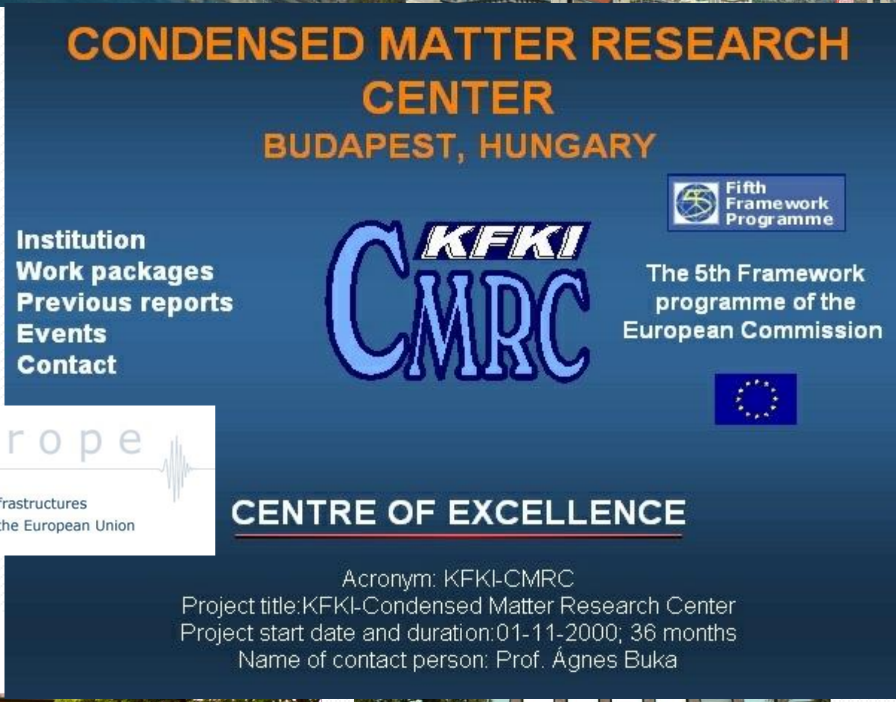
Laser Physics and Applications at Wigner Research Centre for Physics

Aladár Czitrovszky

AWAKE workshop “Laser plasma generation for particle acceleration”, April 08.2016

Wigner Research Centr for Physics



CONDENSED MATTER RESEARCH CENTER

BUDAPEST, HUNGARY

Institution
Work packages
Previous reports
Events
Contact

The 5th Framework programme of the European Commission

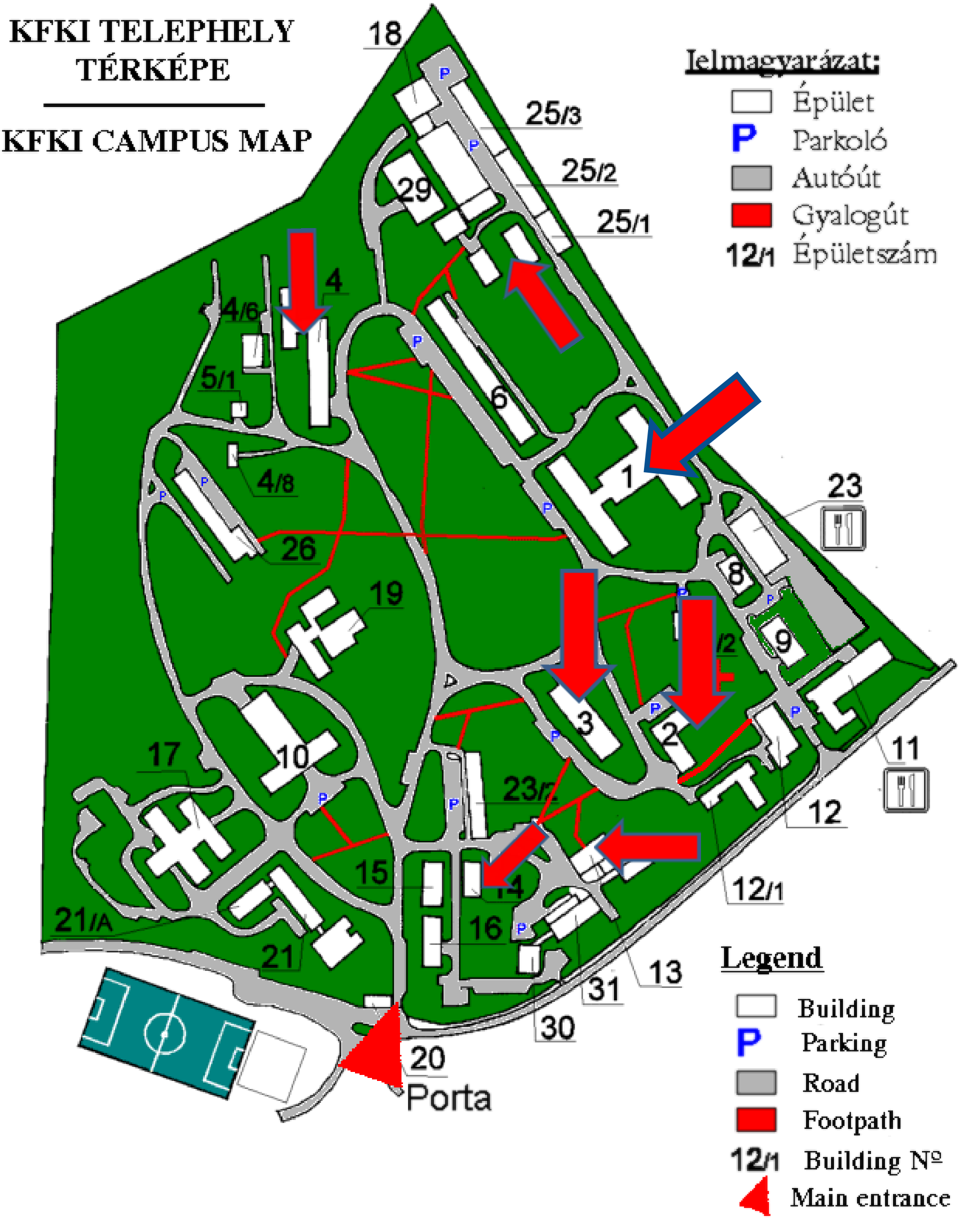
CENTRE OF EXCELLENCE

Acronym: KFKI-CMRC
Project title:KFKI-Condensed Matter Research Center
Project start date and duration:01-11-2000; 36 months
Name of contact person: Prof. Ágnes Buka

LaserlabEurope

Laserlab
Europe

The **"Integrated Initiative"** of European Laser Infrastructures
in the 7th Framework Programme of the European Union



WIGNER Research Centre for Physics, HAS

359 employees
+ 20 Prof. Emer.

Flagship projects at the WIGNER RCP:

1. High Energy Physics

CERN

ALICE

CMS Compact Muon Solenoid

ATLAS

TOTEM

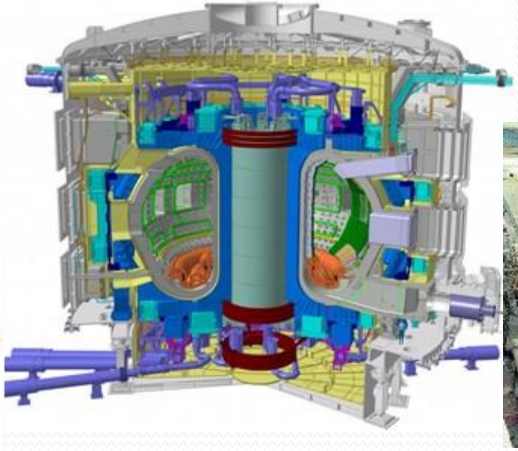
WLCG

RD51

SHINE NA61

2. Fusion Energy Research (EURATOM) [Plasmadiagnostics]

EFDA JET



ITER
Chadarache

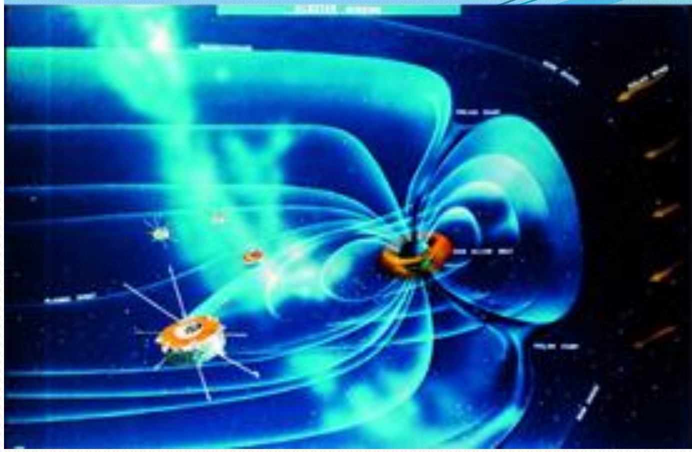
MAST, Culham

KSTAR, South Korea

3. Space Science & Technology

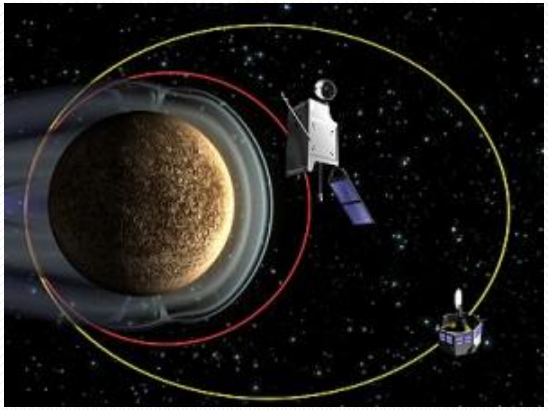
Comet Halley: Vega 1/2 (1986)

Saturn&Titan: Cassini (2004)



Earth: CLUSTER Mission (2001-14)

Rosetta – Philae probe (2004-14)

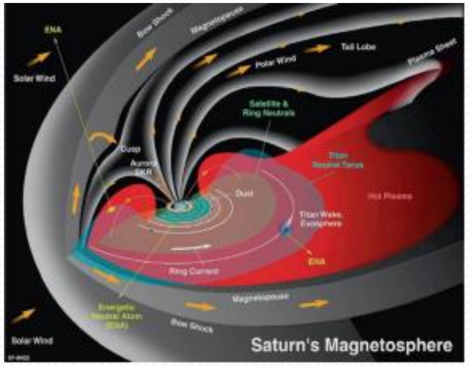


Mercury: BepiColombo (2014)

ISS: Plasma Wave Complex (2011)

Venus Express (2006)

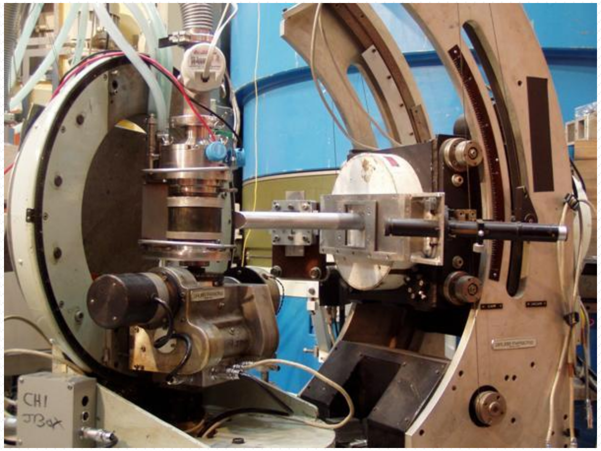
Saturn's Magnetosphere



4. Budapest Neutron Center (BNC) [Experience in infrastructure management]

BUDAPEST Reactor (10 MW)

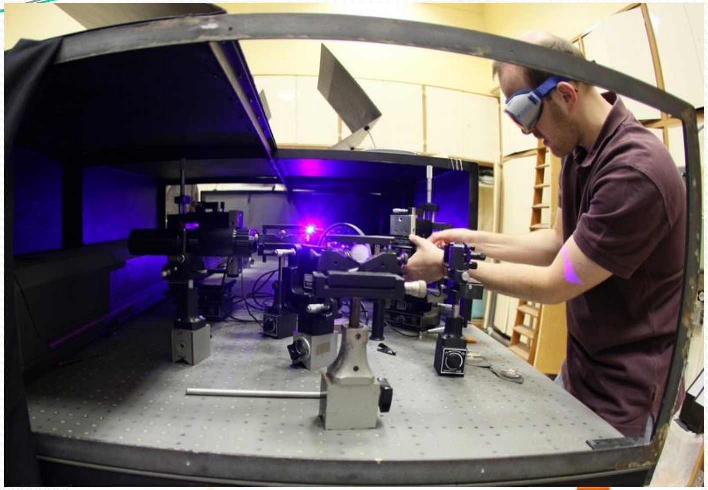
GINA polarized neutron reflectometer

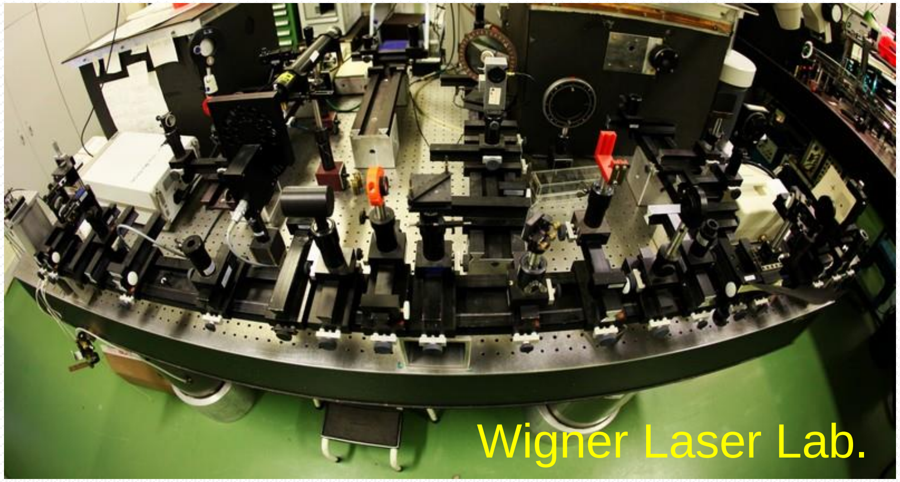


MTEST diffractometer

Cold Neutron Laboratory

5. Laser Physics and Quantum Optics [femtosecond lasers → attosecond]

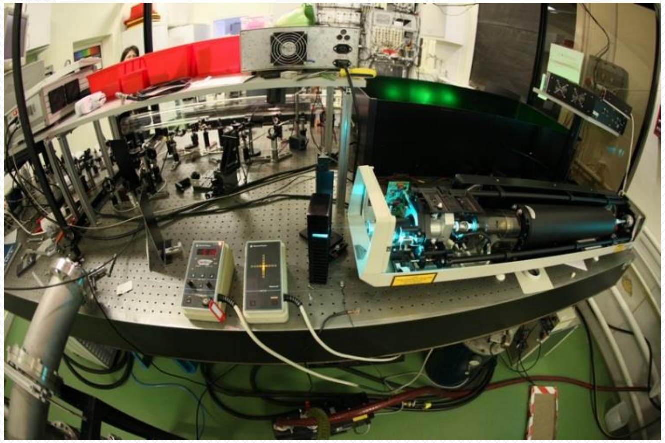


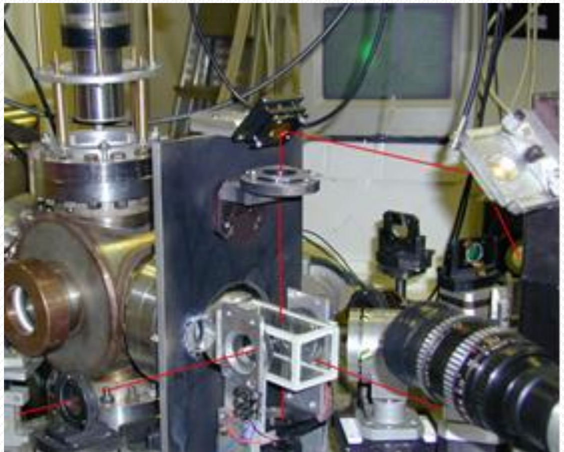


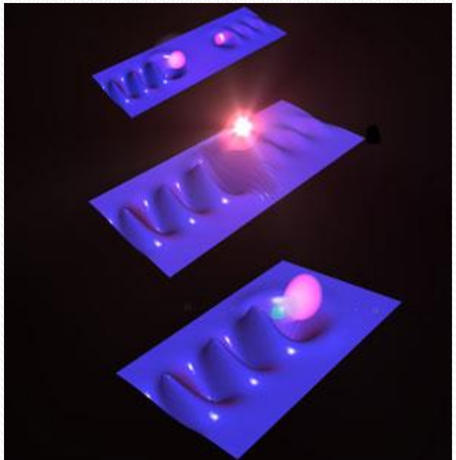
eli
extreme light infrastructure

Szeged [LPWFA]
Prag
Bucharest

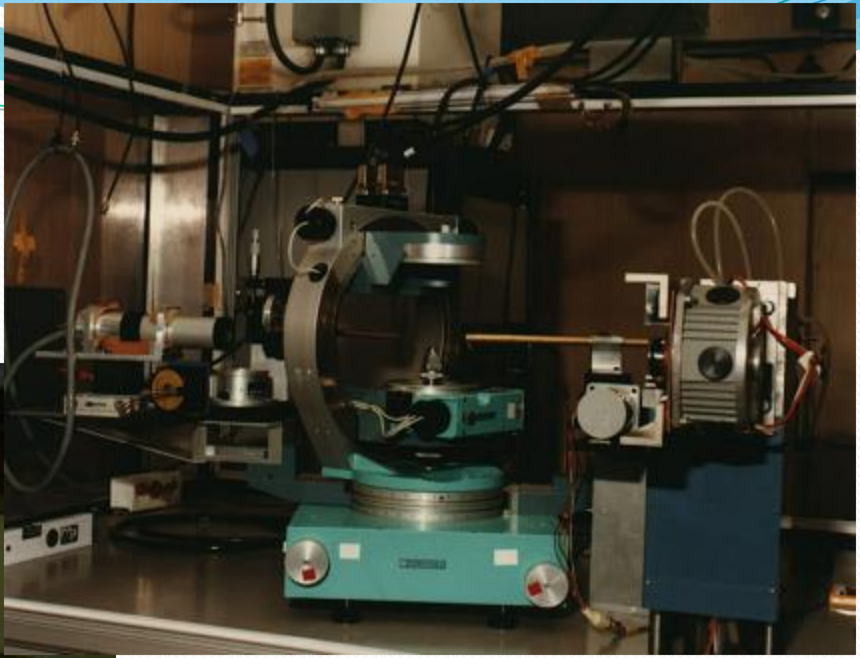
Plan: CERN - PDPWA
Proton Driven
Plasma Wave
Accelerator research

