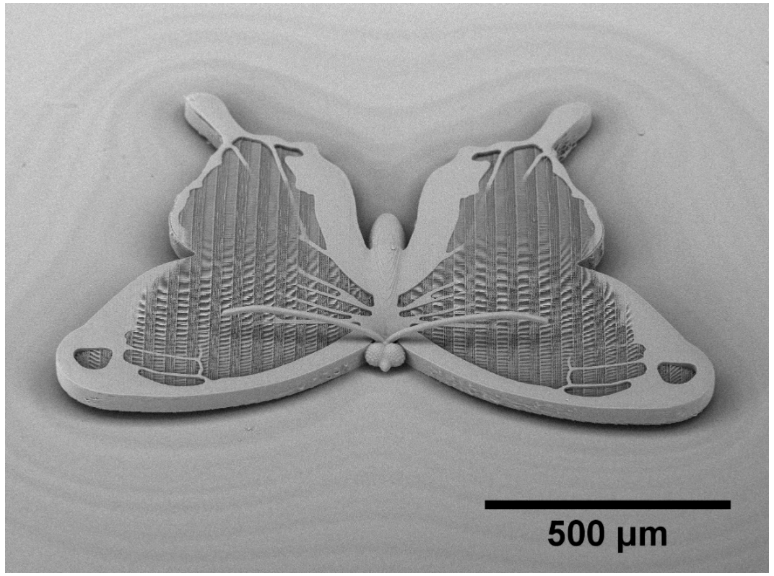
JRA Highlights
Joint JRA Meeting, Florence 9-10 Oct. 2019

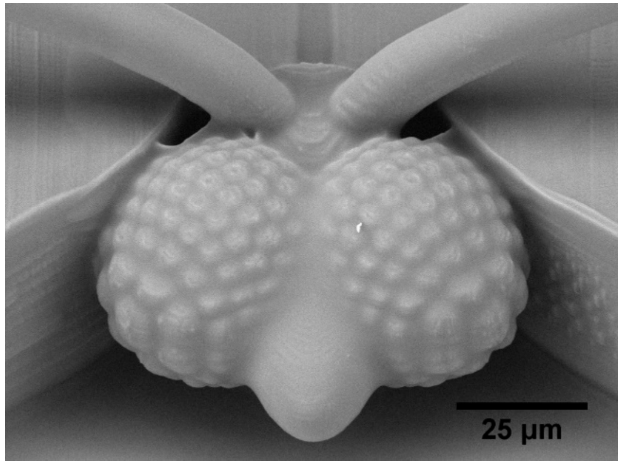
1. *Meso-Scale (Multi-Scale) Laser 3D Printing of Biomaterials*
2. *Multimodal spectroscopy for tissue diagnostics*
3. *Stimulated Raman scattering (SRS) microscopy*
4. *Time-Domain Diffuse Correlation Spectroscopy*
5. *Development of sources and instrumentation for X-ray spectroscopy & imaging*
6. *Two-dimensional Electronic Spectroscopy*
7. *Coherent Beam Combination update and Fast Pointing Beam Stabilisation*
8. *Thin-disc and volume laser based mid-IR sources*
9. *High-rep. rate, single-shot, measurement of the carrier-to-envelope offset phase*
10. *Advanced Attosecond Working Stations for Material Science Studies*
11. *Preparing laser accelerated proton beams for dose controlled irradiation studies*
12. *Targetry*

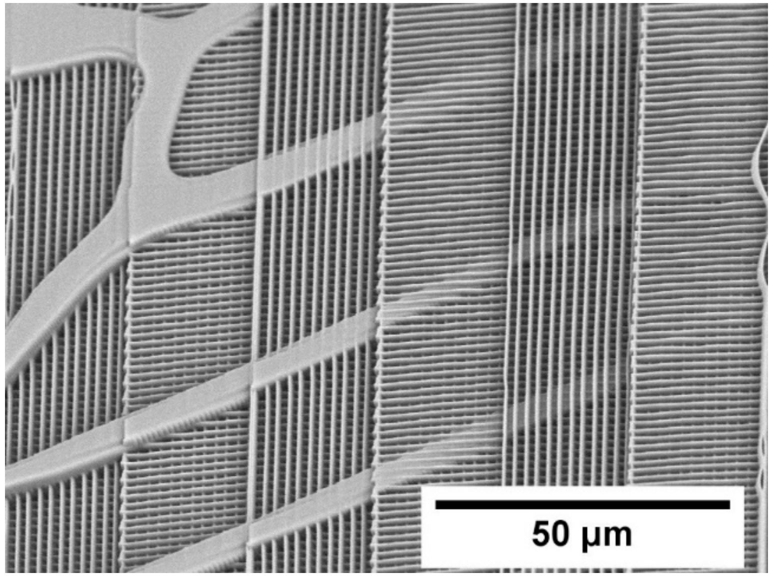
1A - Meso-Scale (Multi-Scale) Laser 3D Printing of Biomaterials

Vilnius University

FORTH
INSTITUTE OF ELECTRONIC STRUCTURE AND LASER





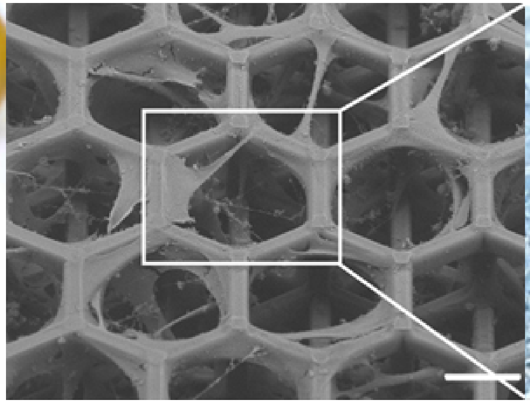


A problem associated with direct laser writing 3D lithography (two-photon polymerization) is the limited throughput, an inevitable stitching/overall object size and a choice of materials.

1B - Meso-Scale Laser 3D Printing of Bio-Materials

from natural biodegradable/biocompatible to synthetic tunable properties composites towards pure inorganics

Proteins – Biopolymers – Hydrogels – Acrylates – Epoxies-Organic-Inorganic Hybrids

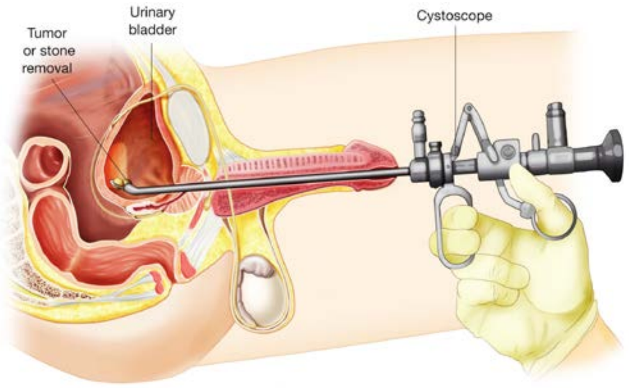


Scientific papers proposing the solution and acknowledging LL JRA BIOAPP:

- L. Jonušauskas, D. Gailevičius, S. Rekštytė, T. Baldacchini, S. Juodkazis, M. Malinauskas, Mesoscale Laser 3D Printing, Opt. Express 27(11), 15205-15221 (2019); https://doi.org/10.1364/OE.27.015205, OSA [IF-3.356].
- A. Butkutė, L. Čekanavičius, G. Rimšelis, D. Gailevičius, V. Mizeikis, A. Melninkaitis, T. Baldacchini, L. Jonušauskas, M. Malinauskas, Optical Damage Thresholds of Microstructures Made by Laser 3D Nanolithography, in PrePrints / under review (2019).

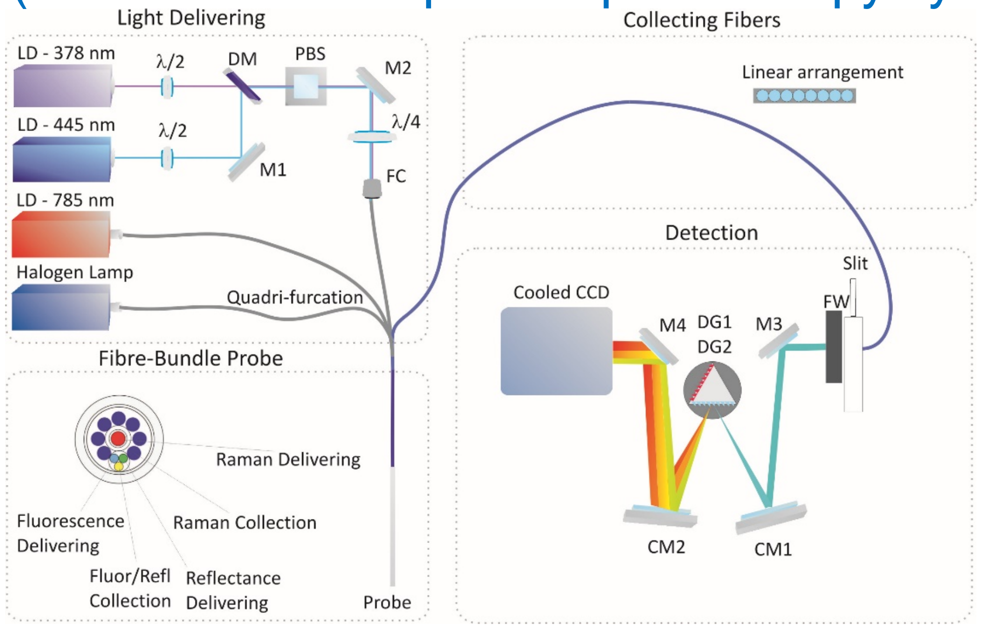
2A - Multimodal spectroscopy for tissue diagnostics

TURBT (Trans-urethral resection of bladder tumour)



- To endoscopically diagnose bladder tumour as well as to perfrom tumour grading and staging
- Biopsy (small) + sectioning + staining
- Difficulties for the pathologists in:
  - Orienting the samples
  - Identify slicing direction
  - <u>Difficult diagnosis</u>

Experimental setup (multimodal fiber-probe spectroscopy system)



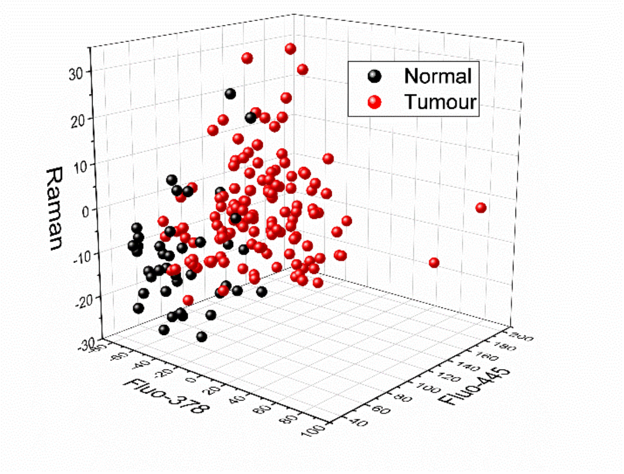
- Laser diodes @378 nm & @445 nm
- Halogen Lamp
- Laser diode @785 nm
- Quadrifuracted probe (EMVision LLC)
- Spectrograph (grating 600 lines/mm)
- Cooled CCD camera (Horiba Syncerity)

