Introduction to ELI-ALPS Facility

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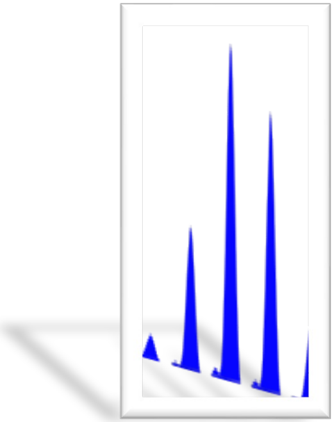
Head Secondary Sources division, ELI ALPS



Prague, 2023

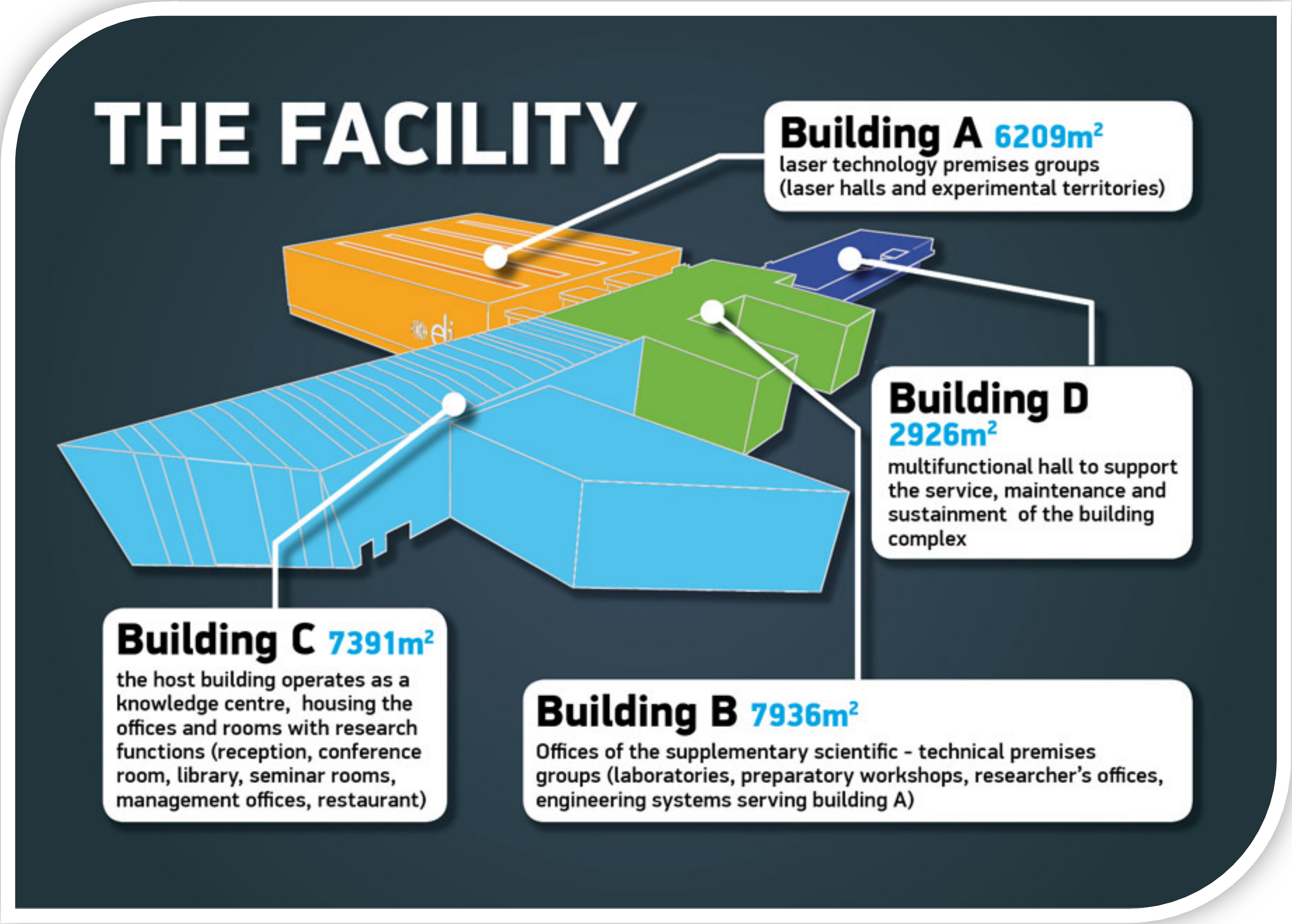
IMPULSE

SZÉCHENYI 2020
HUNGARIAN GOVERNMENT
European Union
European Regional Development Fund
INVESTING IN YOUR FUTURE

Outline

- Brief relevant overview: ELI-ALPS
- Ongoing related activity
- Potential development relevant to the project

ELI-ALPS


THE FACILITY
Building A 6209m²
laser technology premises groups
(laser halls and experimental territories)
Building D
2926m²
multifunctional hall to support the service, maintenance and sustainment of the building complex
Building C 7391m²
the host building operates as a knowledge centre, housing the offices and rooms with research functions (reception, conference room, library, seminar rooms, management offices, restaurant)
Building B 7936m²
Offices of the supplementary scientific - technical premises groups (laboratories, preparatory workshops, researcher's offices, engineering systems serving building A)

ELI ALPS Facility Layout

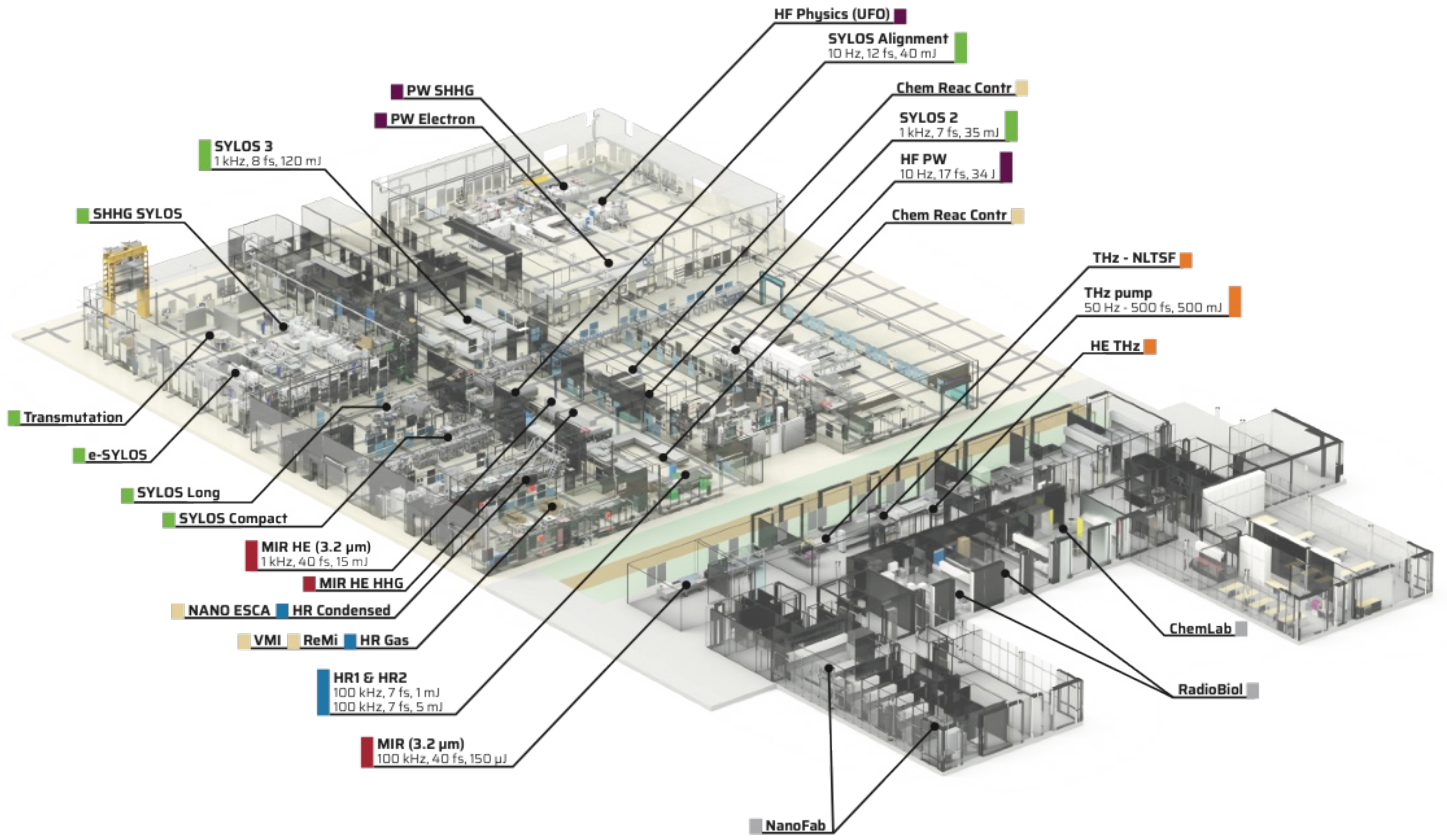
ELI ALPS

(Attosecond Light Pulse Source)

ELI ALPS is a leading research facility in ultrafast physical processes as well as a world-class centre for generating outstanding biological, chemical, medical and materials science results.

Research fields and applications:

- Development of attosecond light sources and measurement techniques
- Radiobiological applications
- Energy research: solar cells, artificial photosynthesis,
- High-peak-power photonics
- Information technology, materials science and nanoscience
- Particle acceleration with few cycle laser pulses



eli

Virtual tools

(b)

10^{12-14} → 10^{14-16} → 10^{16-17} → 10^{17-23}

Strong Field Solvers
SFA-Simulators
TDSE Solvers
Real Time-TDDFT

Ionisation, Strong field charge dynamics, Quantum non-perturbative processes

Hydrodynamic codes
ESTHER
MULTI-fs
CHIC
CRASH

Ionisation, Pre-Plasma formation, Plasma fluid expansion

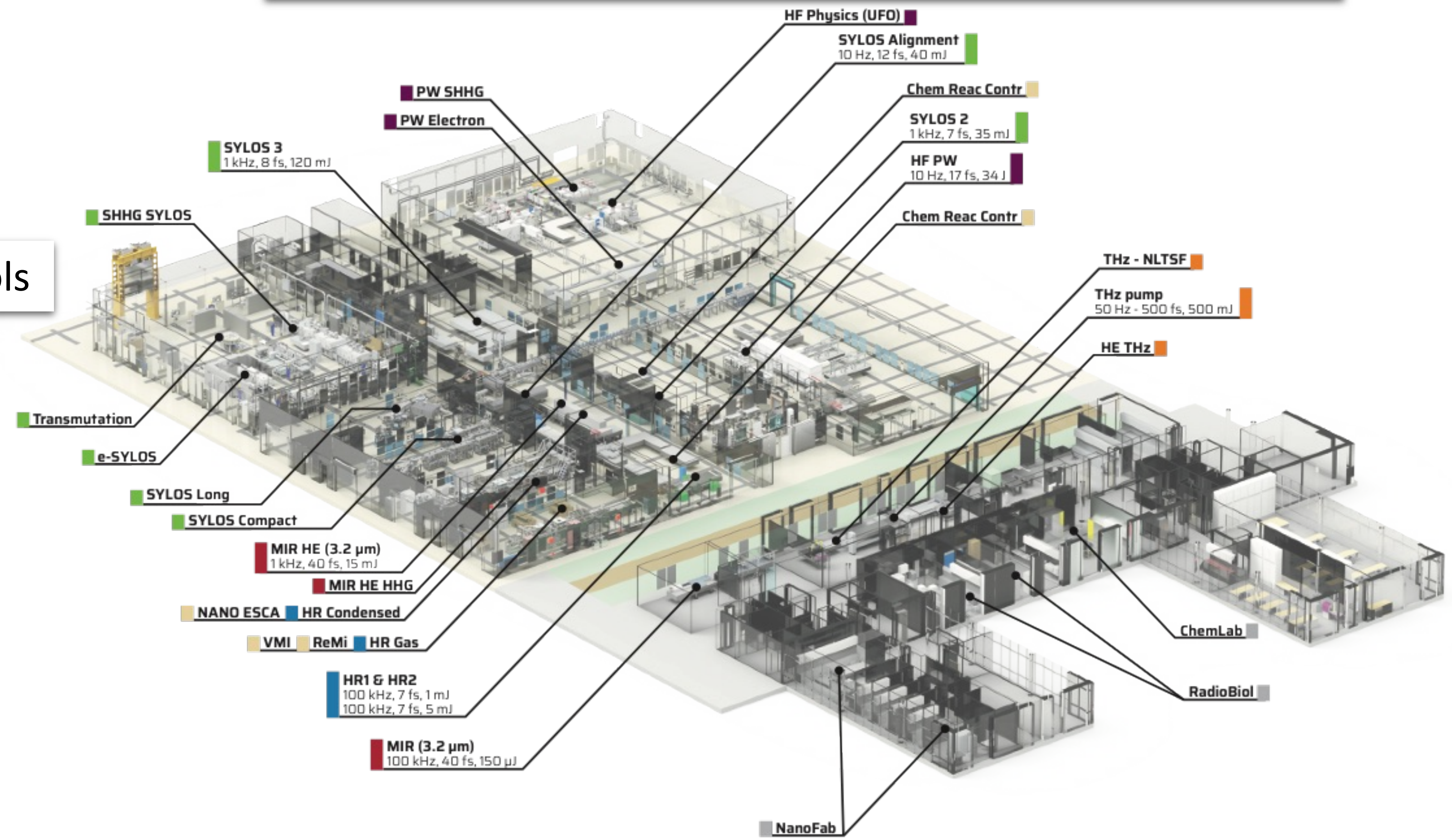
Particle In Cell (PIC)
WarpX
SMILIE/OSIRIS
EPOCH/CALDER
LPIC++
PIConGPU

Simplified PIC
WAKE
FBPPIC
CALDER-CIRC

Relativistic Charge dynamics (particle acceleration), Plasma field dynamics (absorption, HHG)

Simulation tools in intense ultrafast laser matter interaction

Real tools

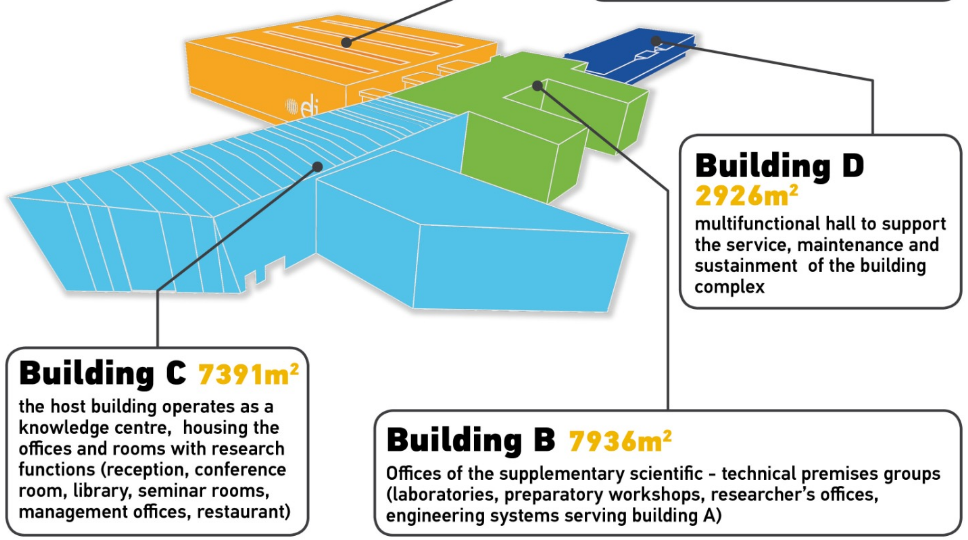


Experiments

- Material science and recollision physics in generation medium
- Ultrafast semiconductor optoelectronics
- Ultrafast material change
- Plasma optics
- Laser accelerator physics
- Attosecond resolved plasma physics
- Attosecond collective phenomena
- Tomography and imaging
- Flash Radiobiology with e and high energy THz
- Strong field quantum optics
- Pump probe attosecond physics
- Intense nano-photonics
- The micro macro connection