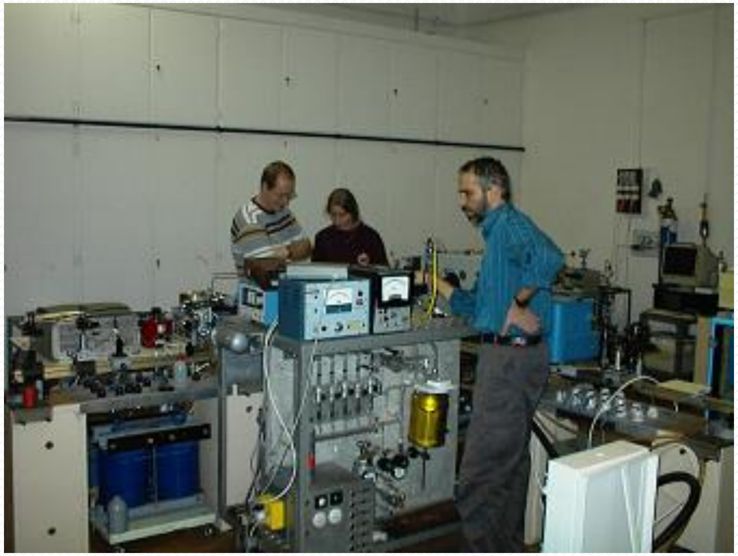




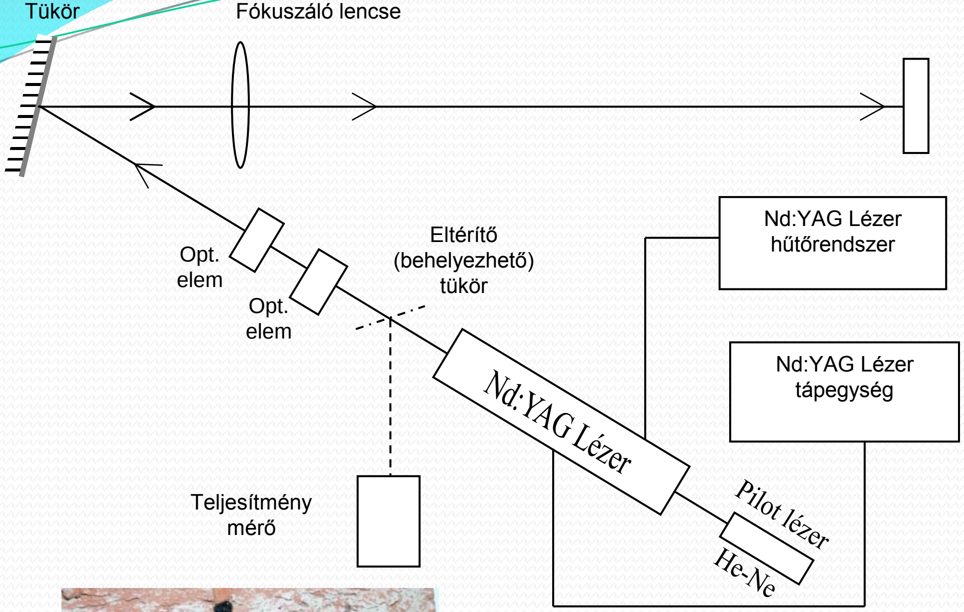


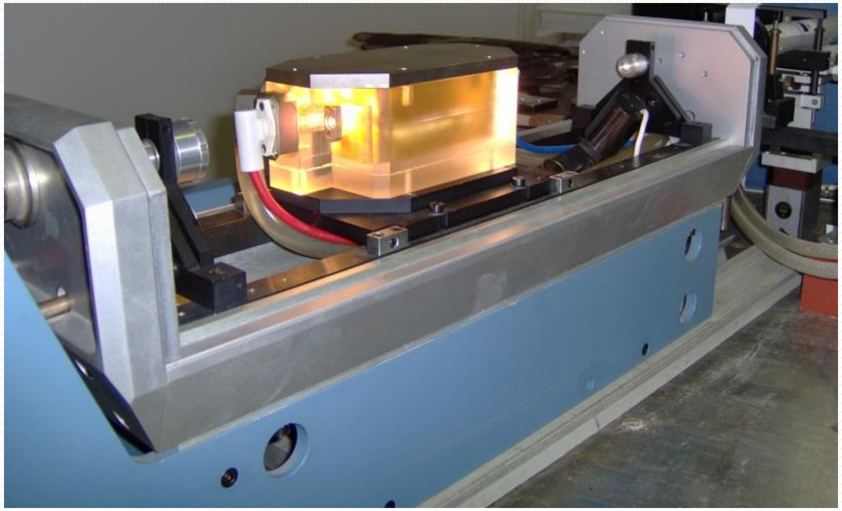
Laser Physics Lab

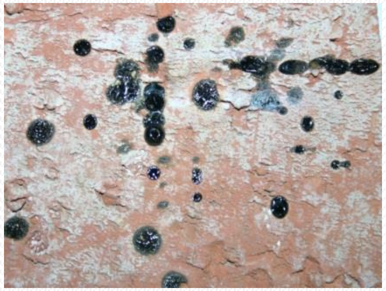




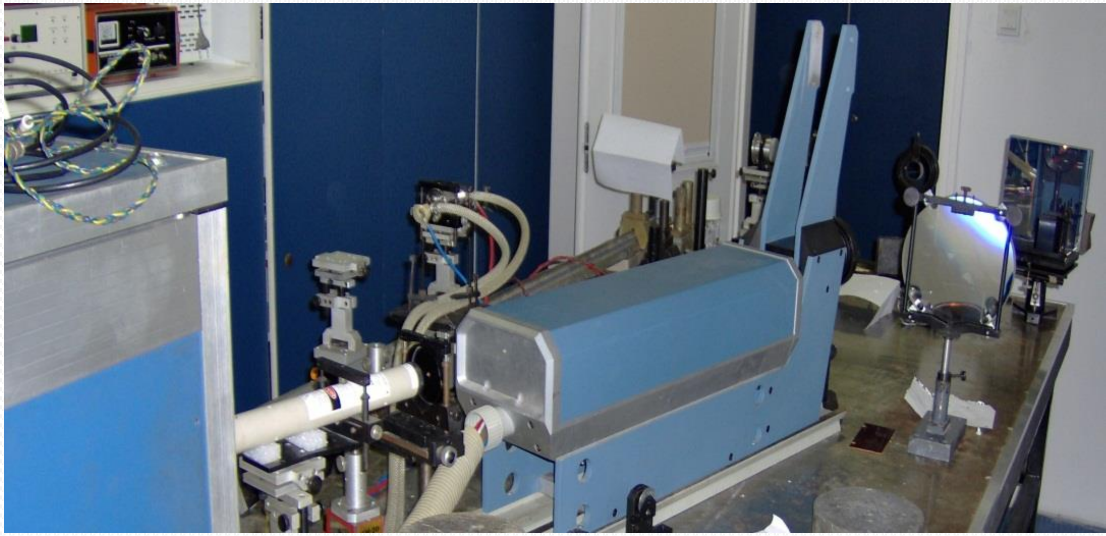
Development of solid state CW lasers



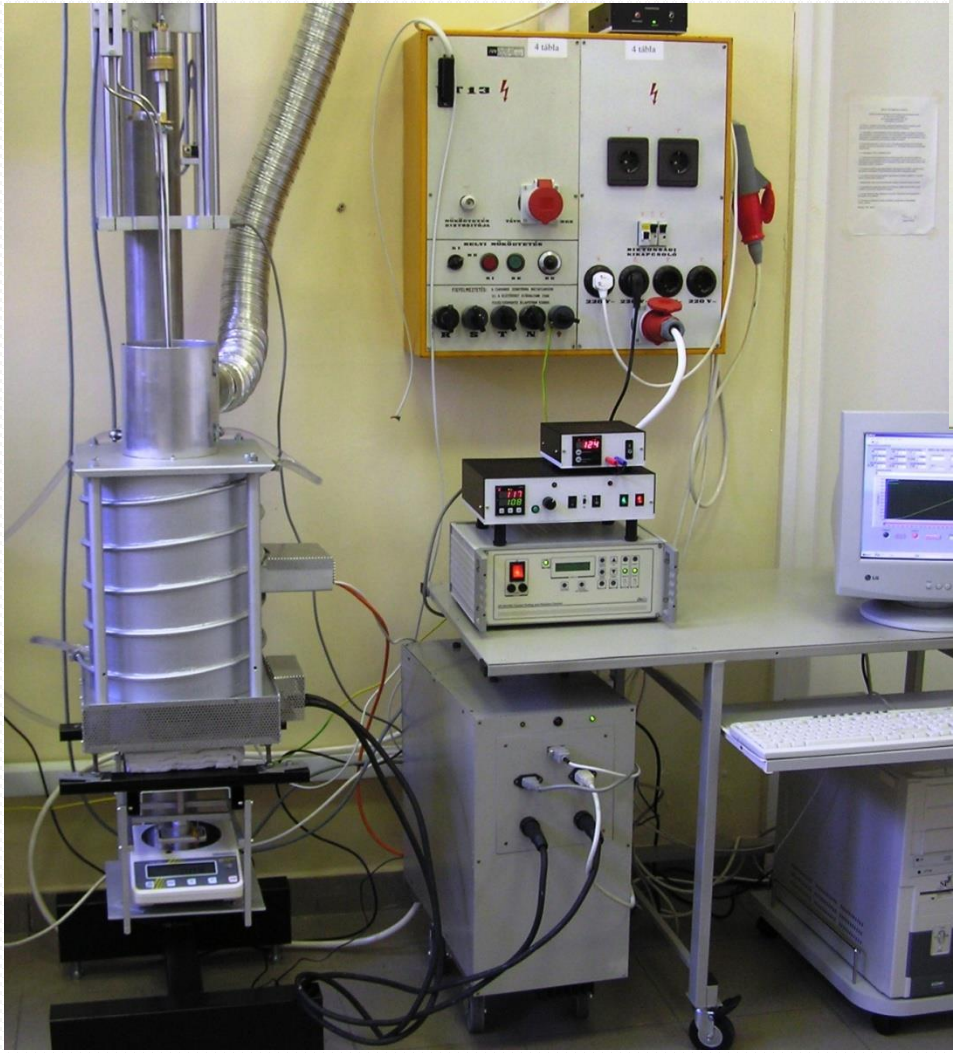




Nd:YAG solid state laser,
1.064 micron wavelength,
6.3 mm beam diameter,
Laser power 125 W CW
Laser beam divergence ~ 2 mrad
Pilot laser: 5 mW He-Ne laser
0.632 micron wavelength



Crystal technology



PC controlled crystal growing Facility

Raman- and fluorescent-spectroscopy

Optical coating technology and development of special optical layers

Development of the first chirped laser mirrors

- **invention** and technological development of **"chirped" dielectric laser mirrors** (R. Szipőcs, 1993)
- **shortest laser pulses (4.5 fs)** was generated by a Ti:sapphire system utilizing chirped mirrors for dispersion compensation

PUSHING THE LIMITS

of Femtosecond Technology: Chirped Dielectric Mirrors

By Robert Szipöcs, Andreas Stingl, Christian Spielmann, and Ferenc Krausz

Snapshot: The authors explain the theory behind ultrashort pulses and offer a new method — chirped dielectric mirrors — for achieving sub-10 fsec pulses.

One of the major trends in laser physics today is the research and development of femtosecond laser sources. The motivation for generating short electromagnetic waveforms comes from many areas of science and technology. Ultrashort optical pulses are capable of taking "snapshots" of the state of matter and hence following the evolution of ultrafast processes at the microscopic level. Probing charge-carrier dynamics in semiconductors, the formation and breaking of chemical bonds, or time-resolved studies of photoisomerisation in biology are just a few examples of a number of intriguing applications. The generation of pulses shorter than previously possible would benefit many application fields and calls for a precise dispersion control over increasingly broad bandwidths in femtosecond laser oscillators as well as in subsequent optical systems. With the advent of chirped multilayer dielectric mirrors, feedback and phase dispersion control over unprecedented bandwidths have become feasible, thus opening the way for further advances in femtosecond technology.

Optical pulse propagation in dispersive media

Short electromagnetic waveforms (henceforth pulses) can be thought of as a superposition of long, quasi-monochromatic wavepackets of different carrier frequencies. For a particular spectral intensity distribution, minimum pulse duration is achieved when the centers of the wavepackets coincide in space. Under these conditions the pulse is referred to as Fourier-limited or transform-limited because the shortest pulse attainable with the spectral intensity distribution given has been realized.

If such a transform-limited pulse is sent through a dispersive medium, in which wavepackets of different carrier frequency propagate at different velocities, the pulse envelope will be broadened and carried by a time-varying instantaneous frequency at the output, as illustrated in Figure 1. Dispersion can be quantified by expanding the phase retardation $\phi(\omega)$ of a dispersive system about the center of the pulse spectrum ω_0 in the form

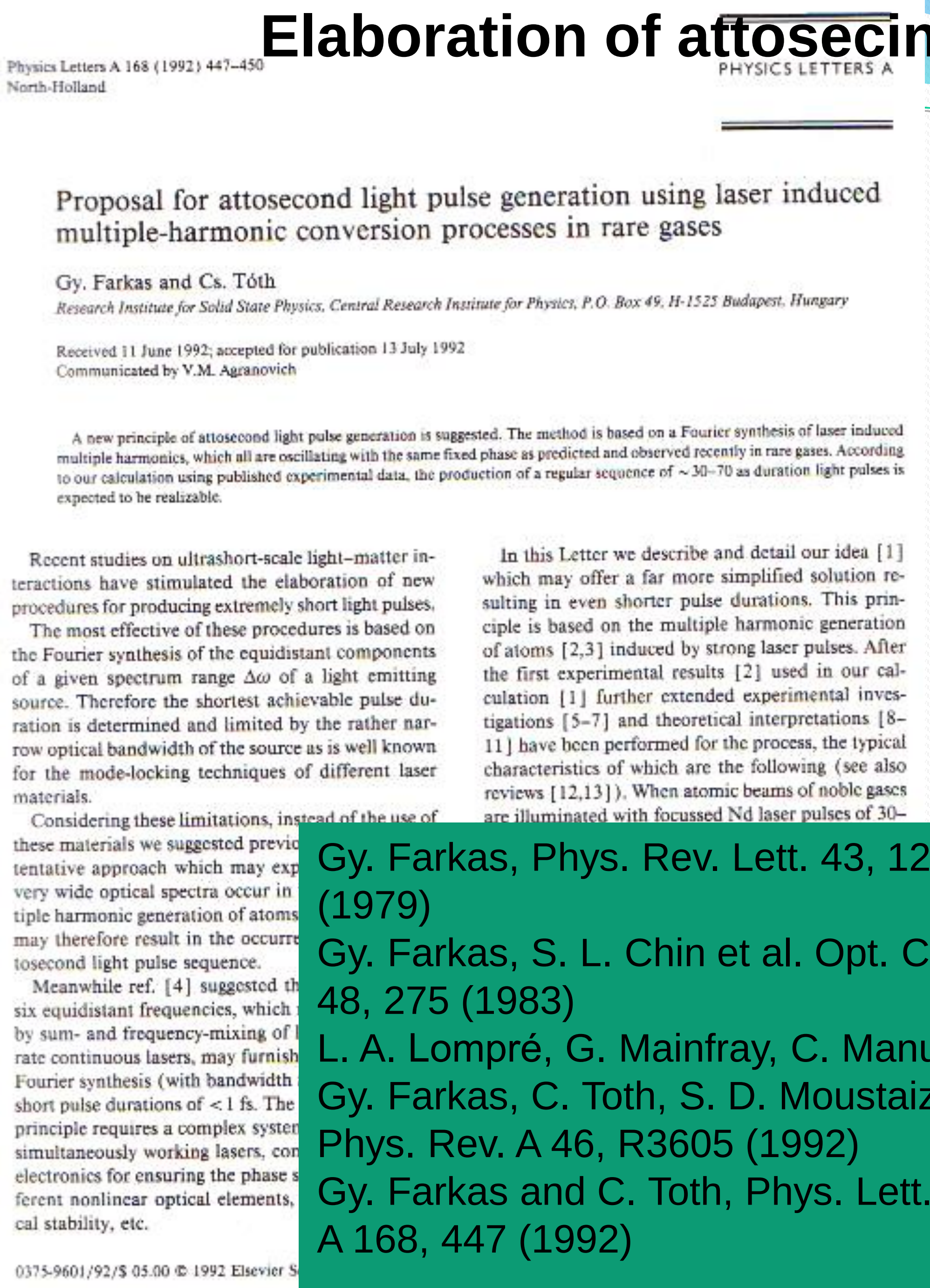
$$\phi(\omega) = \phi_0 + \phi'(\omega-\omega_0) + {}^1\!/_2\,\phi''(\omega-\omega_0)^2 + {}^1\!/_6\,\phi'''(\omega-\omega_0)^3 + \ldots \quad (1)$$

where $\phi_0 = \phi(\omega_0)$, and the derivatives ϕ', ϕ'', etc. are also evaluated at ω_0. The first derivative ϕ' is called group delay because it gives the time taken by the center of the pulse to reach the output of the wave-propagating medium. The higher-order terms in the expansion describe a frequency dependence of the group delay,

Figure 1. Optical pulse propagation through a dispersive medium: a frequency-dependent group delay leads to a pulse broadening and to a carrier frequency sweep.