Probe tip

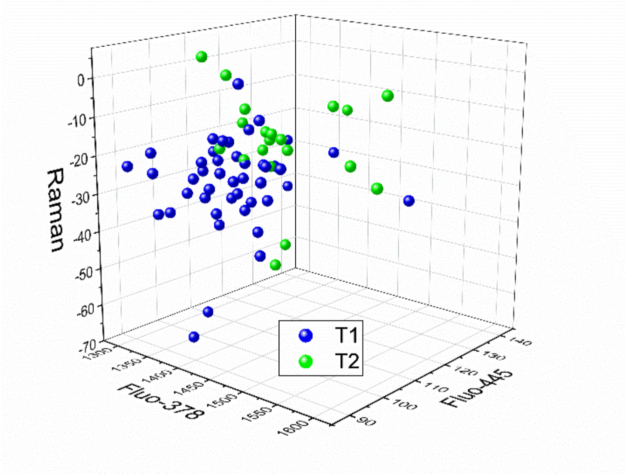
R. Cicchi, A. Cosci, S. Rossari, D. Kapsokalyvas, E. Baria, V. Maio, D. Massi, V. De Giorgi, N. Pimpinelli, and F.S. Pavone, J Biophoton **7**, 86-95 (2014)

2B - Bladder tumor staging

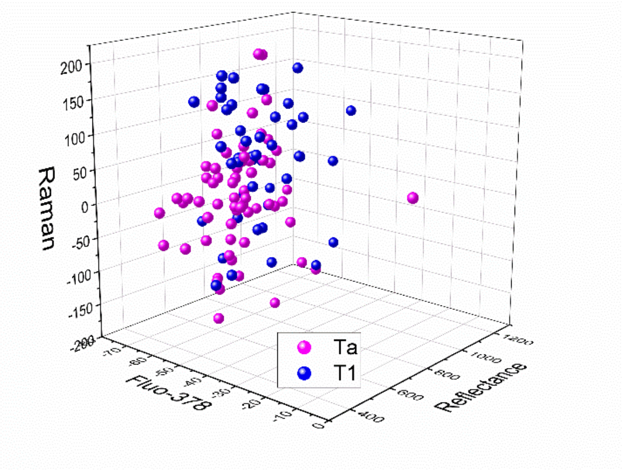
Normal vs Tumour



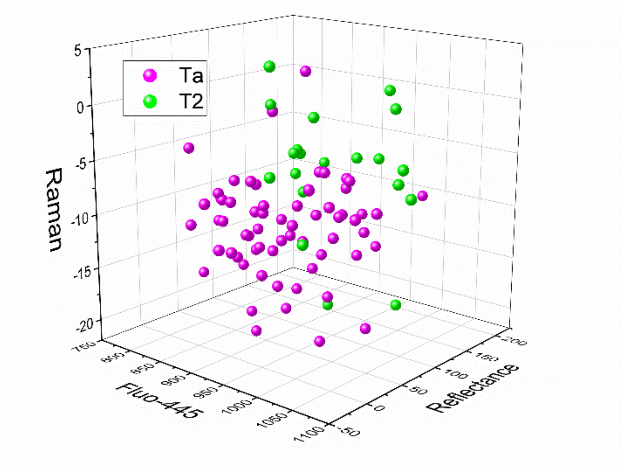
T1 vs T2



T1 vs Ta



T2 vs Ta

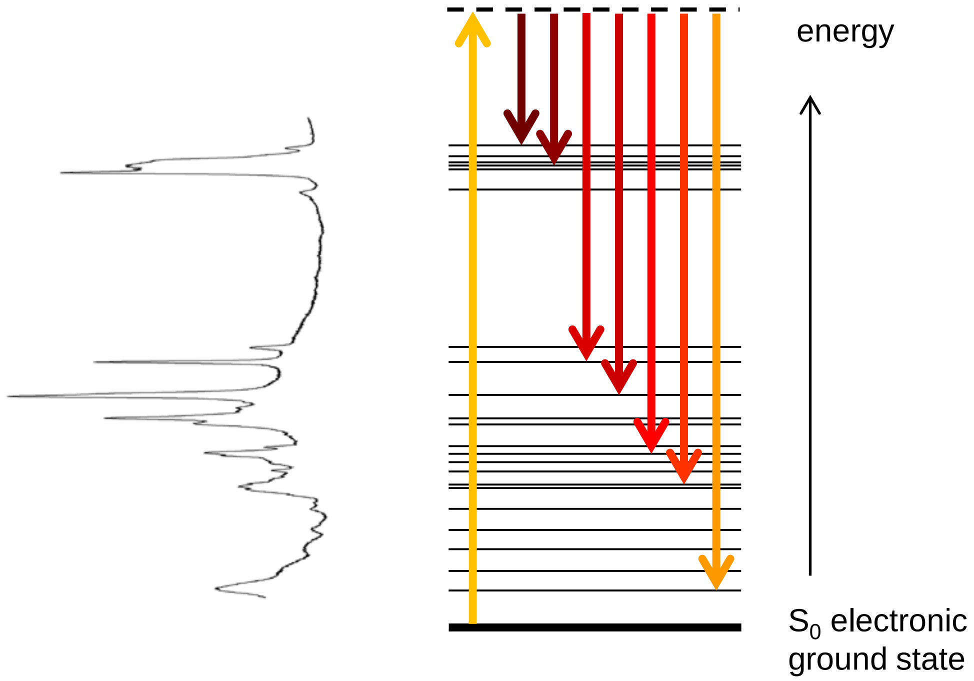


	Specificity (%)	Sensitivity (%)	AUC (%)
normal vs tumour	90	74	91
T1 vs T2	80	85	85
T1 vs Ta	73	71	75
T2 vs Ta	80	80	86

E. Baria, S. Morselli, S. Anand, R. Fantechi, G. Nesi, M. Gacci, M. Carini, S. Serni, R. Cicchi, and F.S. Pavone, J Biophoton **12**, (2019) DOI: 10.1002/jbio.201900087

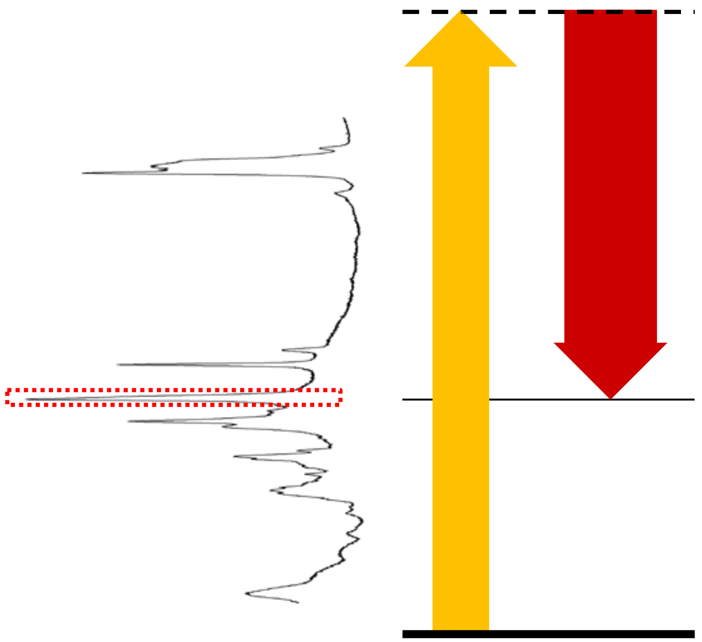
3A - Stimulated Raman scattering (SRS) microscopy

Conventional Raman scattering



Complete vibrational spectra, but slow!

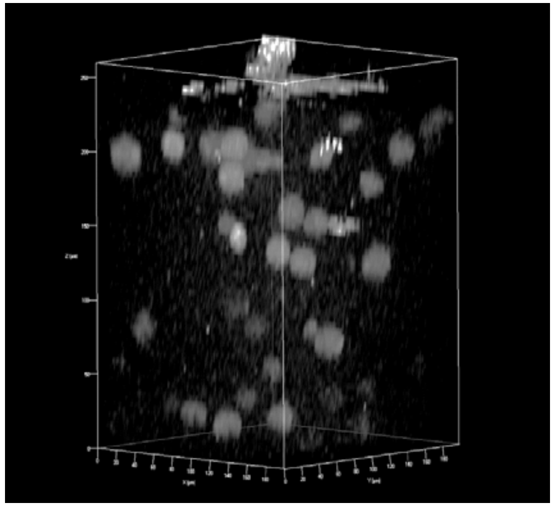
Stimulated Raman scattering



Requires two pulsed lasers; much faster for mapping

3B - Recent SRS developments

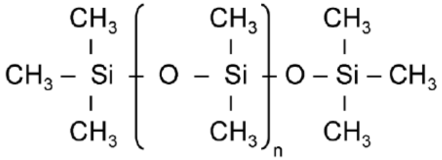
Long-wavelength SRS (using the OPO idler output in combination with 1064 nm pump beam) enables deeper imaging



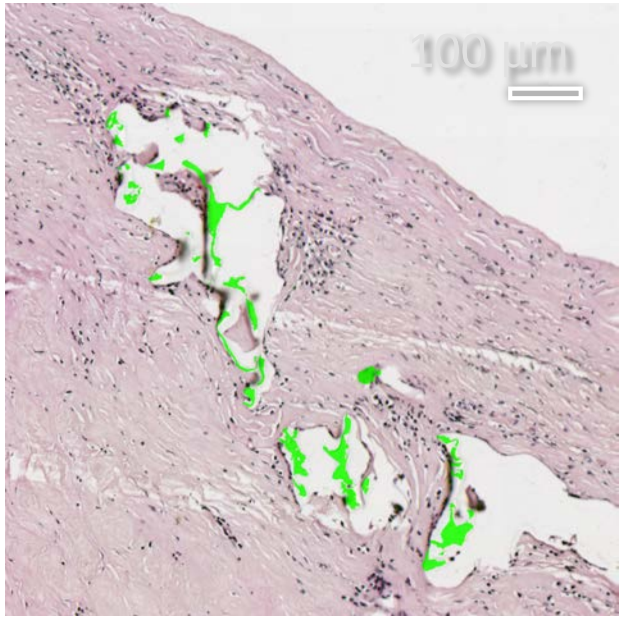
3D distribution of 15-µm polyethylene microspheres embedded in a silicone rubber matrix, down to 250 µm

Hyperspectral SRS at 6 wavenumbers was developed to detect and identify microplastic particles (down to 10 µm) in harbour sediment

We found a total of 12 000 particles/kg sediment



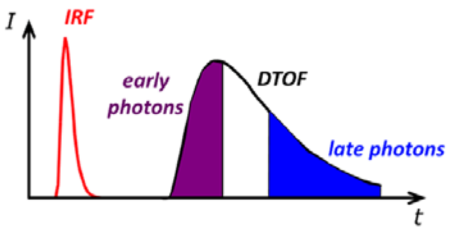
Polydimethylsiloxane (PDMS)



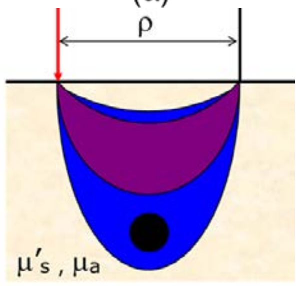
Leaking silicone gel from breast implants is a major problem, but it is invisible to the pathologist

Silicone can be detected by SRS microscopy at 2905 cm^{-1} (C-H stretch vibration) and then overlaid (in green) on a standard H&E image.