……In gas-solid-liquid-plasma and designed matter

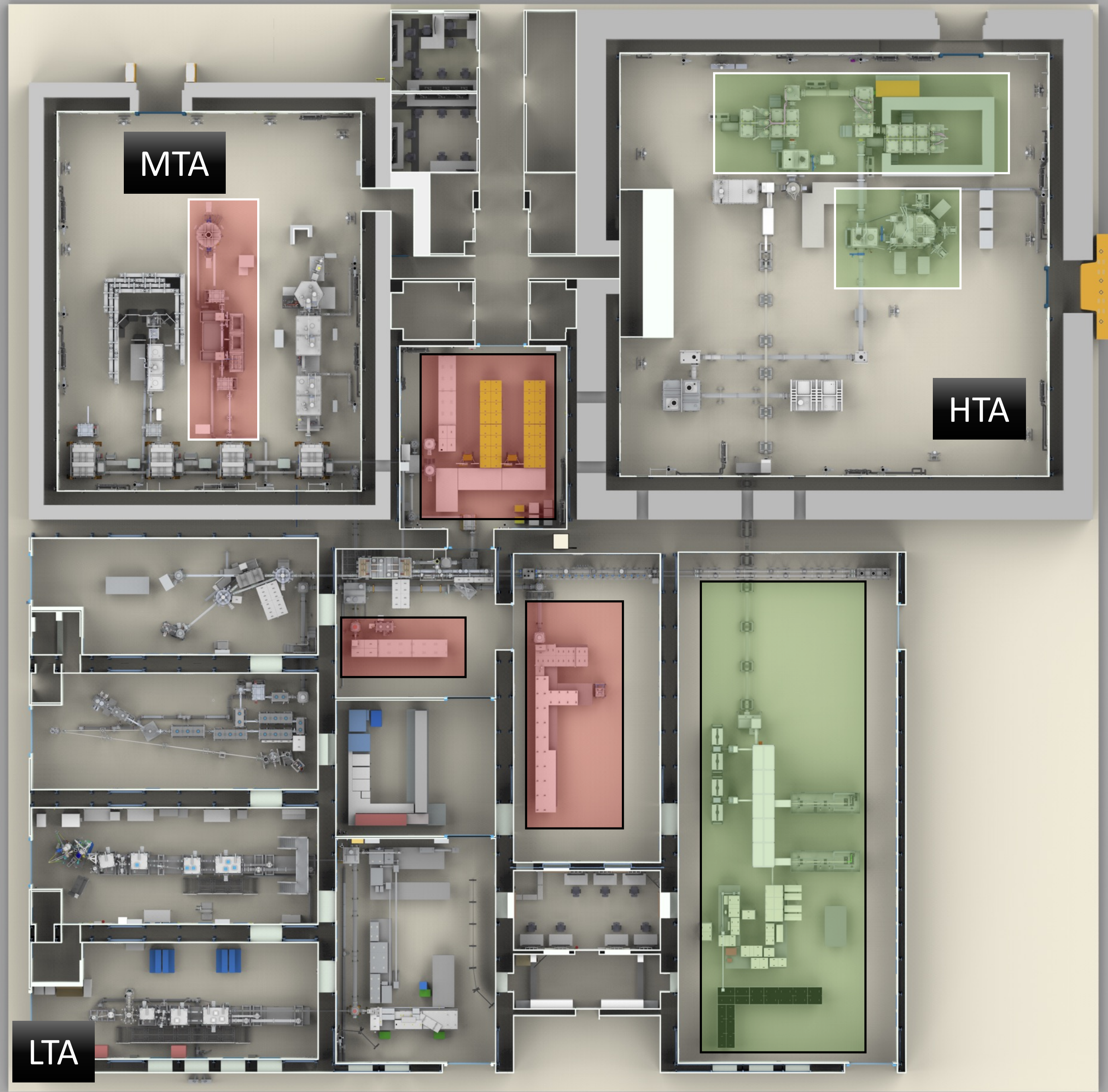
THE FACILITY



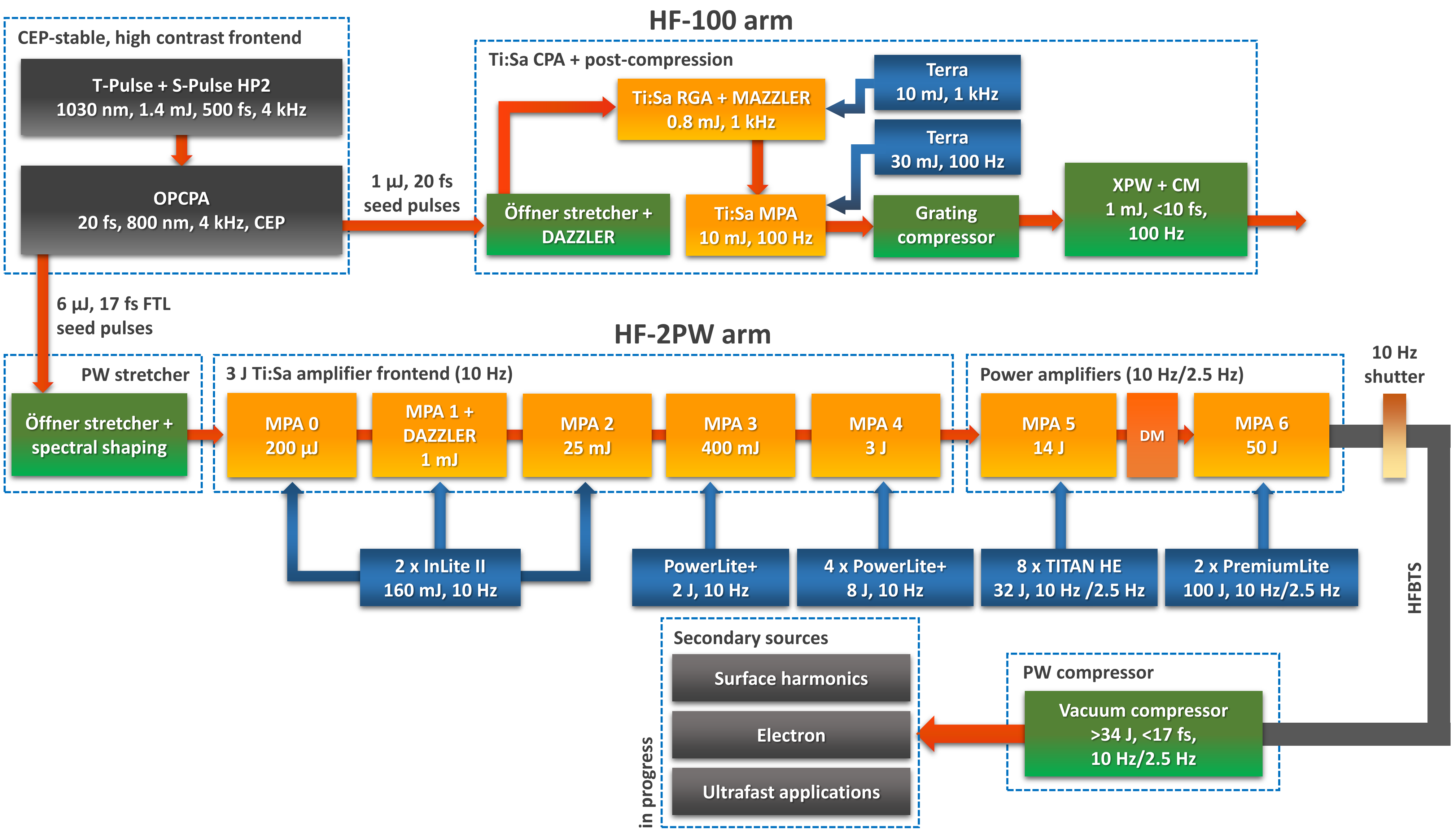
LASER SOURCES		SECONDARY SOURCES
HR1 100 kHz, 6.5 fs, 1 mJ, CEP 250 mrad	HR Beam Delivery	Atto1: GHHG HR
HR2 100 kHz, 6.5 fs, 5 mJ, CEP 250 mrad		Atto2: GHHG HR
SYLOS AL 10 Hz, 12 fs, 40 mJ	SYLOS Beam Delivery	Atto3: GHHG SYLOS
SYLOS2 1 kHz, 7.5 fs, 30 mJ, CEP 250 mrad		Atto4: GHHG SYLOS
SYLOS3 1 kHz, 8 fs, 120 mJ, CEP 250 mrad		Atto5: SHHG SYLOS
		Particle1: e^- SYLOS
MIR 3.2 µm, 100 kHz, 40 fs, 0.15 mJ, CEP 100 mrad		
MIR HE 3.2µm, 1kHz, 40fs, 15mJ, CEP 150mrad		Atto6: HHG MIR
HF PW 2 PW, 10 Hz, 17 fs, 34J	HF Beam Delivery	Atto7: SHHG HF
		Particle2: e^- HF
THzP 50 Hz, 0.5 ps, 0.5J / 1 kHz, 100 fs, 4 mJ	THz Beam Delivery	THz1: spectroscopy
NLTSF pump 1 kHz, 200 fs, 6 mJ		THz2: high energy

EXPERIMENTS

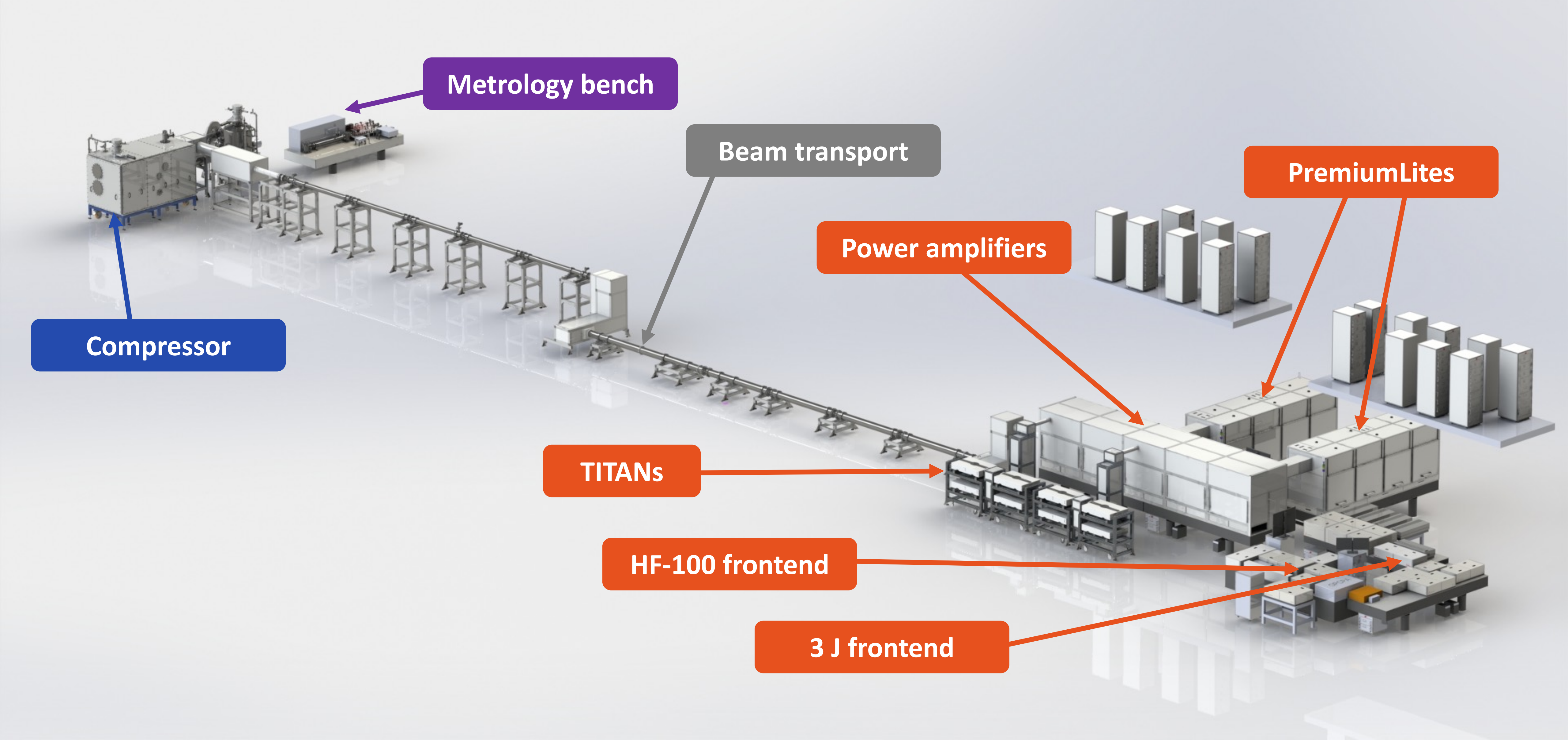
- Attosecond studies in atomic and molecular dynamics
- Condensed matter physics
- Nanophysics, materials science
- High resolution imaging
- Source development and metrology
- Plasma physics
- Radiobiology
- THz spectroscopy



HIGH FIELD LASER: SCHEMATIC VIEW



HIGH FIELD LASER: IN REALITY



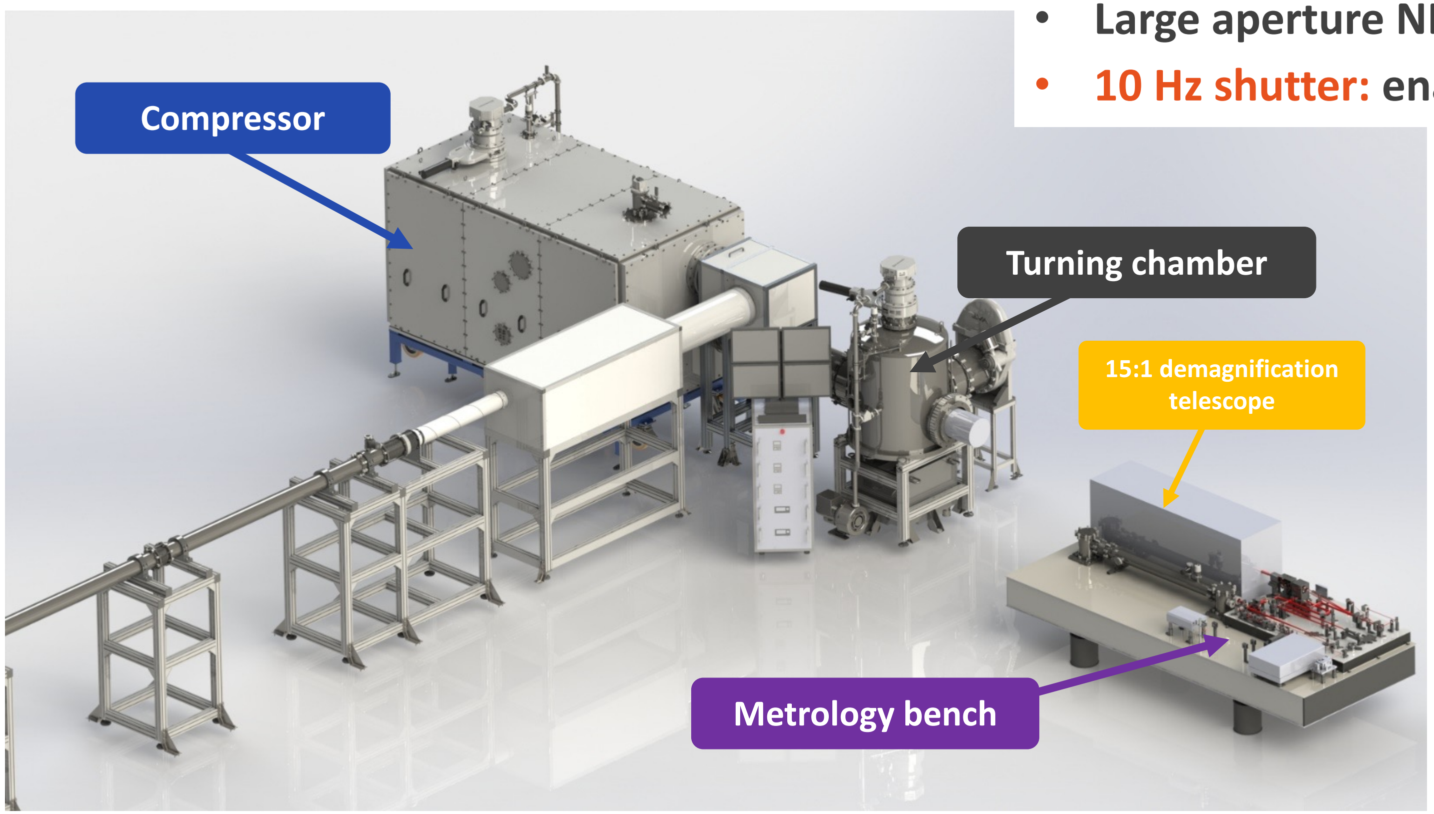
COMPRESSOR AREA AND IN-HOUSE DEVELOPMENTS

Operation modes

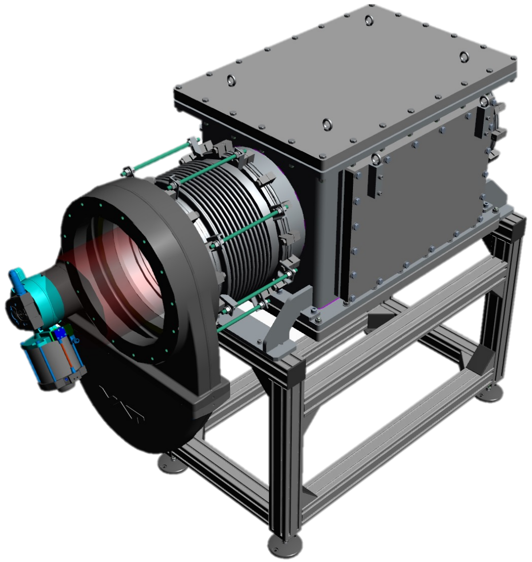
- **Mode 1:** turning mirror IN
- **Mode 2:** turning mirror OUT