Optics & Photonics News/June 1995 17

Elaboration of attosecind pulse generation



Physics Letters A 168 (1992) 447–450
North-Holland

PHYSICS LETTERS A

Proposal for attosecond light pulse generation using laser induced multiple-harmonic conversion processes in rare gases

Gy. Farkas and Cs. Tóth
Research Institute for Solid State Physics, Central Research Institute for Physics, P.O. Box 49, H-1525 Budapest, Hungary

Received 11 June 1992; accepted for publication 13 July 1992
Communicated by V.M. Agranovich

A new principle of attosecond light pulse generation is suggested. The method is based on a Fourier synthesis of laser induced multiple harmonics, which all are oscillating with the same fixed phase as predicted and observed recently in rare gases. According to our calculation using published experimental data, the production of a regular sequence of ~30–70 as duration light pulses is expected to be realizable.

Recent studies on ultrashort-scale light–matter interactions have stimulated the elaboration of new procedures for producing extremely short light pulses.

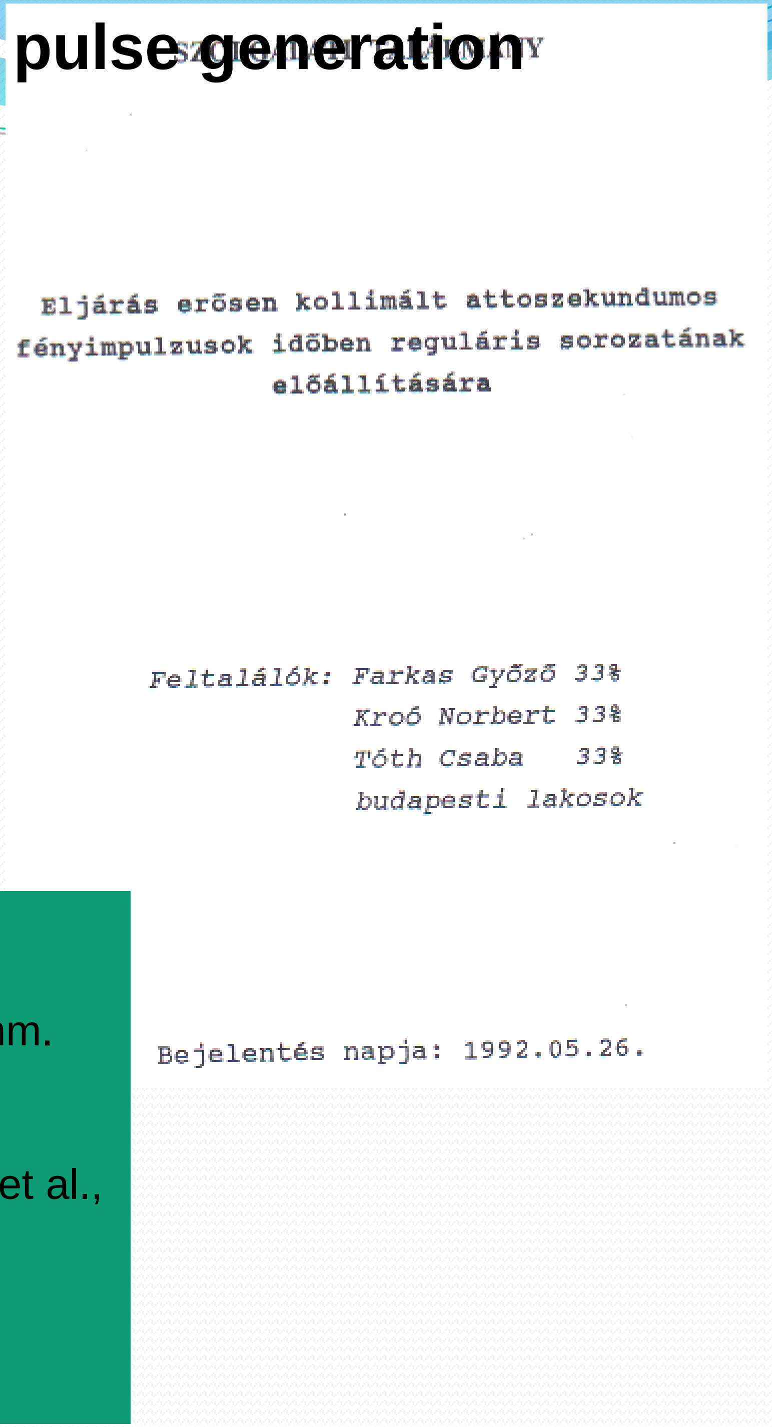
The most effective of these procedures is based on the Fourier synthesis of the equidistant components of a given spectrum range $\Delta\omega$ of a light emitting source. Therefore the shortest achievable pulse duration is determined and limited by the rather narrow optical bandwidth of the source as is well known for the mode-locking techniques of different laser materials.

Considering these limitations, instead of the use of
these materials we suggested previ
tentative approach which may exp
very wide optical spectra occur in
tiple harmonic generation of atoms
may therefore result in the occurre
tosecond light pulse sequence.

Meanwhile ref. [4] suggested th
six equidistant frequencies, which
by sum- and frequency-mixing of
rate continuous lasers, may furnish
Fourier synthesis (with bandwidth
short pulse durations of <1 fs. The
principle requires a complex system
simultaneously working lasers, con
electronics for ensuring the phase s
ferent nonlinear optical elements,
cal stability, etc.

In this Letter we describe and detail our idea [1] which may offer a far more simplified solution resulting in even shorter pulse durations. This principle is based on the multiple harmonic generation of atoms [2,3] induced by strong laser pulses. After the first experimental results [2] used in our calculation [1] further extended experimental investigations [5–7] and theoretical interpretations [8–11] have been performed for the process, the typical characteristics of which are the following (see also reviews [12,13]). When atomic beams of noble gases are illuminated with focussed Nd laser pulses of 30–

Gy. Farkas, Phys. Rev. Lett. 43, 1243
(1979)
Gy. Farkas, S. L. Chin et al. Opt. Comm.
48, 275 (1983)
L. A. Lompré, G. Mainfray, C. Manus,
Gy. Farkas, C. Toth, S. D. Moustaizis et al.,
Phys. Rev. A 46, R3605 (1992)
Gy. Farkas and C. Toth, Phys. Lett.
A 168, 447 (1992)

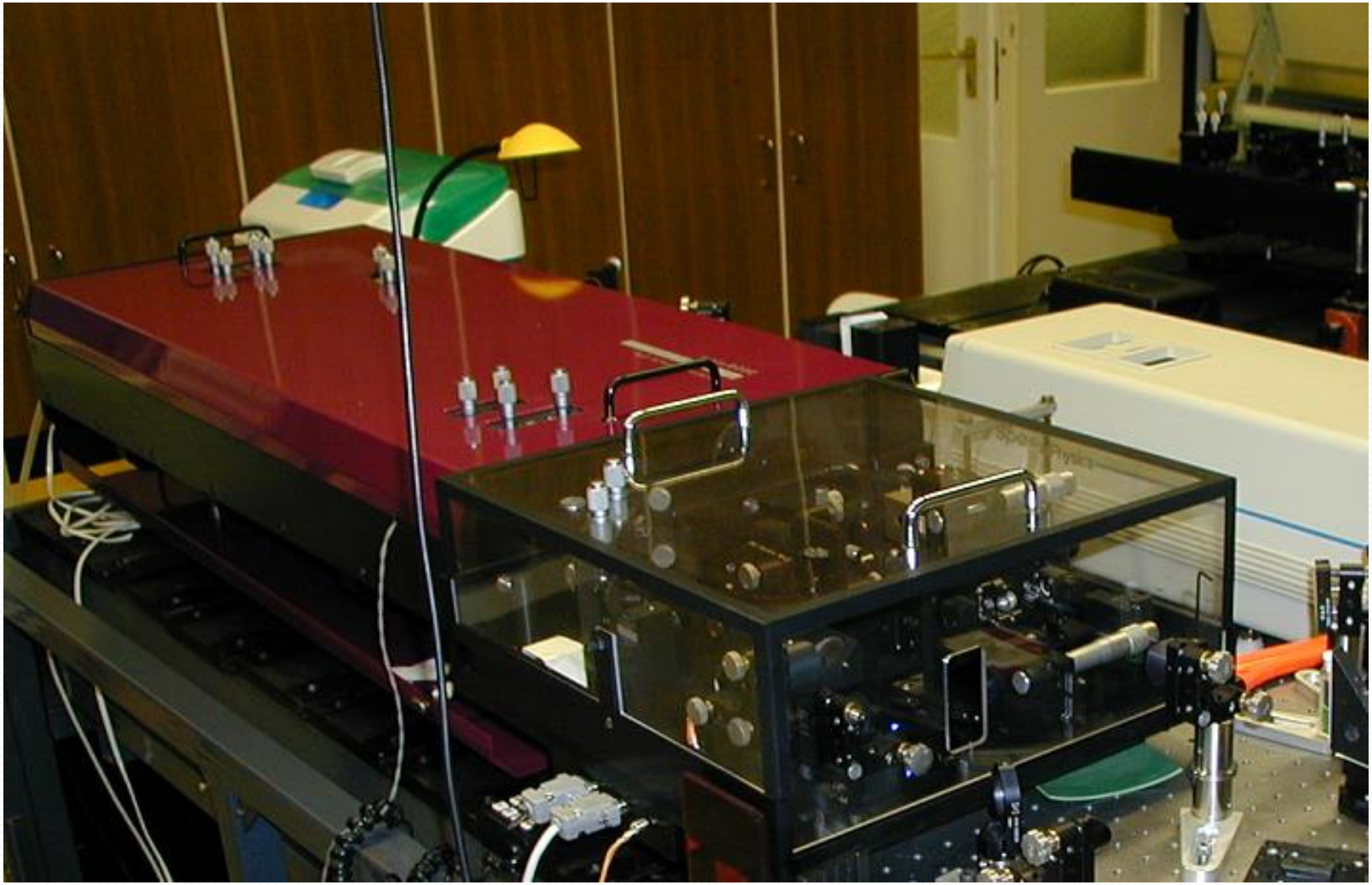


Eljárás erősen kollimált attoszekundumos fényimpulzusok időben reguláris sorozatának előállítására

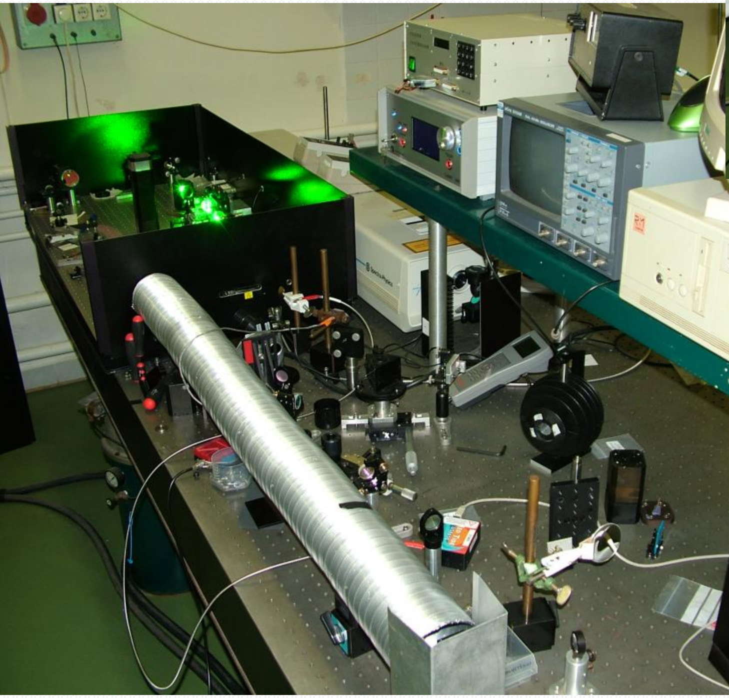
Feltalálók: *Farkas Győző 33%*
Kroó Norbert 33%
Tóth Csaba 33%
budapesti lakosok

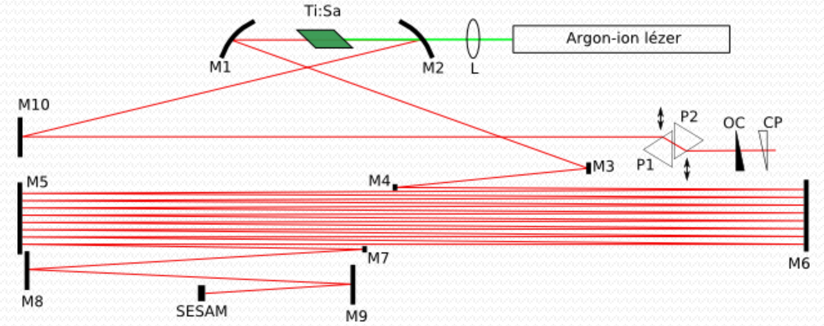
Bejelentés napja: 1992.05.26.

