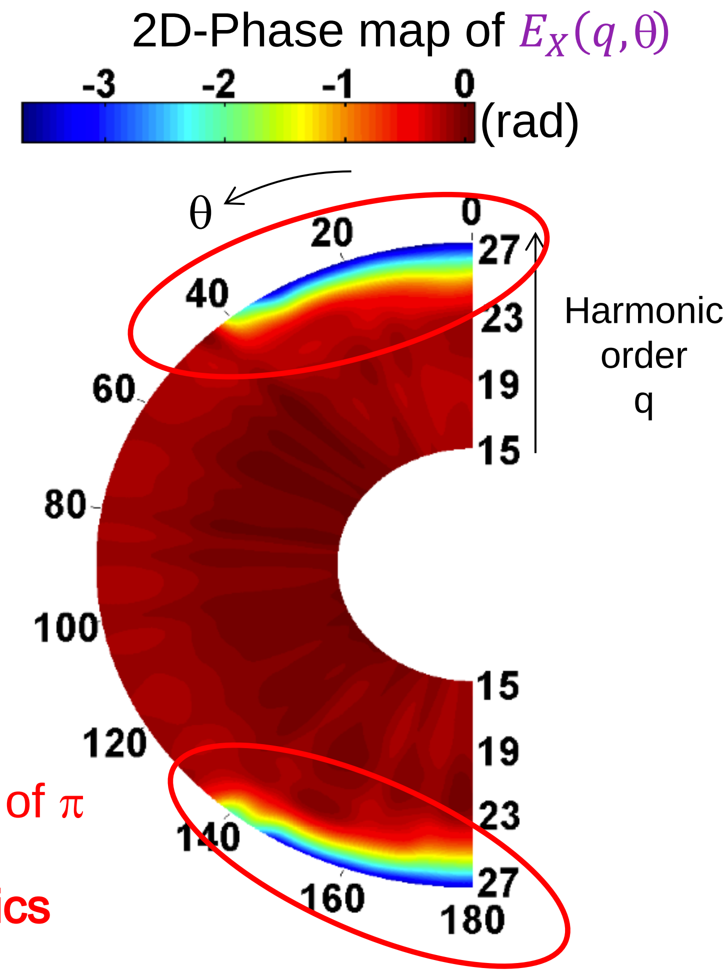
Unique combination

- Quantum interferometry => spectral phase
- Optical (2-source) interferometry => angular phase

Hole dynamics following multi-channel tunnel ionization



Molecule N_2O



=> Destructive interferences : signature of hole dynamics

Extension to mid-IR driving lasers: plateau extension, spectral resolution, tunability
Extension to larger molecules: hydrocarbons
Extension to the study of electronic resonances

$\lambda_L = 0{,}8\ \mu m$