In-house developments

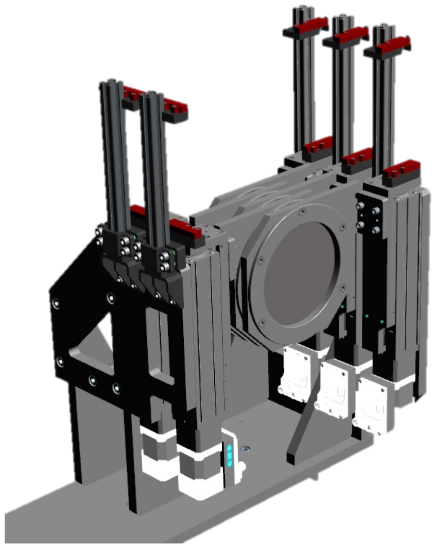
- **Diode laser for co-alignment:** usable for exp. beamlines
- **PW beam dump**
  - Designed for 10 Hz operation @ >34 J pulse energy
  - Tested @ 10 J and 10 Hz for >2 hours
- **Large aperture ND filter stage:** for low energy alignment pulses
- **10 Hz shutter: enabling single shot from 10 Hz or 2.5 Hz!**



PW beam dump



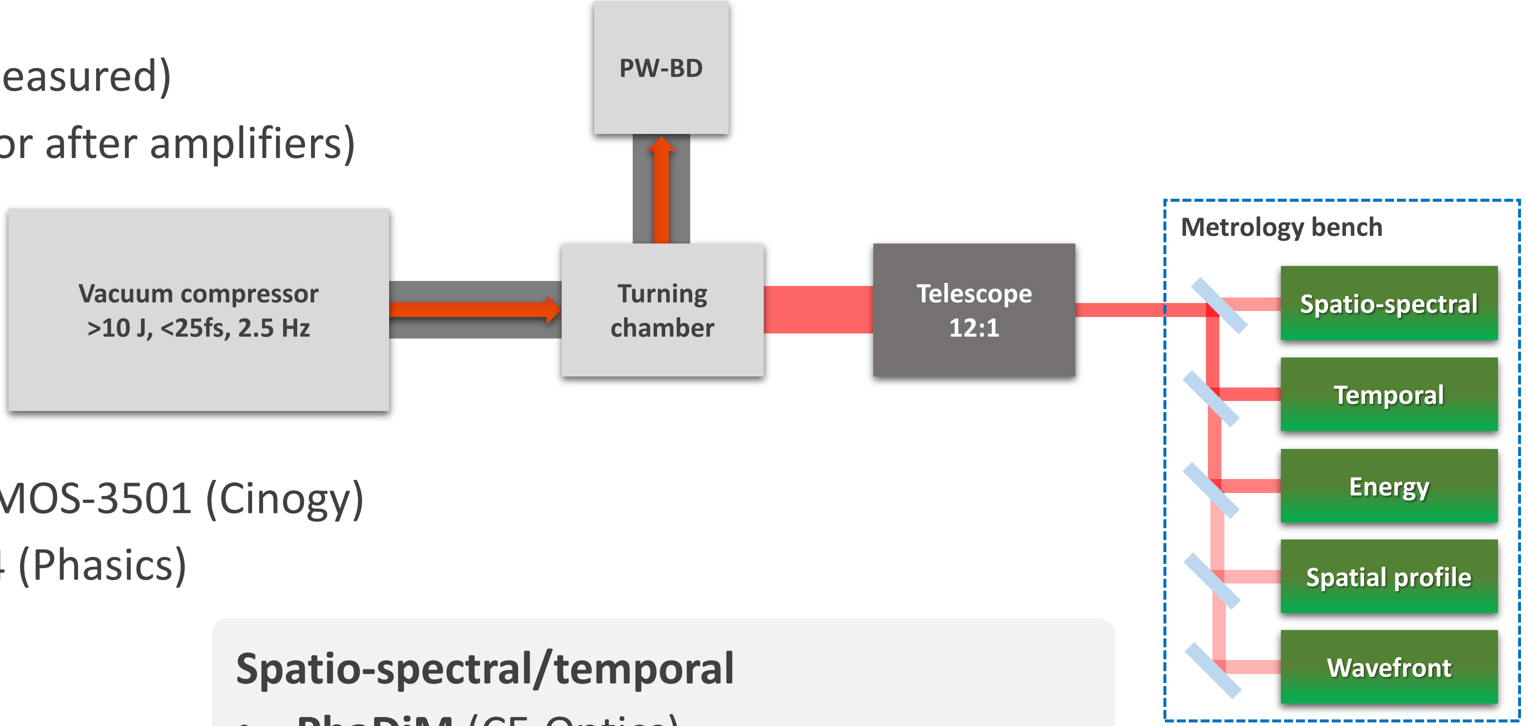
ND filter stage



METROLOGY

Operation modes

- **Mode 1:** turning mirror IN (transmitted pulses measured)
- **Mode 2:** turning mirror OUT (reflective attenuator after amplifiers)



Diagnostics

Spatial

- **High resolution cameras:** CMOS-1.001-Nano, CMOS-3501 (Cinogy)
- **Wavefront sensor:** HASO4 (Imagine Optic), SID4 (Phasics)

Temporal

- **Wizzler** (Fastlite)
- **SEQUOIA** (Amplitude)
- **D-shot R** (Sphere Ultrafast Photonics)
- **Tundra+** (UFI)
- **SEQUOIA HD 2nd gen** (Amplitude, from Q2 2024)

Spatio-spectral/temporal

- **PhaDiM** (CE-Optics)
- **Insight broadband** (SourceLab)
- **Sphere ICE** (Sphere UP, from Q1 2024)
- **MISS-L-B** (FemtoEasy)

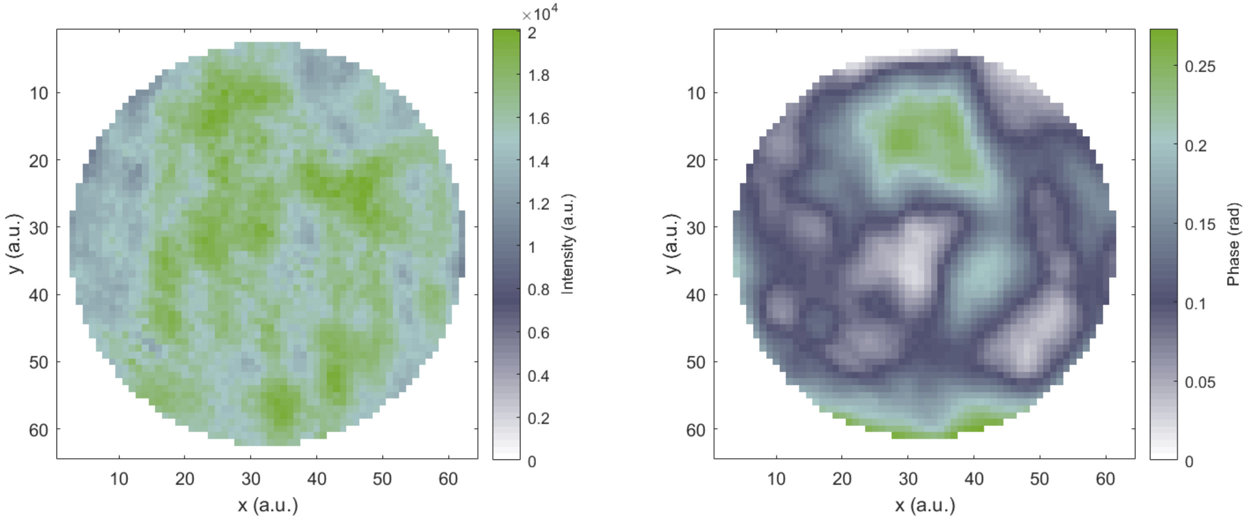
SPATIAL AND TEMPORAL QUALITY

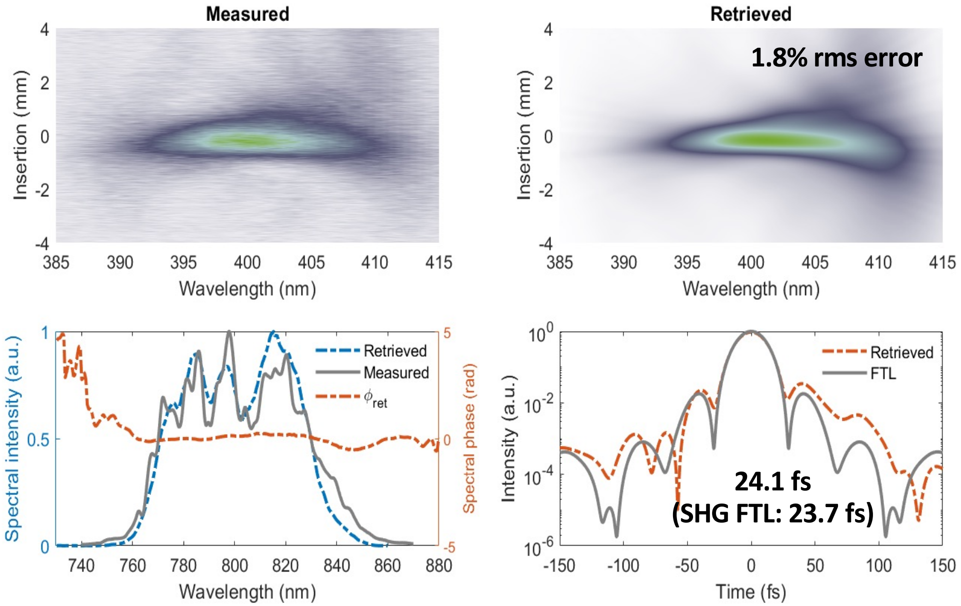
Wavefront

- **Device:** SID4 (Phasics)
- **Measurement location:** in metrology bench
- **Strehl ratio: 0.9** (@1/e^2) @ 10 Hz & 2.5 Hz

Temporal characterization

- **Device:** D-shot R (Sphere Ultrafast Photonics)
- **Measurement location:** collimated beam in metrology bench after NF spatial filtering

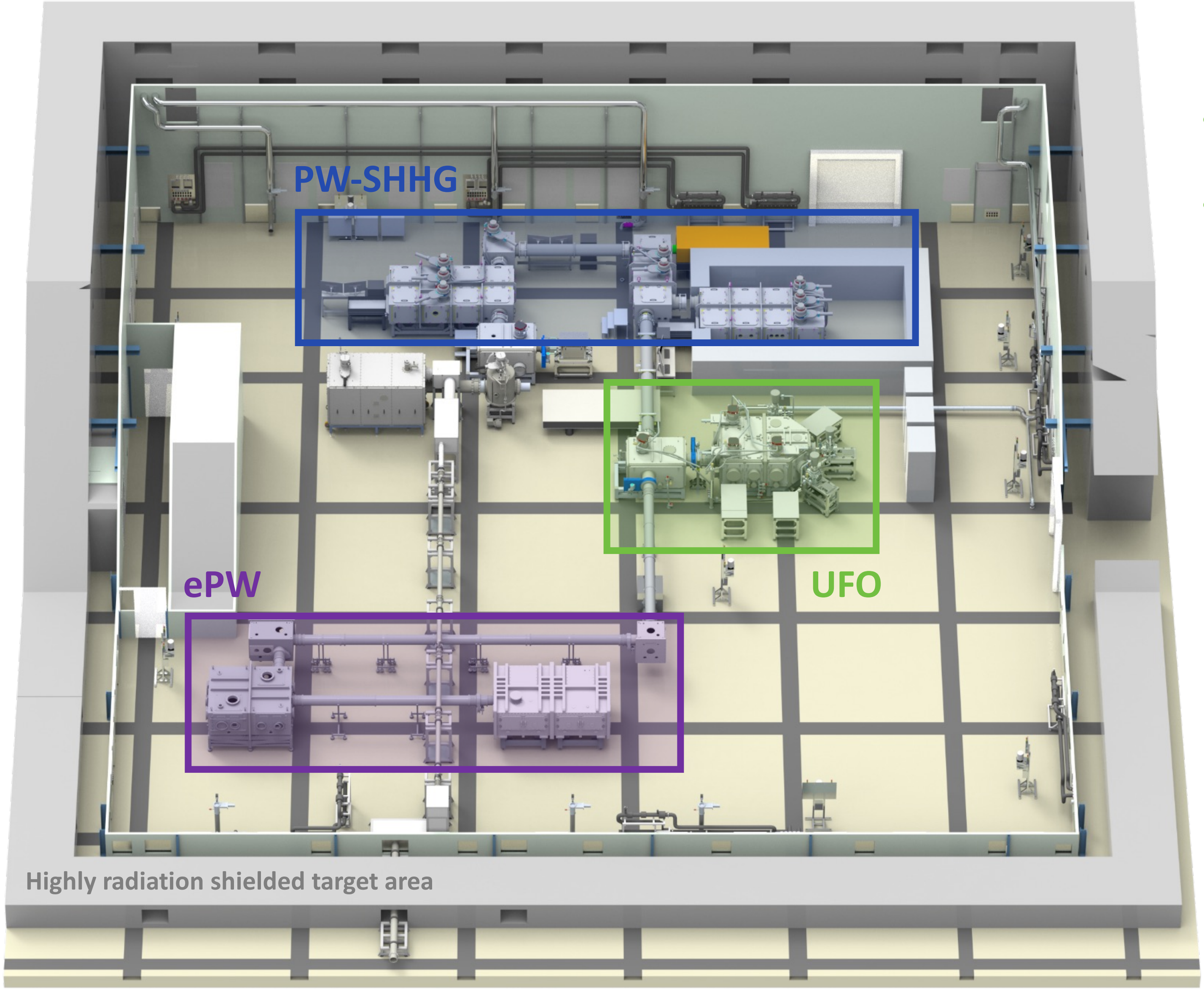




EXPERIMENTAL BEAMLINES IN HTA

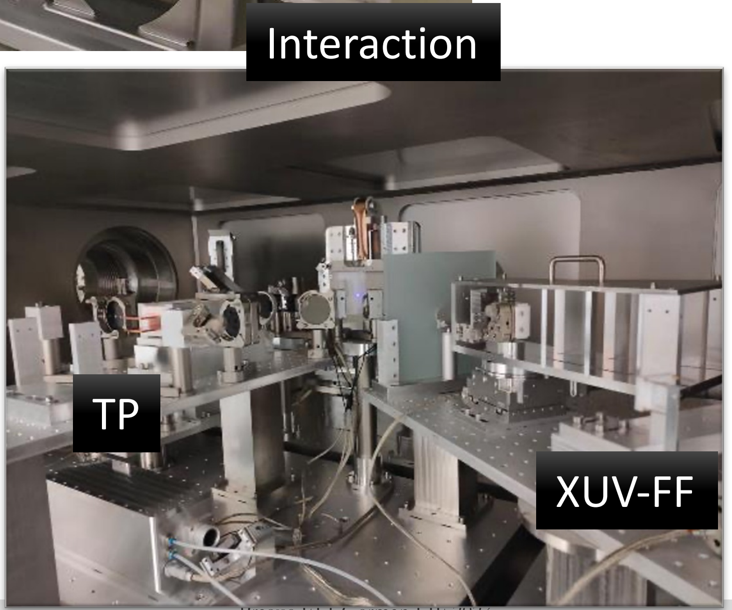
PW-SHHG
- Plasma mirror contrast cleaning
- **Multi-mJ atto** pulses

ePW
- Plasma mirror contrast cleaning
- **Electron:** GeV+
- **X-ray:** 20 keV+



UFO
- Plasma mirror contrast cleaning
- Versatile experimental end-station

SHHG HF PW



TP: Thomson parabola
XUV-FF: Flat field spectro

S. Mondal et.al. ''Surface plasma attosource beamlines at ELI-ALPS'' *JOSA B* **35**, A93 (2018)
https://doi.org/10.1364/JOSAB.35.000A93

