FERMI based Multi- Wave Experiments

C. Masciovecchio
Elettra-Sincrotrone Trieste, Trieste I-34149

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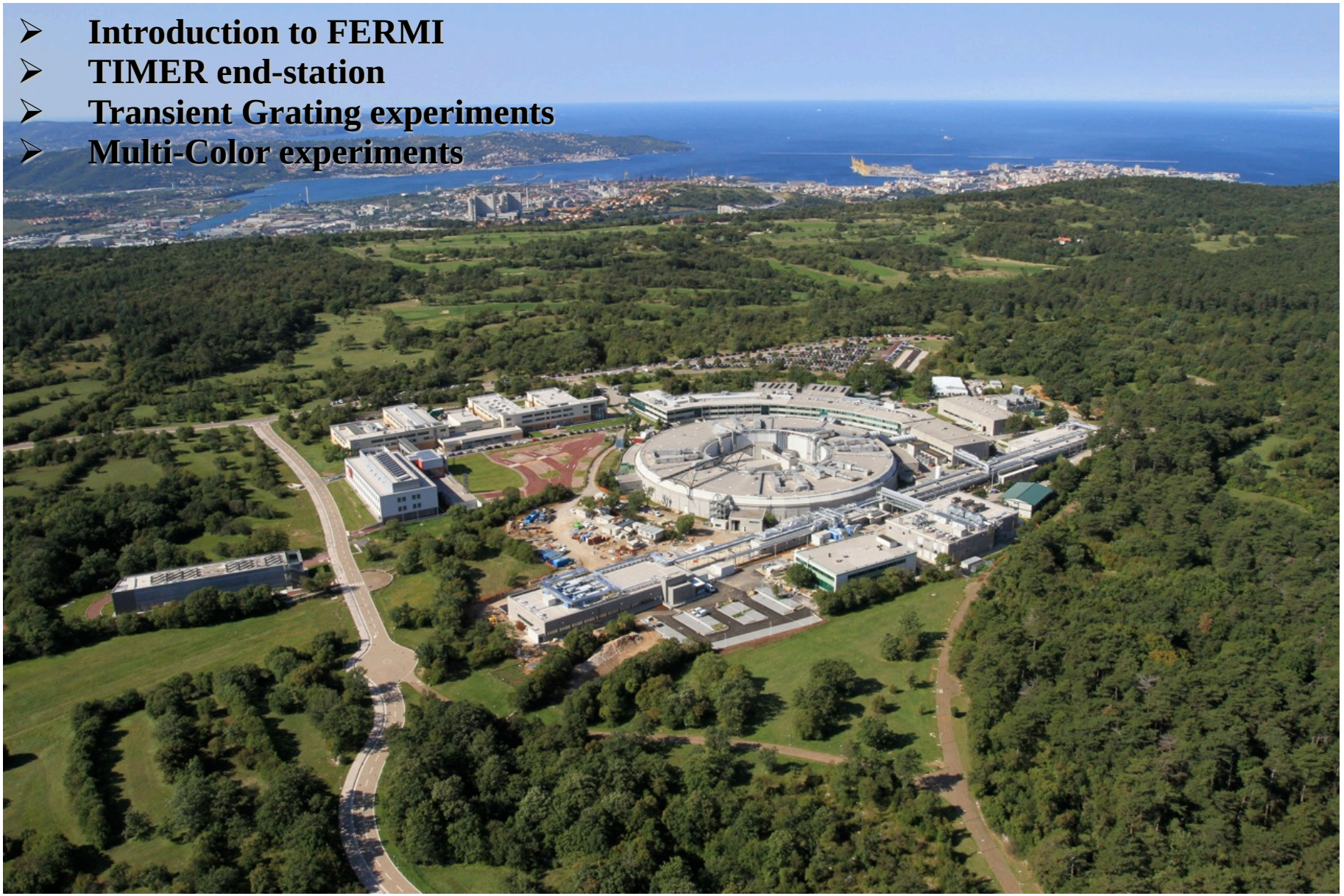
- **Introduction to FERMI**
- **TIMER end-station**
- **Transient Grating experiments**
- **Multi-Color experiments**



Why Free Electron Lasers ?

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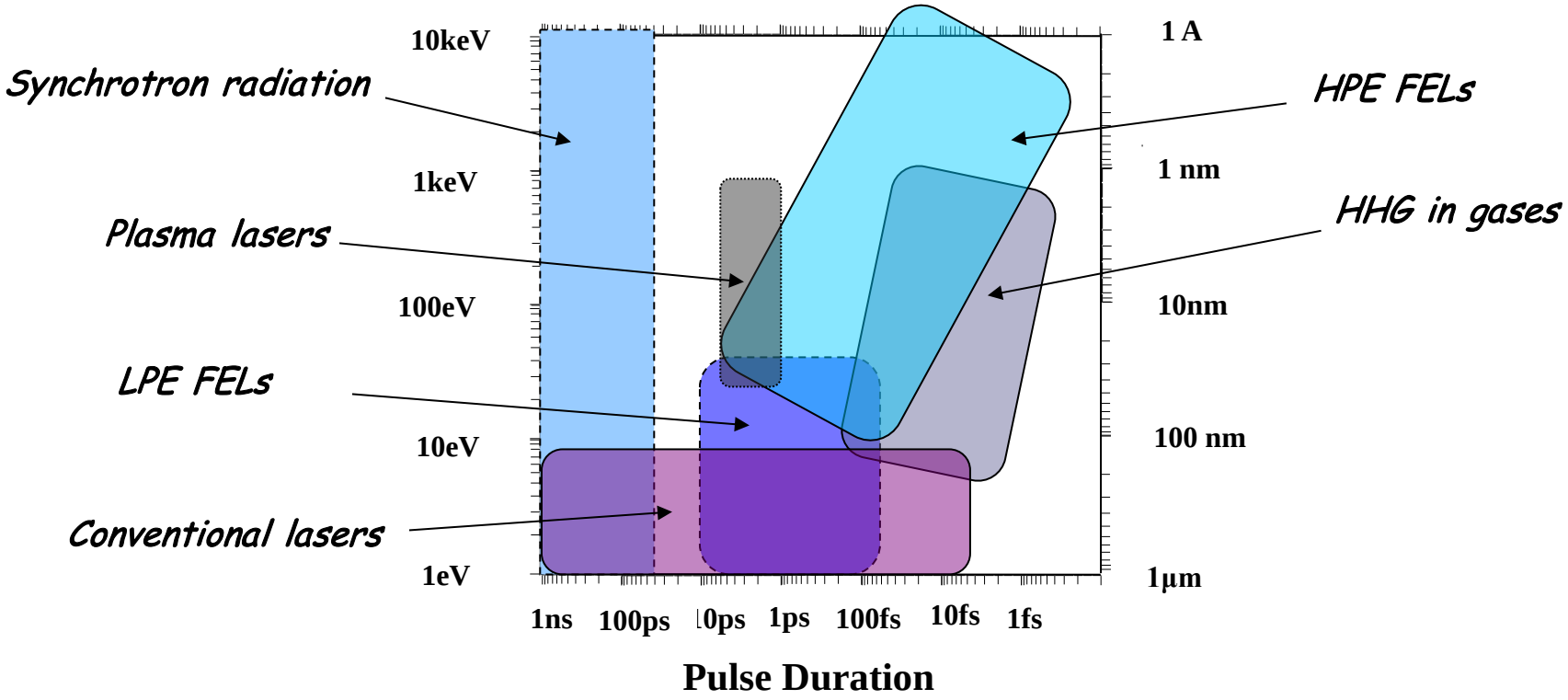

Imaging with high Spatial Resolution **(~ λ)**: fixed target imaging, particle injection imaging,..

Dynamics: four wave mixing (nanoscale), warm dense matter, extreme condition, ...

Resonant Experiments: XANES (tunability), XMCD (polarization), chemical mapping, ……

SASE vs Seeded

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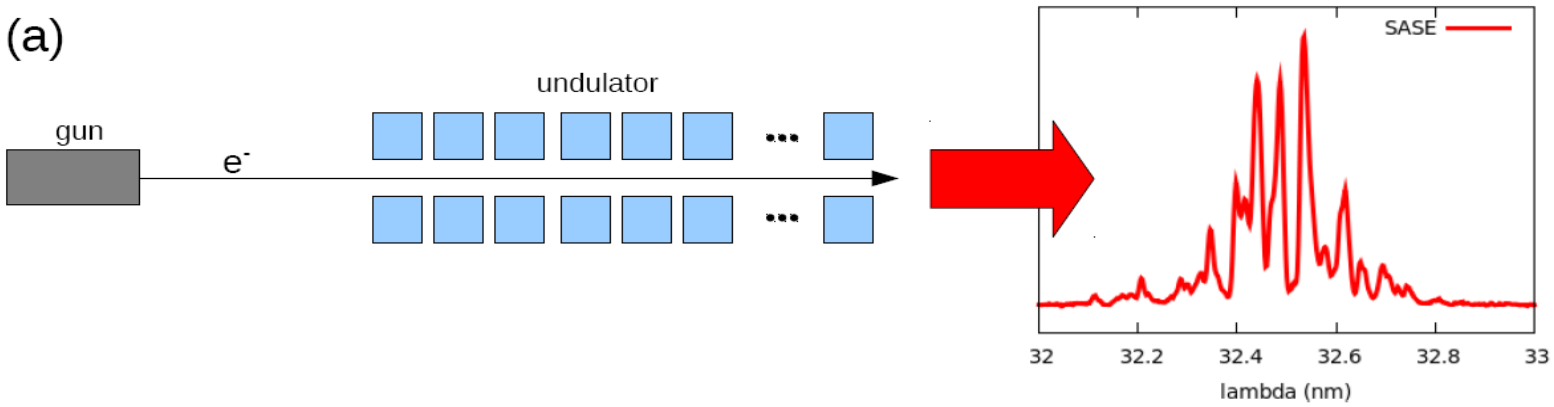

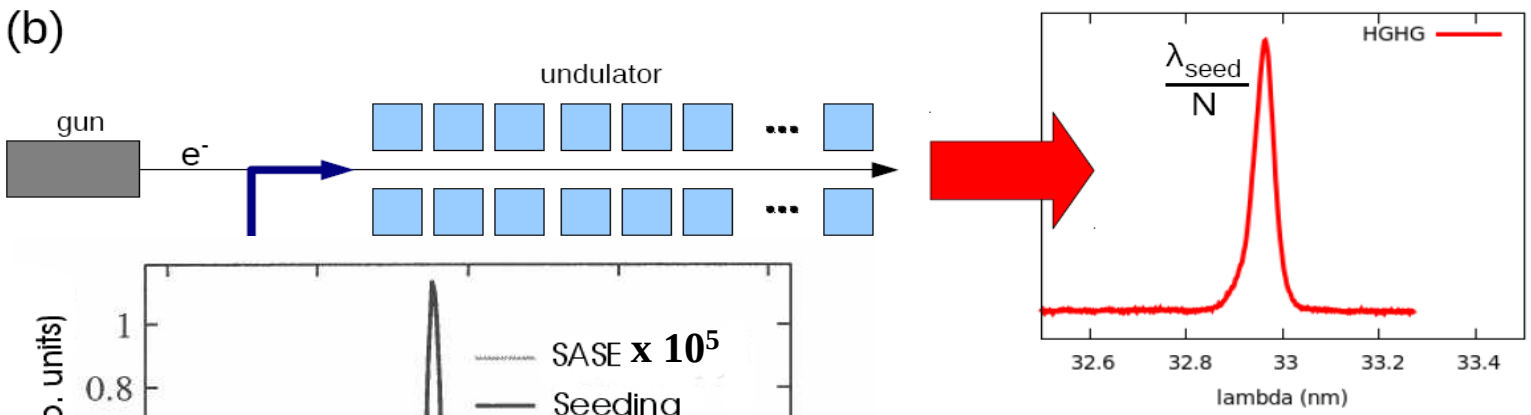

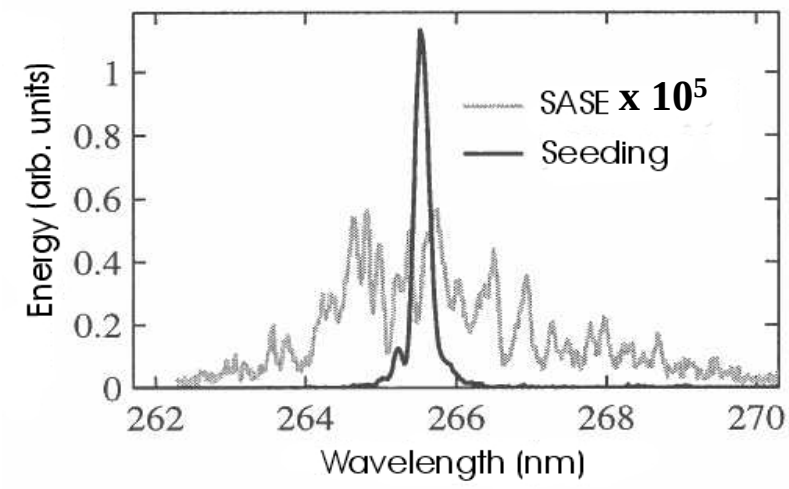

L. H. Yu et al., PRL (2003)

nature photonics
ARTICLES
PUBLISHED ONLINE: 23 SEPTEMBER 2012 | DOI: 10.1038/NPHOTON.2012.233