Development of tunable 100 fs-os Ti:saphire laser



Long-cavity (chirped-pulse) oscillator – P. Dombi

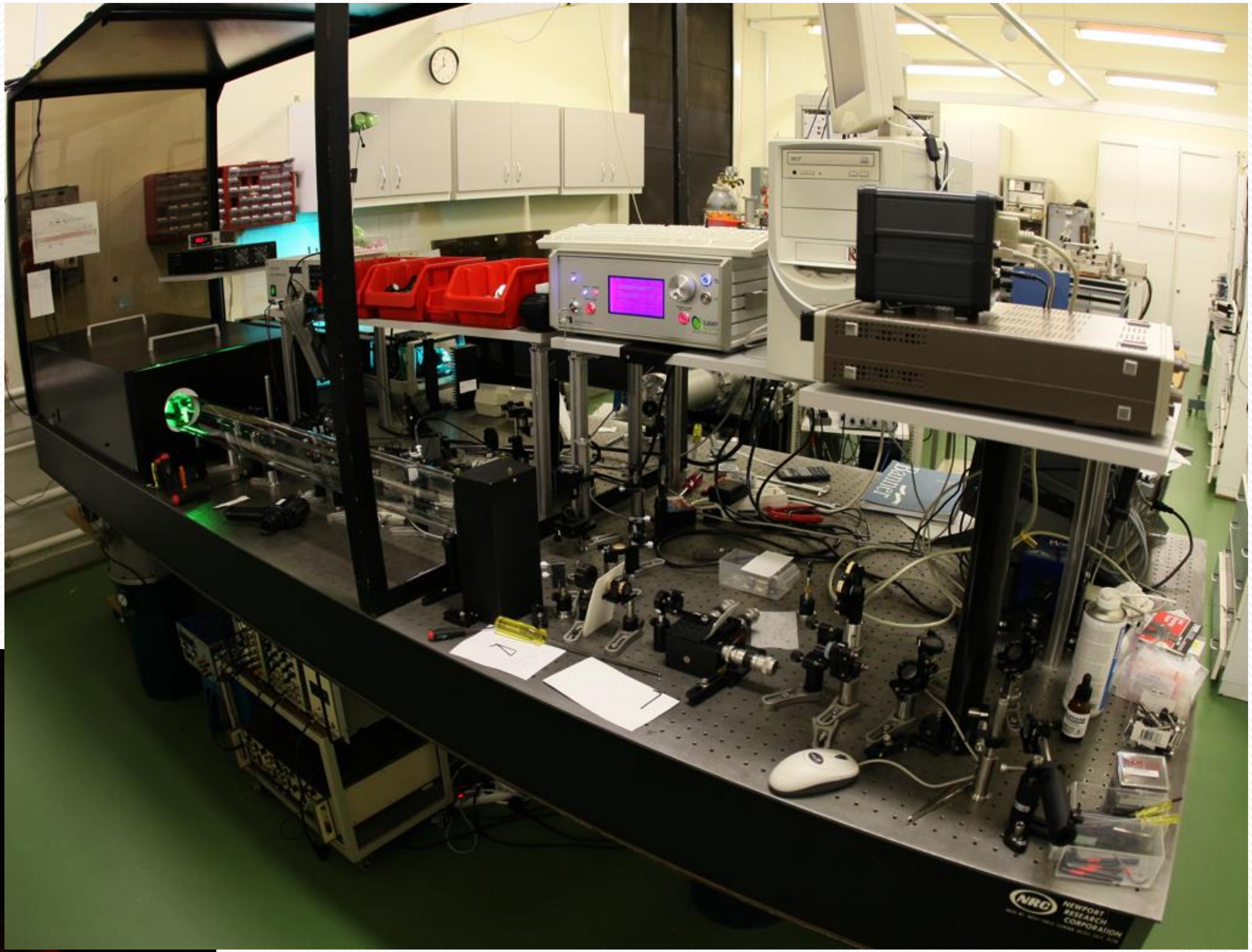




L – 80 m

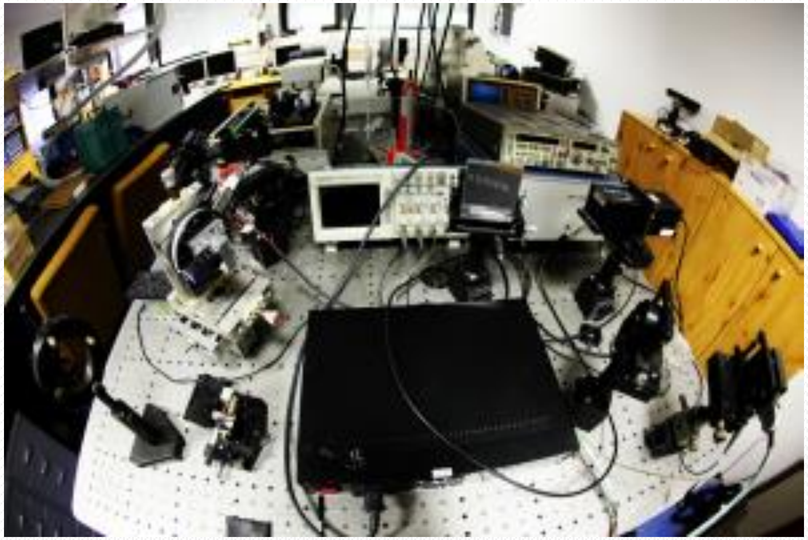
Light-Matter interaction Laboratory

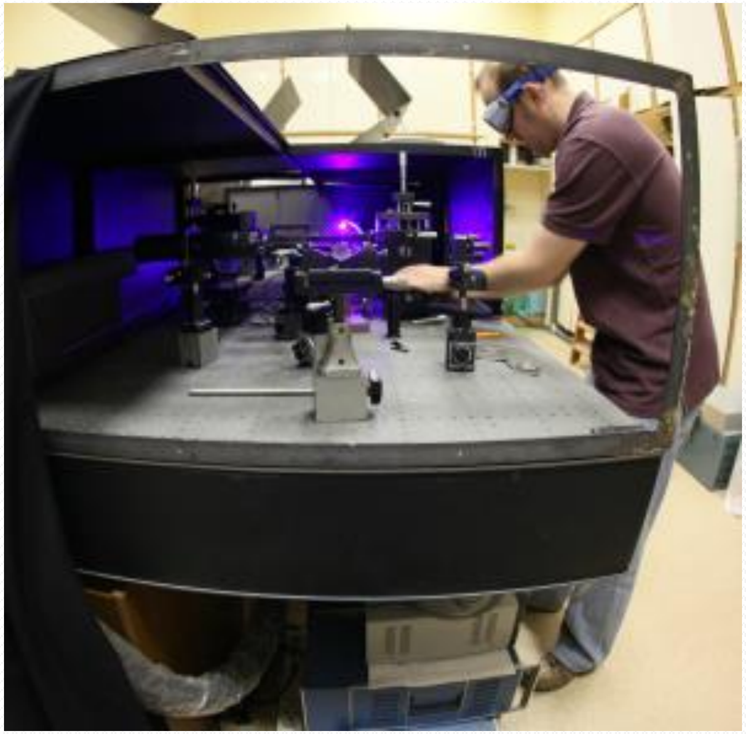
Laser pulse compression



Femtossecond laser system

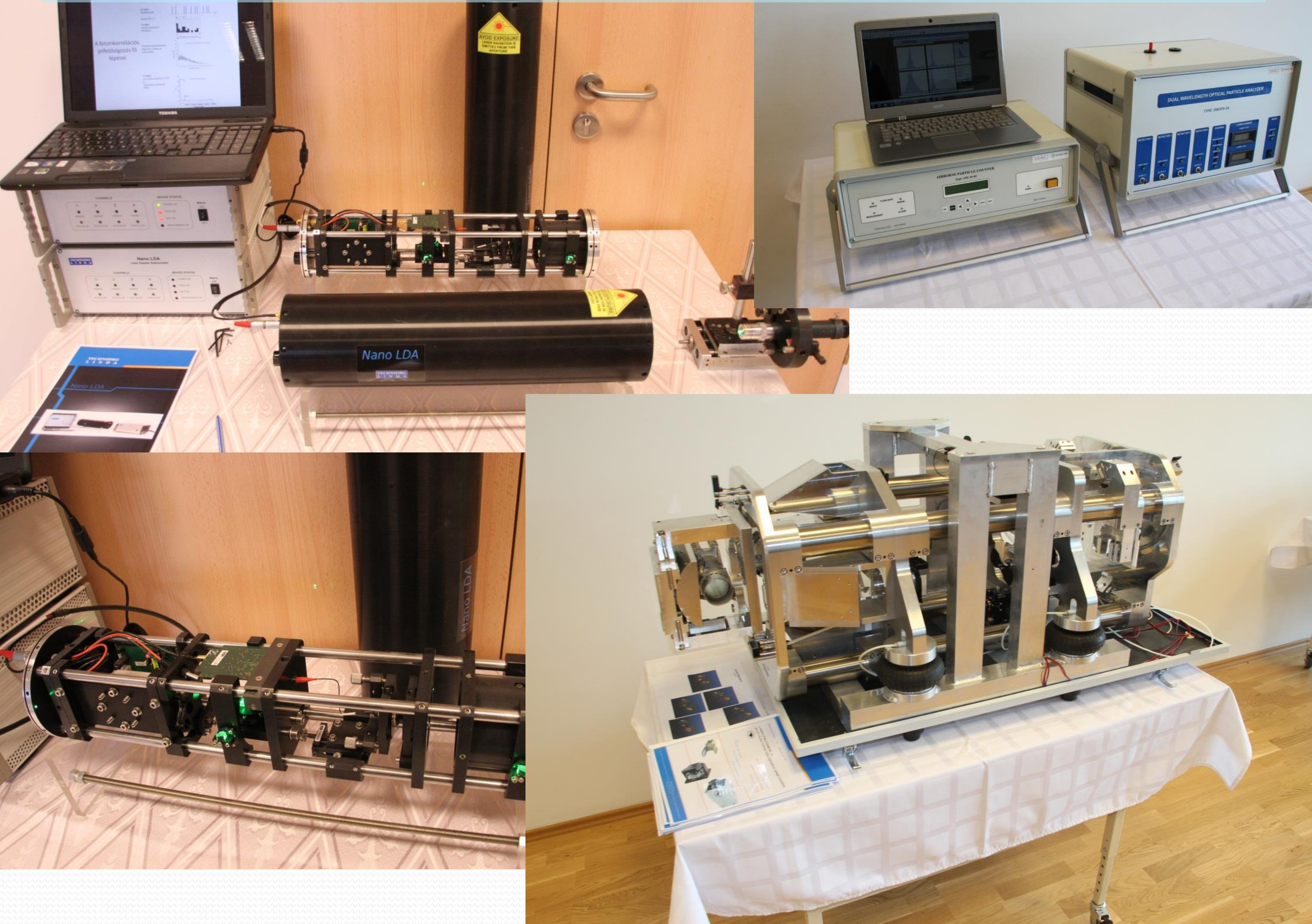
Development of laser measurement systems and instruments