4A - JOINT POLIMI - ICFO LABORATORY ON Time-Domain Diffuse Correlation Spectroscopy (DCS)



(a)



(b)

POLITECNICO
MILANO 1863

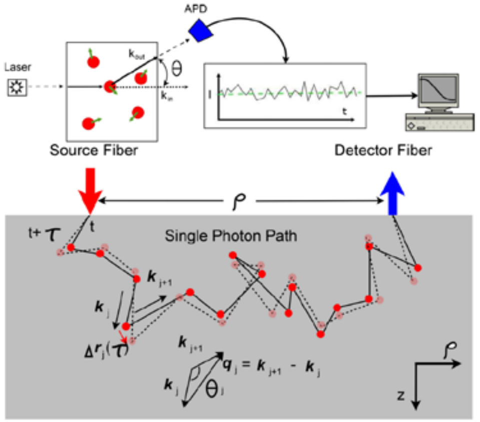
Time-Domain Diffuse Optics

- Optical properties
- Time encodes space

ICFO MEDOPT
Medical Optics Group

Diffuse Correlation Spectroscopy

- Relative Blood flow



POLIMI + ICFO

Time-Domain DCS

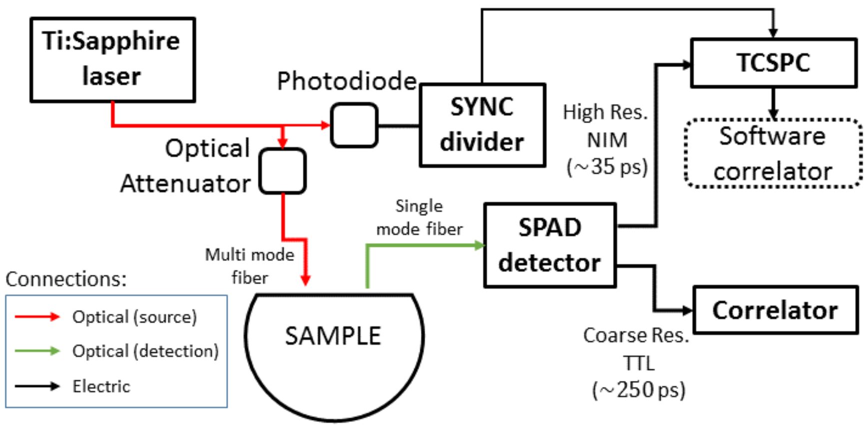
- 4 papers + 3 in progress
- 10 researchers involved

- Depth-resolved (cm) blood flow
- Absolute quantitation

Joint POLIMI+ICFO distributed laboratory
Long-Term perspective: Foundation of TD-DCS towards clinical translations

4B

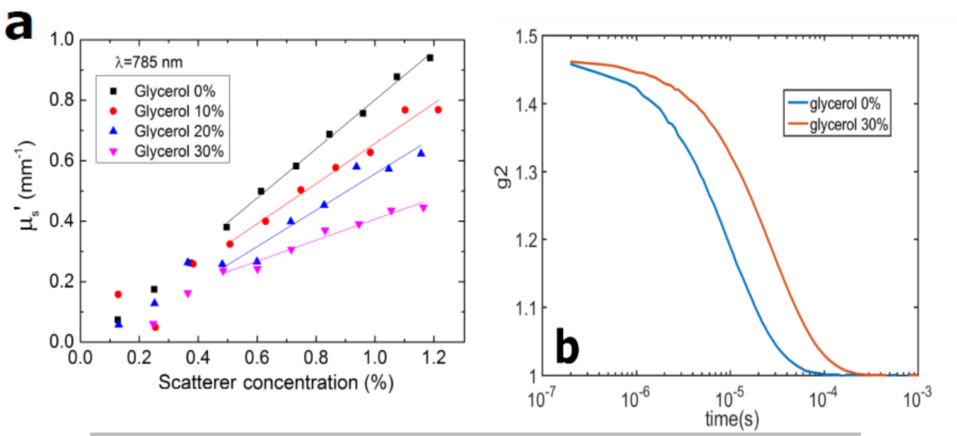
Action 1 – new workstation @POLIMI



M.Pagliazzi *et al.,* Biomed. Opt. Express **8** (2017)

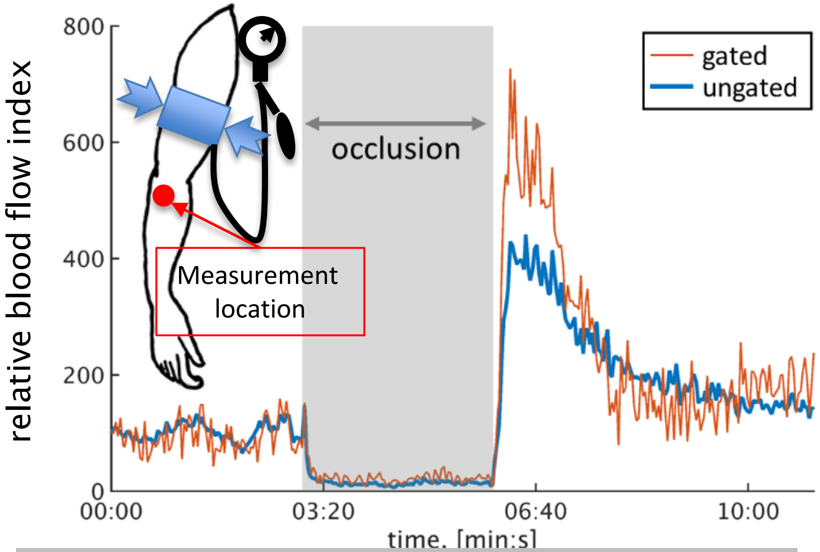
Action 2 – design of reference tissue phantoms

Lipofundin (scattering) + Ink (absorption)
+ Glycerol (viscosity)



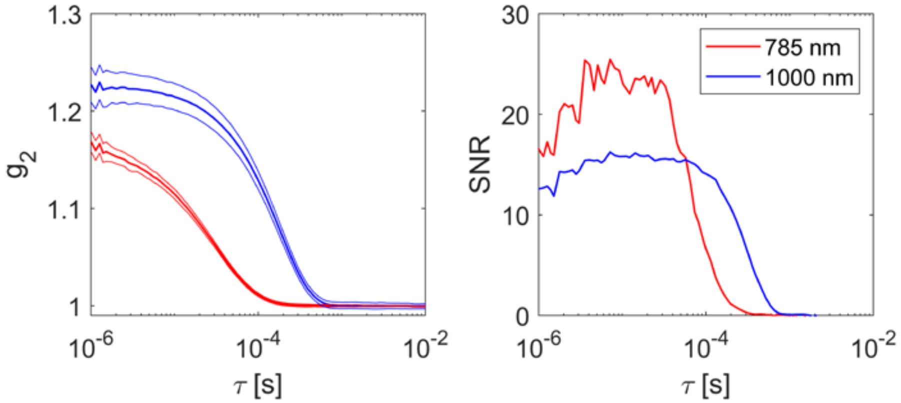
L.Cortese et al., Biomed. Opt. Expr. (2018)

Action 3 – first time-gated in vivo data



M. Pagliazzi et al., Opt.Lett. (2018)

Action 4 – in vivo measurements >1000 mm

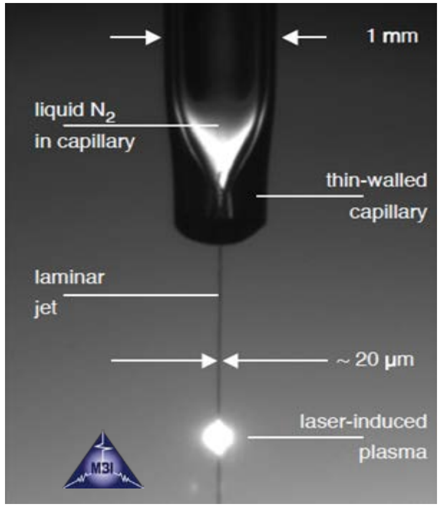


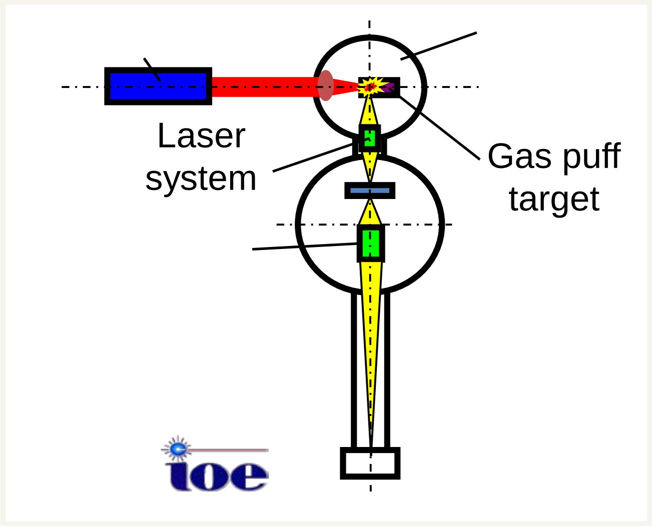
- Higher amplitude (β) and slower decay of g_2
- SNR shifted to higher $\tau \rightarrow$ chance of *parallel detection*

L.Colombo et al., in preparation (2019)

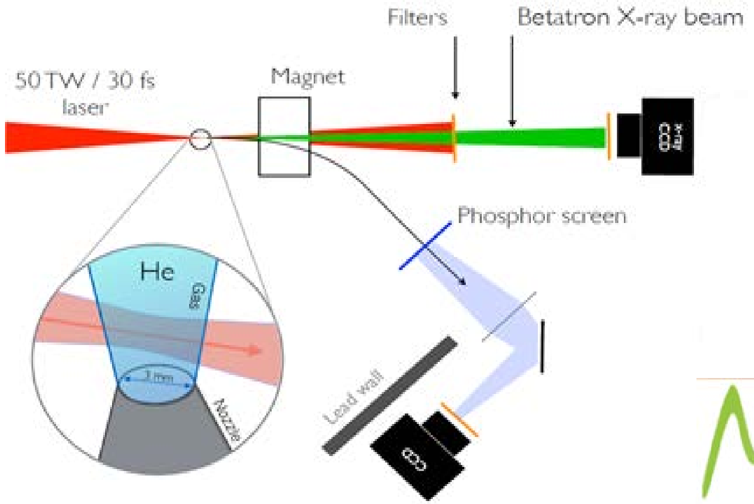
5A - Development of sources and instrumentation for X-ray spectroscopy & imaging