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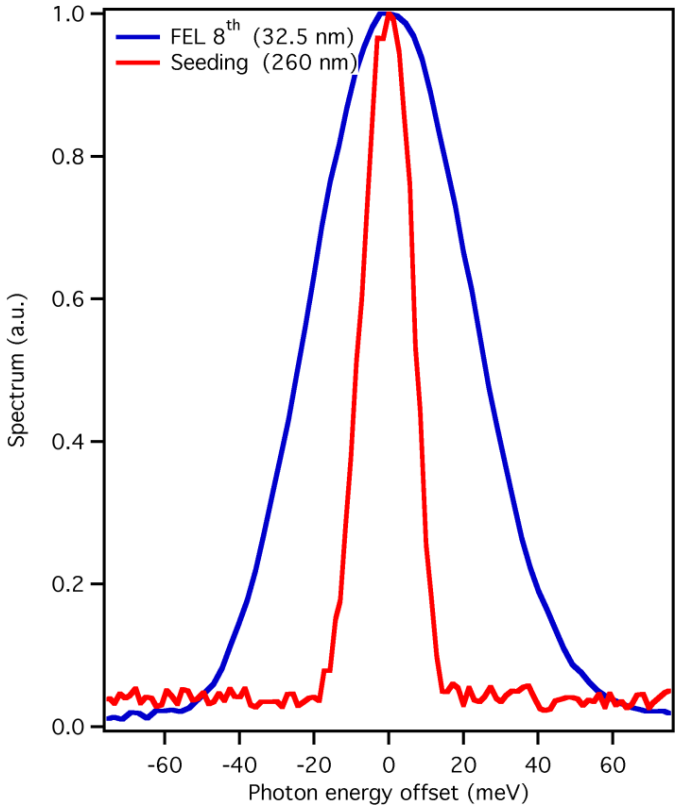
Highly coherent and stable pulses from the FERMI seeded free-electron laser in the extreme ultraviolet

E. Allaria et al., Nat. Phot. (2012)



$\Delta t < 100$ fs

Flux ~ 10^{13} ph/pulse

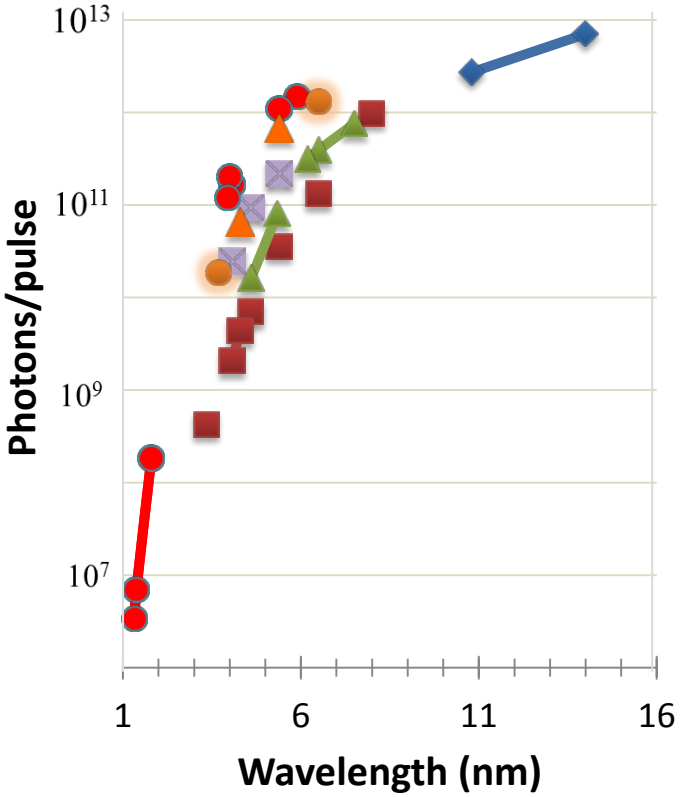
λ ~ (**1**) 10 - 100 nm

Total Control on

Pulse Energy

Time Shape

Polarization



The Experimental Hall

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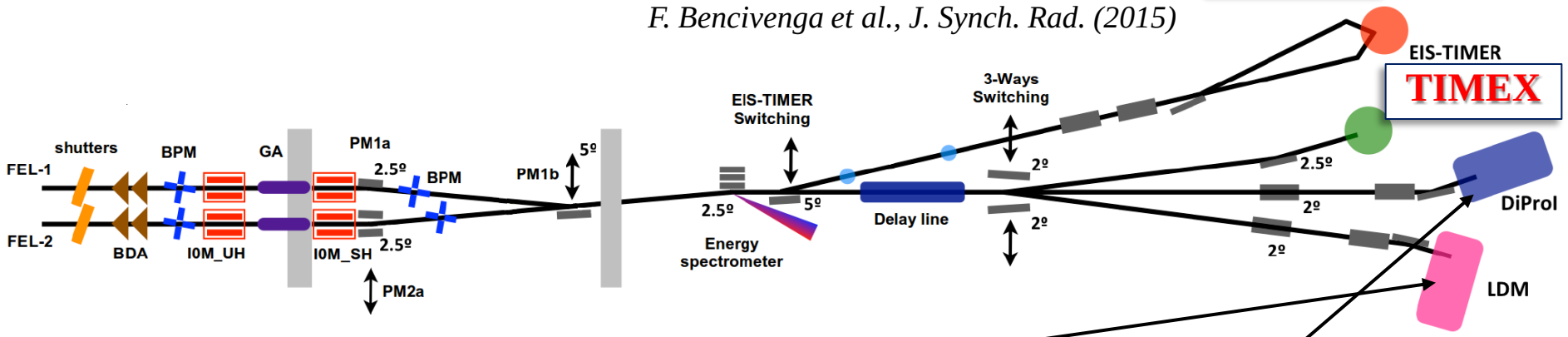
EIS (Elastic & Inelastic Scattering)

C. Masciovecchio et al., J. Synch. Rad. (2015)

Commissioning ← **TIMER**

F. Bencivenga et al., J. Synch. Rad. (2015)



LDM (Low Density Matter)

C. Svetina et al., J. Synch. Rad. (2015)

DIPROI (DIffraction & PROjection Imaging)

F. Capotondi et al., J. Synch. Rad. (2015)

MagneDYN (Magnetic Dynamics)

TeraFERMI (THz beramline)

The Experimental Hall

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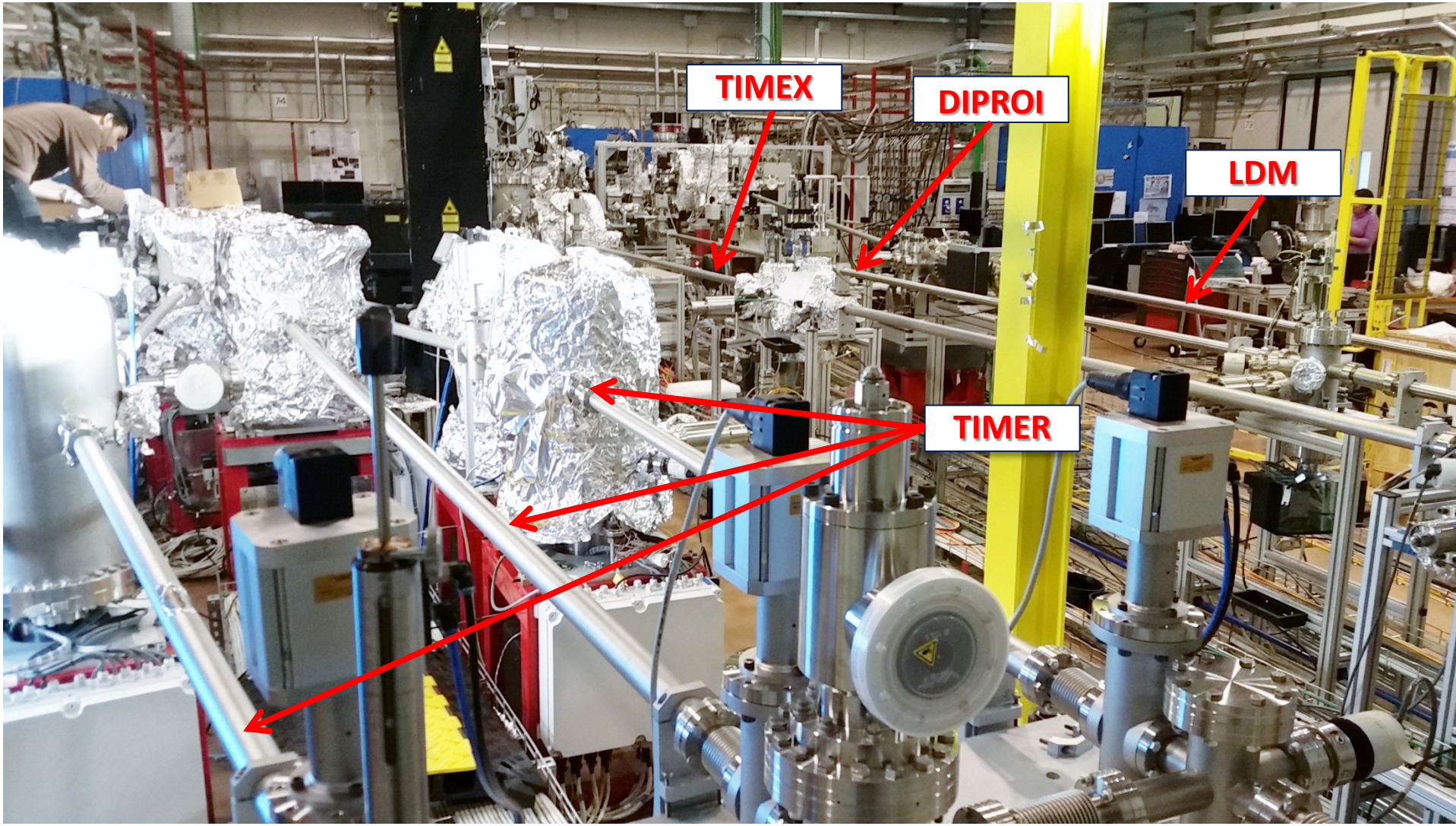