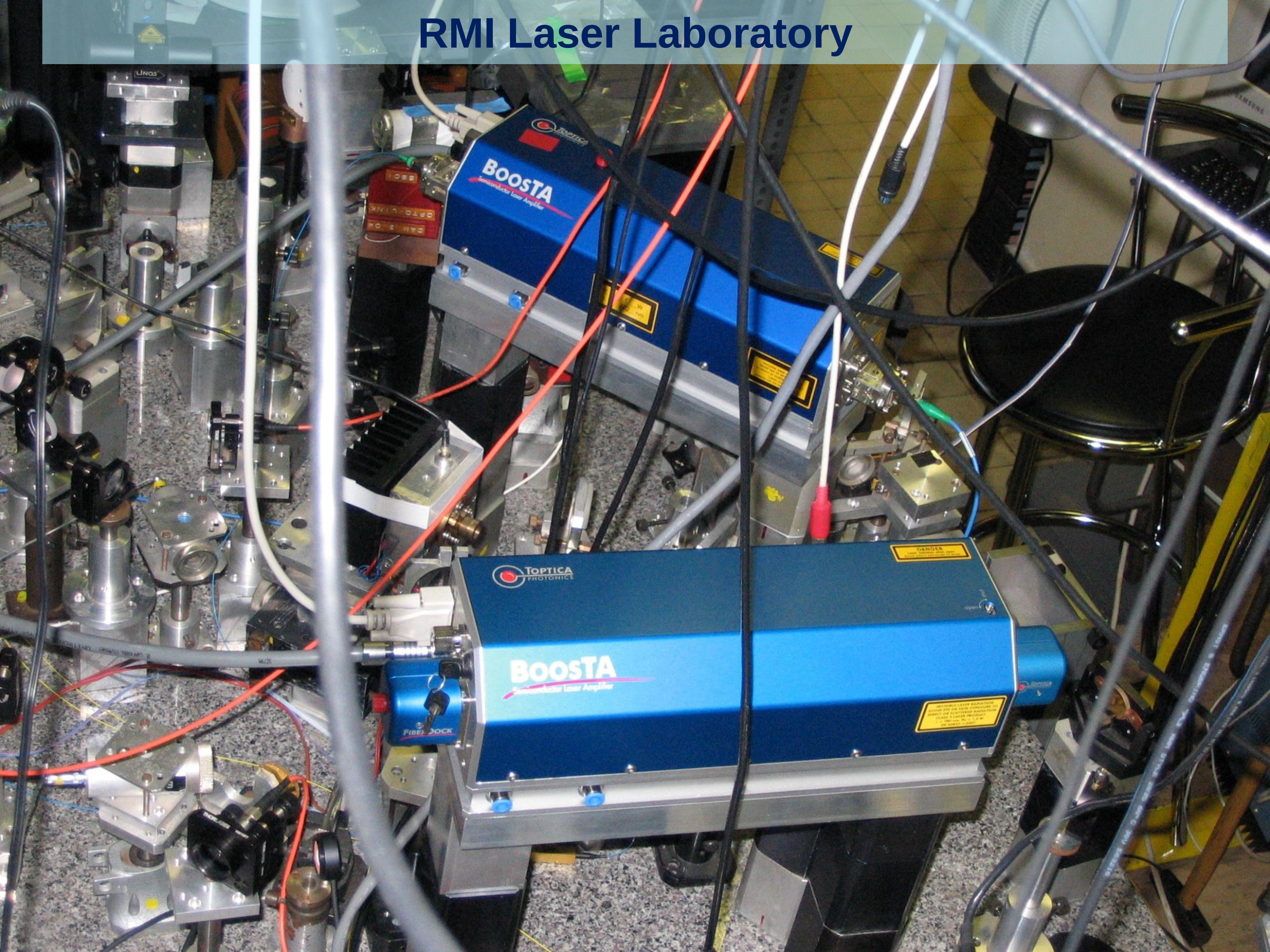


Developed instruments at exhibitions

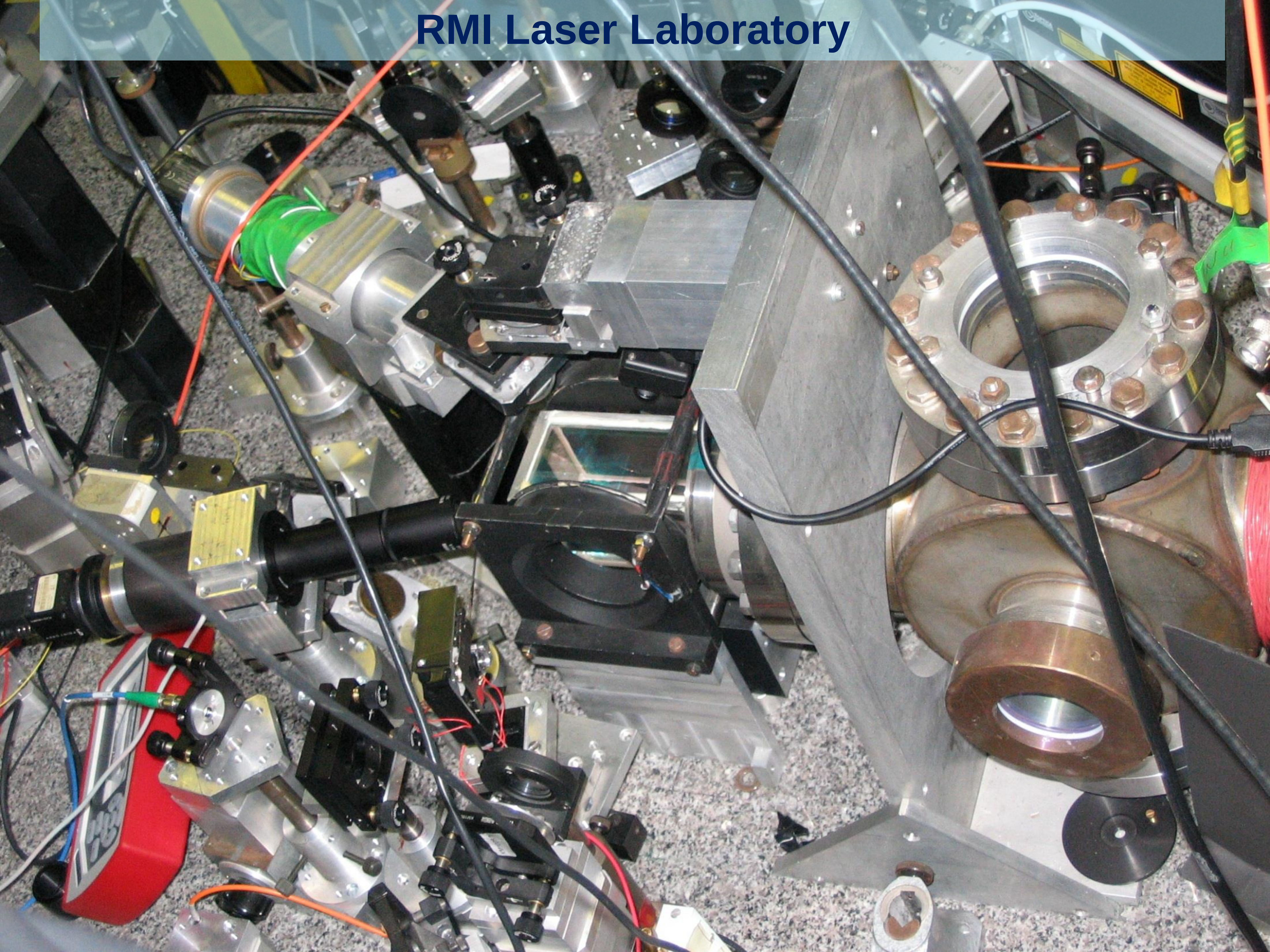
Development of laser-based instruments



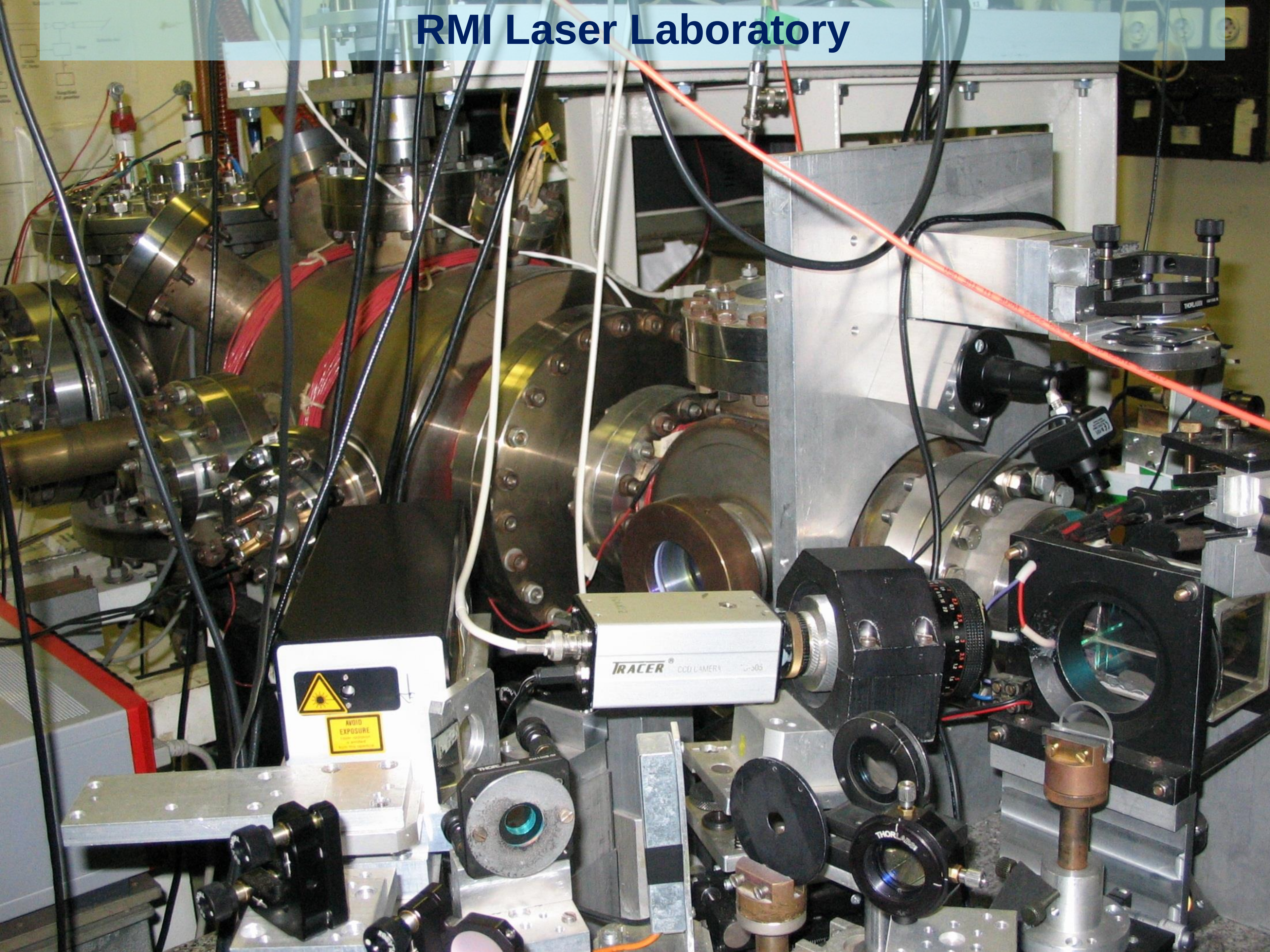
RMI Laser Laboratory



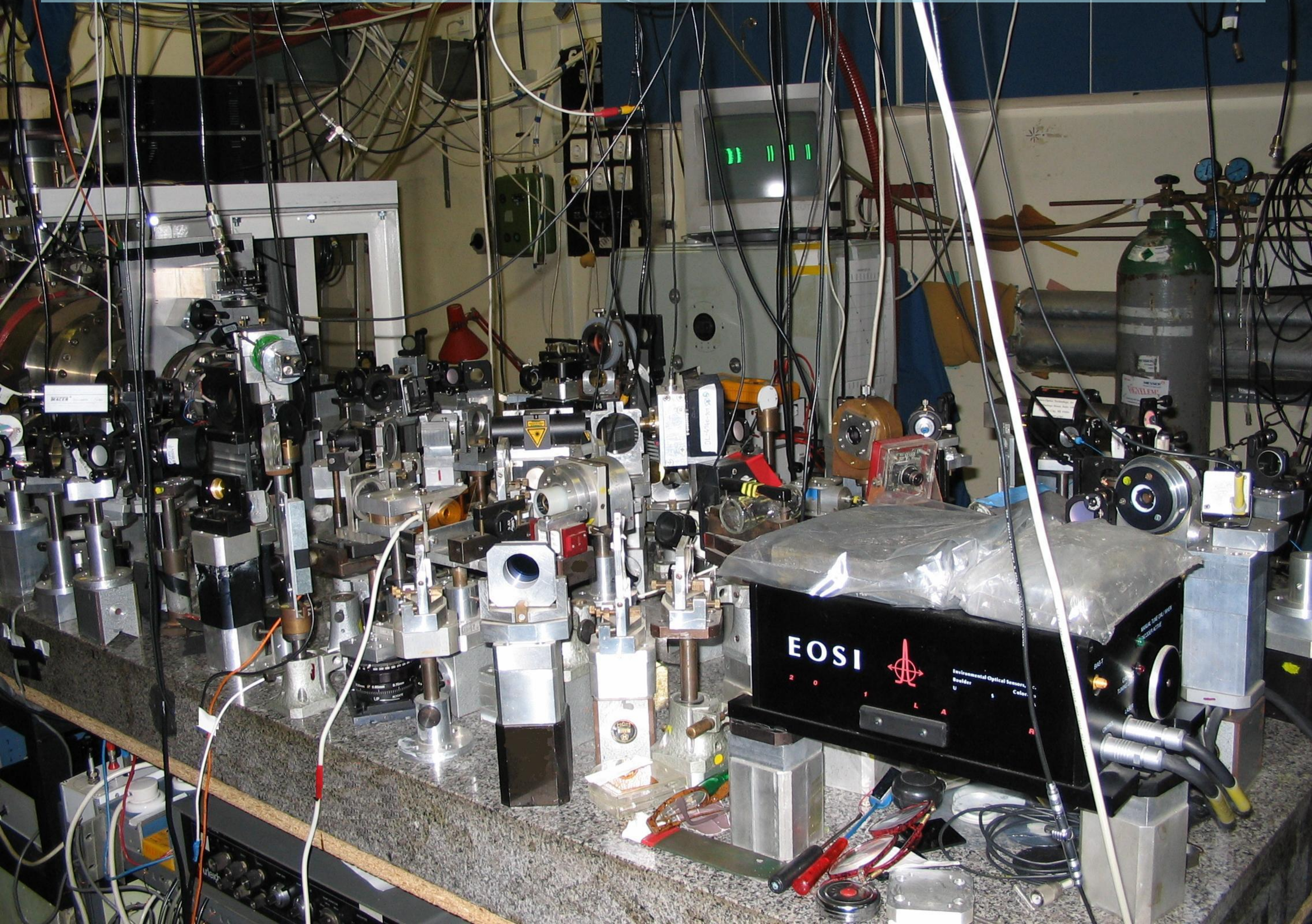
RMI Laser Laboratory



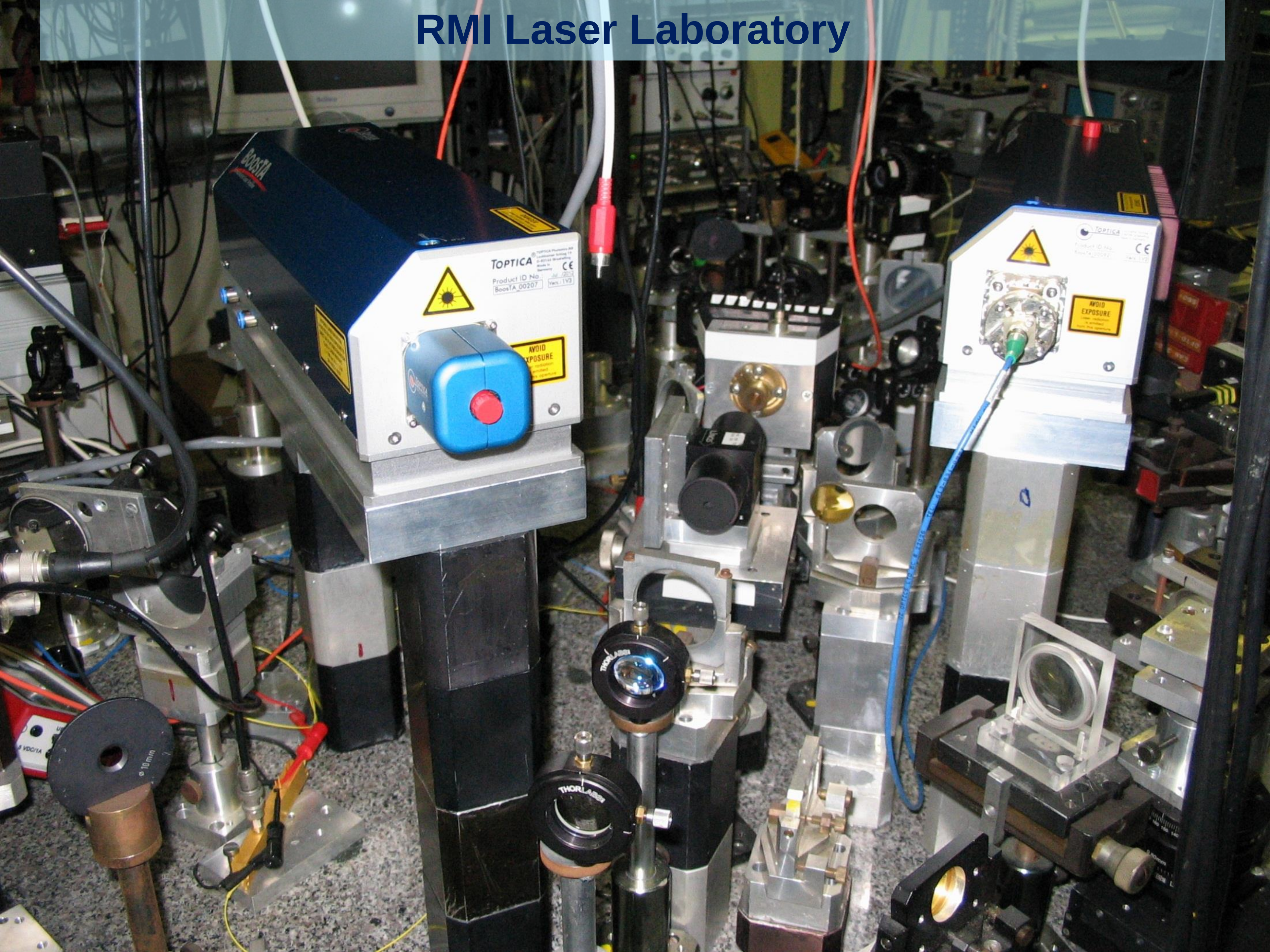
RMI Laser Laboratory



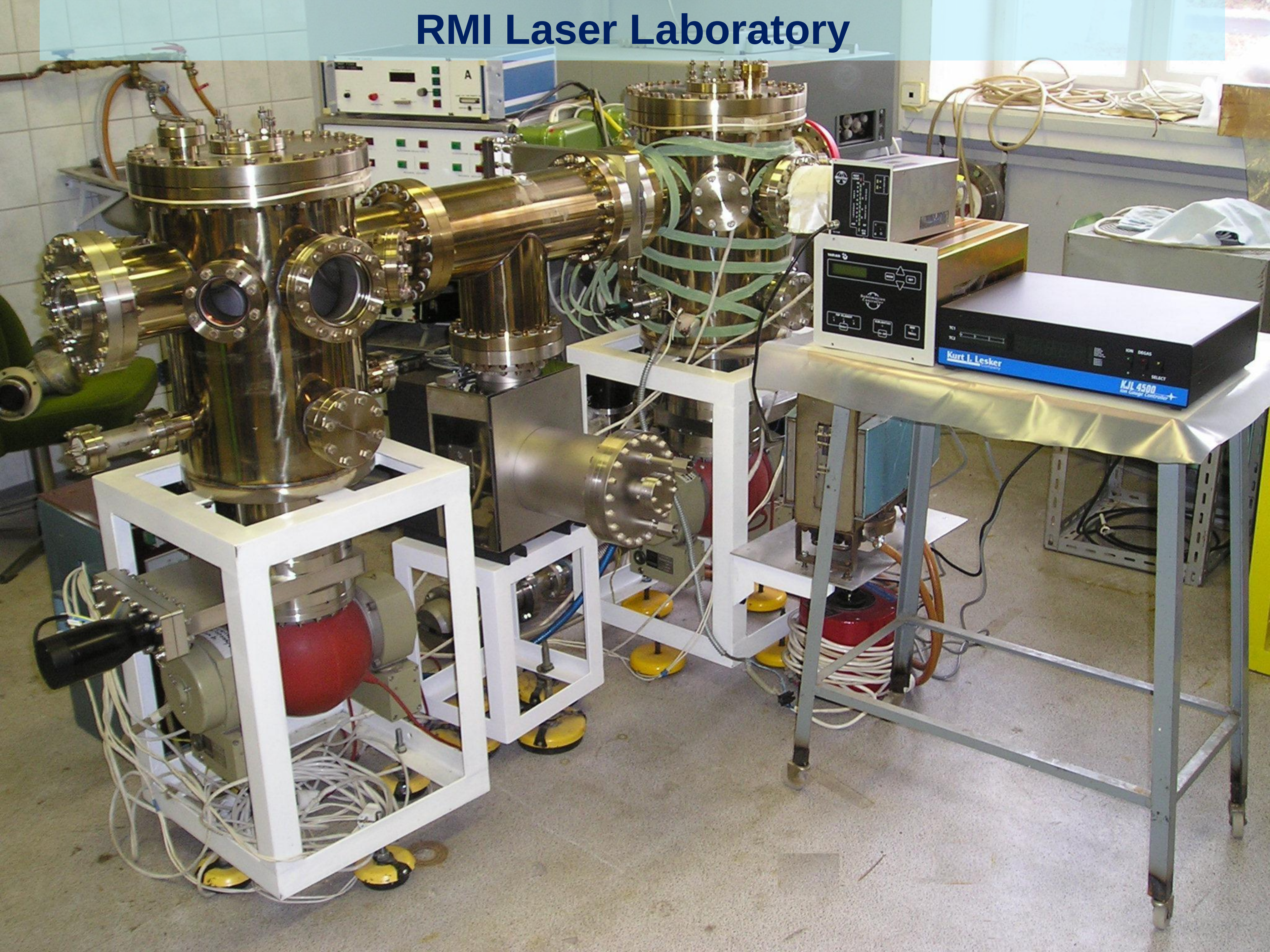
RMI Laser Laboratory



RMI Laser Laboratory



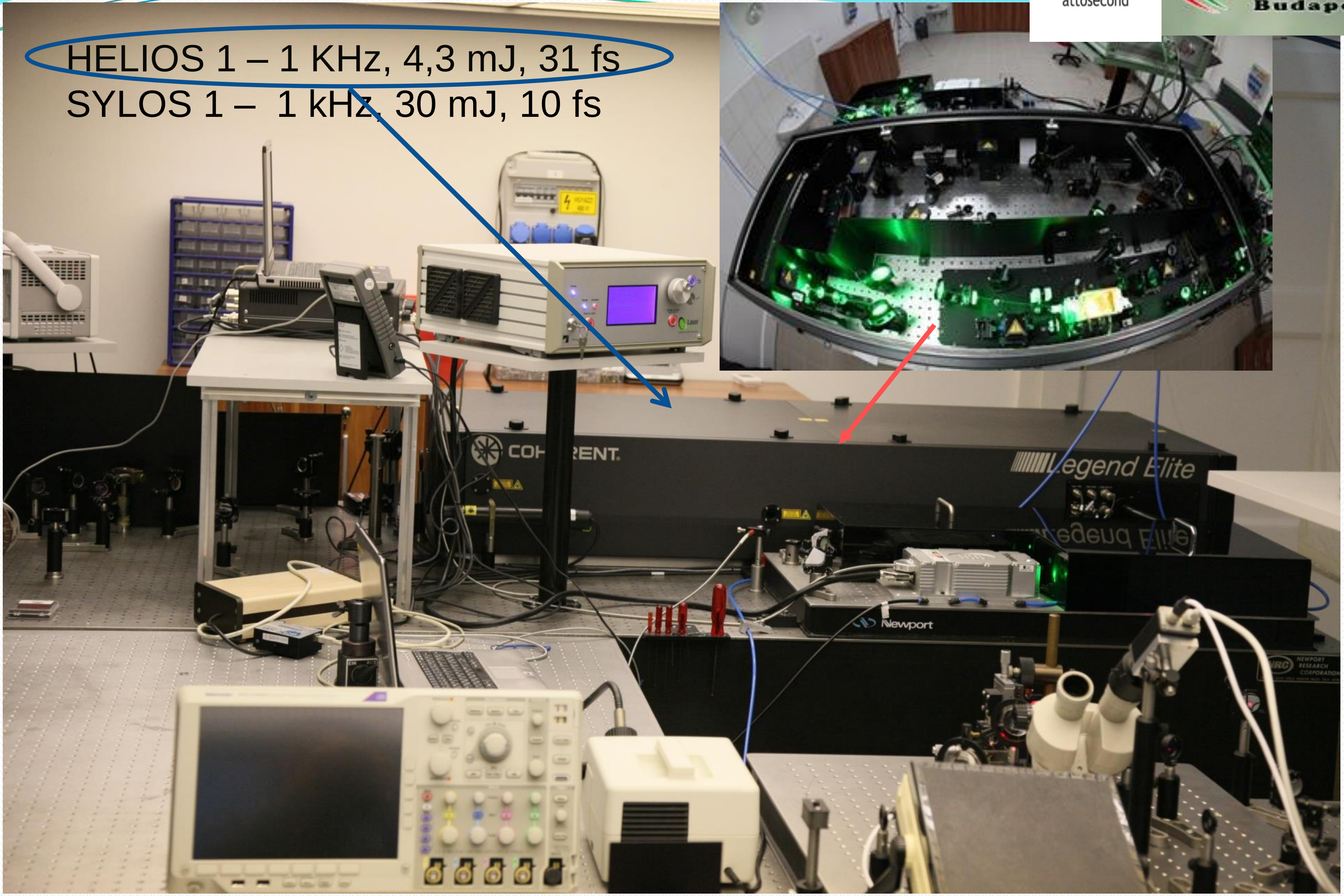
RMI Laser Laboratory

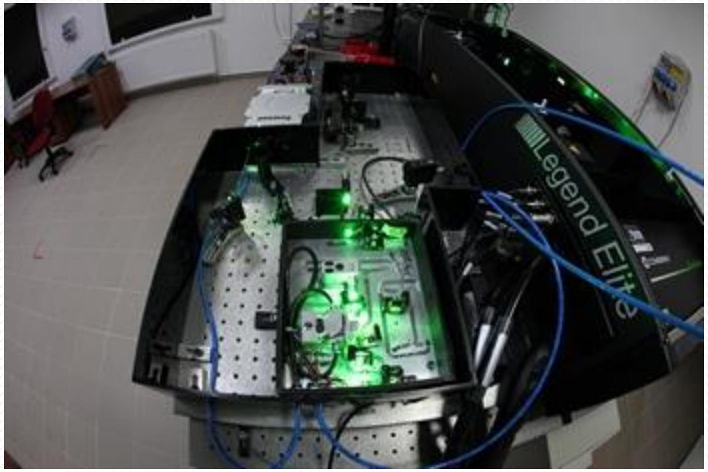


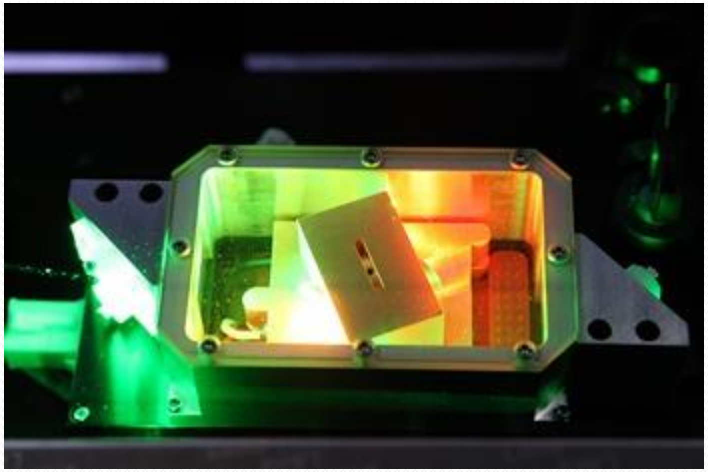
hELIos Laser Lab

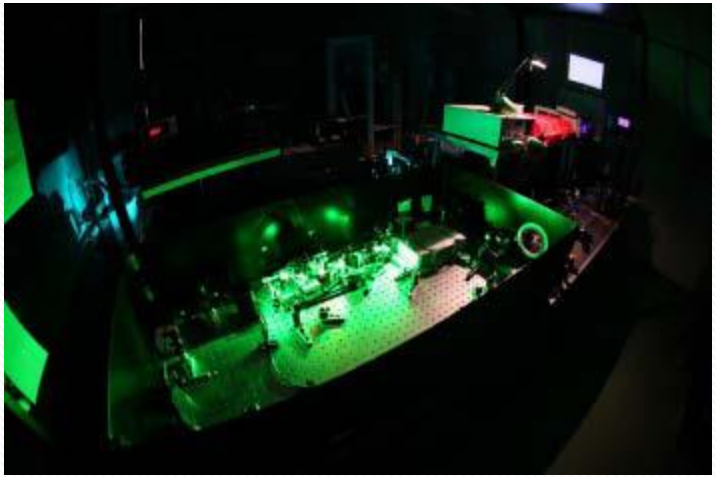
Clean room < 10 000