Laser-produced plasma X-ray sources (LPP)

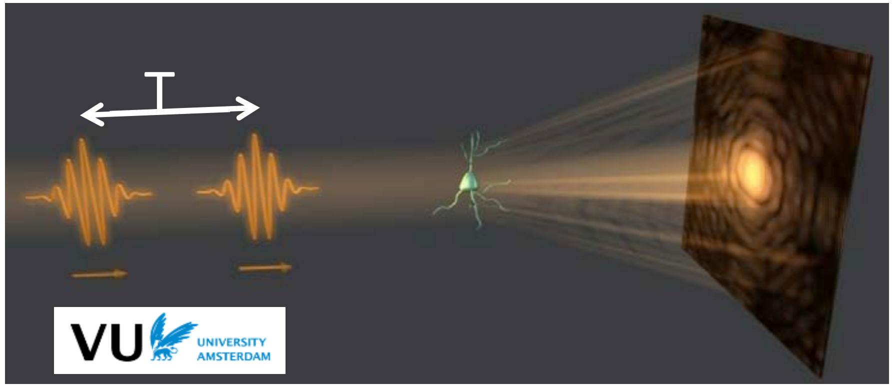




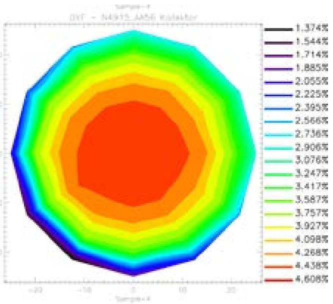
Betatron radiation



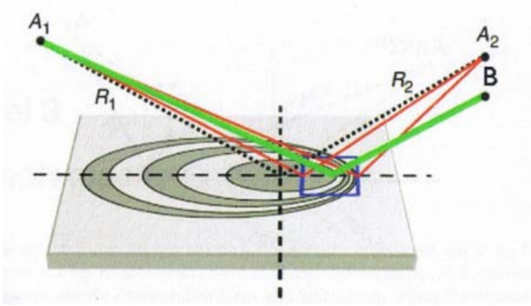
High Harmonic Generation (HHG)

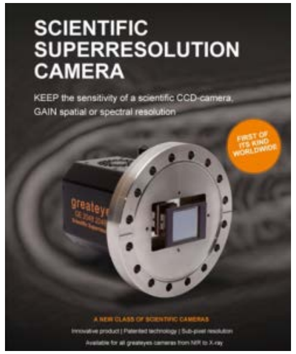


Optics, spectrometers, detectors



optiX fab.

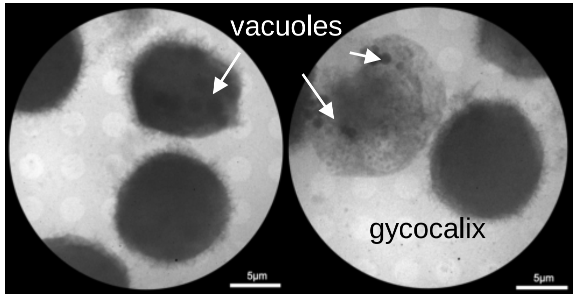




IAP nano optics berlin nob BLiX greateyes

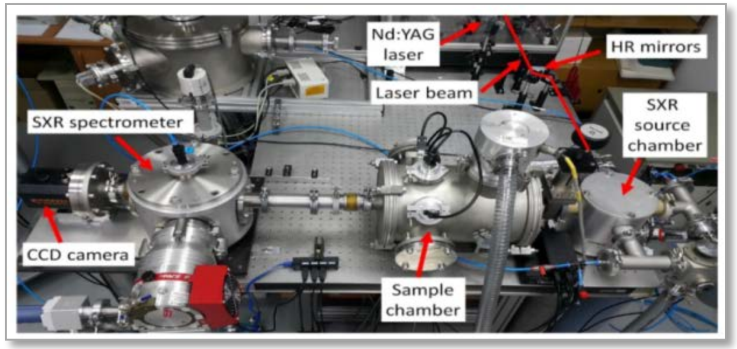
5B - Applications

X-ray microcopy in the lab

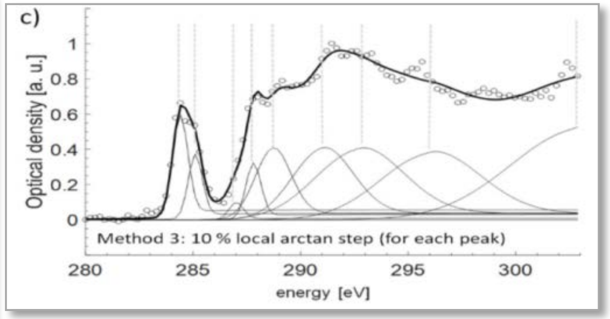


Soft X-ray microscopy of cryo-fixated THP-1 Cells. Inner structures as well as the glycocalix are clearly visible.

Soft X-ray spectroscopy in the lab



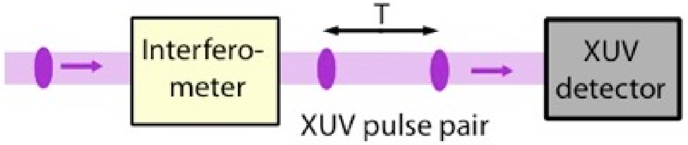
Experimental setup

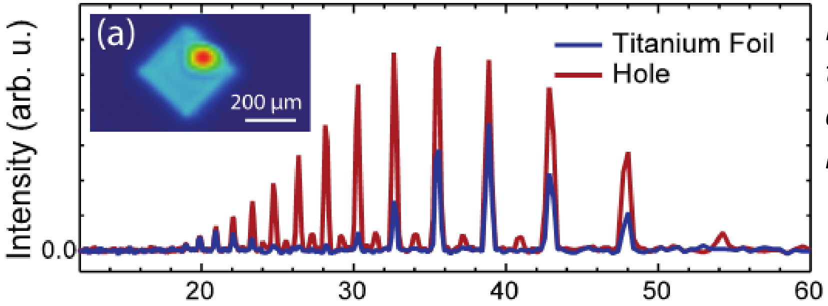


NEXAFS spectrum for a 1 µm thick PET sample

Wachulak et al. Optics Express 26, 8260 (2018)

Spatially resolved HHG spectroscopy

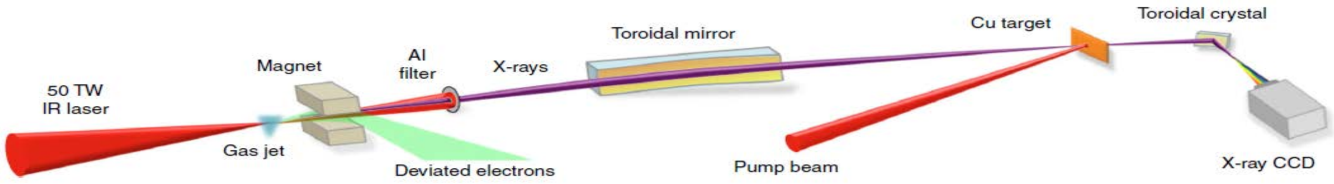




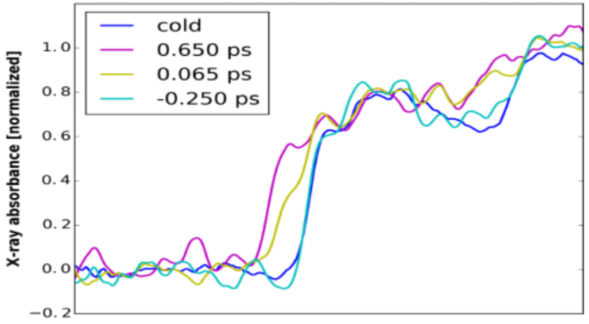
Measurement of transmission through a Ti/Si_3N_4 film 17-55 nm range.

*Jansen et al., Optica **3**, 1122 (2016)*

Warm dense matter investigated using betatron radiation



Heating a copper foil with a temporal resolution better than 50 fs.



*B. Mahieu et al., Nat. Comm. **9** 3276 (2018)*

6A -Two-dimensional Electronic Spectroscopy

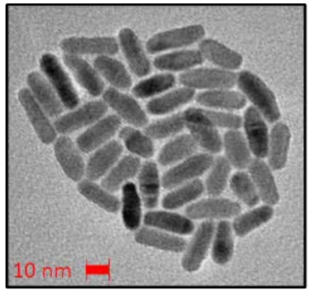
Goal: increase the availability of **2D spectroscopies to the users of Laserlab**, by developing a suite of different experimental techniques coupled to data visualization and analysis tools.

CUSBO

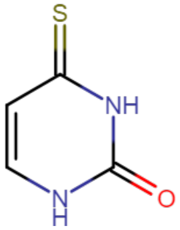
LUND UNIVERSITY

LLC
LUND LASER CENTRE

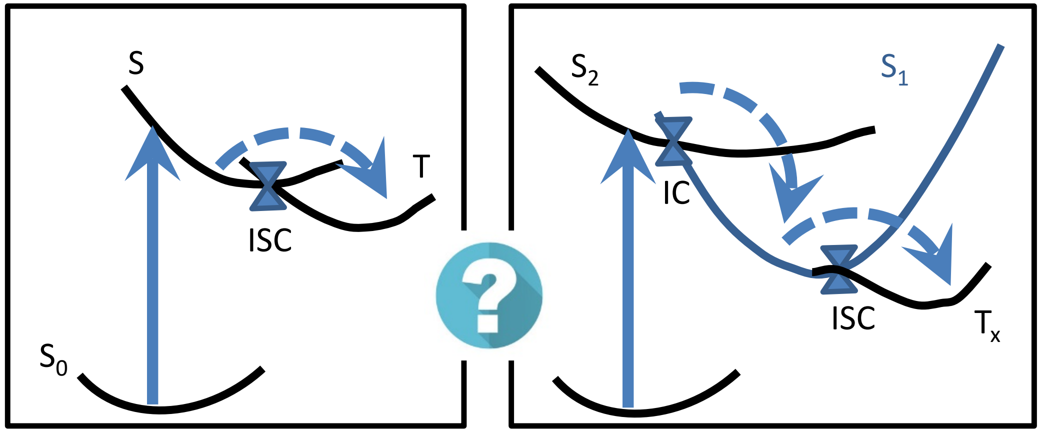
LASERLAB Amsterdam



Characterization of relaxation times and paths in CdSe Nanorods:
2D electronic spectroscopy and **modeling**



Understanding ultrafast dynamics in nucleobasis:
Ultrafast spectroscopy in the UV spectral range