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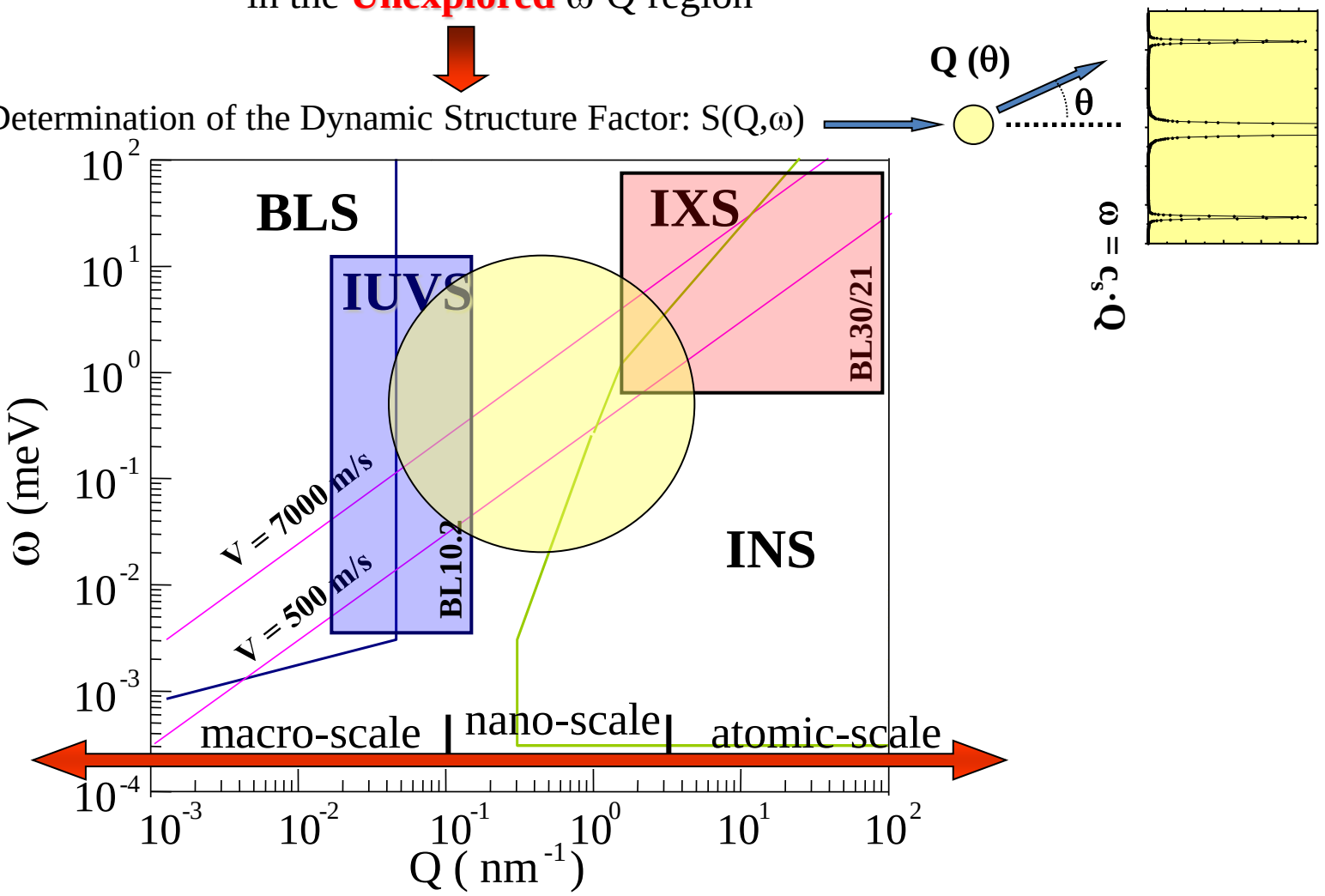
TIMER

TIME-Resolved spectroscopy of mesoscopic dynamics in condensed matter

Challenge: Study Collective Excitations in **Disordered Systems** in the **Unexplored** ω-Q region

Determination of the Dynamic Structure Factor: S(Q,ω)



Why Disordered Systems ?

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Unsolved problems in physics

Condensed matter physics

Amorphous solids

What is the nature of the transition between a fluid or regular solid and a glassy phase? What are the physical processes giving rise to the general properties of glasses?

High-temperature superconductors

What is the responsible mechanism that causes certain materials to exhibit superconductivity at temperatures much higher than around 50 Kelvin?

Sonoluminescence

What causes the emission of short bursts of light from imploding bubbles in a liquid when excited by sound?

Turbulence

Is it possible to make a theoretical model to describe the statistics of a turbulent flow (in particular, its internal structures)? Also, under what conditions do smooth solution to the Navier-Stokes equations exist?

Glass is a **very general state** of condensed matter → a large variety of systems can be transformed from liquid to glass

The liquid-glass transition cannot be described in the framework of classical phase transitions since T_g depends on the **quenching rate** → one cannot define an **order parameter** showing a critical behaviour at T_g

Why at the nanoscale ?

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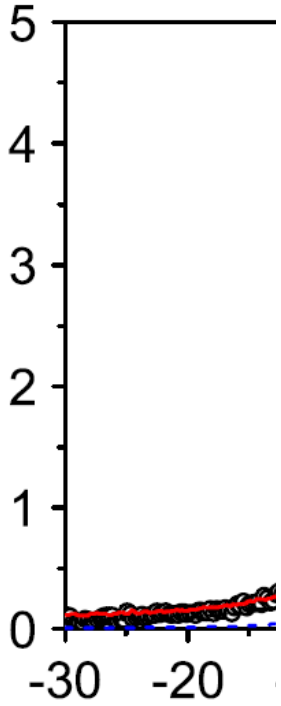
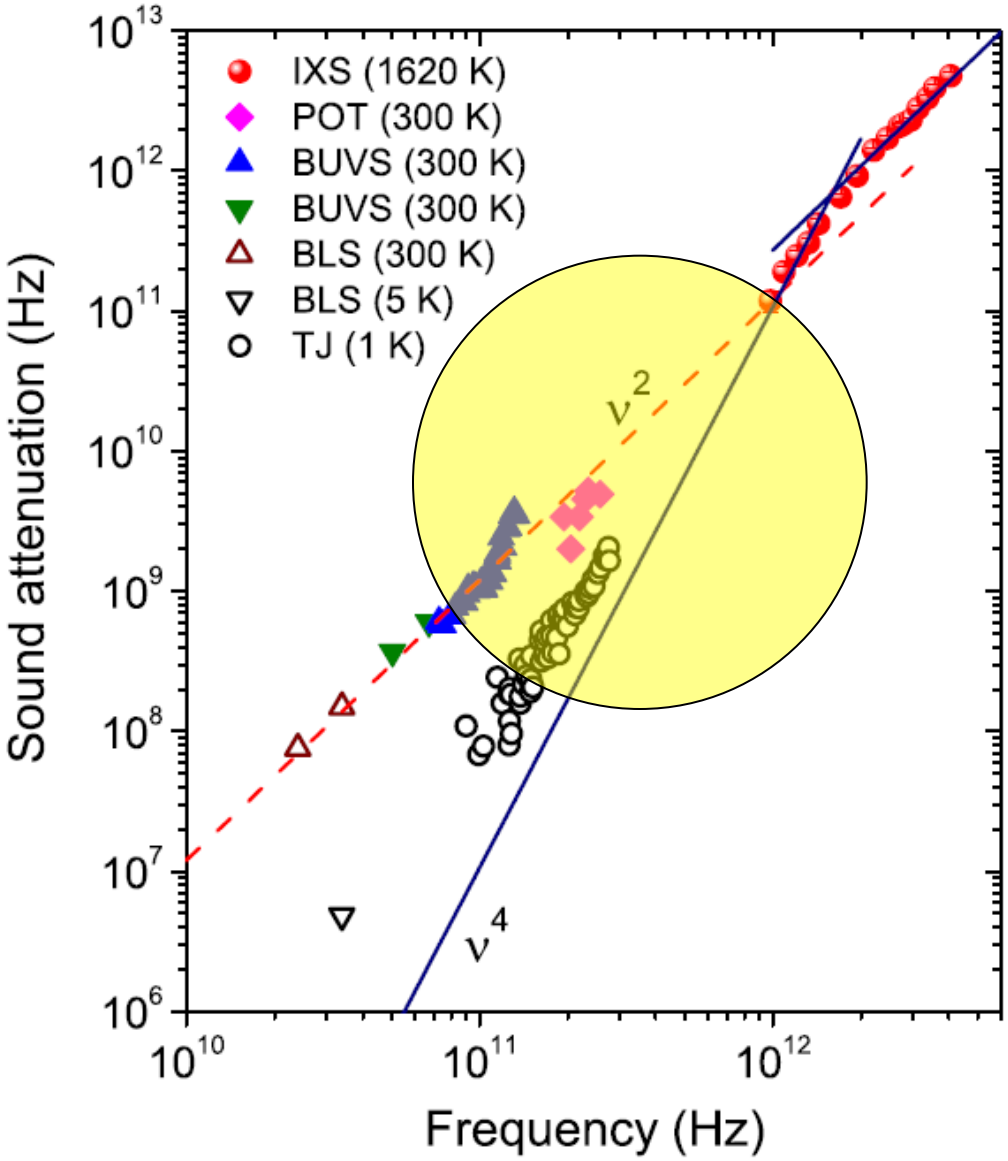
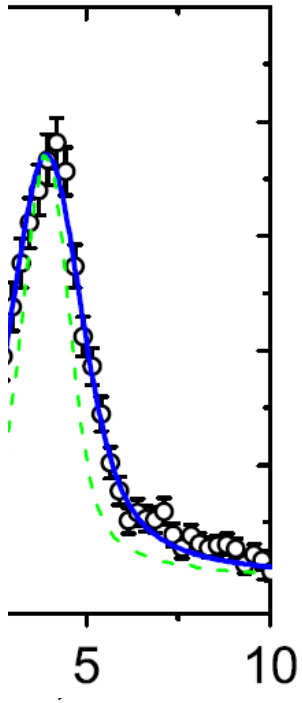
The nature of

ear (V-SiO_2)