O. Jahn et.al. ''Towards intense isolated attosecond pulses from relativistic surface high harmonics'' *Optica* **6**, 280 (2019)
https://doi.org/10.1364/OPTICA.6.000280

A. Nayak et. al. ``Saddle point approaches in strong field physics and generation of attosecond pulses'' *Physics Reports* **833**, 1-52 (2019)
https://doi.org/10.1016/j.physrep.2019.10.002

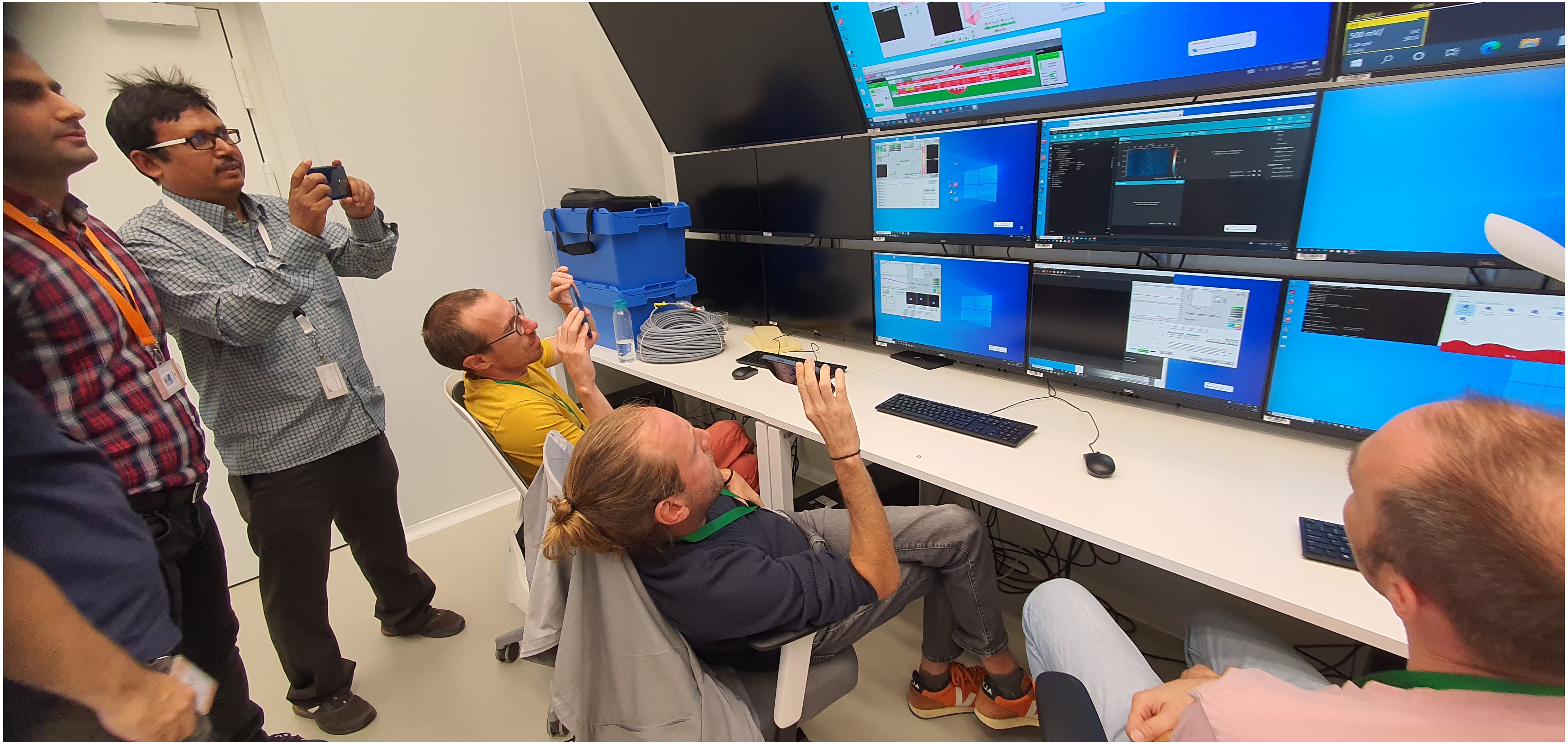
S. Mondal ``Ultrafast Plasma Electron Dynamics: A Route to Terahertz Pulse Shaping'' *Phys. Rev. Applied* **13**, 034044 (2020)
https://doi.org/10.1103/PhysRevApplied.13.034044

T. Lamprou et. al. ``Quantum-Optical Spectrometry in Relativistic Laser–Plasma Interactions Using the High-Harmonic Generation Process: A Proposal'' *Photonics* **8(6)**, 192 (2021)
https://doi.org/10.3390/photonics8060192

S. Mondal ``Intense isolated attosecond pulses from two-color few-cycle laser driven relativistic surface plasma'' *Sci. Rep.* **12**, 13668 (2022)
https://doi.org/10.1038/s41598-022-17762-3

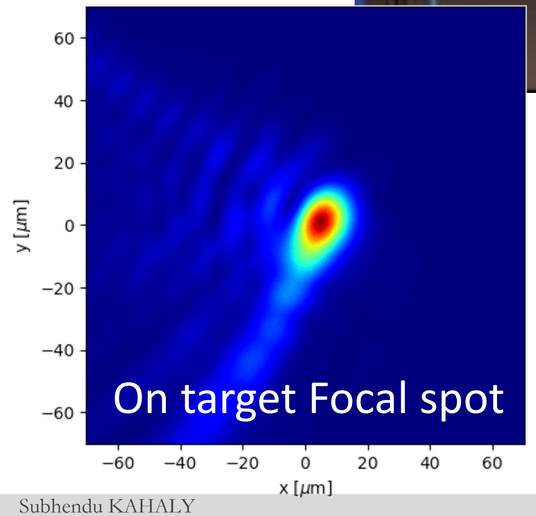
S. Choudhary ``Controlled transition to different proton acceleration regimes: near-critical density plasmas driven by circularly polarized few cycle pulse'' In Print *Matter Radiat. Extremes* (2023)
https://doi.org/10.48550/arXiv.2303.12121

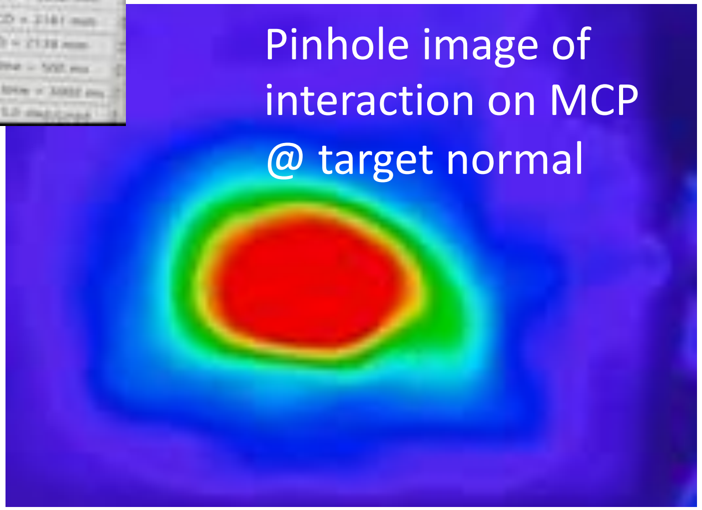
27th September 2023: 1st ever HF Laser shot on solid target in SHHG HF…..Control room



SHHG HF PW

- 4 J on target
- No DM on the laser side (damaged)
- Quick test with crude alignment
- Single shot mode tested with laser@2.5 Hz
- Target motion
- Trigger functioning tested
- CC tested

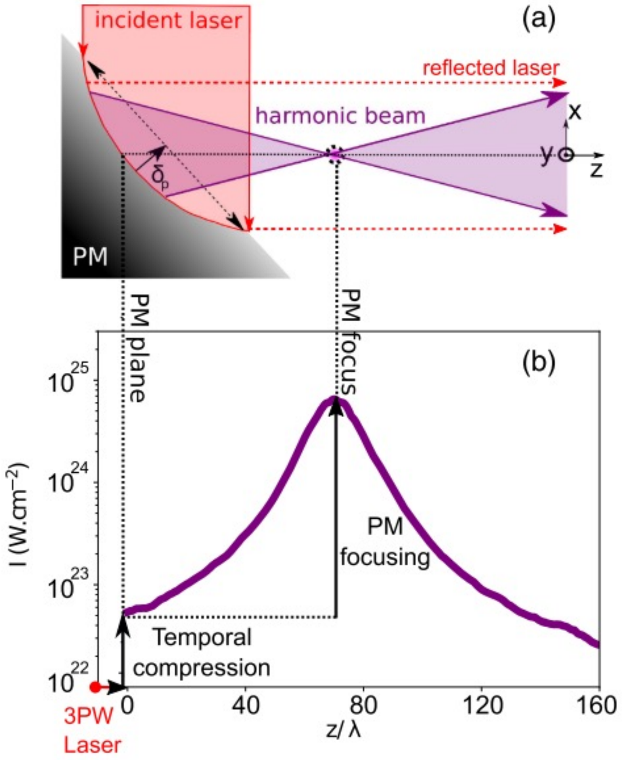




27th September 2023: 1st HF Laser few practice
Shooting on solid target in SHHG HF

Matter under extreme intensity with PM

(otherwise unattainable with the currently available laser technology)



PHYSICAL REVIEW LETTERS 123, 105001 (2019)

Achieving Extreme Light Intensities using Optically Curved Relativistic Plasma Mirrors

Henri Vincenti*
LIDYL, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91 191 Gif-sur-Yvette, France

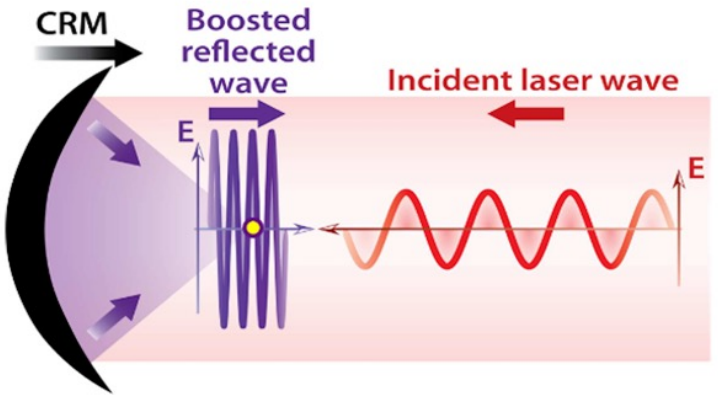


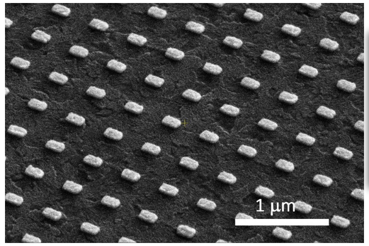
Figure 1. Sketch of principle of a CRM boosting the *E*-field of a light wave. The yellow dot indicates the CRM focus in vacuum.

High Power Laser Science and Engineering, (2021), Vol. 9, e6, 13 pages.
doi:10.1017/hpl.2020.46
HIGH POWER LASER SCIENCE AND ENGINEERING

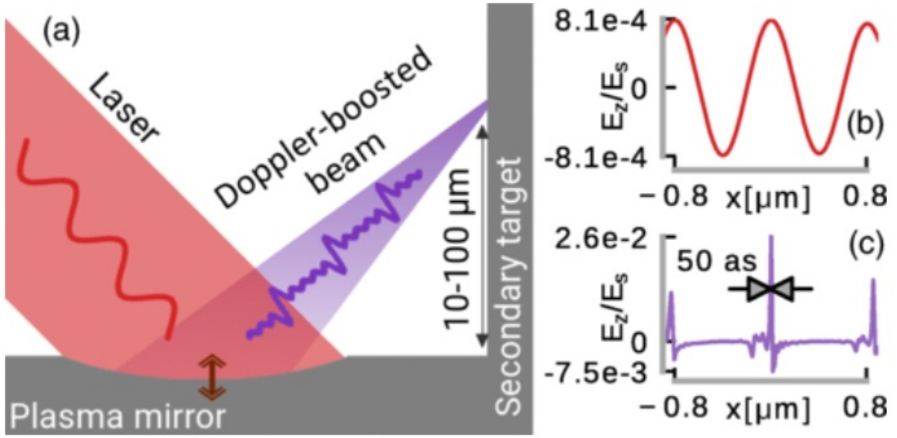
PERSPECTIVE

Reflecting petawatt lasers off relativistic plasma mirrors: a realistic path to the Schwinger limit

Fabien Quéré and Henri Vincenti
LIDYL, CEA-CNRS, Université Paris-Saclay, 91191 Gif-sur-Yvette, France
(Received 8 November 2020; accepted 18 November 2020)



FIB, EBL Nanofabrication unit, optoelectronical sample preparation, condensed matter analysis

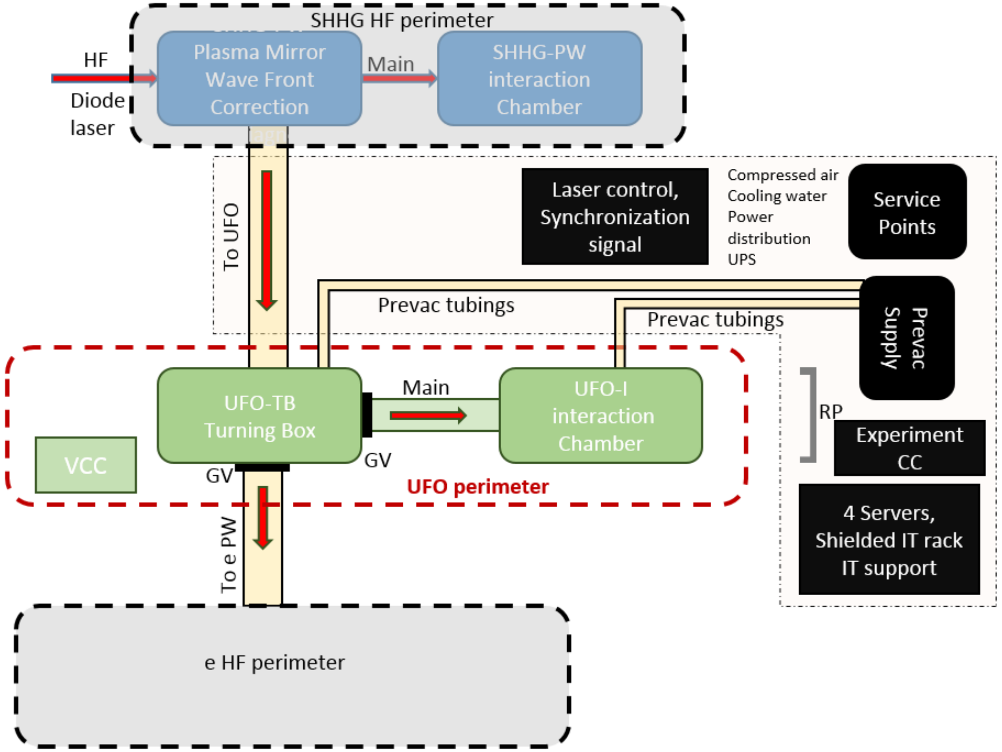


Probing Strong-Field QED with Doppler-Boosted Petawatt-Class Lasers

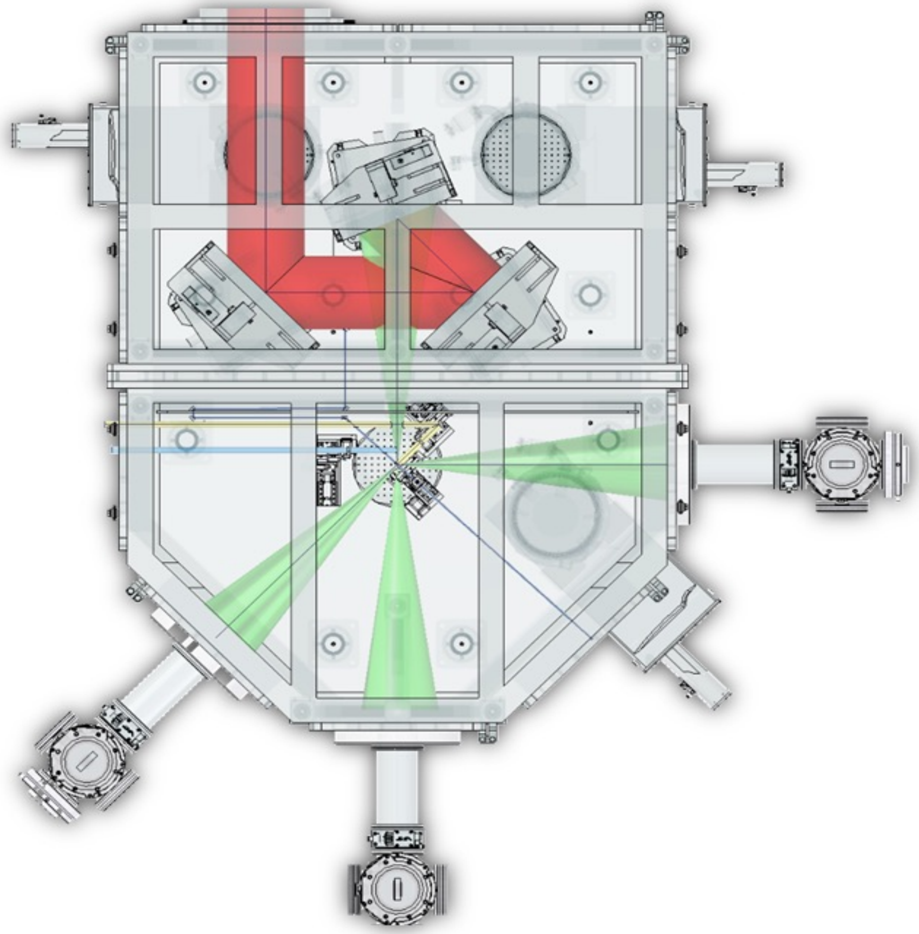
L. Fedeli, A. Sainte-Marie, N. Zaim, M. Thévenet, J. L. Vay, A. Myers, F. Quéré, and H. Vincenti
Phys. Rev. Lett. **127**, 114801 – Published 10 September 2021