6B - Main achievements

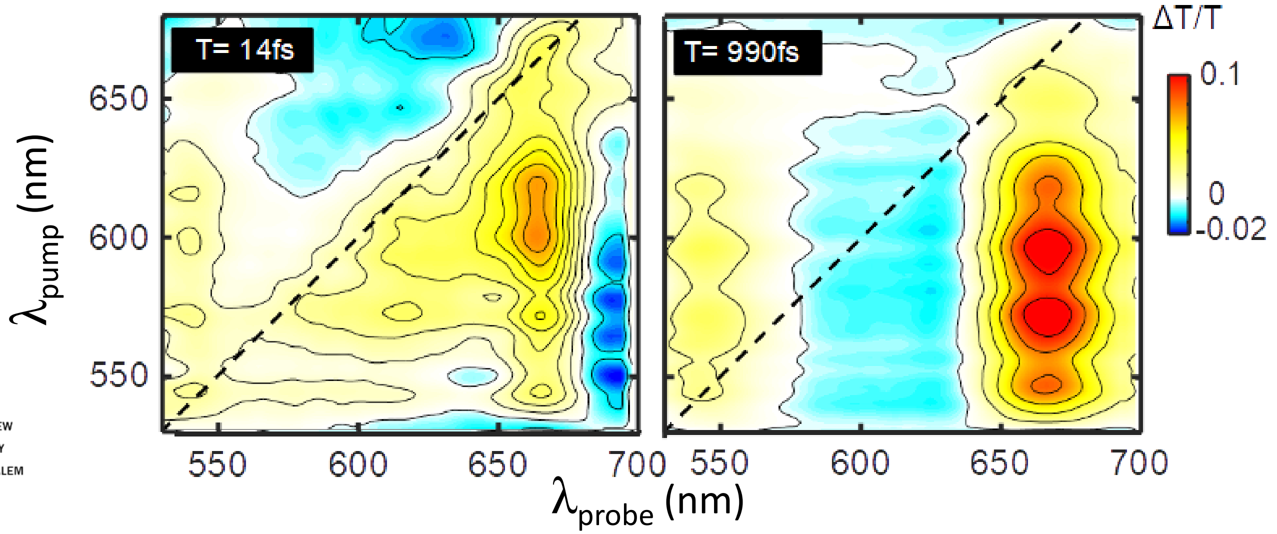
CdSe nanorods

2DES + Global analysis:

- relaxation from *high energy excitons* to an *intermediate state*: **124-fs** time constant
- relaxation to the *lowest exciton*: **217-fs** time constant

Collaboration with Prof. Uri Banin

THE HEBREW UNIVERSITY OF JERUSALEM



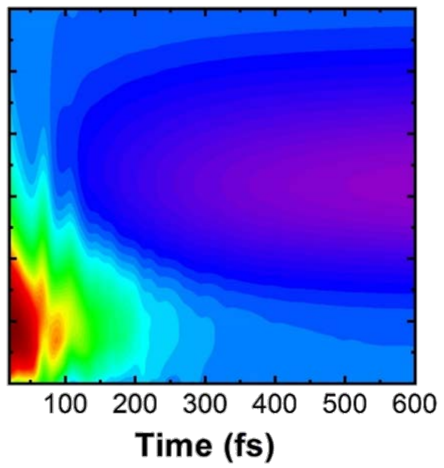
4-Thiouracyl

UV spectroscopy system:

- Sub-20 fs UV pulses at 270 and 330nm
- Evidence of an intermediate state mediating internal conversion

Experimental

Simulated



Collaboration with Prof. M. Garavelli and Ivo van Stokkum

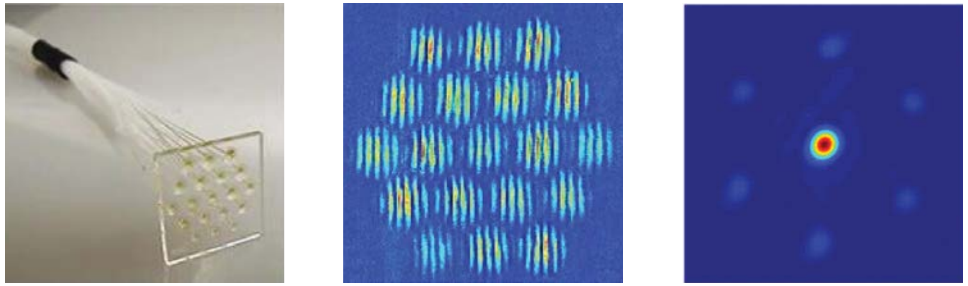
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

VU VRIJE UNIVERSITEIT AMSTERDAM

R. Borrego-Varillas *et al.*, J. Am. Chem. Soc. **140**, 16087 (2018)

7A - LULI, France : Coherent Beam Combination update

- CBC demonstrated with 19 passive fibers in the femtosecond regime



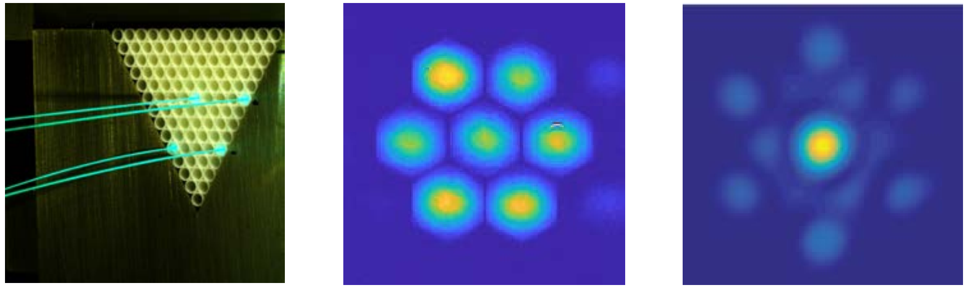
Laserlab Berlin spring 2017

- 49.5% combining efficiency
- 300 fs combined pulse
- λ/60 RMS phase stability

J.Le Dortz et al., "Highly scalable femtosecond coherent beam combining demonstrated with 19 fibers", Opt. Lett. 42, 1887-1890 (2017)

- First demonstration w/ 7 femtosecond high-power fiber amplifiers

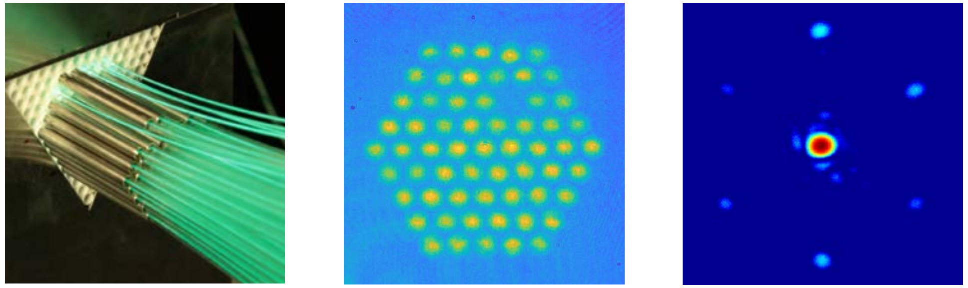
Laserlab Garching spring 2018



- 71 W @ 48% combining efficiency (55MHz) (46% @ B = 5 rad; 2 MHz)
- 216 fs combined pulse
- λ/55 RMS phase stability

A.Heilmann et al., "Coherent beam combining of seven fiber chirped-pulse amplifiers using an interferometric phase measurement" Opt. Exp. 26, 31542-31553 (2018)

- Scaling to 61 fibers

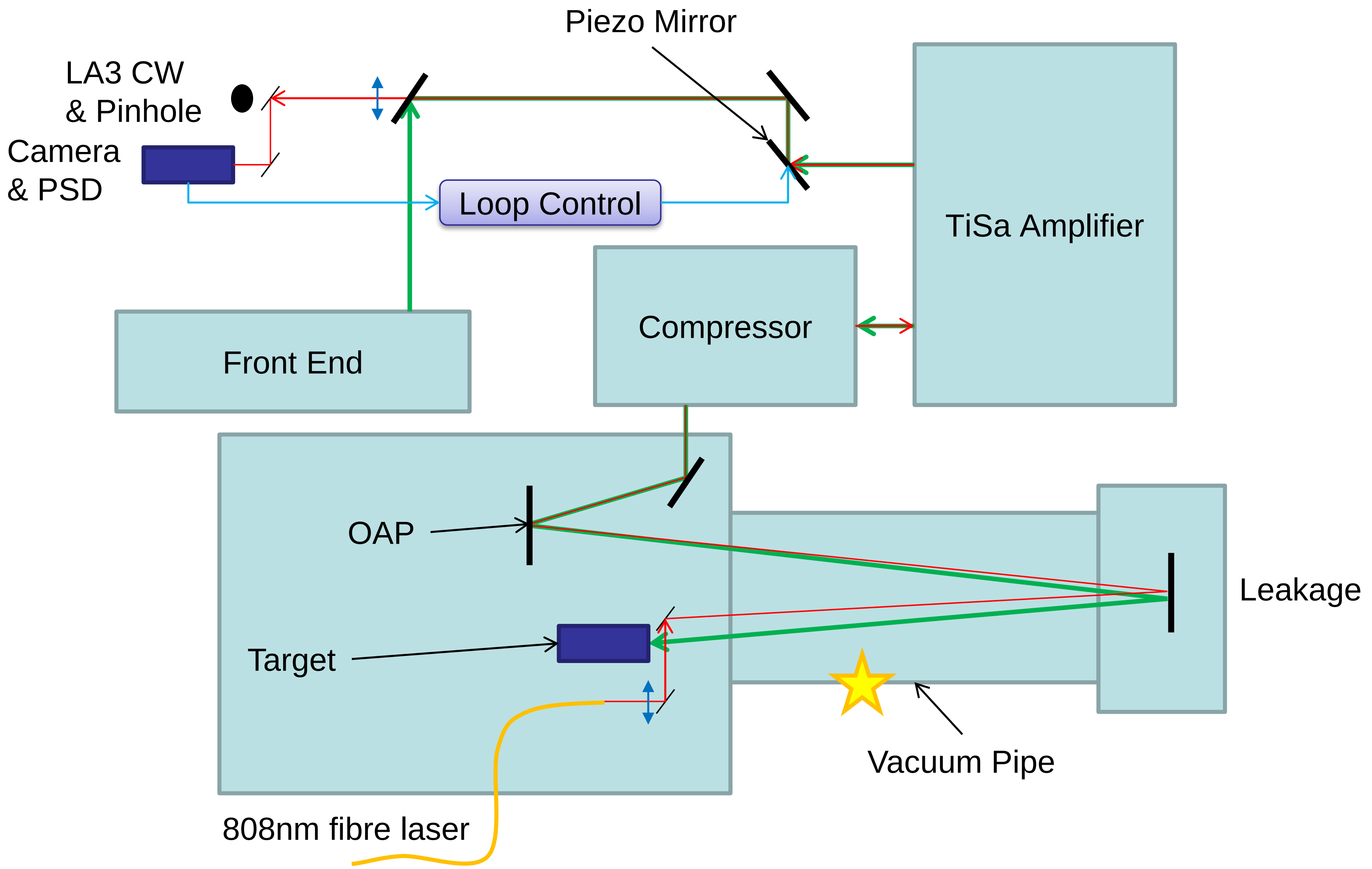


- 96 W @ 46% combining efficiency (55MHz)
- 221 fs combined pulse
- λ/100 RMS phase stability

Laserlab Florence Fall 2019

I.Fsaifes et al., "Coherent Beam combining of 60 femtosecond fiber amplifiers« ,Invited, Feb 4th, Photonic West, SF, CA, USA

7B - RAL, UK: Fast Pointing Beam Stabilisation on Gemini



8A - Thin-disc and volume laser based mid-IR sources

Development of thin-disk and volume laser based pump lasers

- Moderate repetition rates up to a few kHz.
- High energy up to a few hundred mJ.