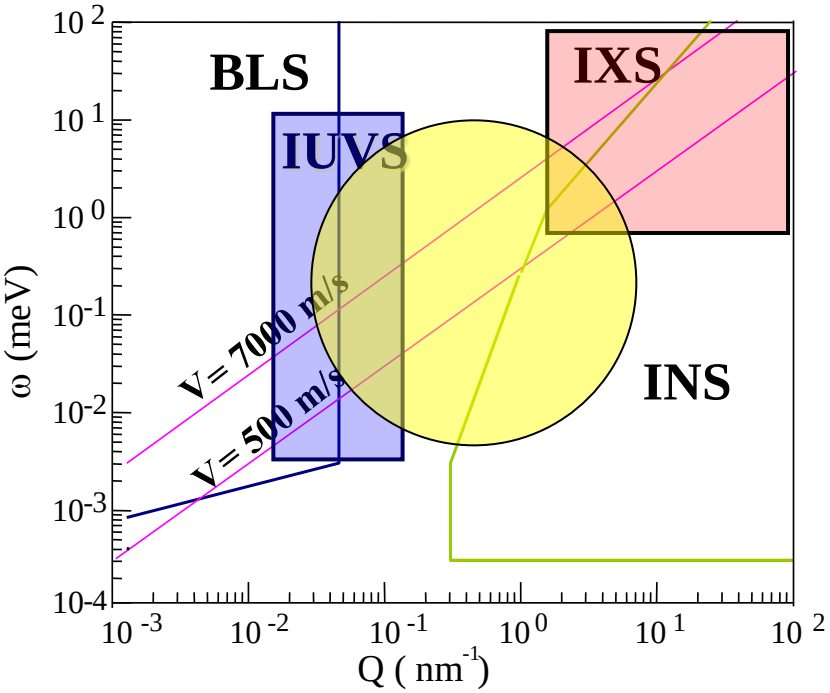




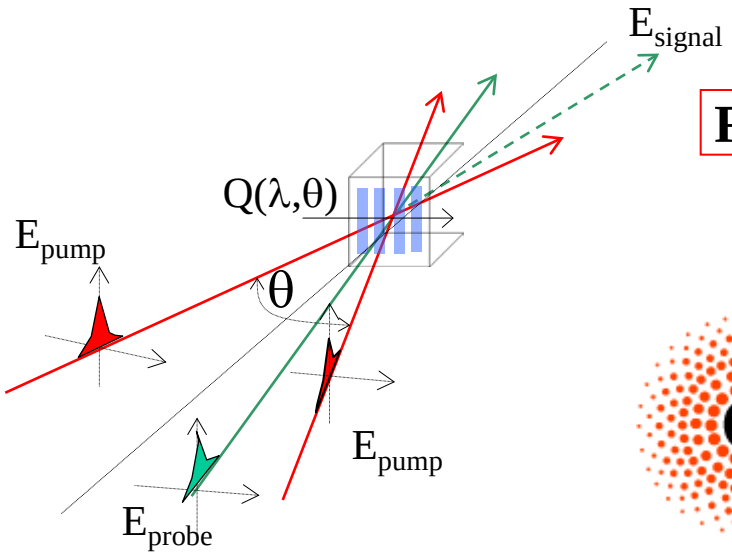


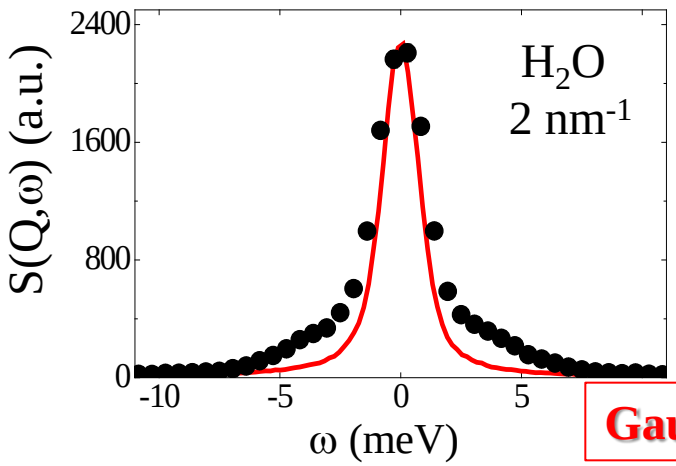
Funda

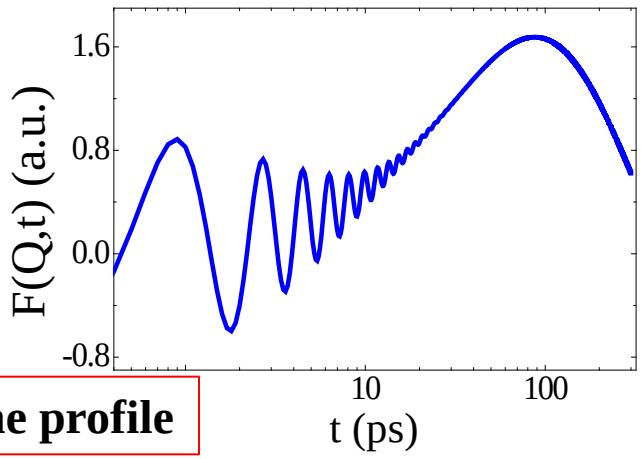
TIMER



Solution: Free Electron Laser based
Transient Grating Spectroscopy







Gaussian-like time profile

Typical Infrared/Visible Set-Up

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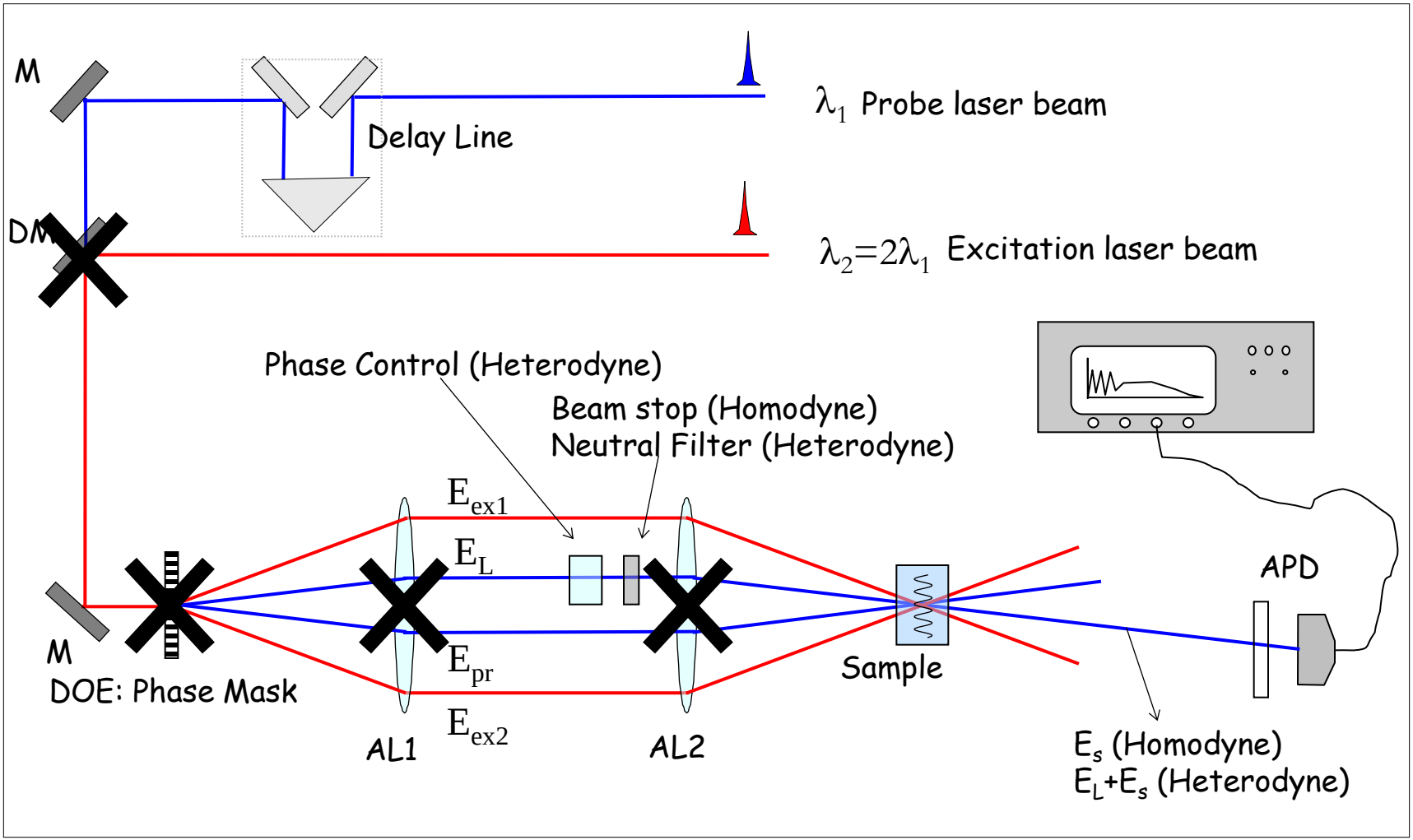

Challenge: Extend and modify the set-up for UV Transient Grating Experiments

TIMER Layout

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3rd harmonic (probe)

2θ

θ_B

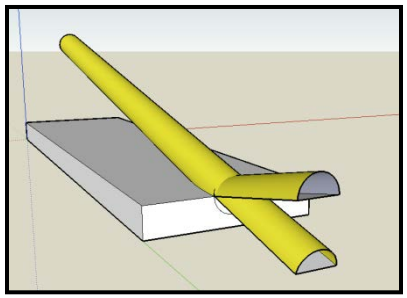
Delay line: 4 ML mirrors (abs 1st, reflect 3rd harm), time delays up to ~ 3 ns

FEL pulse:1st and 3rd harmonic ($\lambda_3 = \lambda_1/3$)

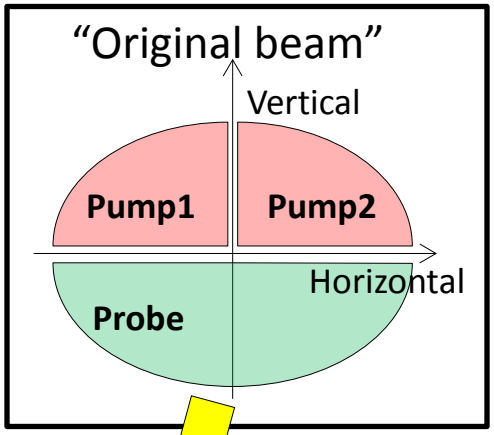
1st harmonic (pump)

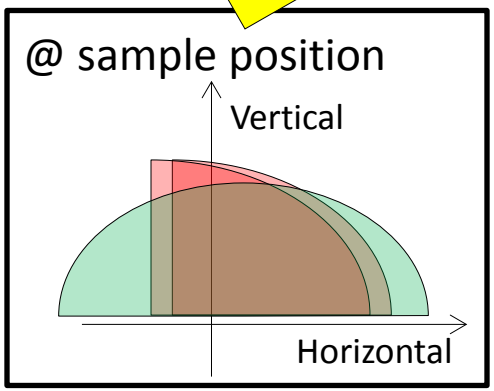
Focusing mirror

Plane Mirrors "beam splitters"



Beam waist





Feasibility @ DIPROI

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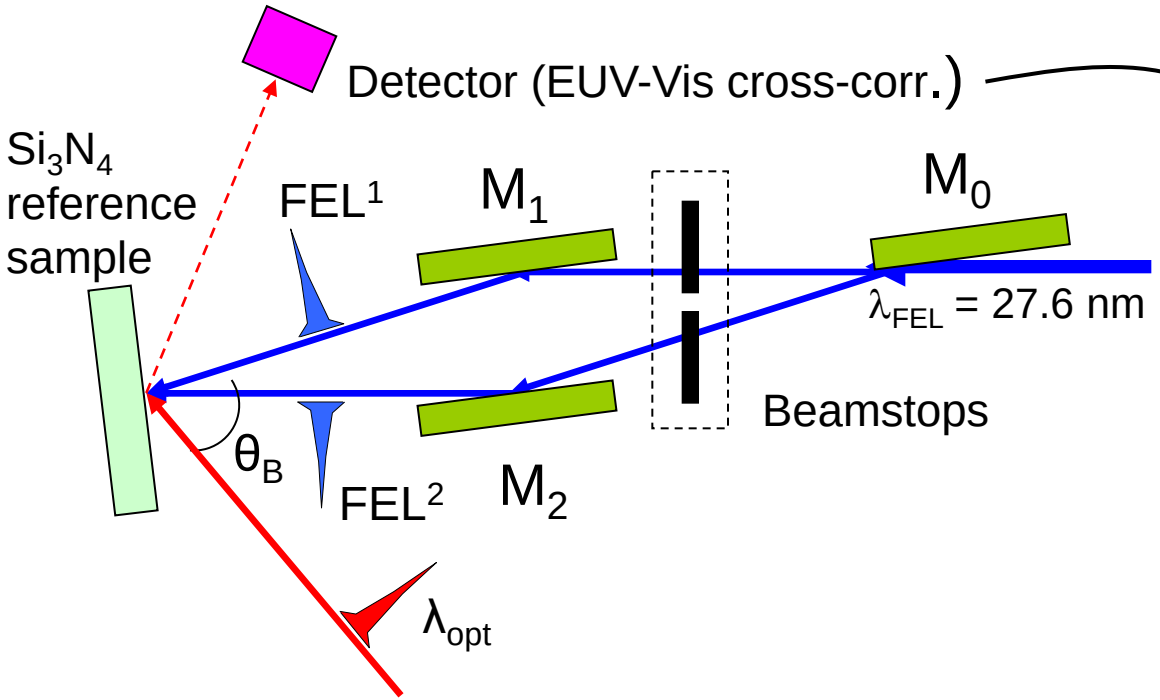

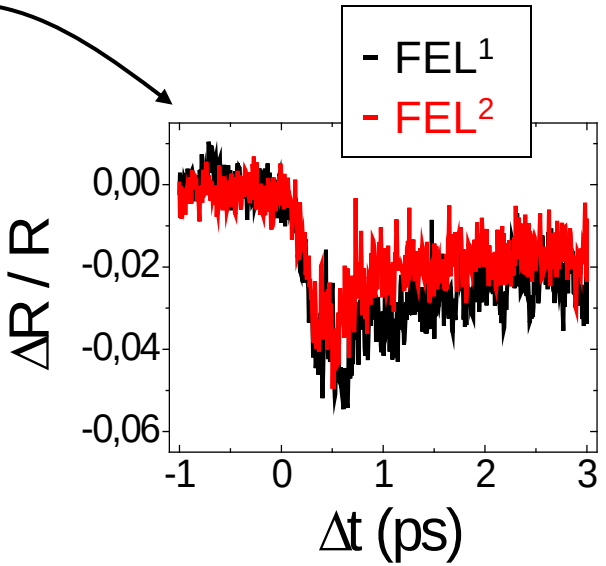

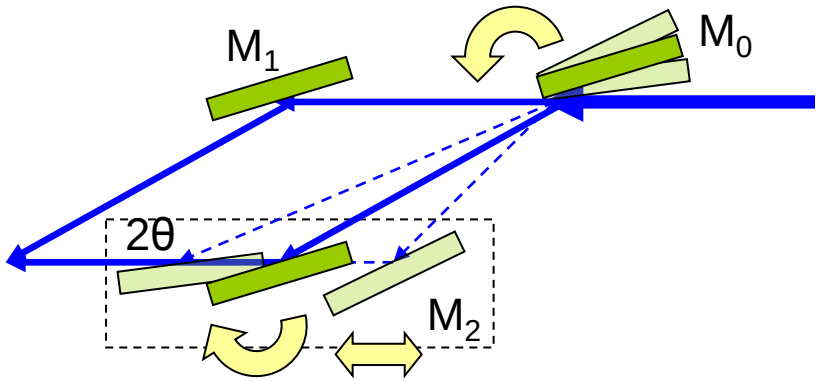

± 0.5 ps at 2θ = constant

F. Bencivenga et al., NIMA (2010)
R. Cucini et al., NIMA (2011)
R. Cucini et al., Opt. Lett. (2011)
F. Casolari et al., Appl. Phys. (2014)
M. Danailov et al. Opt. Express (2014)
R. Cucini et al., Opt. Lett. (2014)