UFO(HTA): UltraFast Optics interaction station

UFO(HTA): Capacity and Capability



UFO-HF: Ultra Fast Optics-HF

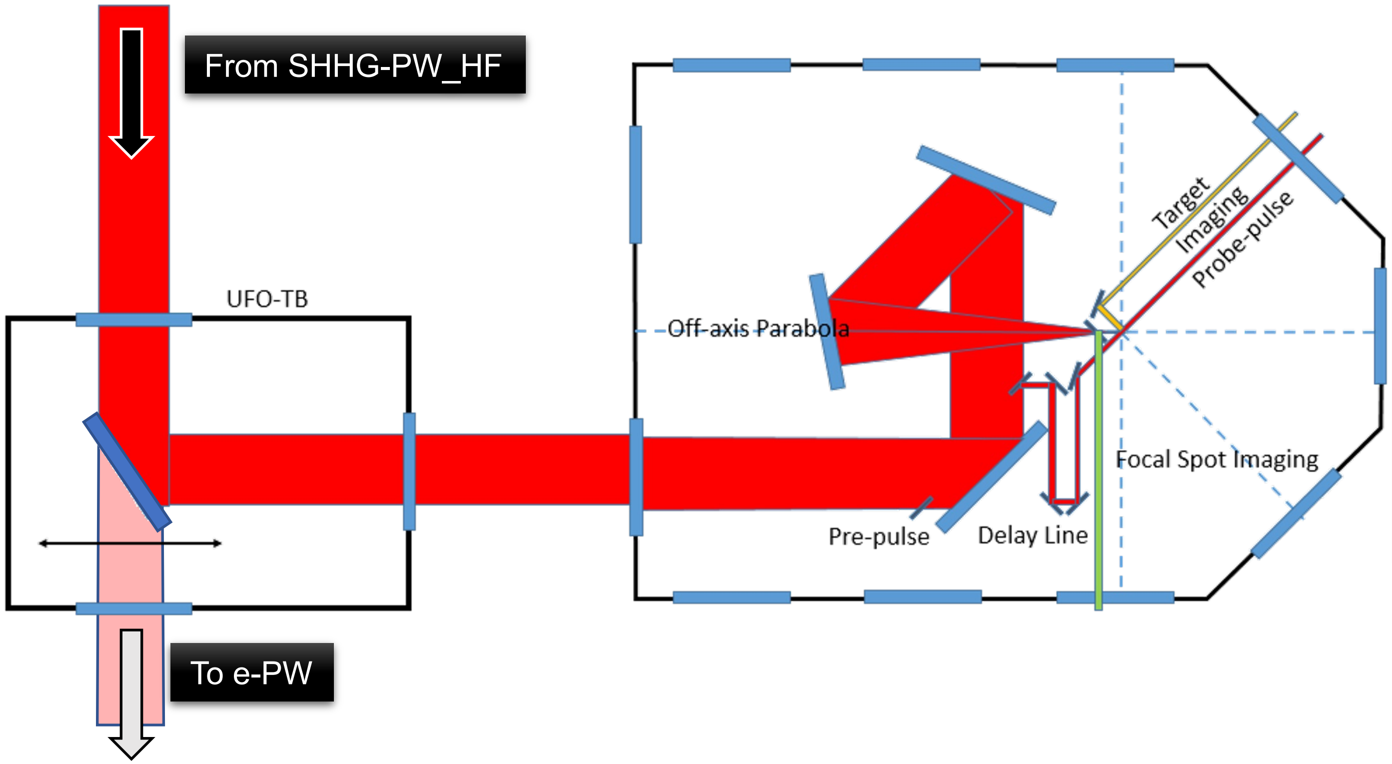


Allowed Targets:
- Solid foil target
- Undersense gar-jet target
- Liquid film target

Flexible configuration:
- Pump-pre-pulse set up @ PW
- Varying angle of incidence (both 0^0 and 45^0 AOI)
- Radially symmetric diagnostic placement option (180^0 observation of interaction)

Diagnostics:
- Plasma optical diag (R/T)
- Charge resolved particle diags (TP)
- Single shot plasma probing
- Pump probe set up
- EMP measurement diag

Applications:
- Material reflectometry (R/T)
- Time resolved laser matter interaction experiments
- Relativistic HHG experiments on foil and gas
- Relativistic nanophotonics
- Plasma based THz generation experiments
- Solid and Gas based particle acceleration in tight focussing configuration
- Ultrafast shock-wave physics
- Single shot plasma probing
- Materials and Plasma dynamics
- Laser generated EMP experiments

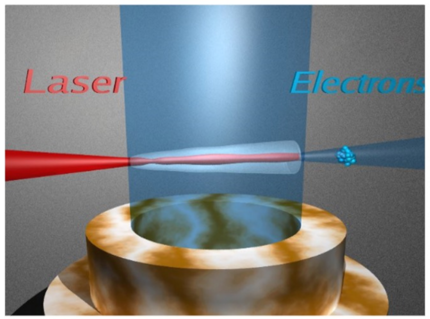


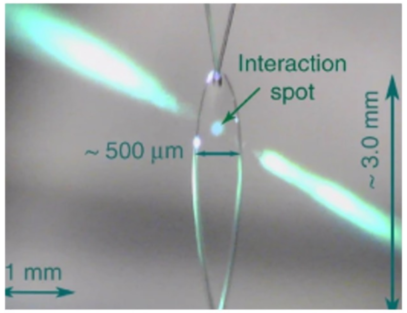
Capacity:
- allow cylindrically observation of interaction point (if needed)
- diversity of experiments

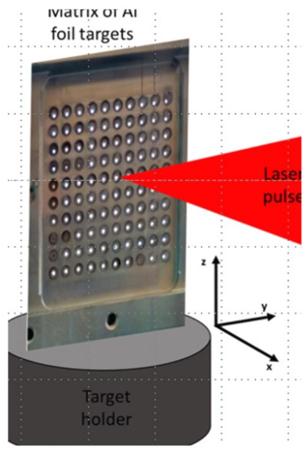
Capability:
- all phase material plasma
- user defined target experiments
- in-house development

Pump-Optical probe

Potential development
Pump-SeSo probe
Multi-beam 20-80 configuration



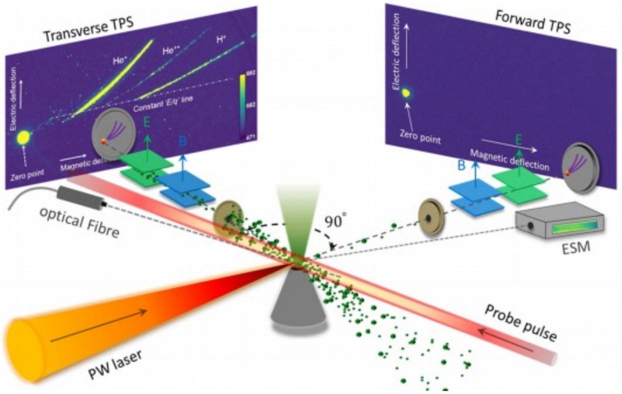




Different target configurations: Solid/liquid

Special targets

Near critical gas targets
(ion acceleration)



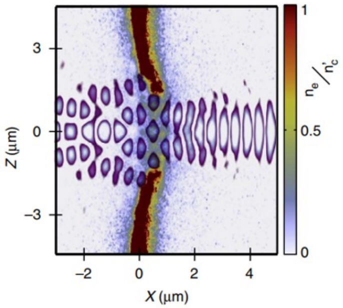
scientific reports

OPEN

Electrostatic shock acceleration of ions in near-critical-density plasma driven by a femtosecond petawatt laser

Prashant Kumar Singh[1,7], Vishwa Bandhu Pathak[1,7], Jung Hun Shin[1], Il Woo Choi[1,2], Kazuhisa Nakajima[1], Seong Ku Lee[1,2], Jae Hee Sung[1,2], Hwang Woon Lee[1], Yong Joo Rhee[1], Constantin Aniculaesei[1], Chul Min Kim[1,2], Ki Hong Pae[1,2], Myung Hoon Cho[1], Calin Hojbota[1,3], Seong Geun Lee[1,3], Florian Mollica[4,5], Victor Malka[5,6], Chang-Mo Ryu[1], Hyung Taek Kim[1,2] & Chang Hee Nam[1,3]

Near critical foil targets
(relativistic transparency)



nature COMMUNICATIONS

ARTICLE

Received 1 Mar 2016 | Accepted 12 Aug 2016 | Published 14 Sep 2016

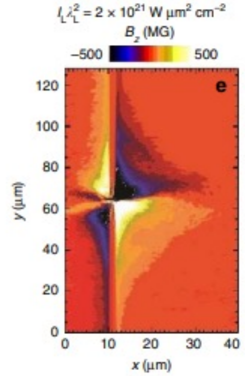
DOI: 10.1038/ncomms12891

OPEN

Towards optical polarization control of laser-driven proton acceleration in foils undergoing relativistic transparency

Bruno Gonzalez-Izquierdo[1], Martin King[1], Ross J. Gray[1], Robbie Wilson[1], Rachel J. Dance[1], Haydn Powell[1], David A. Maclellan[1], John McCreadie[1], Nicholas M.H. Butler[1], Steve Hawkes[1,2], James S. Green[2], Chris D. Murphy[3], Luca C. Stockhausen[4], David C. Carroll[2], Nicola Booth[2], Graeme G. Scott[1,2], Marco Borghesi[5], David Neely[1,2] & Paul McKenna[1]

Foil targets
(MG B-field metrology)



nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-017-02436-w

OPEN

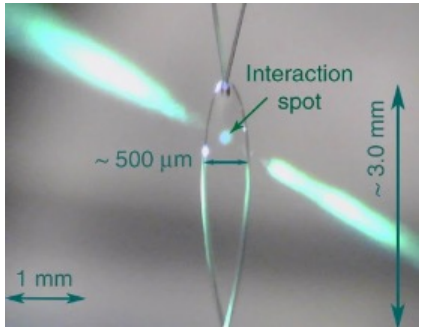
Self-generated surface magnetic fields inhibit laser-driven sheath acceleration of high-energy protons

M. Nakatsutsumi[1,2,4], Y. Sentoku[3,5], A. Korzhimanov[6], S.N. Chen[1,6], S. Buffechoux[1], A. Kon[3,7,10], B. Atherton[8], P. Audebert[1], M. Geissel[8], L. Hurd[1,11], M. Kimmel[8], P. Rambo[8], M. Schollmeier[8], J. Schwarz[8], M. Starodubtsev[6], L. Gremillet[9], R. Kodama[3,4,7] & J. Fuchs[1,6]

Different target configurations: Solid/liquid

Special targets

Liquid shaped targets
(relativistic plasma)



nature COMMUNICATIONS

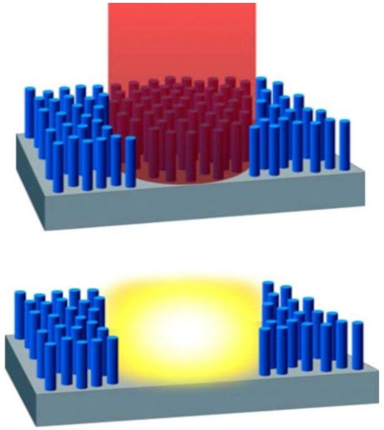
ARTICLE

DOI: 10.1038/s41467-018-06040-4 OPEN

Extreme-ultraviolet high-harmonic generation in liquids

Tran Trung Luu[1], Zhong Yin[1], Arohi Jain[1], Thomas Gaumnitz[1], Yoann Pertot[1], Jun Ma[1] & Hans Jakob Wörner[1]

Designed CNT targets
(relativistic HEDP)

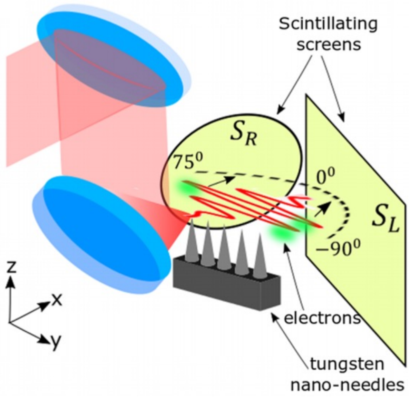


LETTERS
PUBLISHED ONLINE: 1 SEPTEMBER 2013 | DOI: 10.1038/NPHOTON.2013.217
nature photonics

Relativistic plasma nanophotonics for ultrahigh energy density physics

Michael A. Purvis[1], Vyacheslav N. Shlyaptsev[1], Reed Hollinger[1], Clayton Bargsten[1], Alexander Pukhov[2], Amy Prieto[3], Yong Wang[1], Bradley M. Luther[1,3], Liang Yin[1], Shoujun Wang[1] and Jorge J. Rocca[1,4]*

Designed tip targets
(relativistic nano-photonics)



SCIENTIFIC REPORTS

OPEN

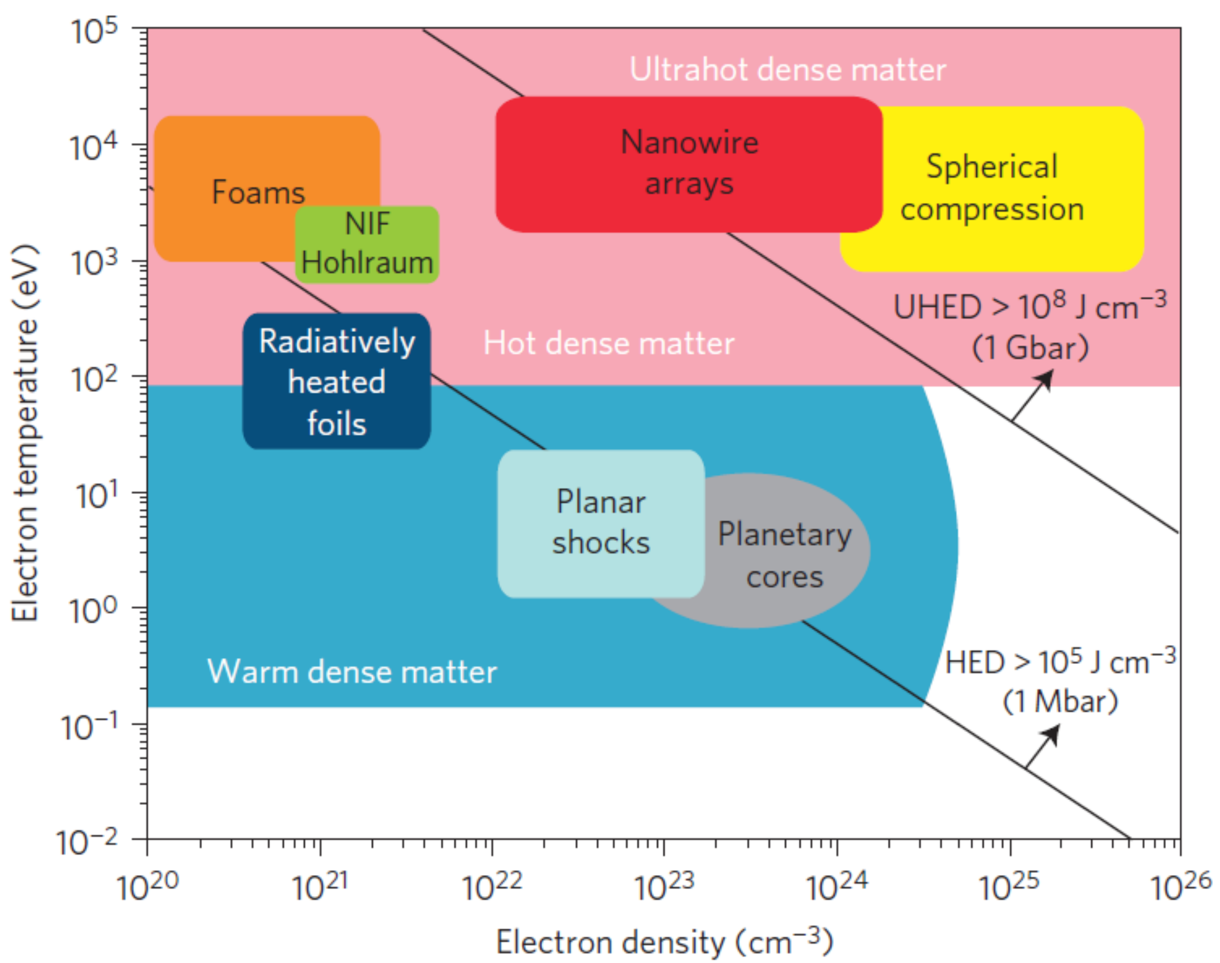
Sub-cycle dynamics in relativistic nanoplasma acceleration