Implementation of pump lasers in OPCPAs

- Demonstrate the potential of the developed laser sources as pumps for OPCPA systems.
- Develop mid-IR sources in the 1.6-2.7 μm and 5-10 μm ranges.
- Applications in the study of ultra-fast phenomena

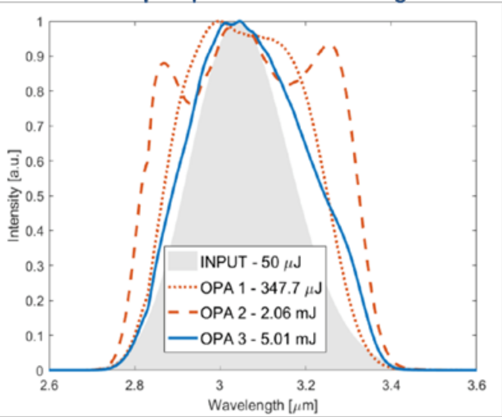
Highlights from: MPQ, IST, FVB-MBI

8B - Highlights: From pump development and OPCPA design to applications with mid-IR OPCPAs

Pump for OPCPA: Development of 100 mJ, 1030 nm Yb-based CPA completed. OPCPA design: KTA/MgO:LN based 5 mJ OPCPA at 3 µm.

3-stage OPA (2xMgO:LN+KTA)

Output spectrum for each stage



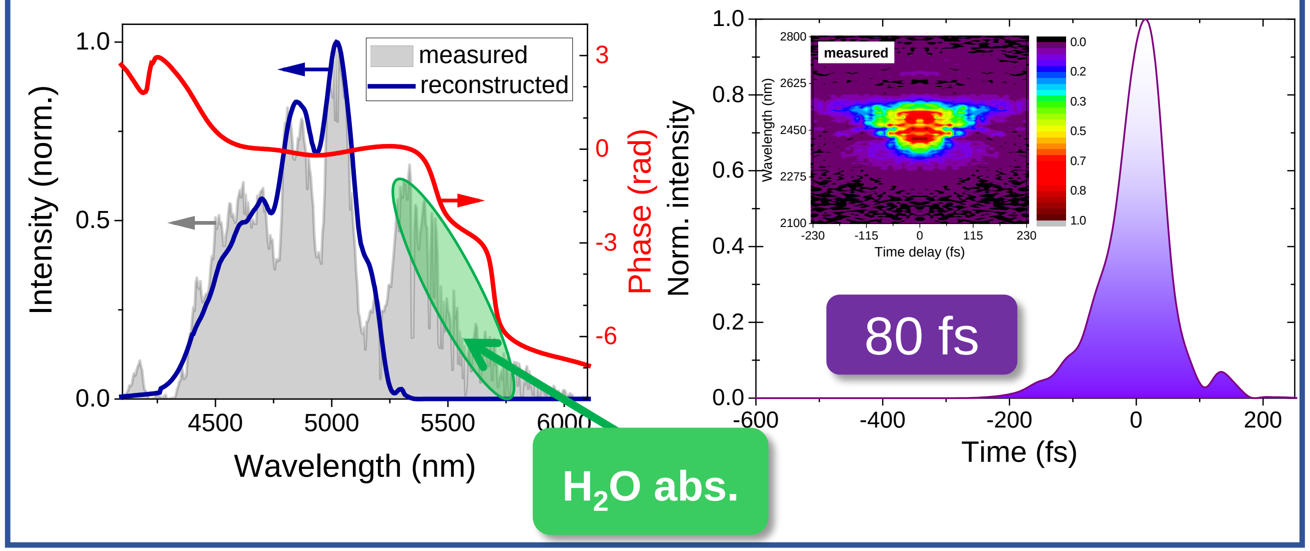
List of parameters used

Stage	OPA1	OPA2	OPA3
Crystal	MgO:LN	MgO:LN	KTA
Pump (mJ)	4	16	40
Length (mm)	3.6	2	1.4
θ (°)	46.7	46.7	41.6
α (°)	5.1	5.1	NC
Out energy (mJ)	**0.348**	**2.06**	**5.01**
Out FTL (fs)	**53**	**47**	**52**

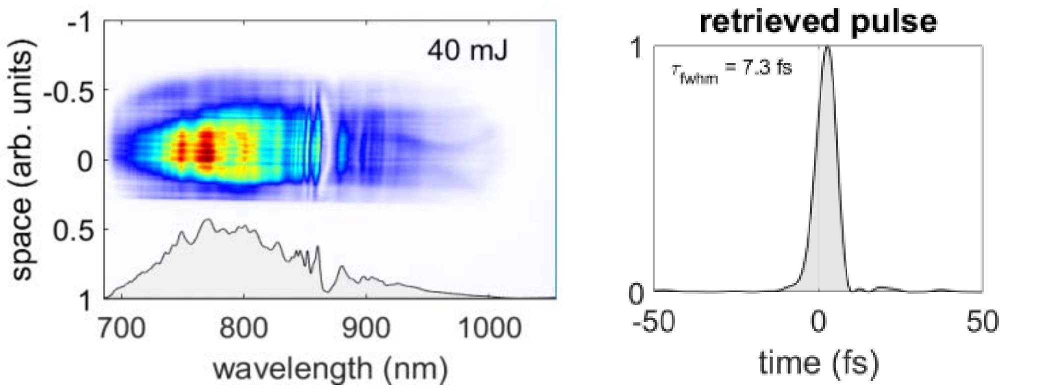
Output: 5 mJ (8.4% eff.), 52 fs

Combining MgO:LN and KTA allows preserving the bandwidth for multi-mJ pulses

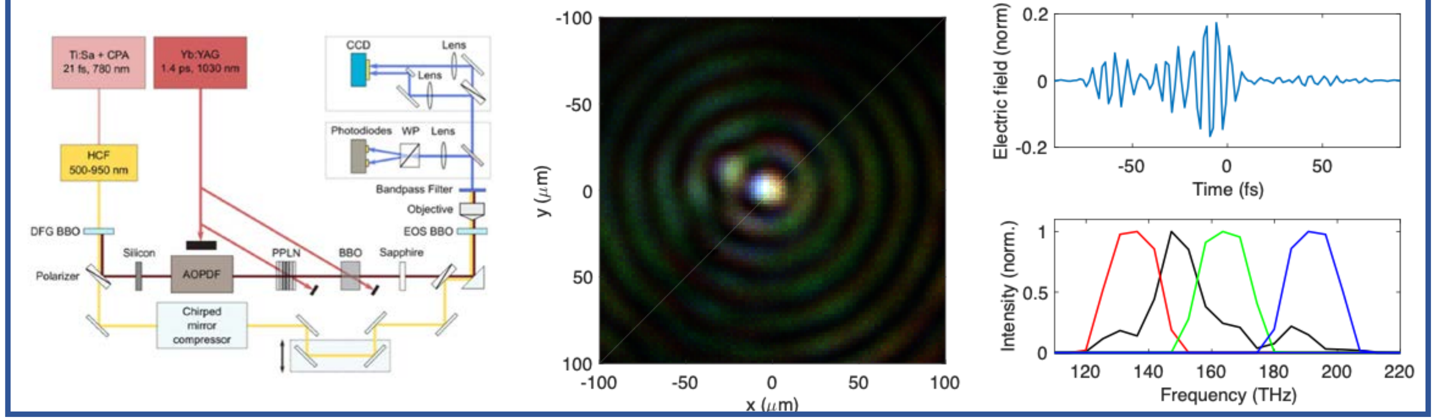
Pump for OPCPA: Development of 1 kHz, 55 mJ, 2 µm Ho-YLF CPA ZGP-based OPCPA : 3.2 mJ, 80 fs at 5 µm.



Pump for OPCPA: Development of 100 Hz, 300 mJ, 1030 nm Yb:YAG thin-disc amplifier. OPCPA : 40 mJ, < 8 fs at 800 nm.



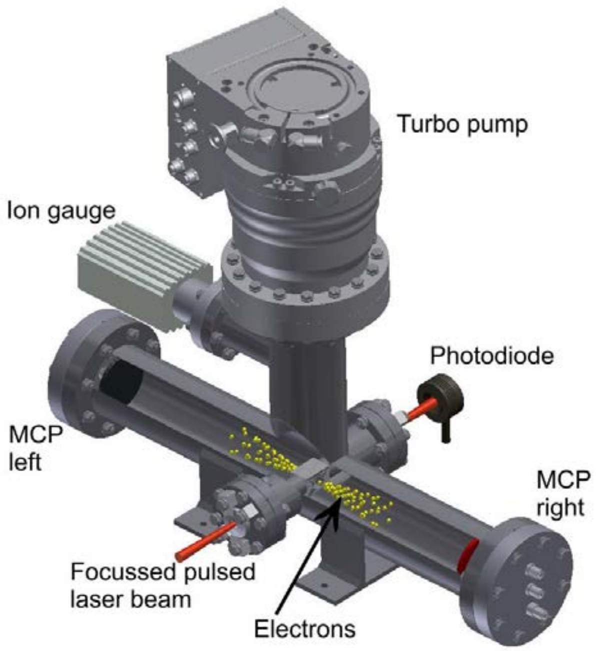
2 µm OPCPA pumped by Yb:YAG amplifier at 1030 nm. Application: spatially resolved electro-optical sampling of beam focused with metasurface axicon.



9A - High-repetition rate, single-shot, measurement of the Carrier-to-envelope (CEP) offset phase

Two main approaches for CEP measurements of amplified laser pulses exist.