FEL Transient Grating Experiments on V-SiO_2

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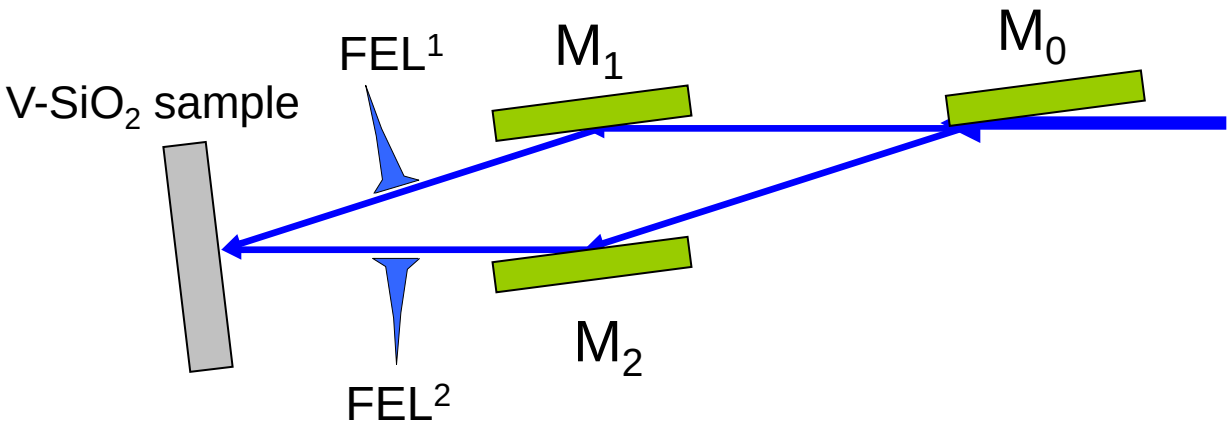
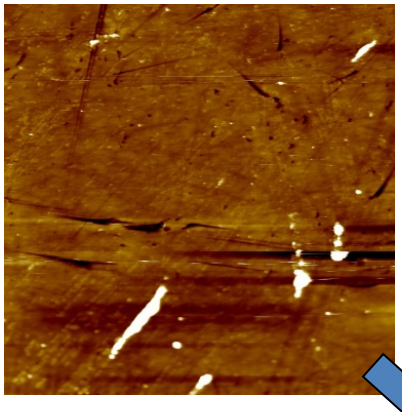


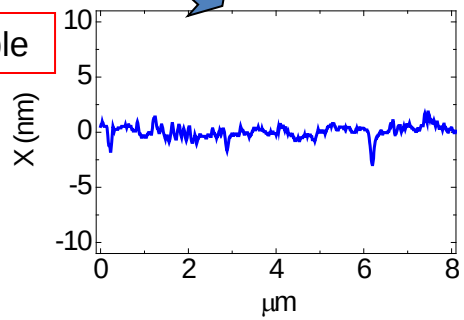
λ_{FEL} = 27.6 nm

Inprints on SiO_2
→ $2\theta = 5.975^{o}$

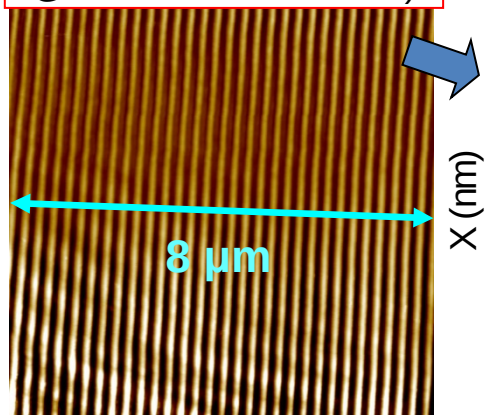
Grating visibility after multi-shot explosure
→ FEL^1-FEL^2 optical path difference < λ_{FEL}

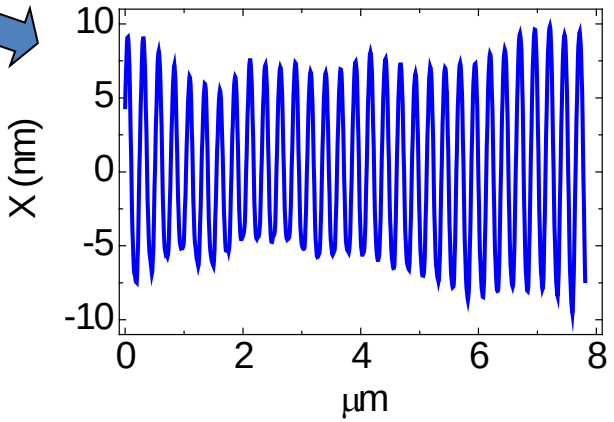


Clean sample



Permanent gratings on SiO_2 (after 1000's shots @ FEL flux > 50 mJ/cm²)





LETTER
doi:10.1038/nature1434

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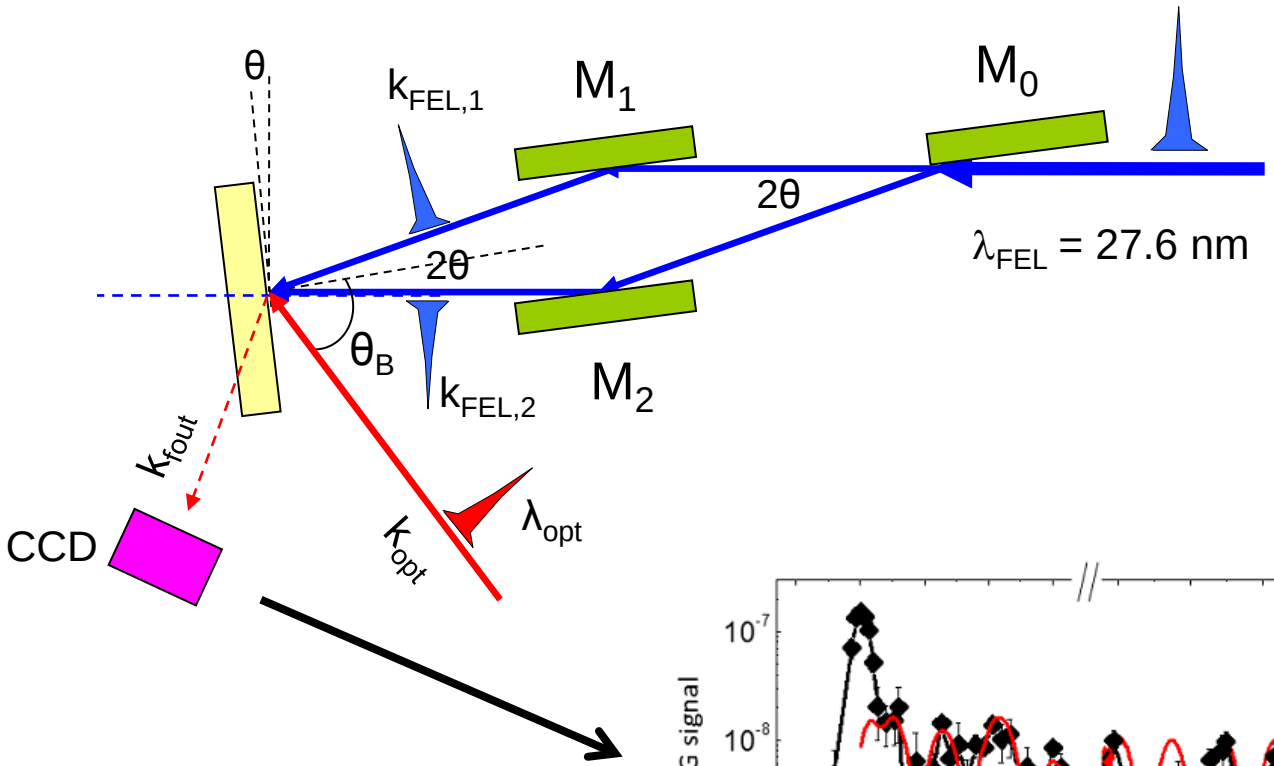
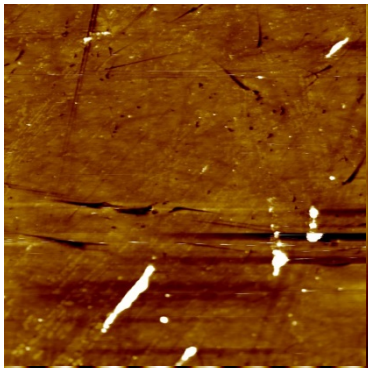
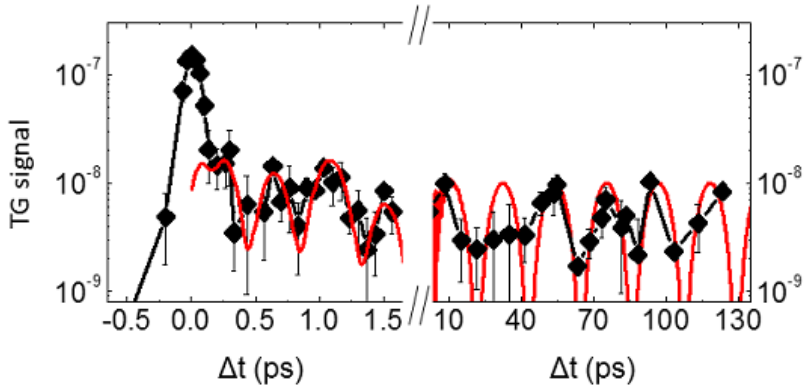
Four-wave mixing experiments with extreme ultraviolet transient gratings

F. Bencivenga et al., Nature 2015







Transient Grating Experiments on V-SiO_2

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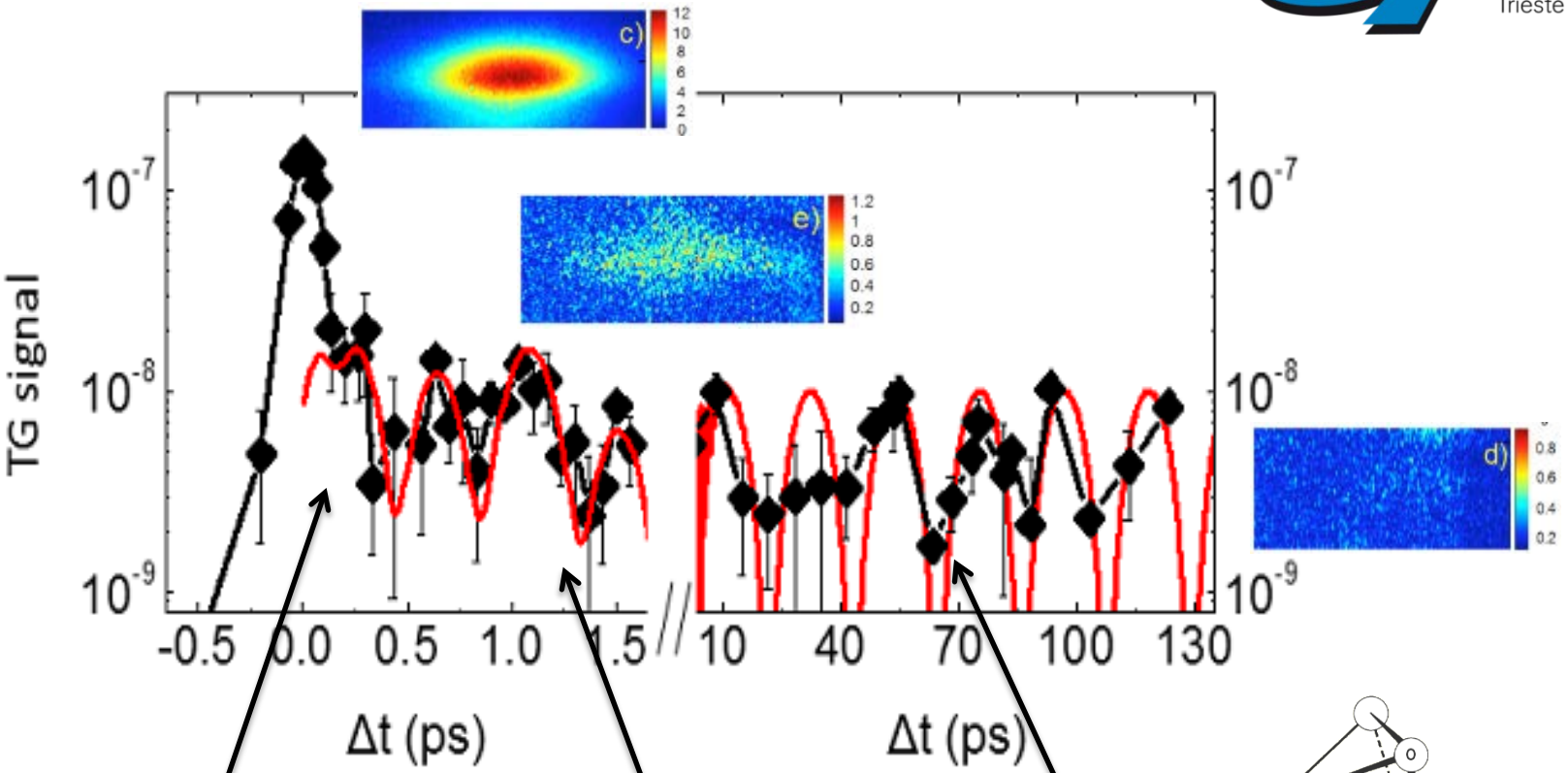
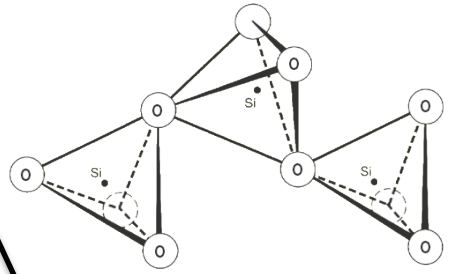