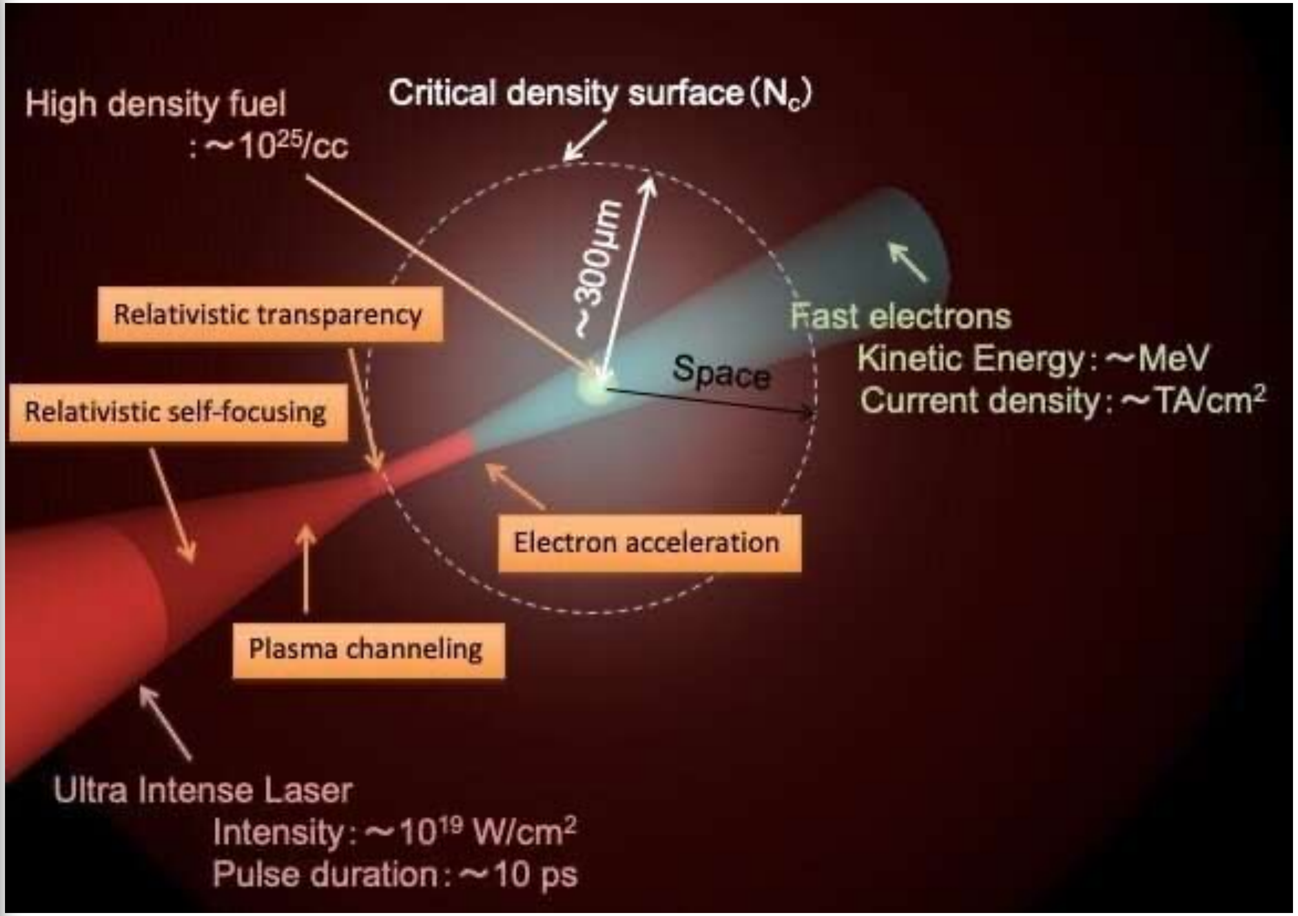
D. E. Cardenas[1,2], T. M. Ostermayr[1,2], L. Di Lucchio[3], L. Hofmann[1,2], M. F. Kling[1,2], P. Gibbon[3,4], J. Schreiber[1,2] & L. Veisz[1,5]

Relevance for LIF: Laser plasma

Multiscale

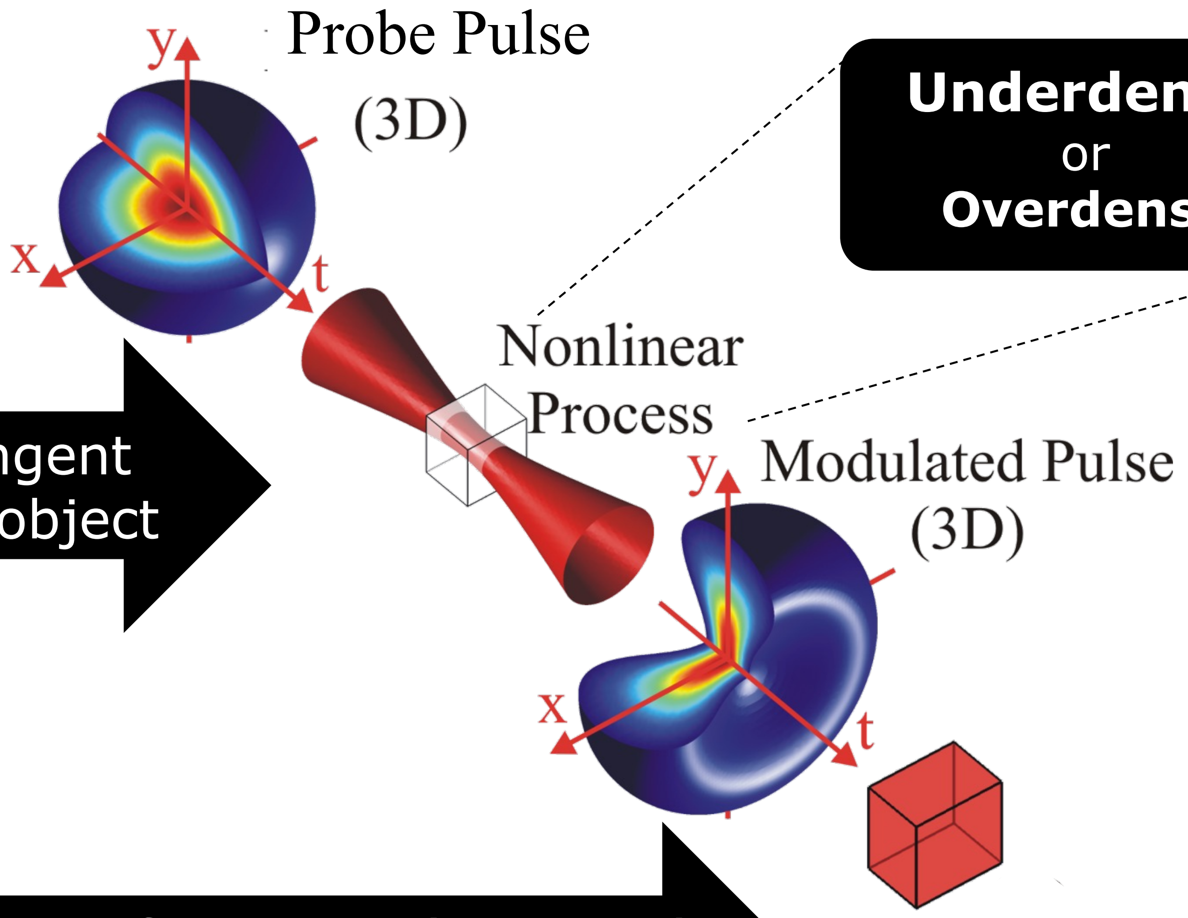
Multiphysics





https://phys.org/news/2020-01-relativistic-effects-laser-fusion-approach.html

Optical probing of the plasma



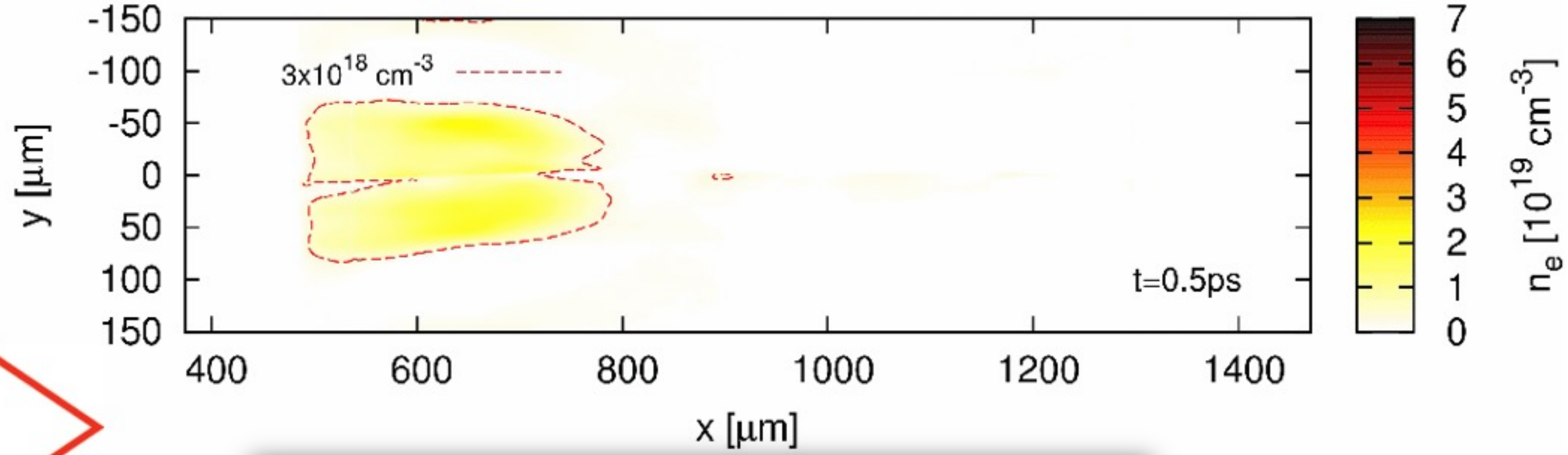
Underdense
or
Overdense

Plasma: birefringent
phase object

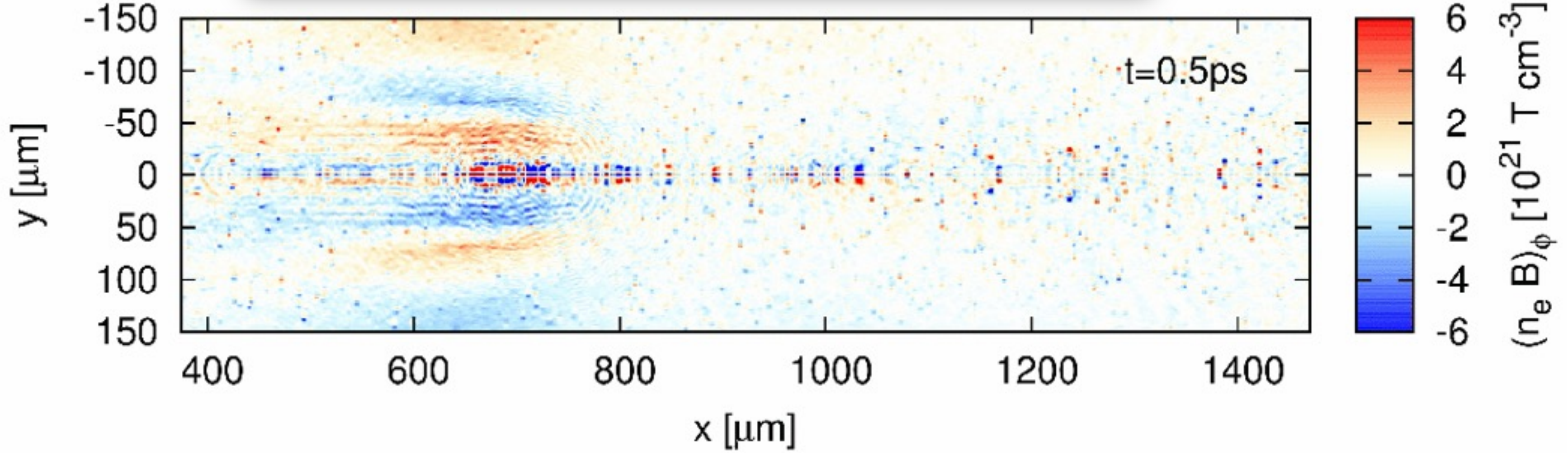
Probing: interferometry (SDI, FDI)
polarimetry

optical diagnostic

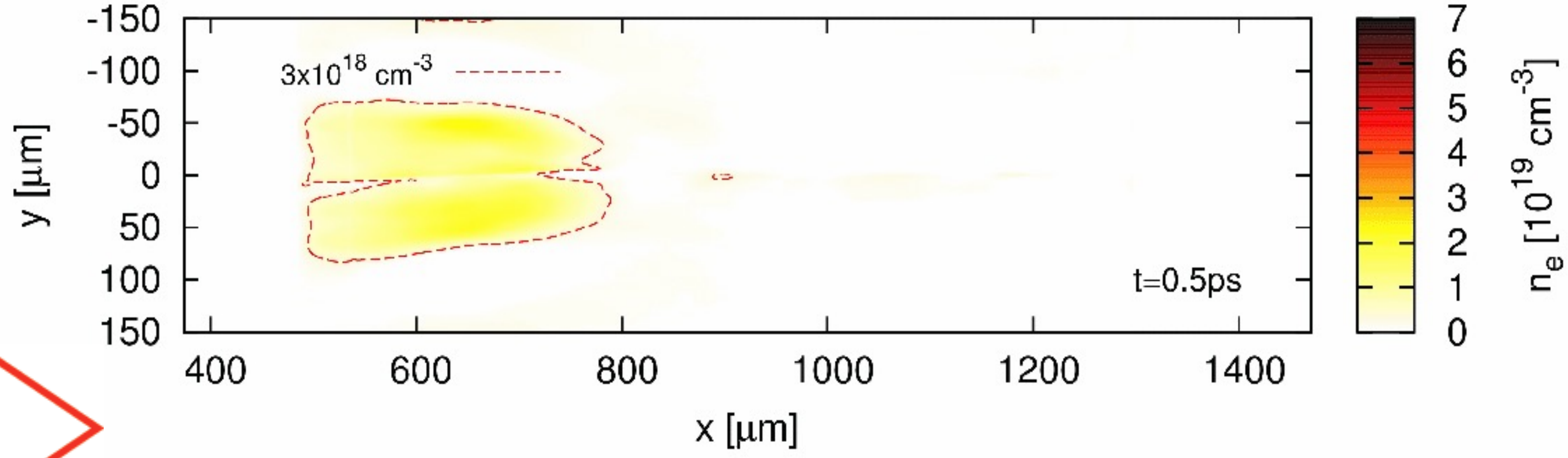
Online diagnostics: phase recording, B mapping



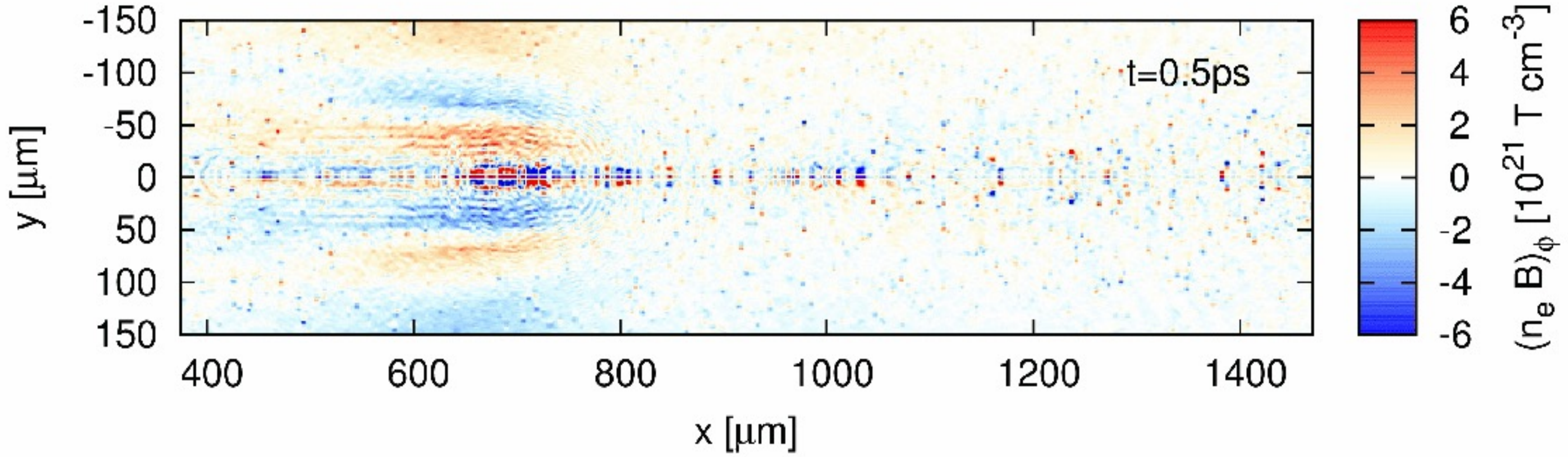
Measured fields are in the range 50 - 100T



fs movie with micrometer resolution !