HELIOS 1 – 1 KHz, 4,3 mJ, 31 fs
SYLOS 1 – 1 kHz, 30 mJ, 10 fs



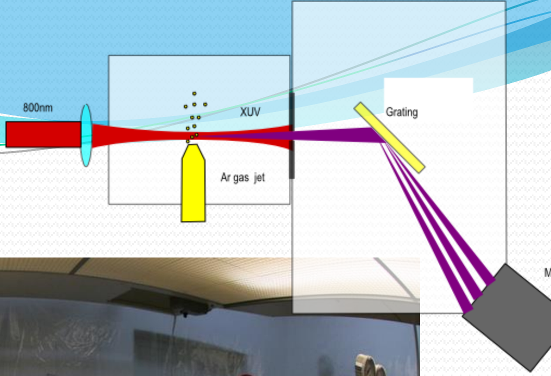






HELIOS 1 – 1 KHz, 4,3 mJ, 31 fs

Generation of high harmonics



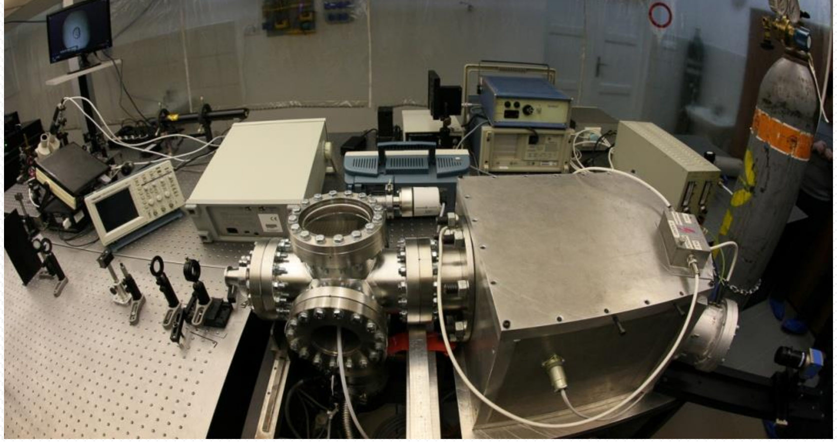
Laser parameters:

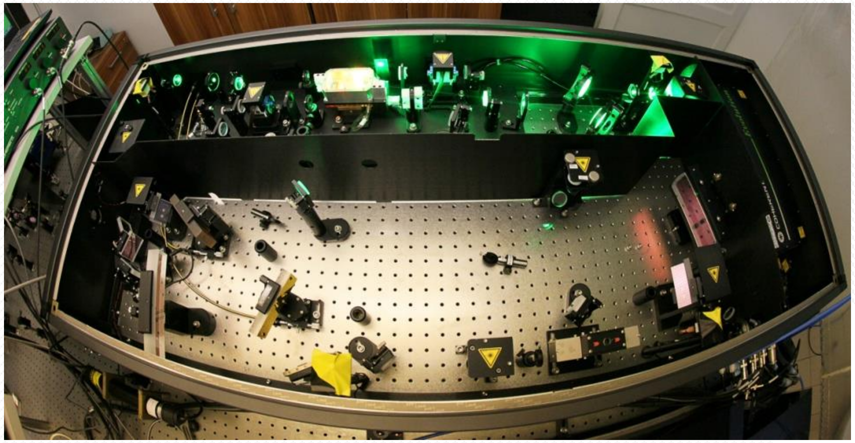
E_{imp}=4,1 mJ, τ =30-35 fs, λ= 800 nm

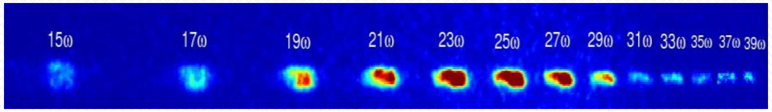
- f_{rep}= 1kHz

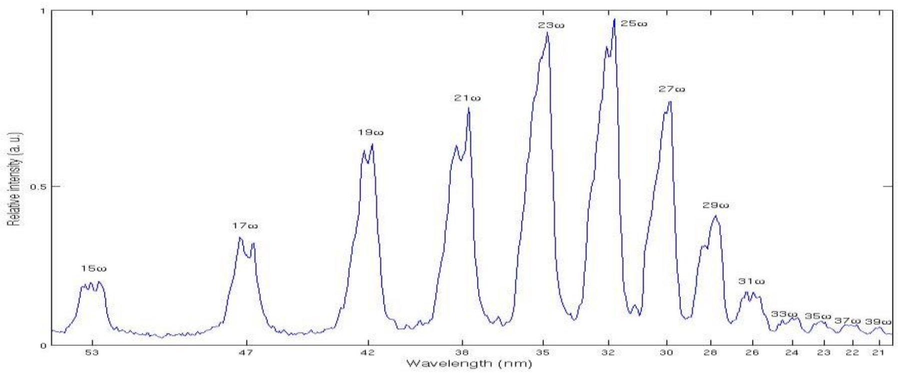
Focusing:

- f = 30 cm I ≈ 9,5 $\times$ 10^{15} W/cm^2
- E_{max} ≈ 2,7 $\times$ 10^9 V/cm





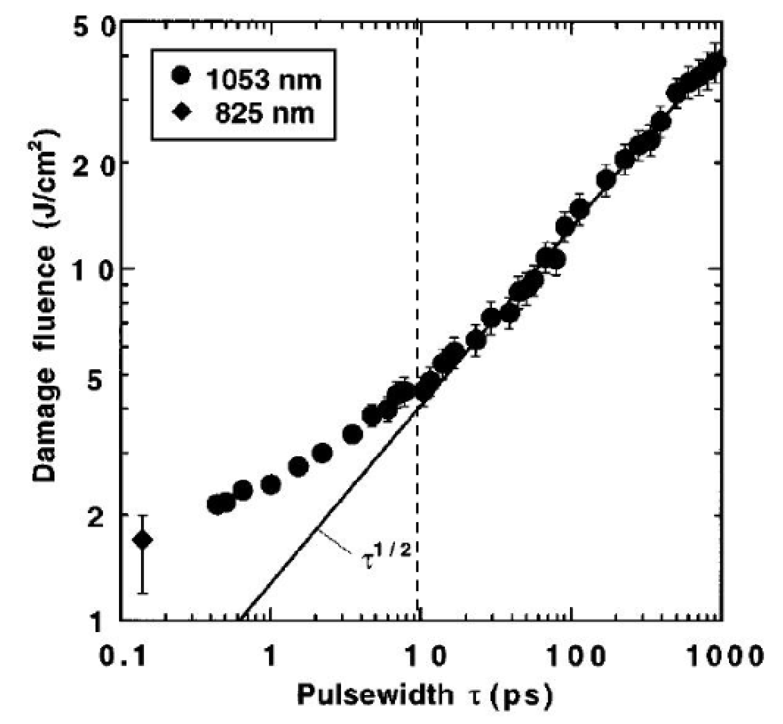


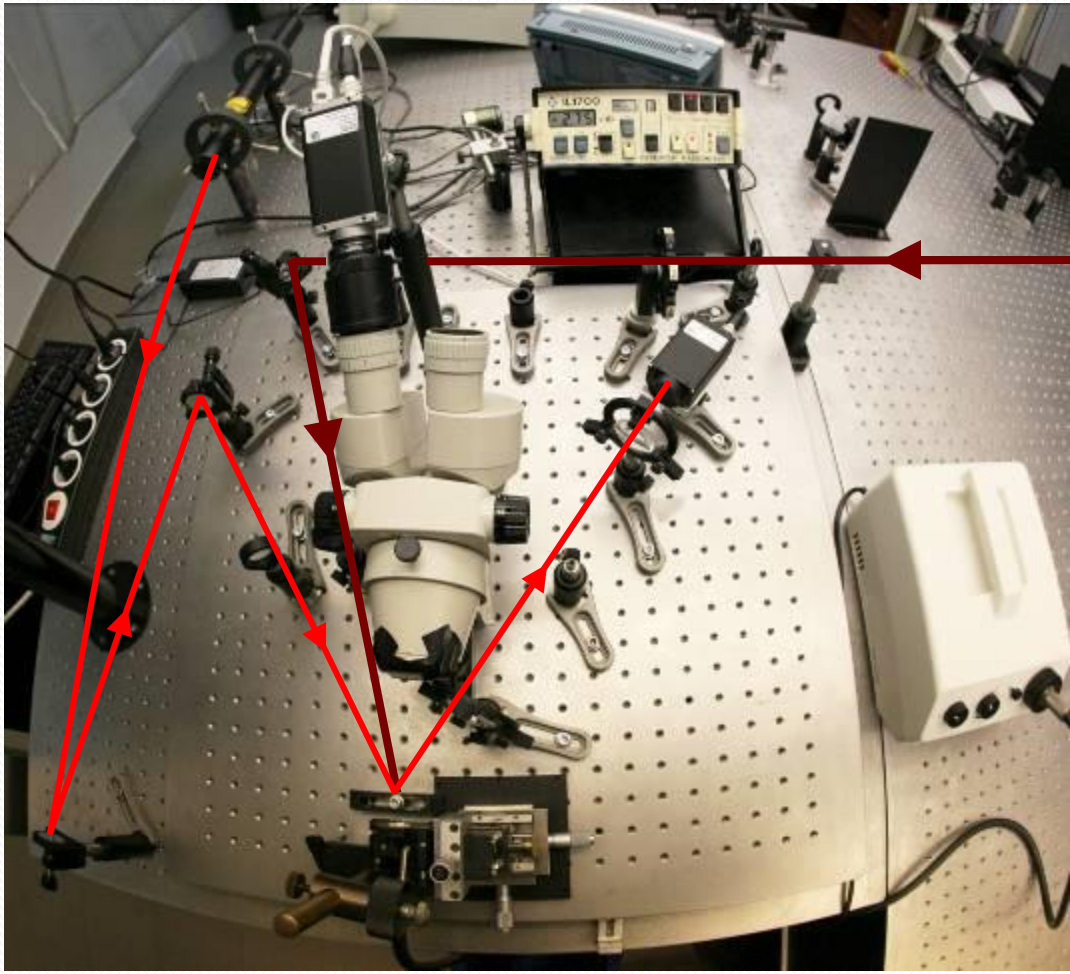


Measurement of demage threshold

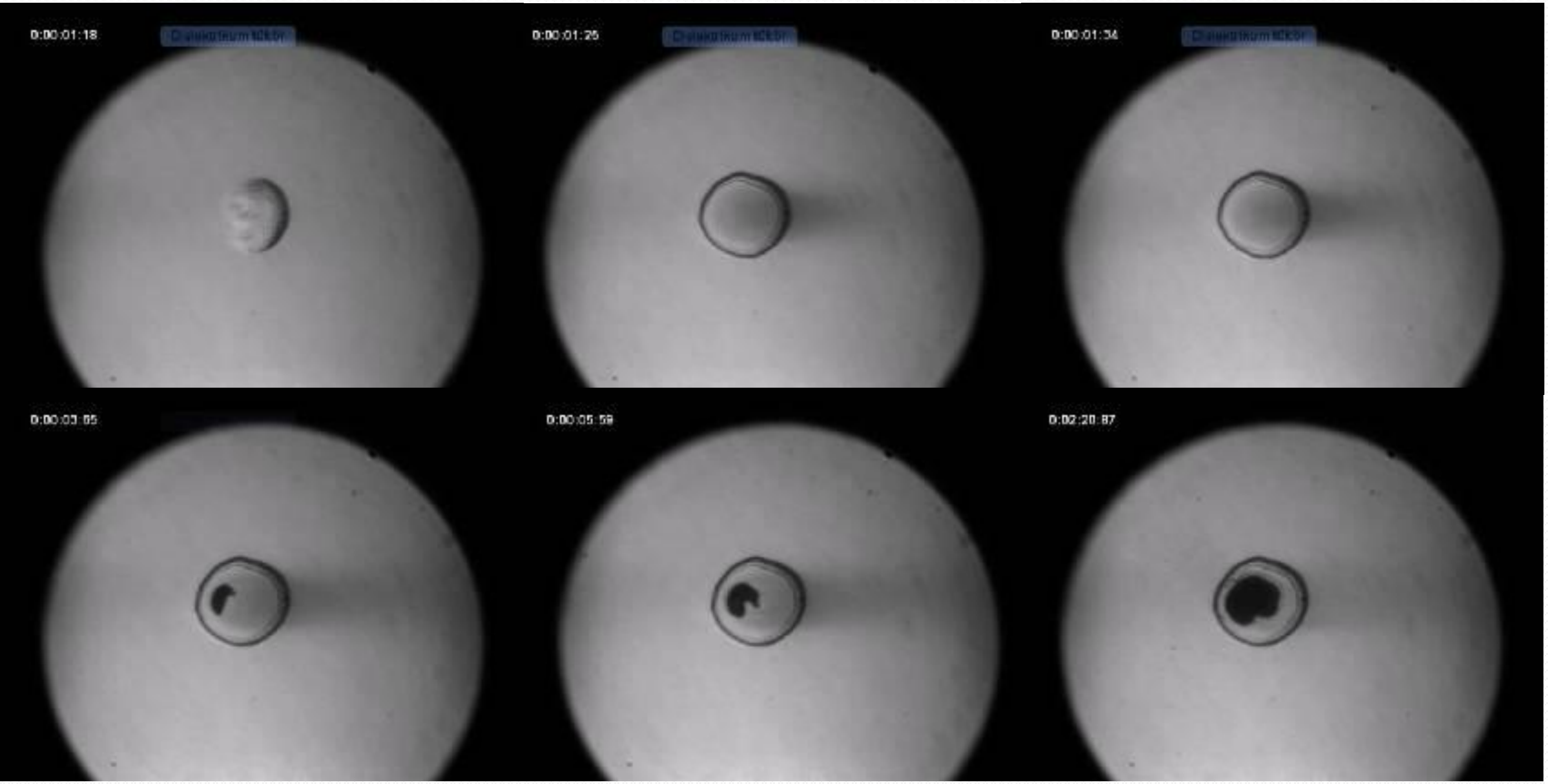
Main parameters:

Pulse energy	0.5 mJ
Spot size	10 μm (FWHM)
Pulse duration	35 fs (FWHM)
Rep. Rate	1 kHz
Intensity	125 J/cm^2





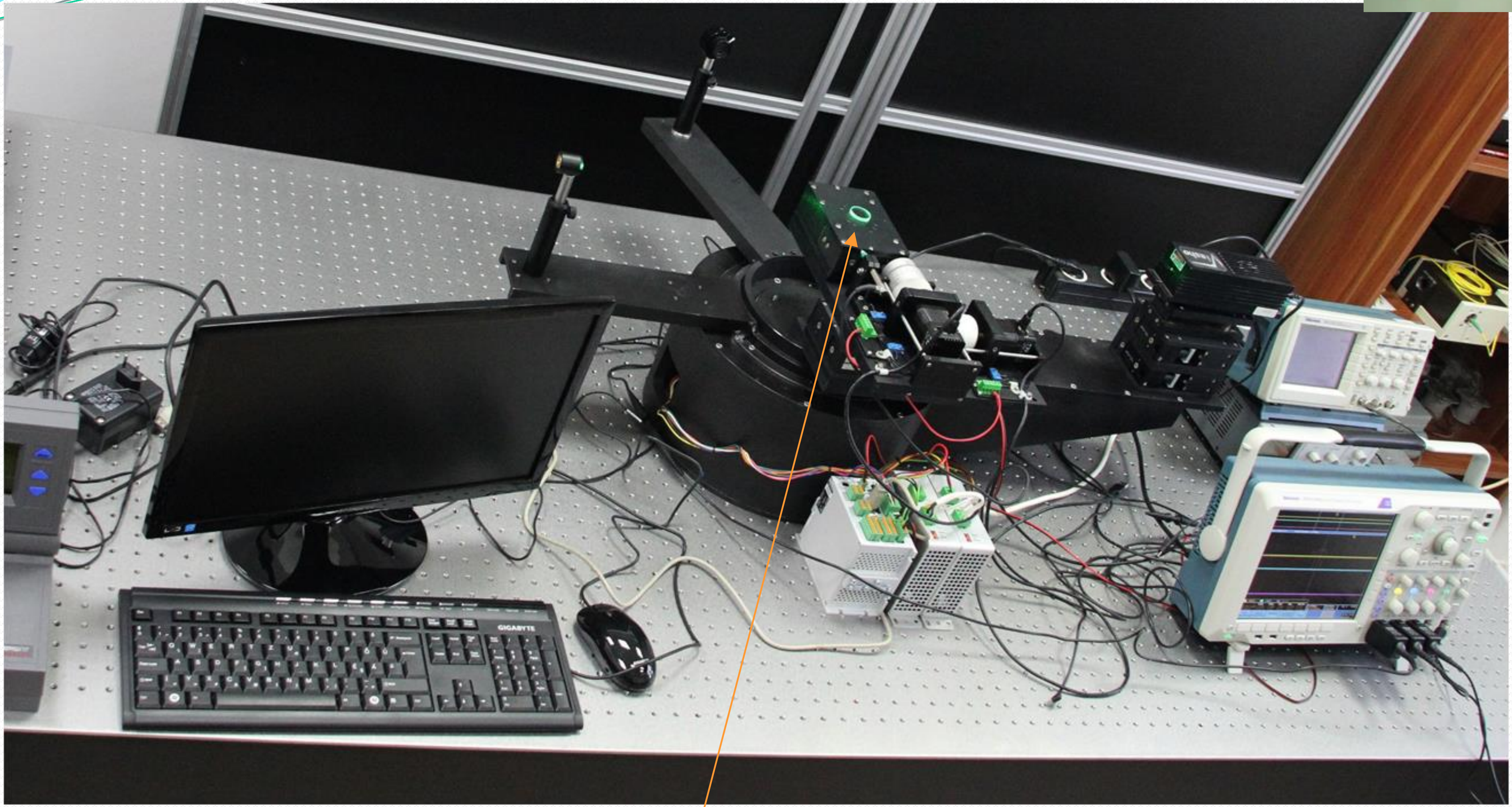
Measurement of demage threshold

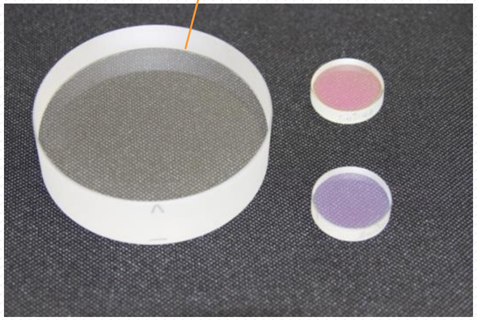


Dielectric mirror TiO_2-SiO_2 24 layers, HR, 800nm, polarization 45o eli attosecond

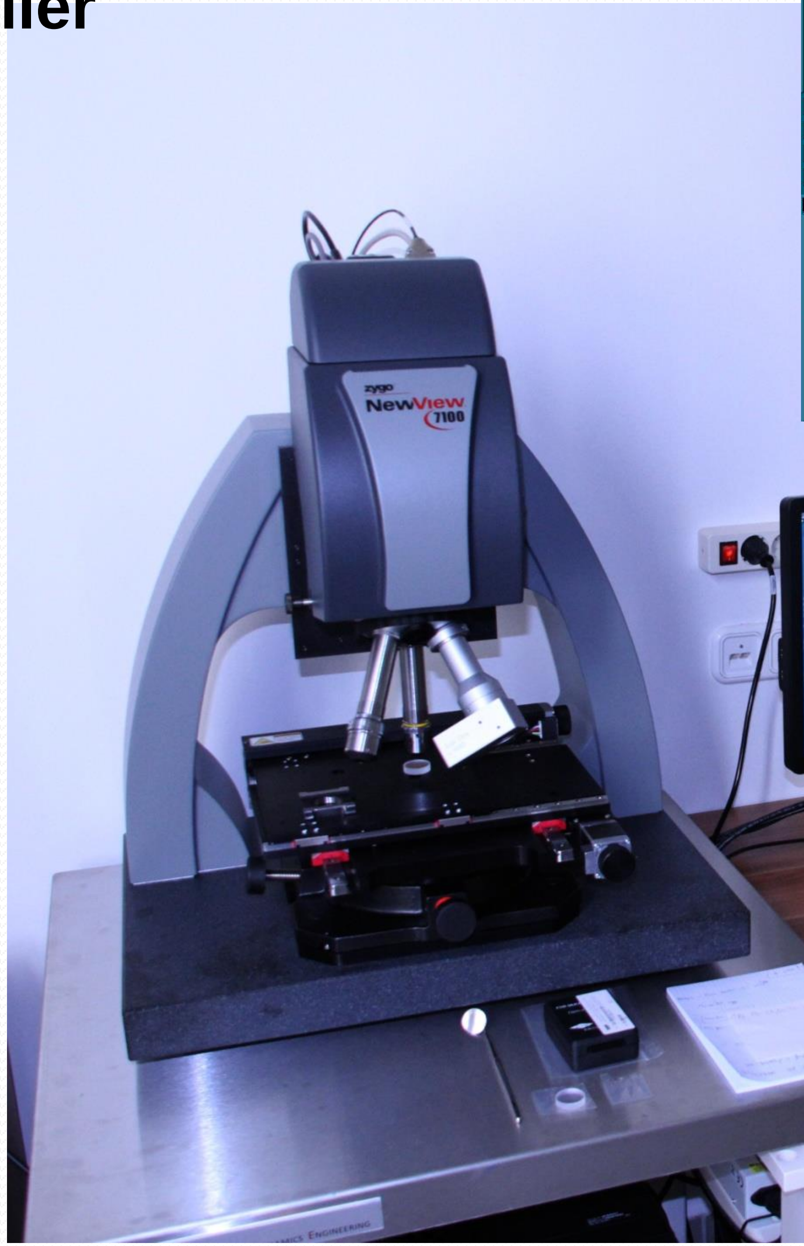
Helios program Budapest

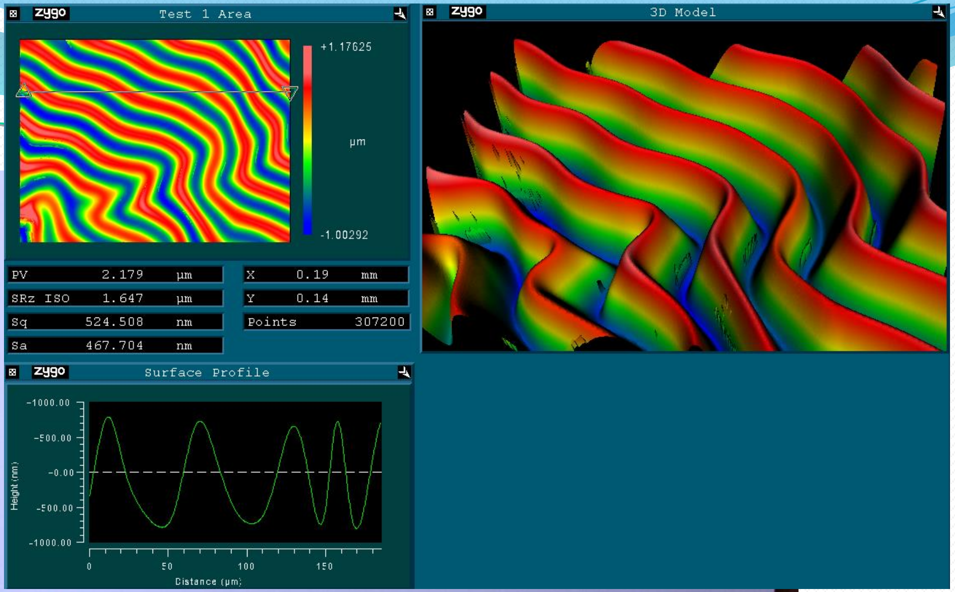
Testing of the optical homogenity of optical elements



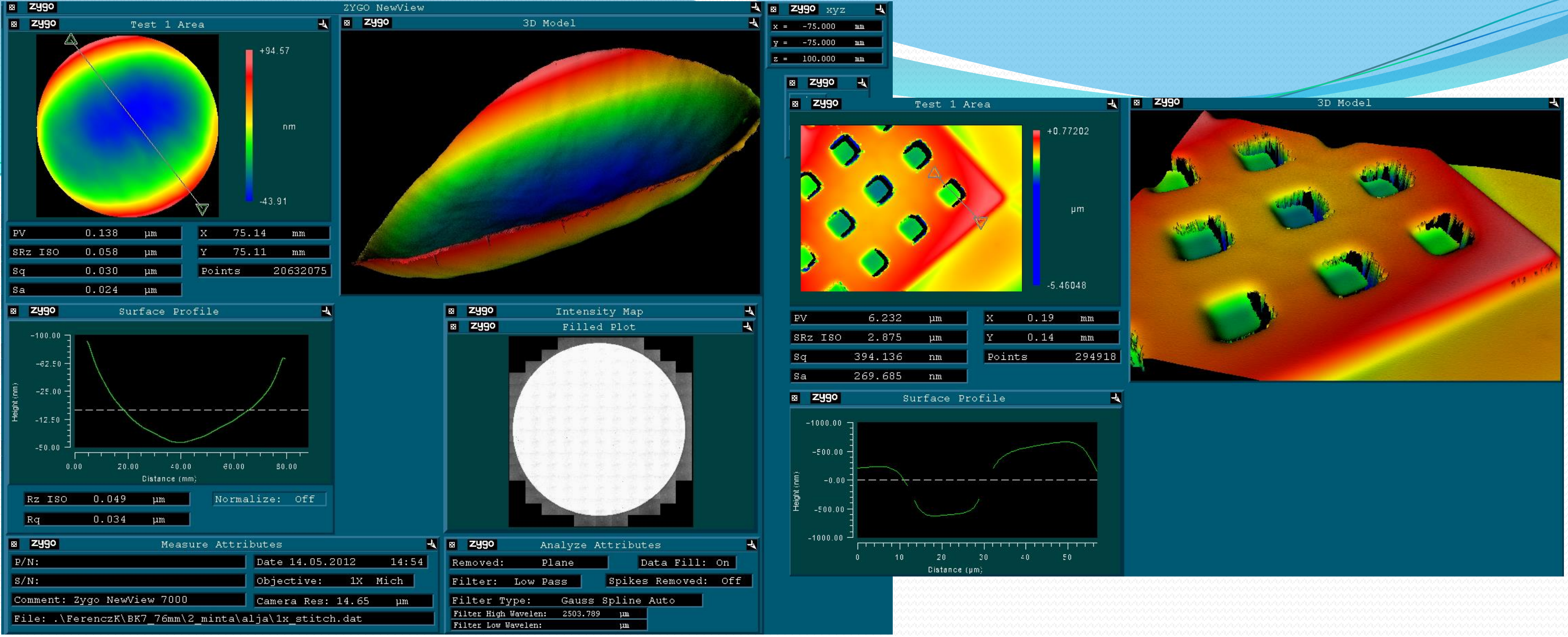


3D interferometric surface profiler





PV	2.179	µm
SRz ISO	1.647	µm
Sq	524.508	nm
Sa	467.704	nm
X	0.19	mm
Y	0.14	mm
Points	307200	



PV 0.138 µm
SRz ISO 0.058 µm
Sq 0.030 µm
Sa 0.024 µm
X 75.14 mm
Y 75.11 mm
Points 20632075

Rz ISO 0.049 µm
Rq 0.034 µm
Normalize: Off

Measure Attributes

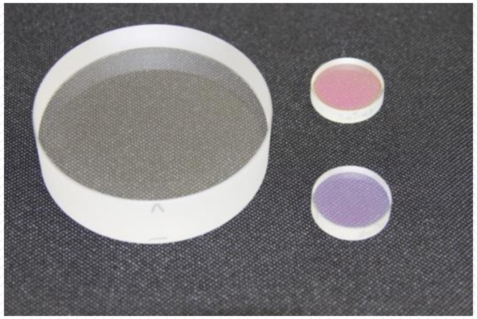
P/N:
S/N:
Comment: Zygo NewView 7000
File: .\FerenczK\BK7_76mm\2_minta\alja\1x_stitch.dat
Date 14.05.2012 14:54
Objective: 1X Mich
Camera Res: 14.65 µm