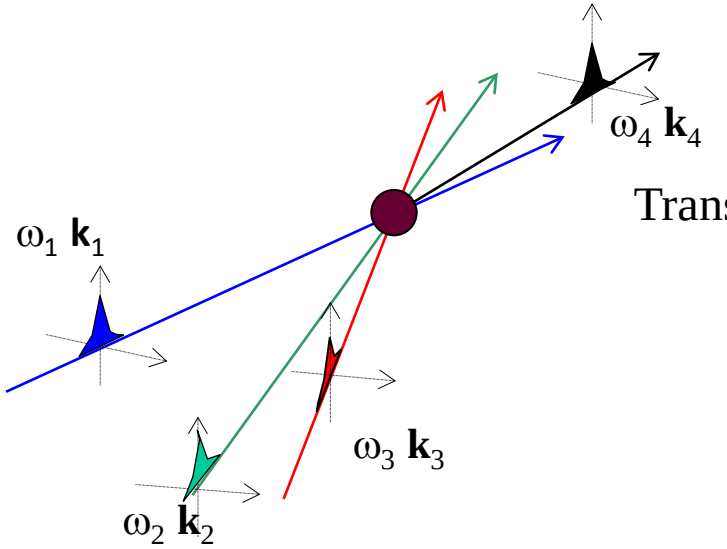


Hyper - Raman modes due to coupled tetrahedral rotations $\nu_2 \approx 4.1$ THz

Raman modes due to tetrahedral bending $\nu_1 \approx 1.2$ THz

Acoustic-like excitations

Four Wave Mixing at FEL's

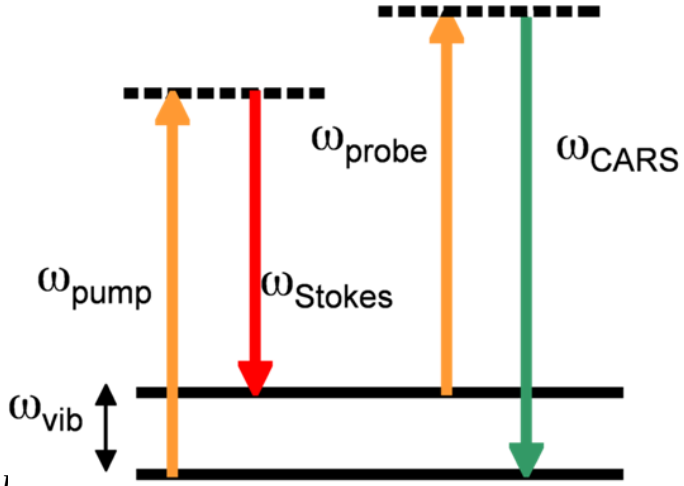


Transient grating is one of **Four Wave Mixing** techniques

Coherent Antistokes Raman Scattering (**CARS**)

P. D. Maker et al., Phys. Rev. (1965)

- Charge transfer dynamics in **metal complexes**
- Charge injection in **metal oxides nanoparticles**
- Quasiparticle diffusion (**Polarons**)



S. Tanaka et al

Measure the coherence between the two different sites → it makes possible to chose where a given excitation is created, as well as where and when it is probed

↓

delocalization of electronic states and charge/energy transfer processes

Multiple pulse configurations

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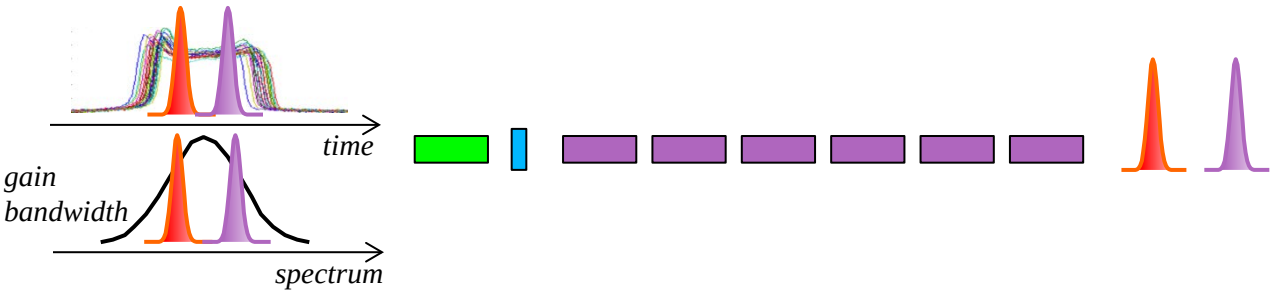
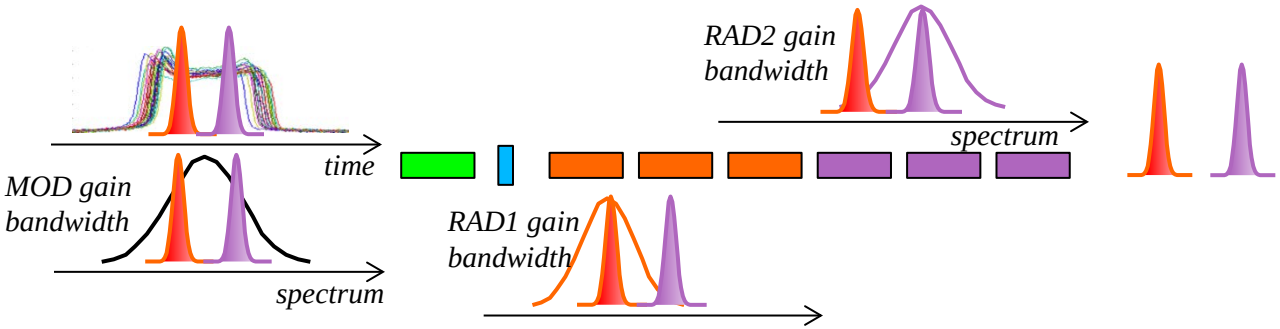
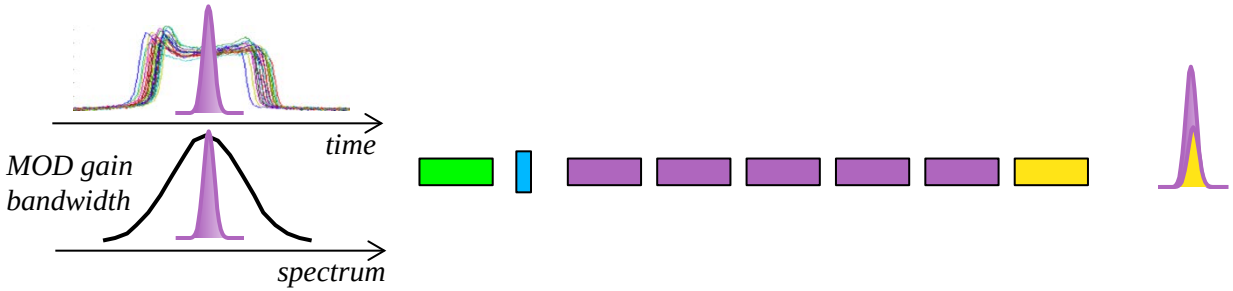
Multiple pulses can be generated by **double pulse seeding**



Spectral separation 0.4-0.7%
(*E. Allaria et al., Nat. Comm 2013*)



Spectral separation 2-3%
or much larger if two radiators are tuned at different harmonics
(Sacchi et al., Nat. Comm. 2016)



Two (almost) temporally superimposed pulses at harmonic wavelengths of the seed. They are correlated in phase that can be controlled with the phase shifter
(K.C. Prince et al., Nat. Phot. acc.)

Multicolor at FERMI

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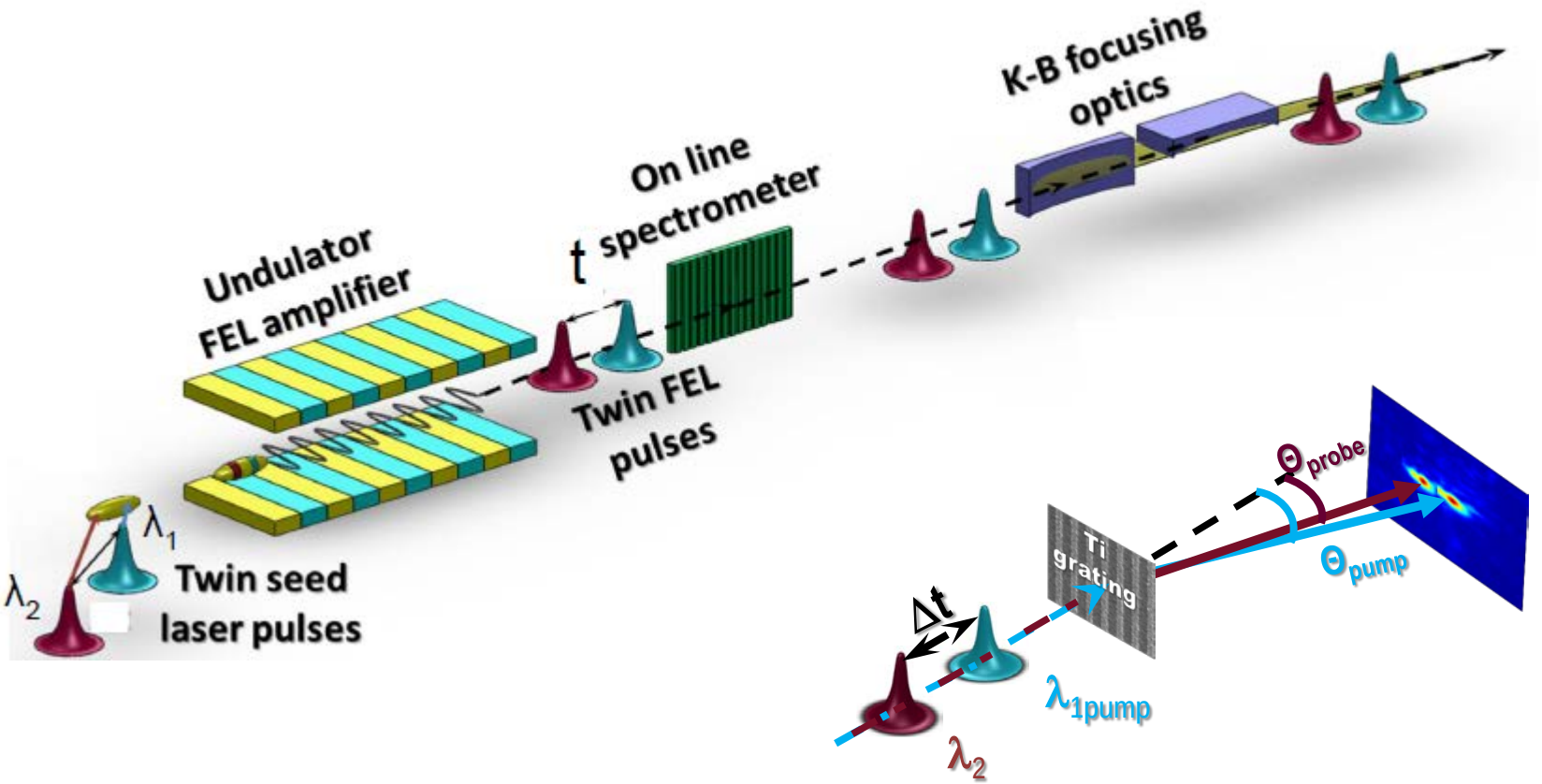
nature COMMUNICATIONS