µm-fs real time movies of magnetic fields



Correlation with backgroung density

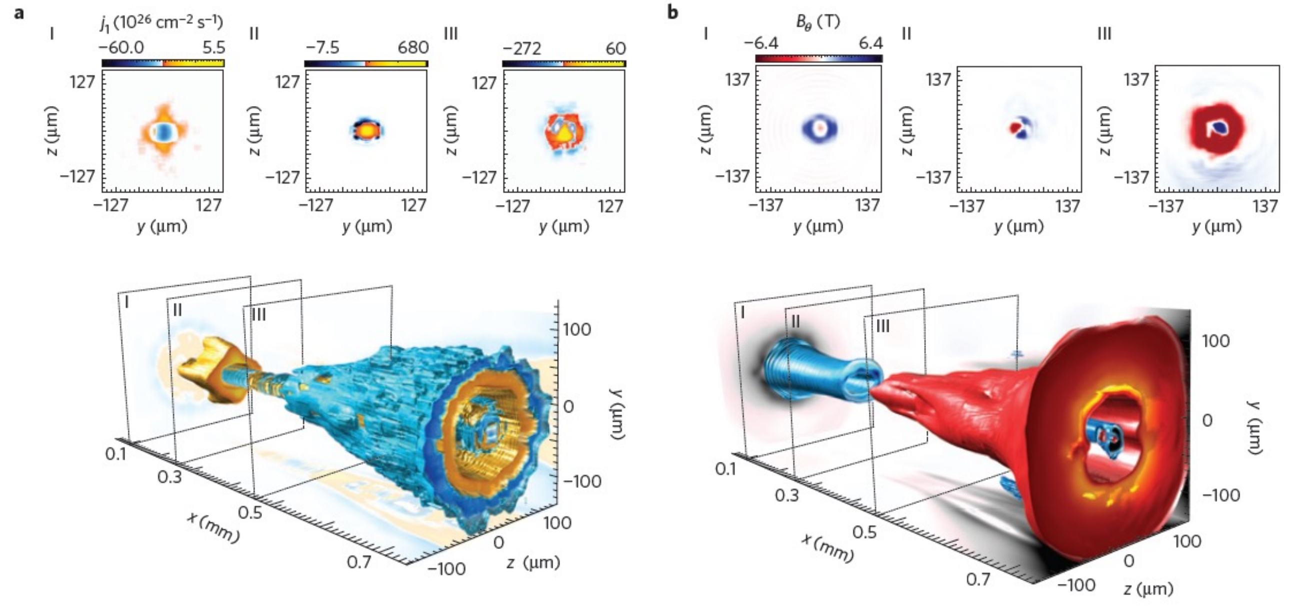
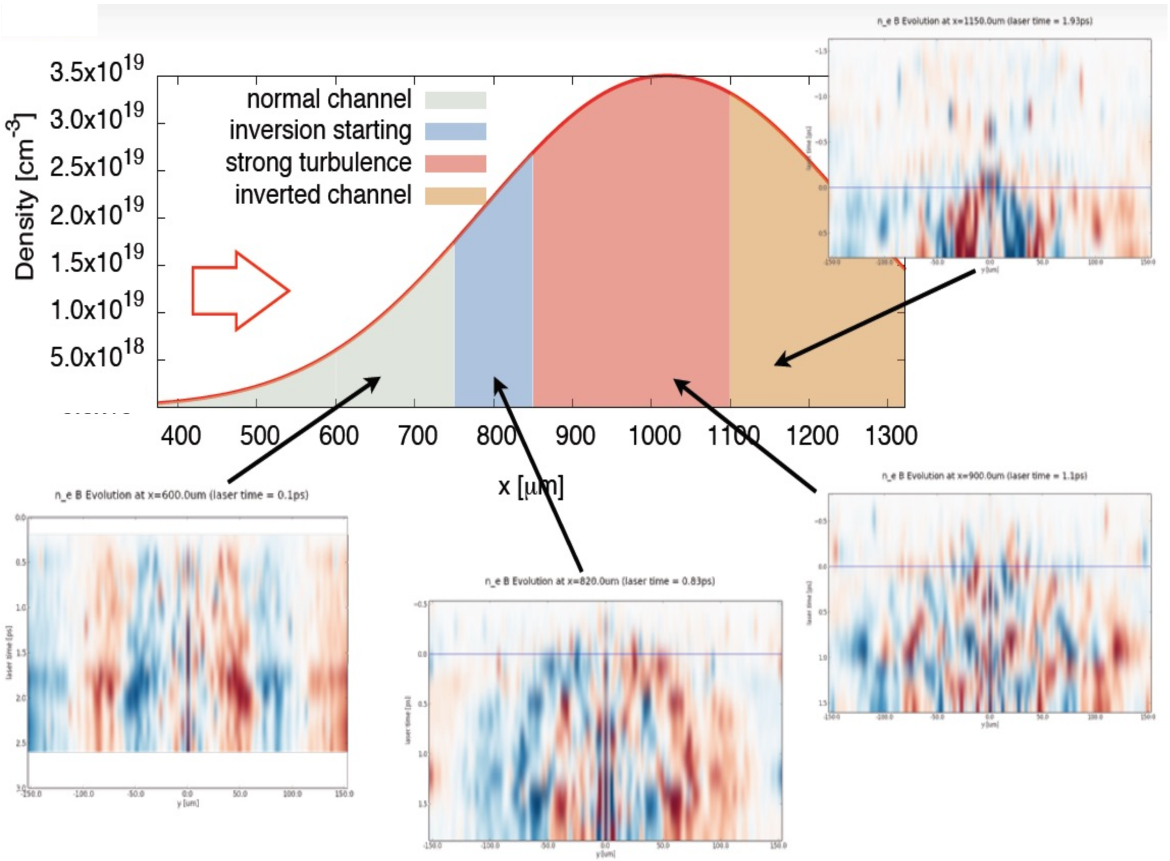


Figure 4 | Summarized results of a full 3D PIC simulation of the experiment. a,b, The final conditions of currents (**a**) and azimuthal magnetic field (**b**) in the plasma are shown after the laser pulse has propagated through the gas; three 2D cuts are shown for improved readability.

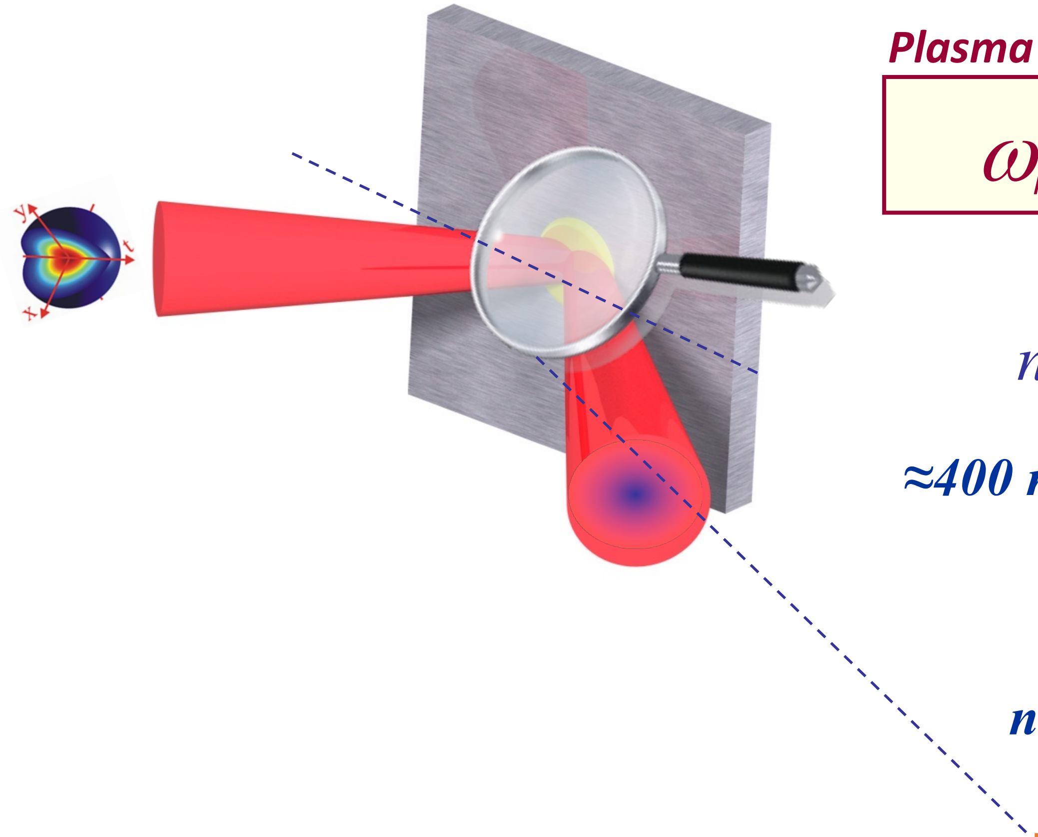


nature physics
LETTERS
PUBLISHED ONLINE: 20 APRIL 2015 | DOI: 10.1038/NPHYS3303

Persistence of magnetic field driven by relativistic electrons in a plasma

Plasma mirrors

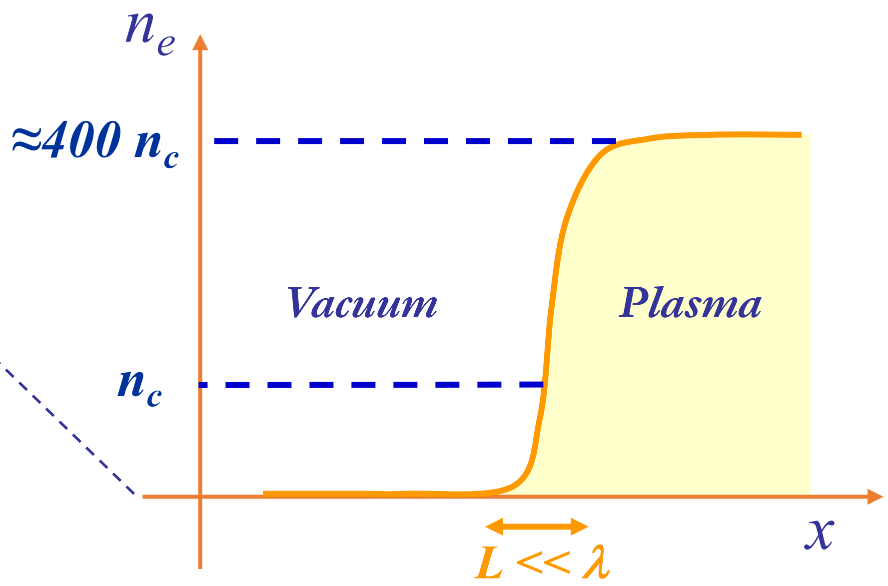
Plasma mirrors are naturally produced (or almost so)
on initially solid targets by intense ultrashort laser pulses



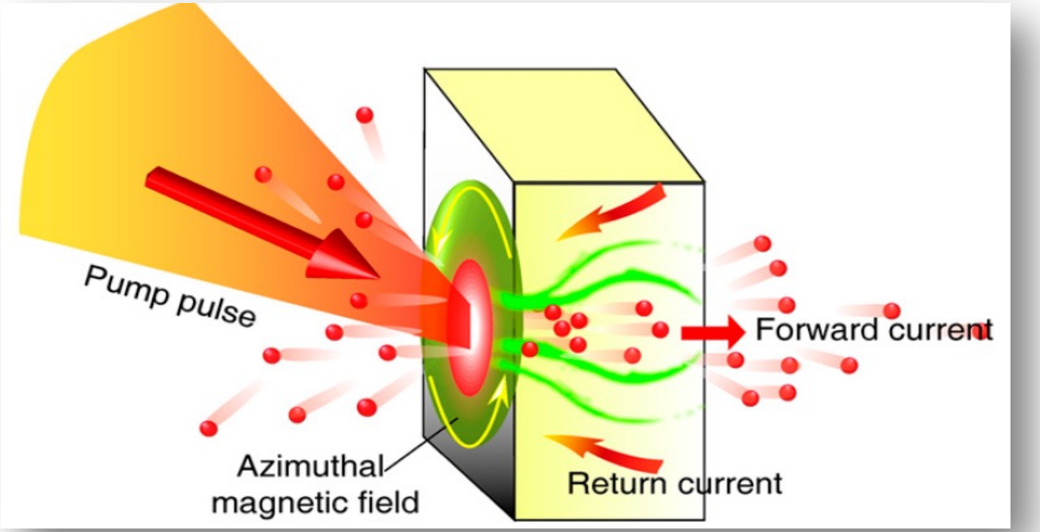
Plasma frequency

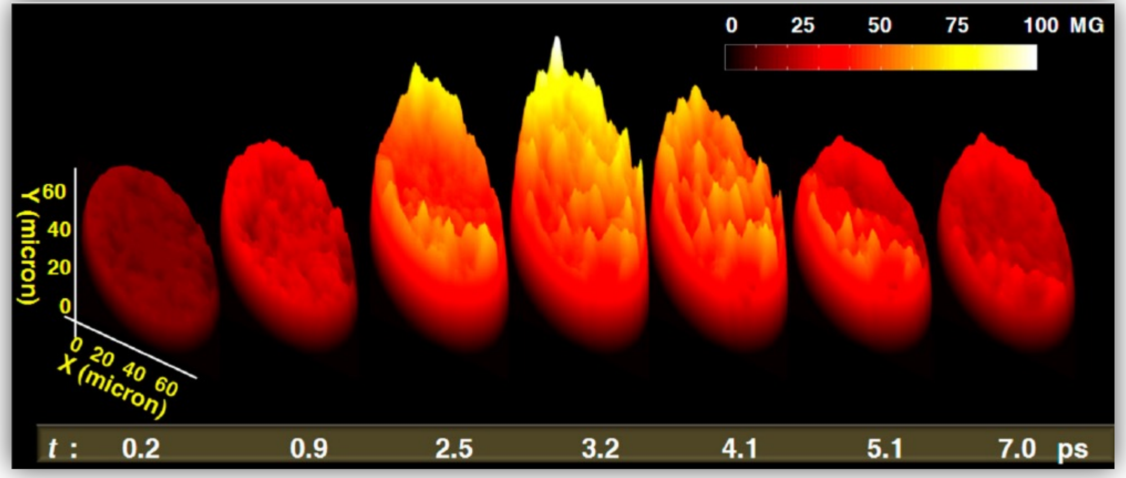
$$\omega_p^2(x) = n_e e^2 / m\varepsilon_0 >> \omega_L^2$$