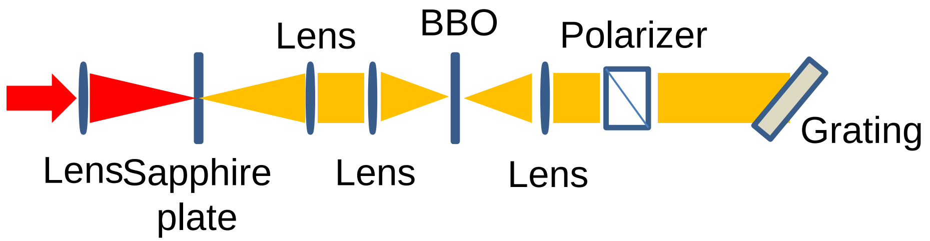
Stereo Above-Threshold Ionization (ATI)



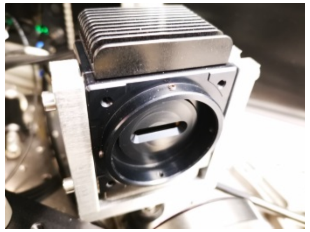
- Needs short pulses to be conclusive
- Complicated setup and analysis
- Absolute measurement

D. Hoff *et al*., Opt. Lett. **43**, 3850 (2018)

f-2f interferometry



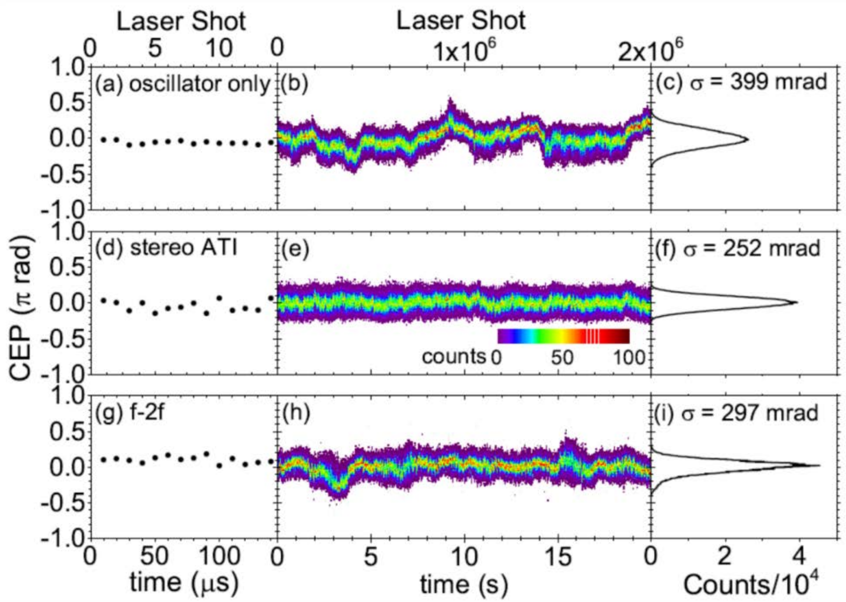
- Simple setup and analysis
- Octave-spanning spectrum required
- Indirect measurement
- Pulse energy to CEP coupling



200 kHz line camera as detector

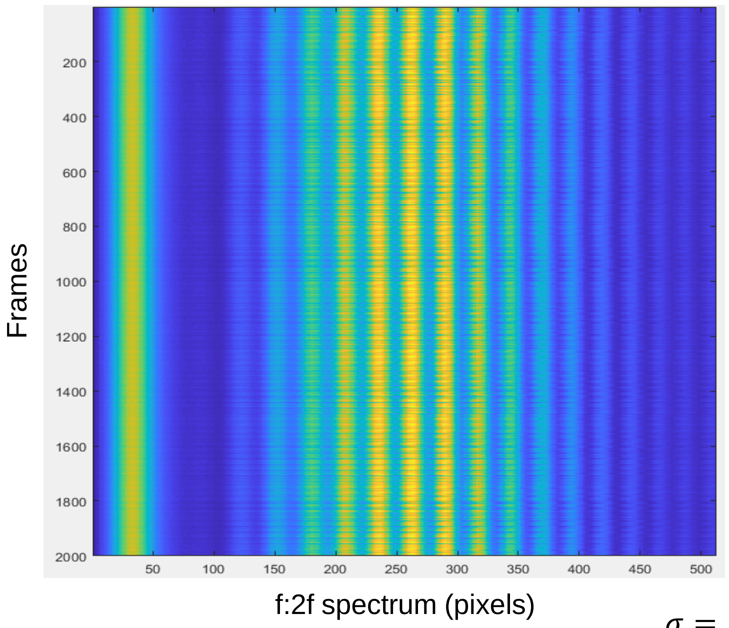
9B - Single-shot, full repetition rate CEP measurements performed in Lund and at MBI

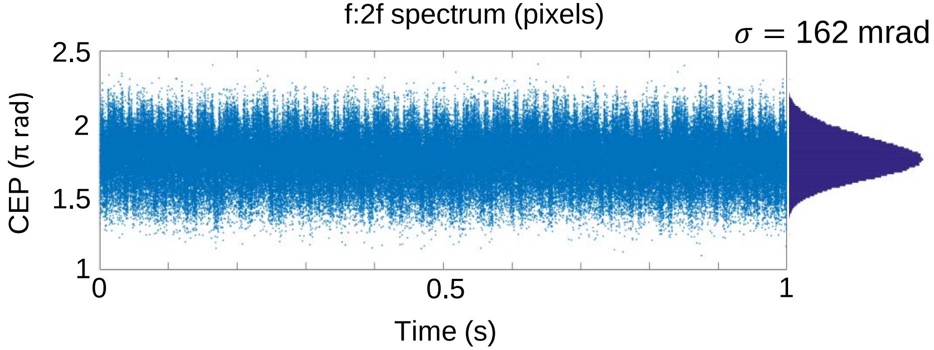
MBI OPCPA measured with Stereo ATI at 100 KHz



D. Hoff *et al*., Opt. Lett. **43**, 3850 (2018)

Lund OPCPA measured with f:2f spectrometry at 200 kHz





10A - Advanced Attosecond Working Stations for Material Science Studies

5 labs were involved

Laser Interactions and Dynamics Laboratory

Institut des Sciences Moléculaires d'Orsay

Institute of Electronic Structure & Laser FO.R.T.H. - I.E.S.L.

Technical University of Munich

Laboratoire d'Optique Appliquée

10B - Main Realisations

Finalized Plateforms

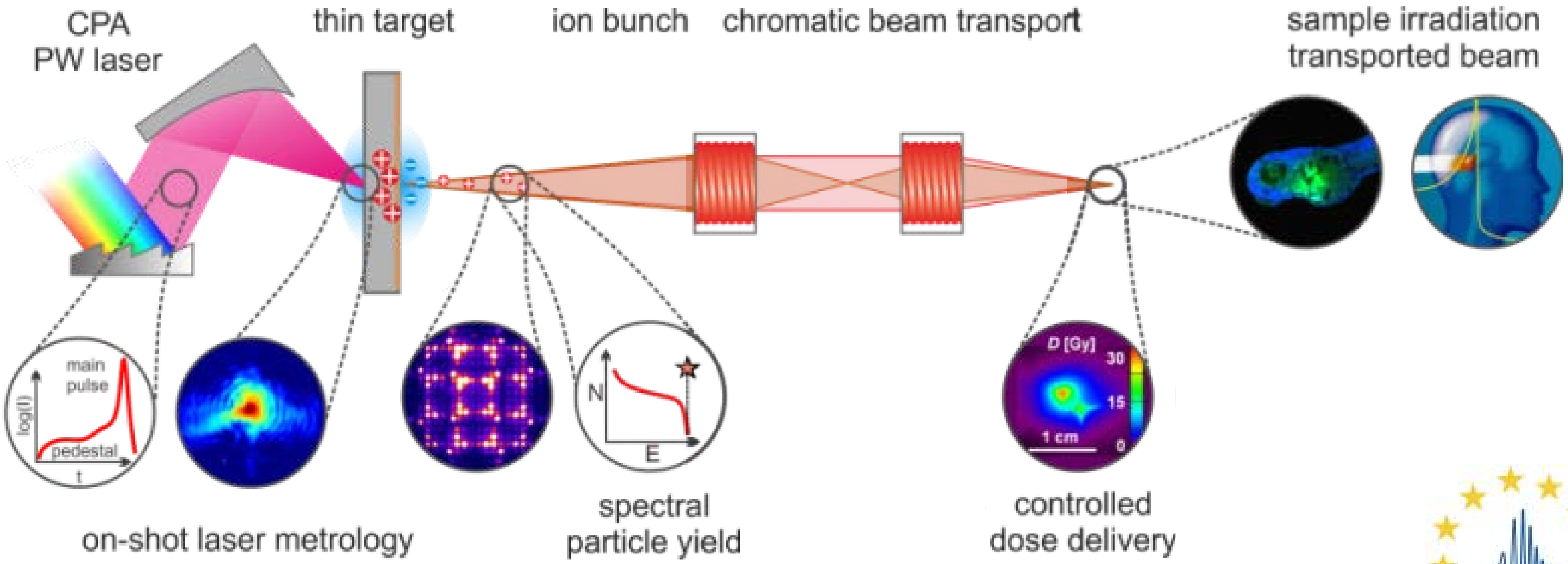
- **LIDYL : ATTOLAB completion : Two high rep-rate XUV-IR beamlines : 2 mJ@10Hz & 15 mJ&1KHz, 23 fs, CEP**
- **ISMO : COLTRIM End Station**
- **FORTH : Long focal High Orde Harmonics beam line**
- **TMU : Attosecond high photon flux beamline (moved from MPQ)**
- **LOA : TW-class, few-cycle pulse laser system at 1kHz**

Scientific Breakthrough (number of publication under preparation)

- **LIDYL : Revealing attoecond photoionization dynamics in Argon Cooper minimas**
- **ISMO : Angle resolved RABBIT: XUV+IR ionization of Ar and Ne**
- **FORTH : more than 0.7 ·10^{14} photons/pulse in XUV through HHG using a double jet**
  A. Nayak et al.,Multiple ionization of argon via multi-XUV-photon absorption induced by 20-GW high-order harmonic laser pulses, Phys. Rev. A ***98****, 023426*
- **TMU : First absolute ionisation time from Electrons in iodine sub-monolayers deposited on a tungsten substrate :** *Ossiander, M. et al. Absolute timing of the photoelectric effect. Nature* ***561,*** *374–377 (2018)*
- **LOA : CEP effects in High Charge MeV electron beams**