E. Allaria et al.,(2013)

Received 24 May 2013 | Accepted 21 Aug 2013 | Published 18 Sep 2013

DOI: 10.1038/ncomms3476 OPEN

Two-colour pump–probe experiments with a twin-pulse-seed extreme ultraviolet free-electron laser



Element selective magnetization dynamics

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nature COMMUNICATIONS

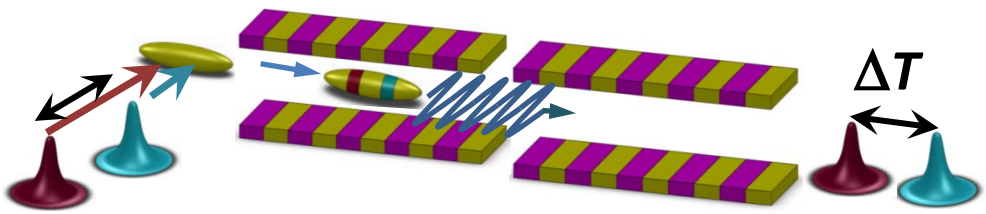
Received 21 Aug 2015 | Accepted 3 Dec 2015 | Published 13 Jan 2016

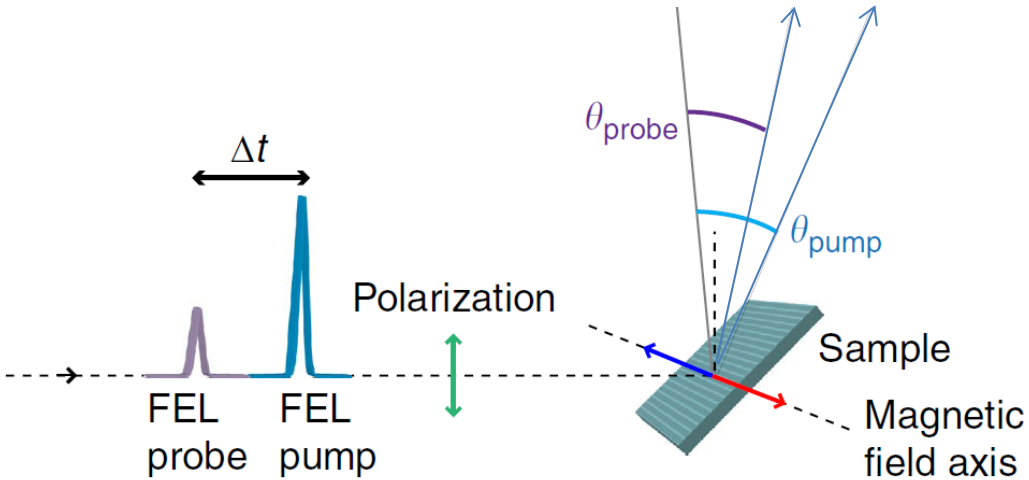
DOI: 10.1038/ncomms10343 OPEN

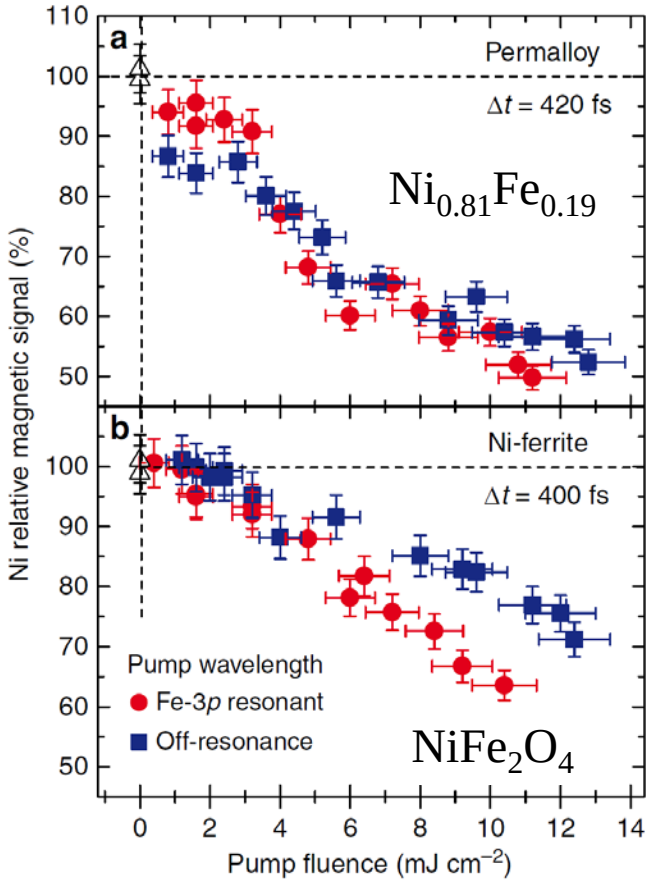
E. Ferrari et al., (2016)

Widely tunable two-colour seeded free-electron laser source for resonant-pump resonant-probe magnetic scattering

Radiators at different harmonics







FERMI based CARS

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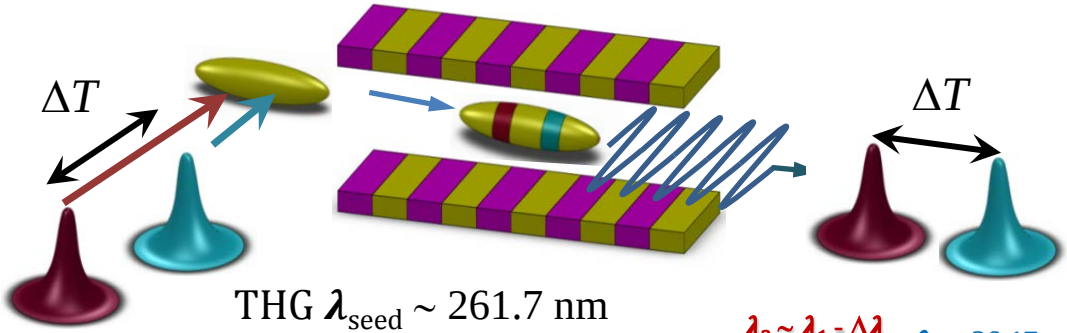
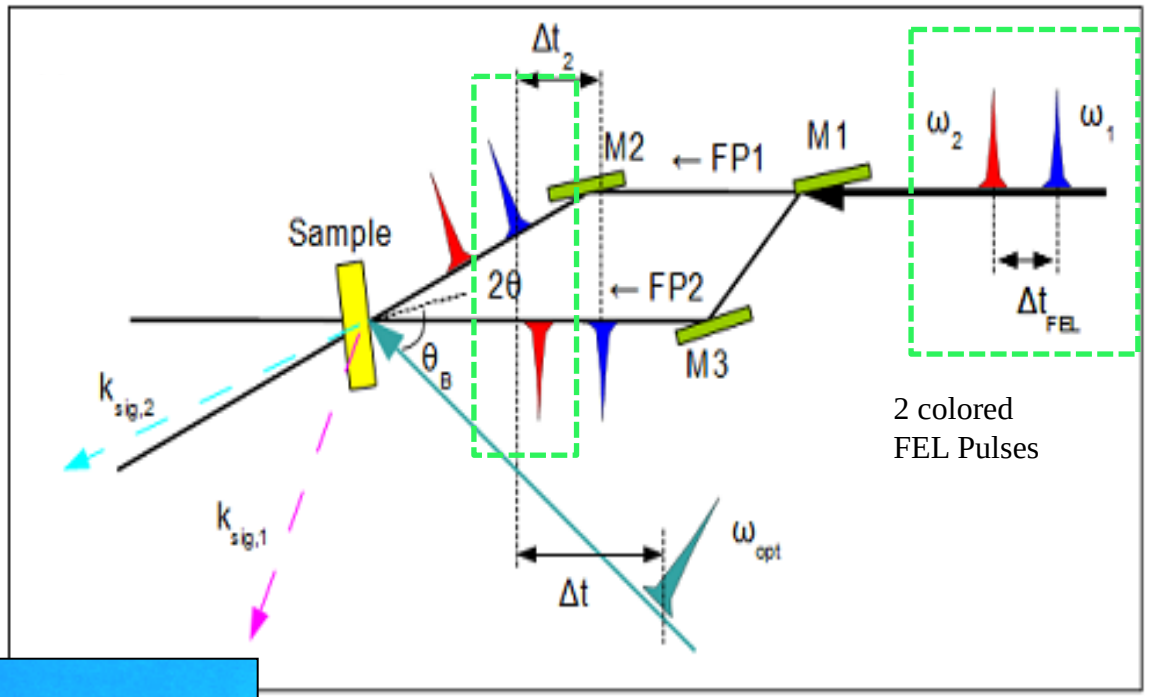


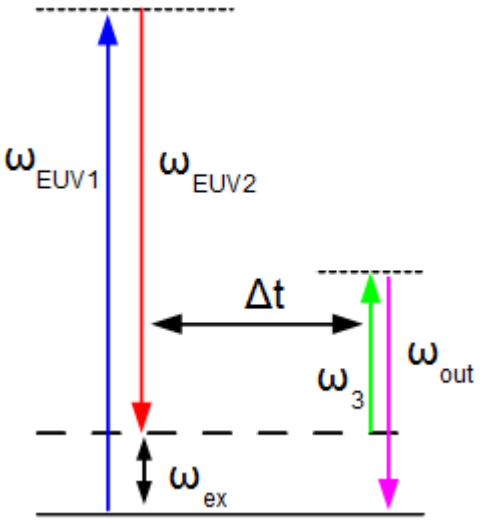
THG λ_{seed} ~ 261.7 nm

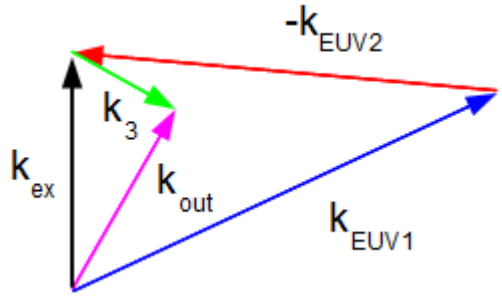
$\lambda_2 \sim \lambda_1 - \Delta\lambda$ $\lambda_1 \sim 26.17$ nm