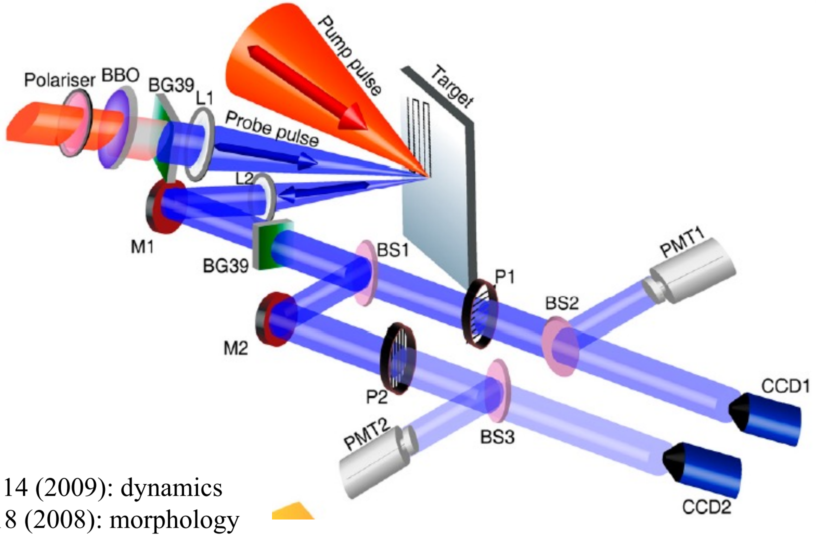
with $n_e \approx 10^{23}$ cm^{-3}

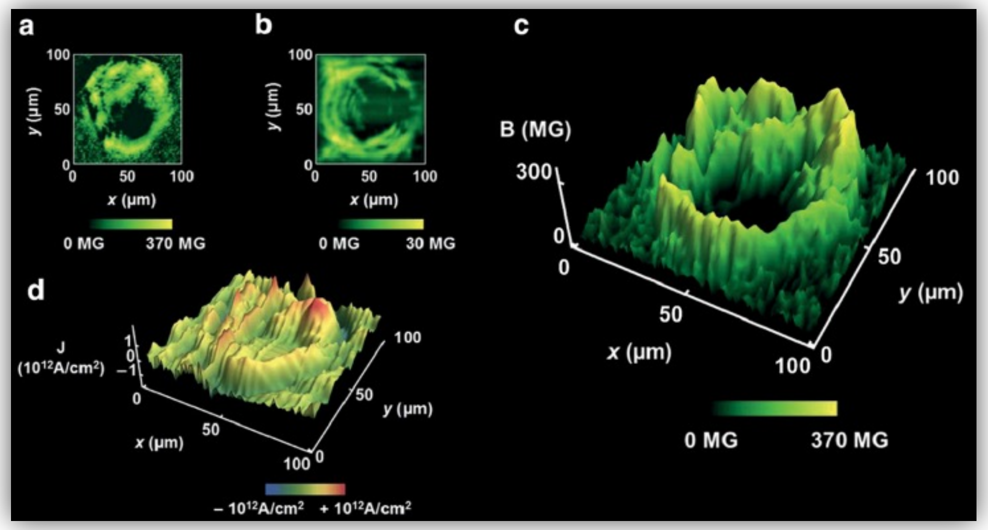


Hot electron transport and dynamics in excited matter









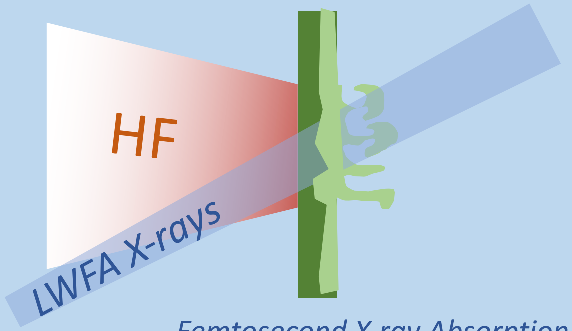
Phys. Plasmas 16, 043114 (2009): dynamics
Phys. Rev. E, 77, 046118 (2008): morphology
PNAS 109, 8011 (2012): space-time resolved
Phys. Rev. Lett, 108, 235005 (2012): CNT

eli

Two beam experiments

SOME SCIENCE DIRECTIONS RELATED TO LASER FUSION ENERGY

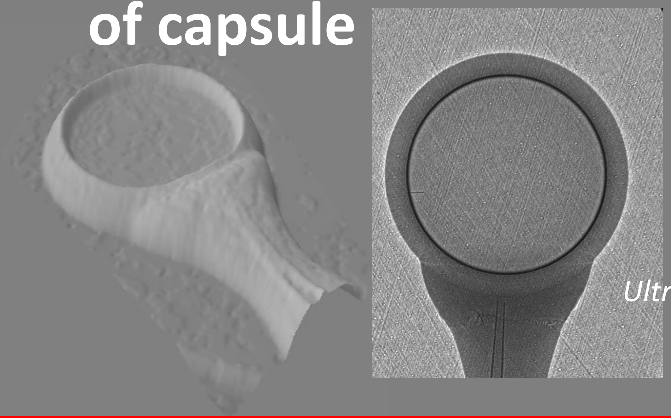
Probing WDP



Femtosecond X-ray Absorption Spectroscopy

- *Hydrodynamic instabilities*
- *Resistivity; High Z spectroscopy*

Phase contrast tomography of capsule



Nonequilibrium warm dense matter investigated with laser-plasma-based XANES down to the femtosecond

Cite as: Struct. Dyn. **10**, 054301 (2023); doi: 10.1063/4.0000202
Submitted: 27 June 2023 · Accepted: 30 August 2023 ·
Published Online: 15 September 2023

F. Dorchies,[1,a)] K. Ta Phuoc,[2] and L. Lechenbourg[3,4]

nature COMMUNICATIONS

ARTICLE

https://doi.org/10.1038/s41467-022-30472-8 OPEN

Check for updates

Proton stopping measurements at low velocity in warm dense carbon

S. Malko[1,2✉], W. Cayzac[3], V. Ospina-Bohórquez[3,4,5], K. Bhutwala[6], M. Bailly-Grandvaux[6], C. McGuffey[6,7], R. Fedosejevs[8], X. Vaisseau[3], An. Tauschwitz[9], J. I. Apiñaniz[1], D. De Luis Blanco[1], G. Gatti[1], M. Huault[1], J. A. Perez Hernandez[1], S. X. Hu[10], A. J. White[11], L. A. Collins[11], K. Nichols[10,11], P. Neumayer[12], G. Faussurier[3,13], J. Vorberger[14], G. Prestopino[15], C. Verona[15], J. J. Santos[4], D. Batani[4], F. N. Beg[6], L. Roso[1] & L. Volpe[1,16,17]

Slide @ JCK

SOME SCIENCE DIRECTIONS RELATED TO LASER FUSION ENERGY

X-ray polarimetry: proposed by JC

- *As a diagnostics of anisotropies (hot electrons, magnetic field etc…) in high intensity-laser plasmas and for High Energy Density science*

VOLUME 68, NUMBER 4 PHYSICAL REVIEW LETTERS 27 JANUARY 1992

Electron Distribution Anisotropy in Laser-Produced Plasmas from X-Ray Line Polarization Measurements

J. C. Kieffer, J. P. Matte, H. Pépin, M. Chaker, Y. Beaudoin, and T. W. Johnston
Institut National de la Recherche Scientifique-Energie, CP 1020, Varennes, Québec, Canada J3X 1S2

C. Y. Chien, S. Coe, and G. Mourou
Ultra Fast Science Laboratory, University of Michigan, Ann Arbor, Michigan 48109

J. Dubau
Observatoire de Paris Meudon, 92195, Meudon, France
(Received 17 September 1991)

- *Polazized X-ray sources (LWFA) by using ionization-induced injection for plasma Science and Material Science*

OPEN

Light: Science & Applications (2017) 6, e17086; doi:10.1038/lsa.2017.86
Official journal of the CIOMP 2047-7538/17
www.nature.com/lsa

ORIGINAL ARTICLE

Stable femtosecond X-rays with tunable polarization from a laser-driven accelerator

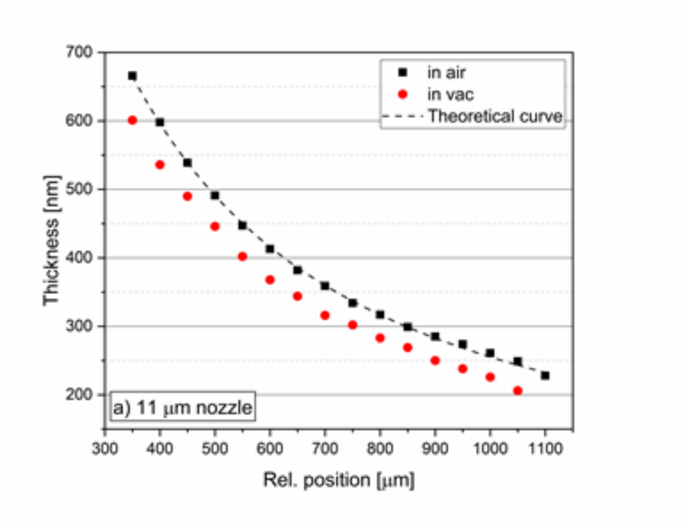
Andreas Döpp[1,2,*], Benoit Mahieu[1,*], Agustin Lifschitz[1], Cedric Thaury[1], Antoine Doche[1], Emilien Guillaume[1], Gabriele Grittani[3], Olle Lundh[4], Martin Hansson[4], Julien Gautier[1], Michaela Kozlova[3], Jean Philippe Goddet[1], Pascal Rousseau[1], Amar Tafzi[1], Victor Malka[1,5], Antoine Rousse[1], Sebastien Corde[1] and Kim Ta Phuoc[1]

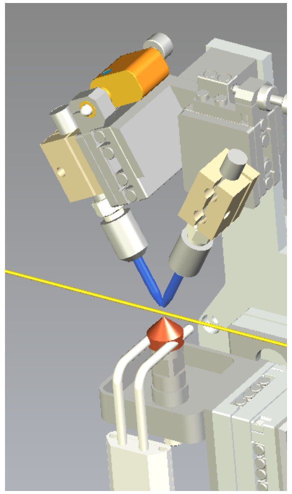
Slide @ JCK

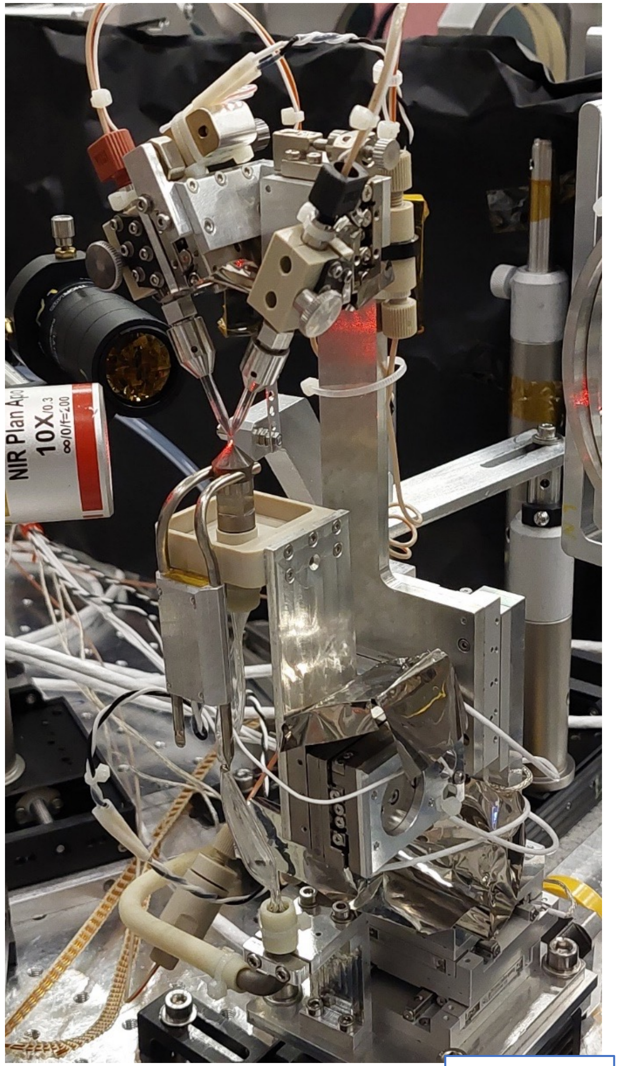
Development of a sub-200nm D_2O liquid leaf target

Advanced Microfluidic Systems GmbH

- Two liquid jets collide from two glass nozzles
- Pulsation damping system for *stability*
- Recirculation system for *continous operation*
- Cold finger for 10^{-4} mbar *vacuum*
- Thickness measurement *in situ, in air and in vacuum*



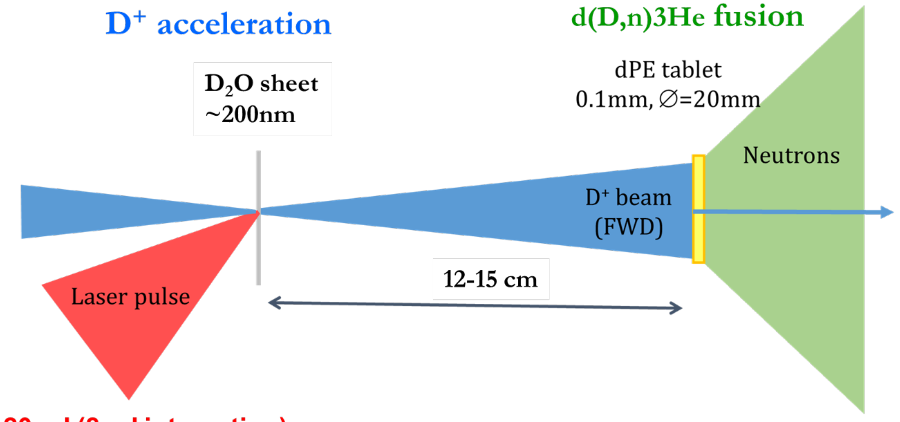




Füle et al, *submitted*.

Slide @ KO

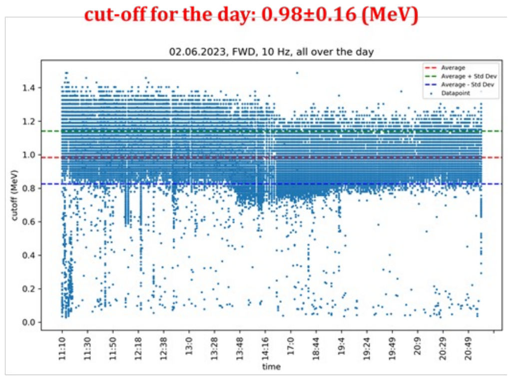
State of the art neutron generation at 10 Hz repetition rate (~6 hours)



20mJ (8mJ interacting)
12 fs, 10Hz

***Deuteron* acceleration from liquid**

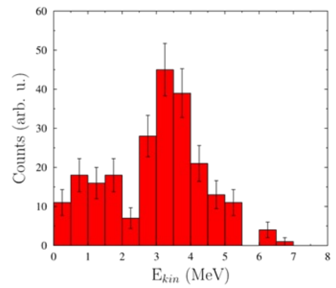
- at 10 Hz, SEA laser
- at *230mW (80mW)* average power
- 200nm D_2O leaf + 0.1mm C_2D_4



***Neutron* generation**

- 200nm D_2O leaf + 0.1mm C_2D_4
- fusion neutron spectra peaks ~3 MeV

~1.5×10⁵ n/s



Achievable by end 2023 at 1kHz: ~ 10^8 n/s

- at *100W (?50W?)* average power

R&D related to LIF

- Development of high repetition rate target systems (liquid leaf, tape target)
- Development of neutron detection (high reprate, pulsed, short bunch duration)
- Exploring novel ideas, pilot experiments

Contact: Karoly Osvay

NLTL National Laser-Initiated Transmutation Laboratory University of Szeged

Slide @ KO

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e acceleration

Nasr Hafiz
Papp Dániel
Lécz Zsolt Ferencz
Majorosi Szilárd
Kovács Zsolt
Mohamed Samir

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National Research, Development and Innovation Office

Horizon 2020 Programme

THANK YOU!