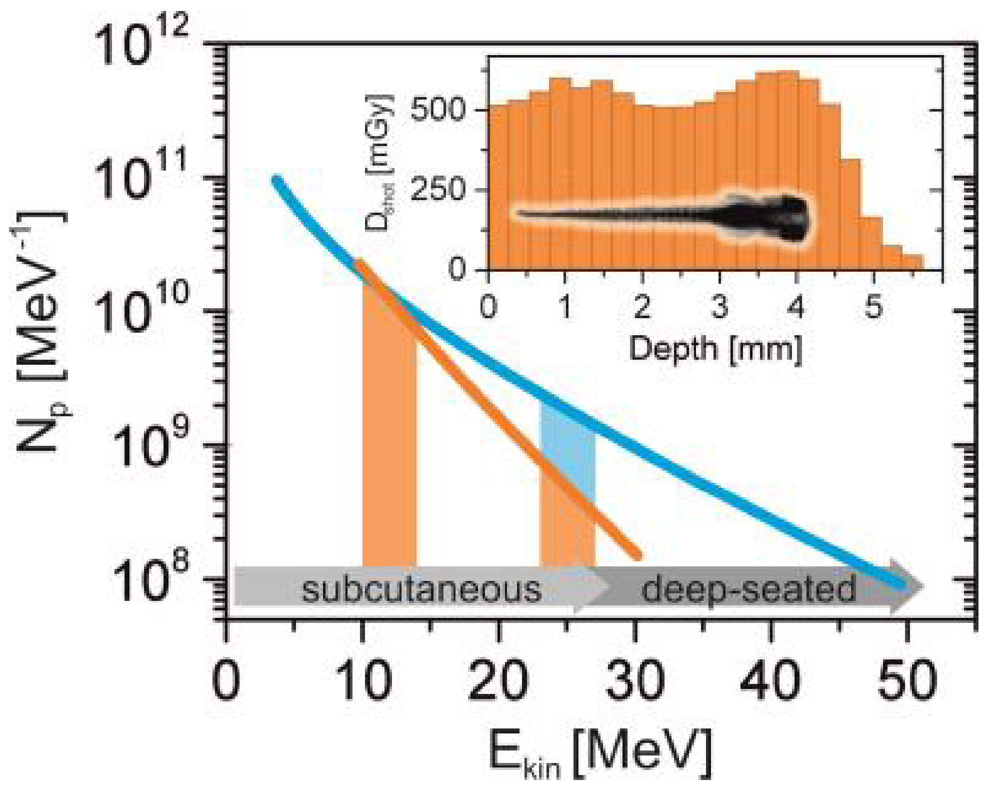
11A - Preparing laser accelerated proton beams for dose controlled irradiation studies

- *Demonstrate mature performance of a laser proton accelerator beyond 50 MeV*
- *Demonstrate controlled dose delivery (and metrology / dosimetry)*
- *Explore new regimes with unique source characteristics (dose rate effects)*



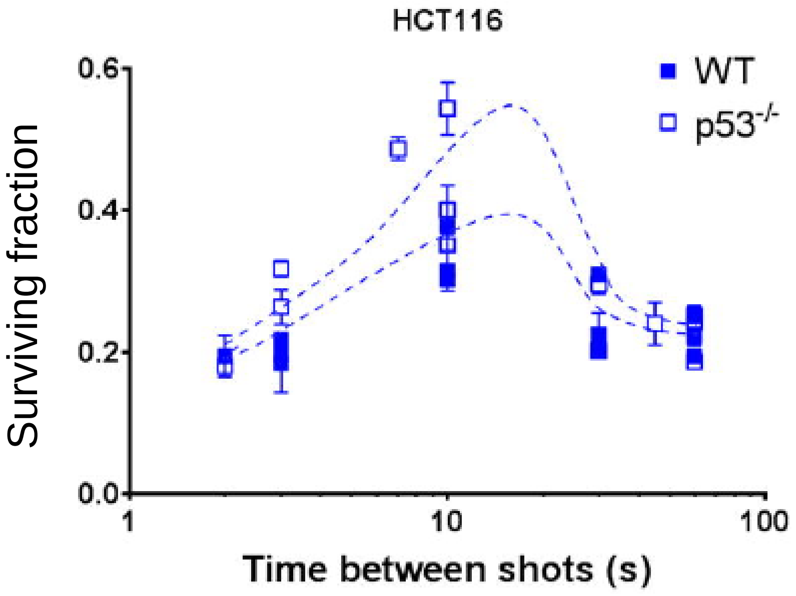
11B - Preparing laser accelerated proton beams for dose controlled irradiation studies

- Spatial and temporal pulse control
- Tailored plasma target conditions
- Complete online (on-shot) metrology
- Pulsed beam matching transport
- And pulsed beam dosimetry



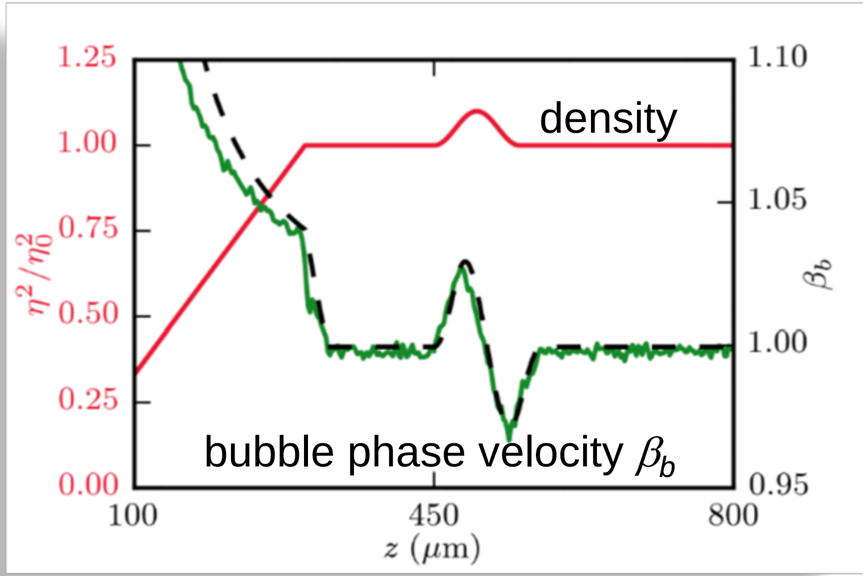
Example of energy increase by controlled target pre-expansion

Example of dose rate dependent tumor cell response



12A -Targetry

- Targets come in many forms: gas, liquid, solid, vacuum
- LASERLAB covers all bases
- Opportunities to collaborate – targets are used in almost all experiments – one group making a target for an experiment = joint activity
- One example of a joint activity: collaboration to develop a gas jet with an ultrashort density variation



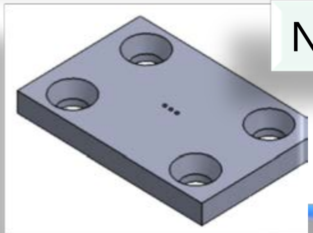
M.P. Tooley et al., PRL 2017

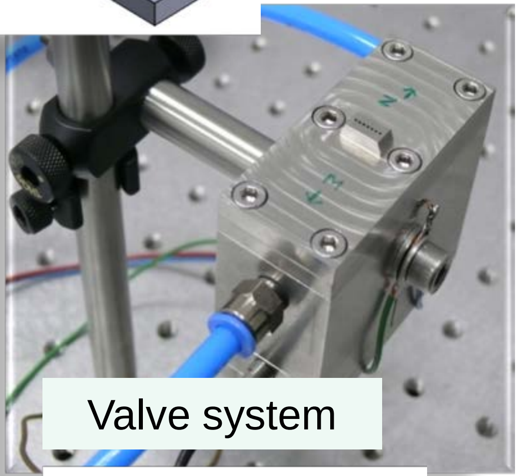
12B - MUT – STRATH collaboration: Elongated gas puff target with a profiled gas density profile for attosecond bunch injection

Motivation and aim:

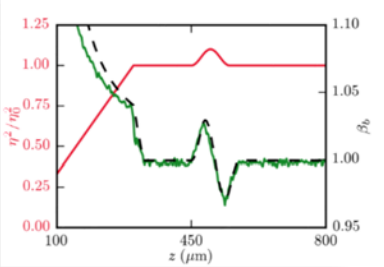
formation of target with a profiled gas density for laser-plasma attosecond electron bunch injection

Nozzle



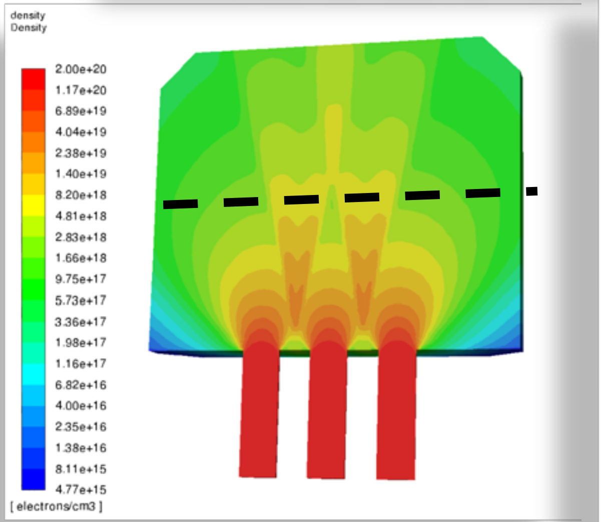


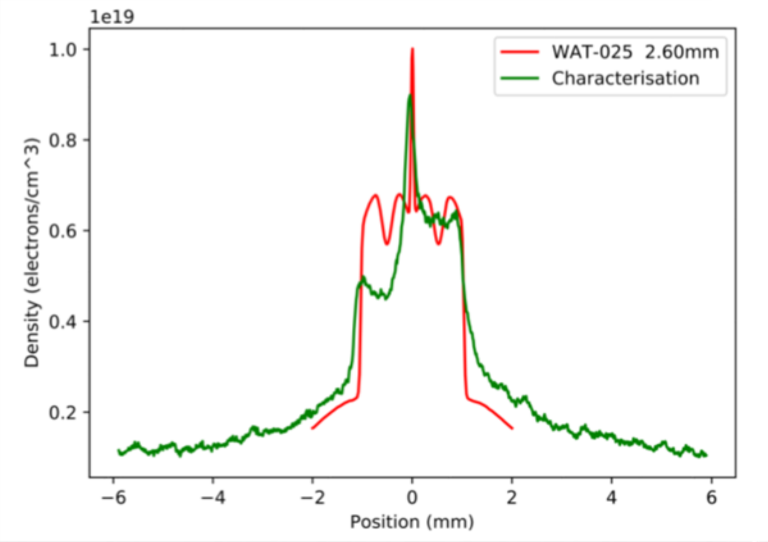
Valve system



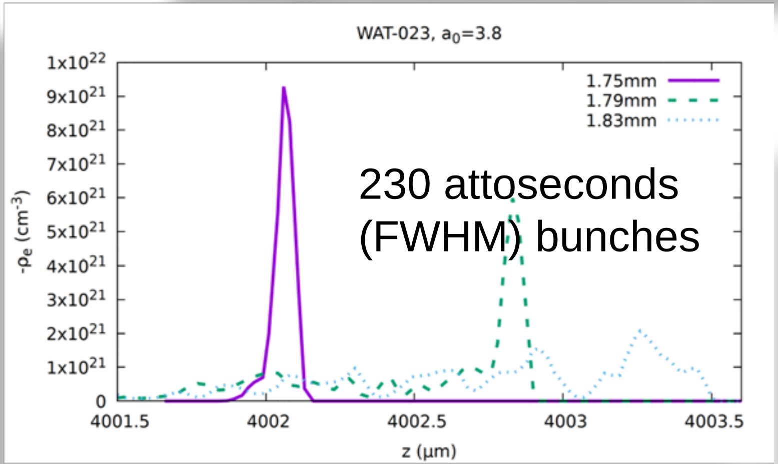
M.P. Tooley et al., PRL 2017

Numerical simulations performed at STRATH





Target characterization measurements at MUT



EUV shadograph