OPA λ_{seed} variable



2 colored FEL Pulses





FERMI based CARS

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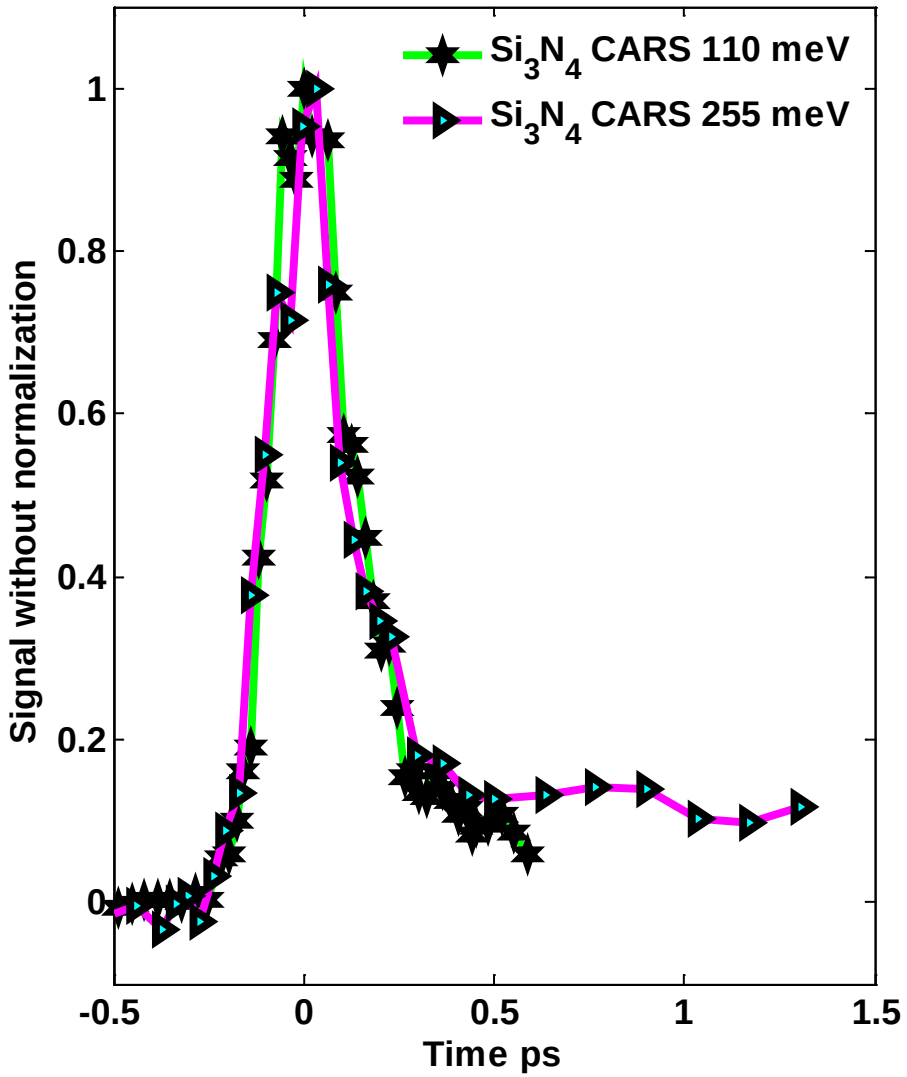

F. Bencivenga et al., in preparation

TIMER commissioning

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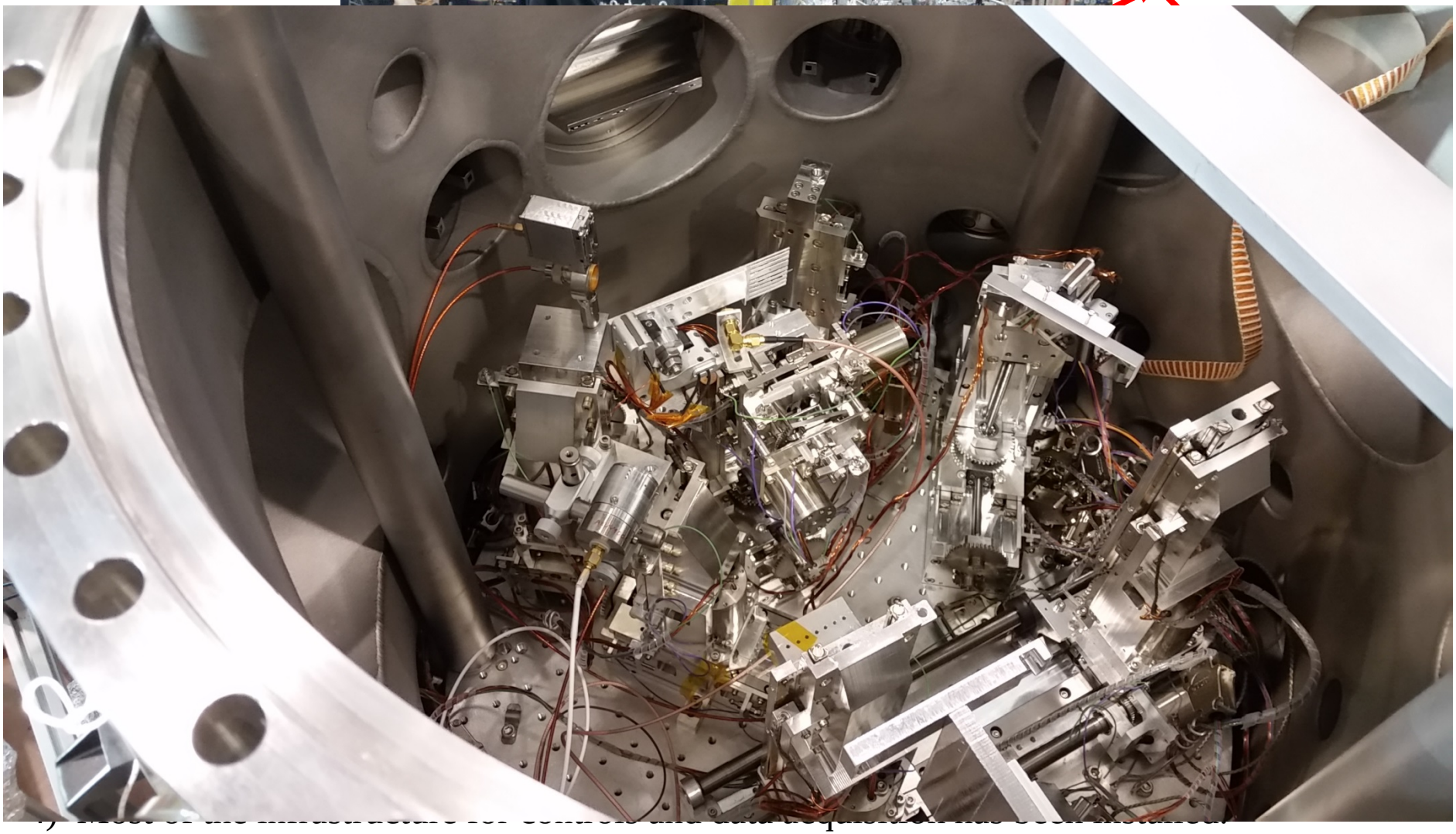
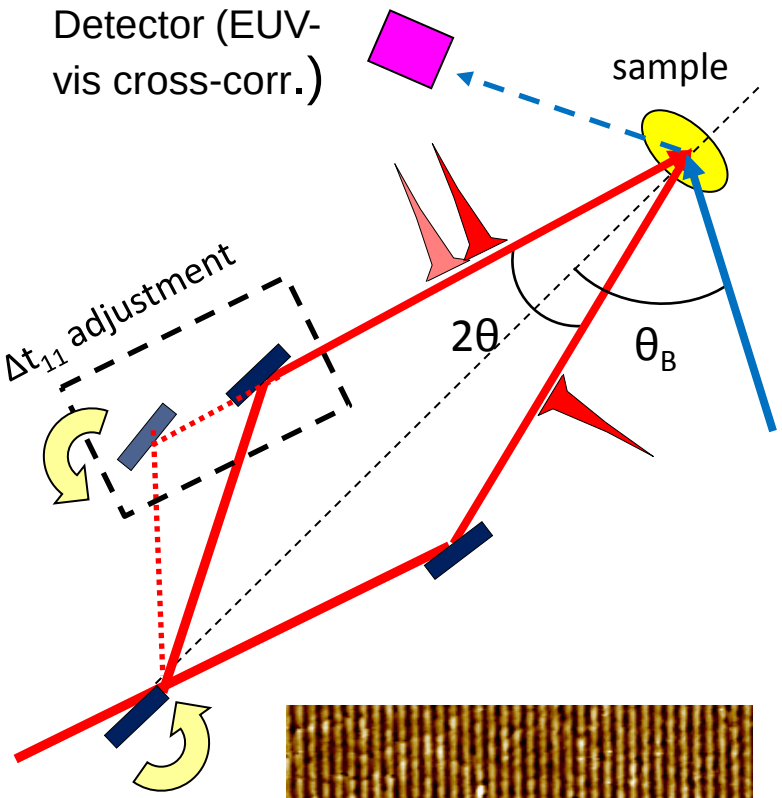
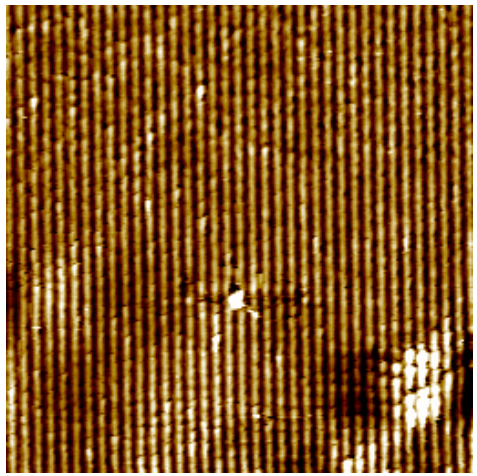
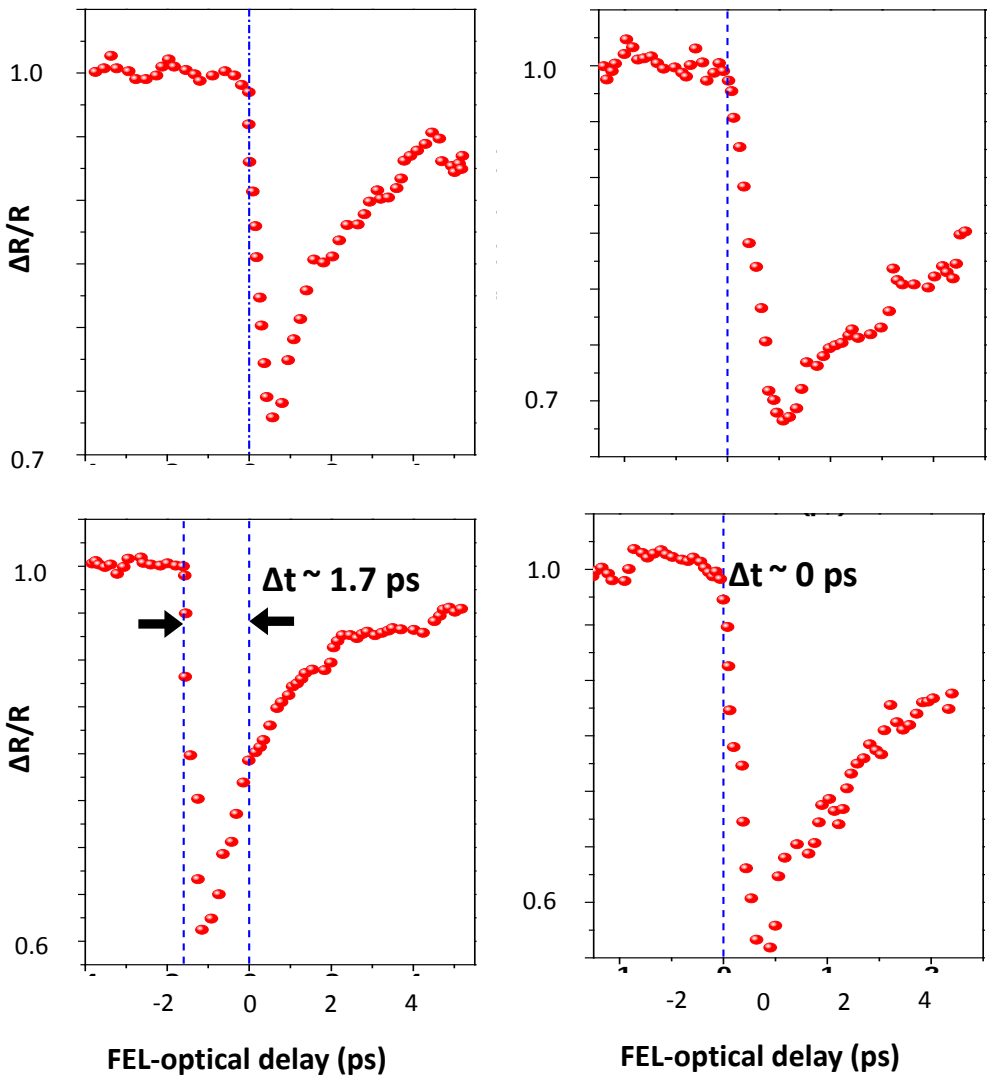


TIMER commissioning







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Elettra Sincrotrone Trieste


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A. Simoncig


M. Kiskinova


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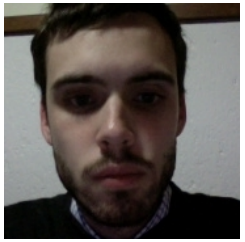
E. Principi


R. Mincigrucci


R. Cucini


K. Nelson


G. Knopp


G. Monaco