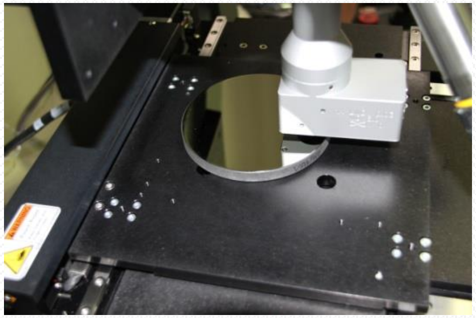
Analyze Attributes

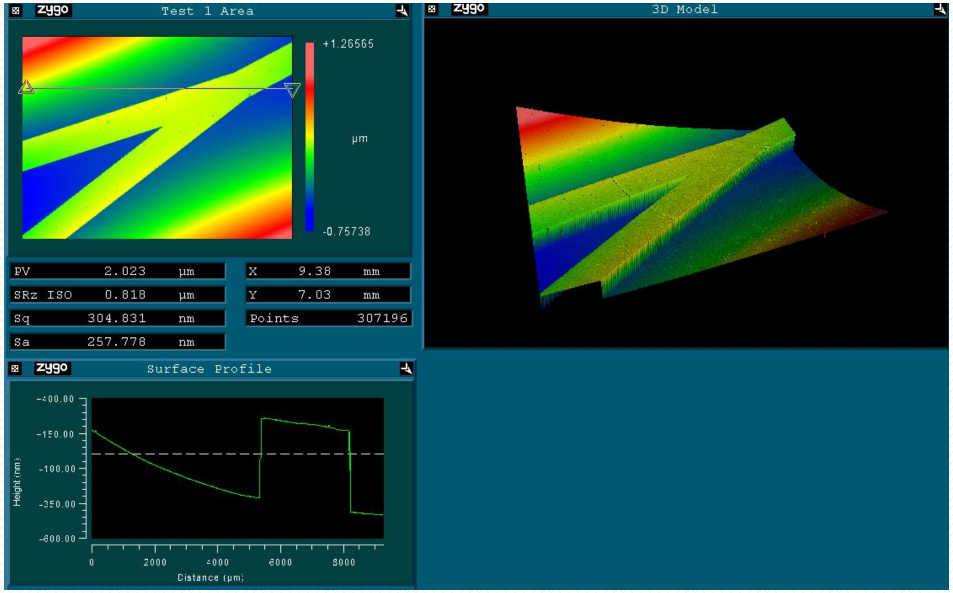
Removed: Plane
Data Fill: On
Filter: Low Pass
Spikes Removed: Off
Filter Type: Gauss Spline Auto
Filter High Wavelen: 2503.789 µm
Filter Low Wavelen: µm

x = -75.000 mm
y = -75.000 mm
z = 100.000 mm

PV 6.232 µm
SRz ISO 2.875 µm
Sq 394.136 nm
Sa 269.685 nm
X 0.19 mm
Y 0.14 mm
Points 294918

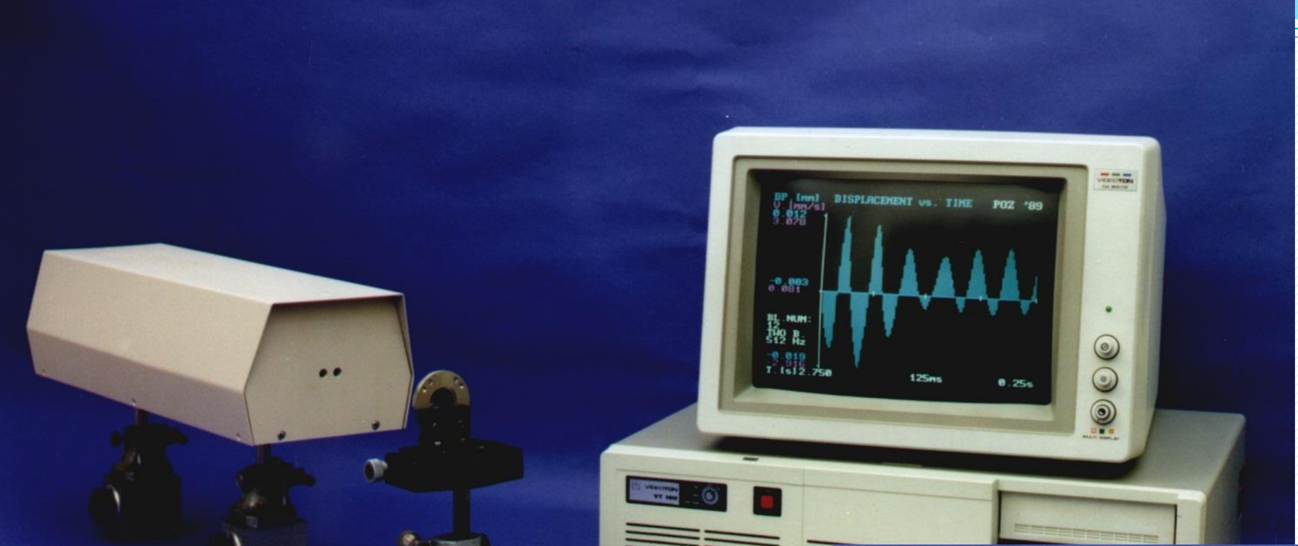


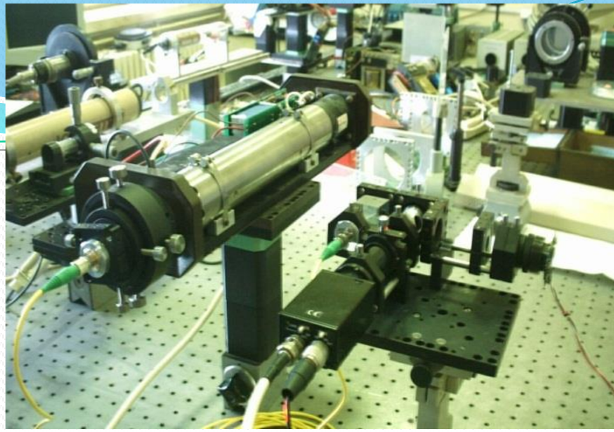


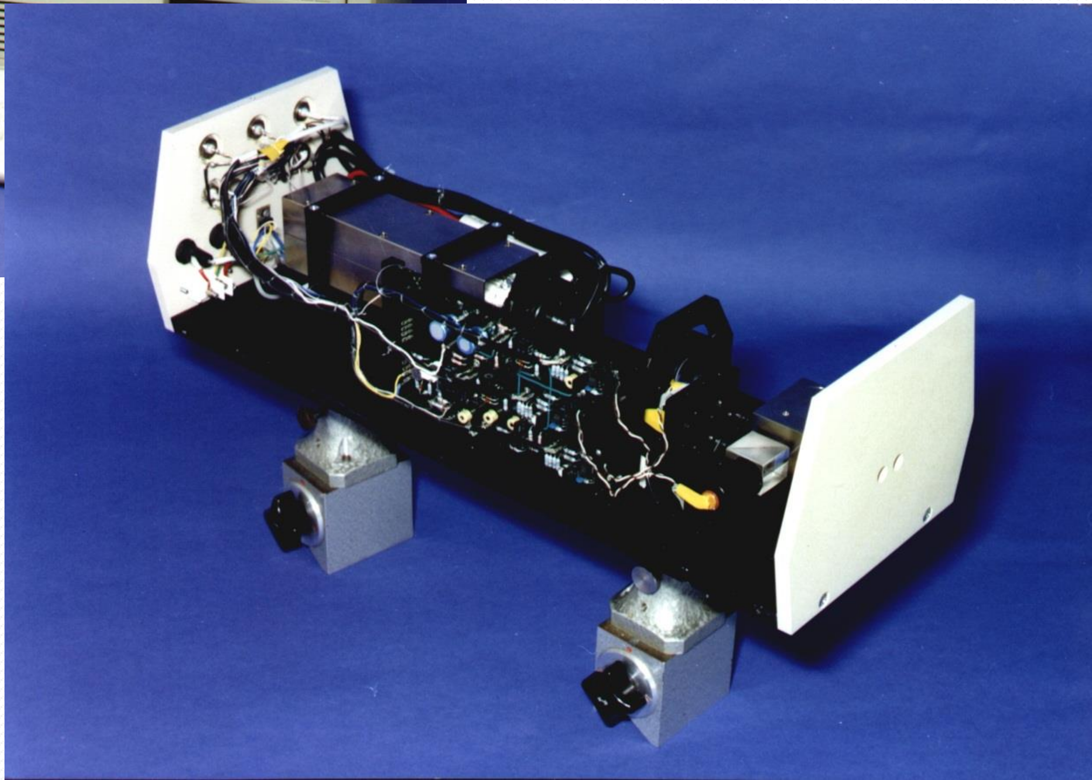


PV 2.023 µm
SRz ISO 0.818 µm
Sq 304.831 nm
Sa 257.778 nm
X 9.38 mm
Y 7.03 mm
Points 307196

Development of interferometers

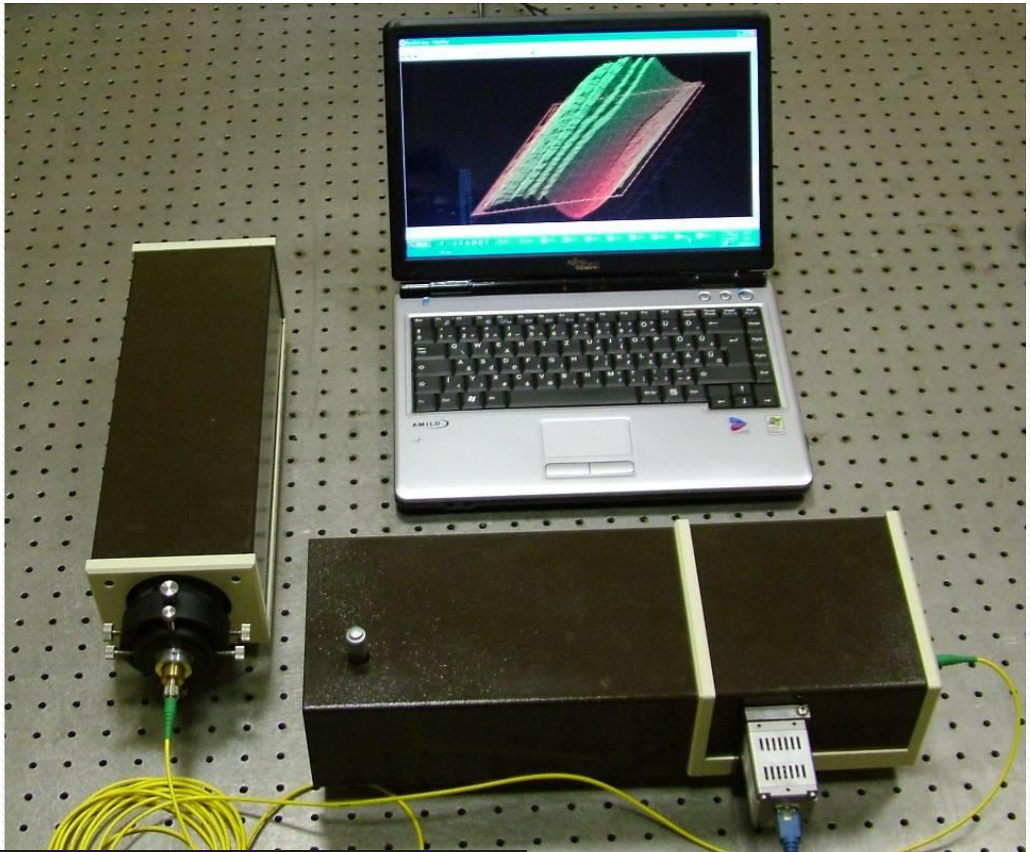


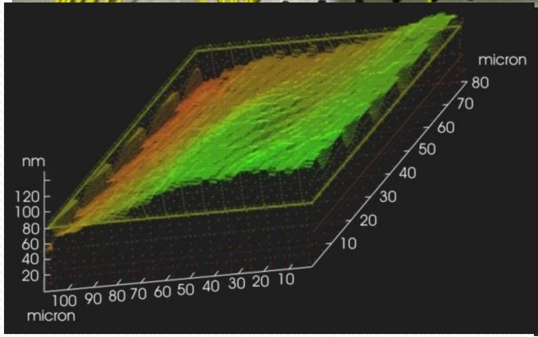


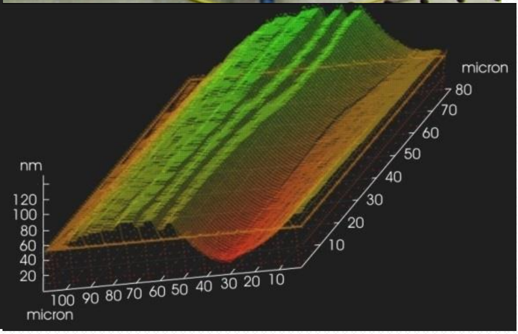


Development of interferometers

Interferometric surface measuring instrument







Light source - frequency stabilised
He-Ne laser, 2mW;

Frequency stability:
short term $\Delta f / f$ – 3x10 E (-10)
long term Df / f – 4x10 E (-9)

Transversal resolution - ~ 1 nm;

Field of view –max. 50 X 50 mm
min. 100 x 100 micron;

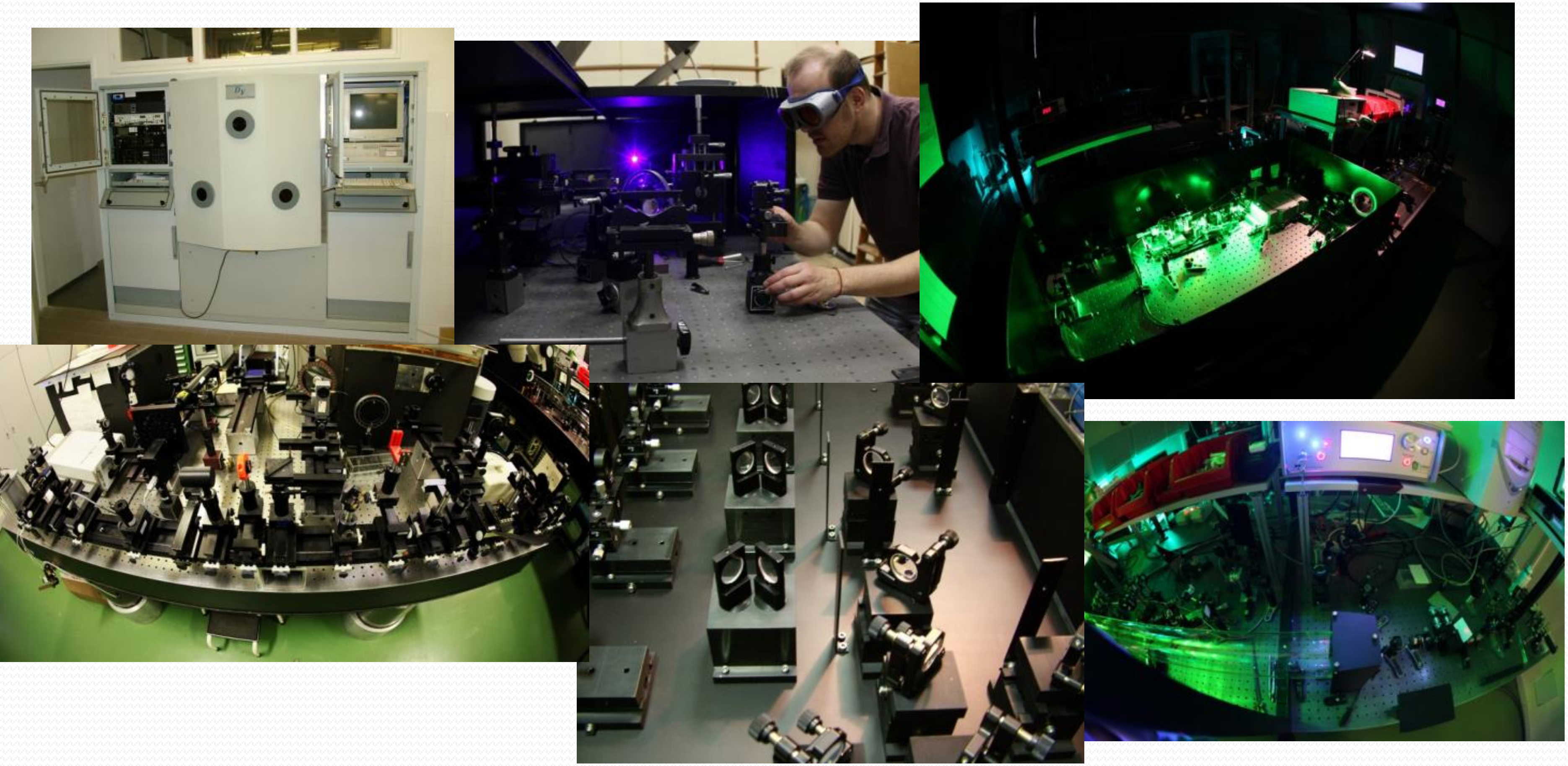
Compensation of phase distortion;

Fringe distance –
L =316,4250 nm;

Resolution ~1 nm;
Phase shift – continuous – 0 - 2π;

hELIos project

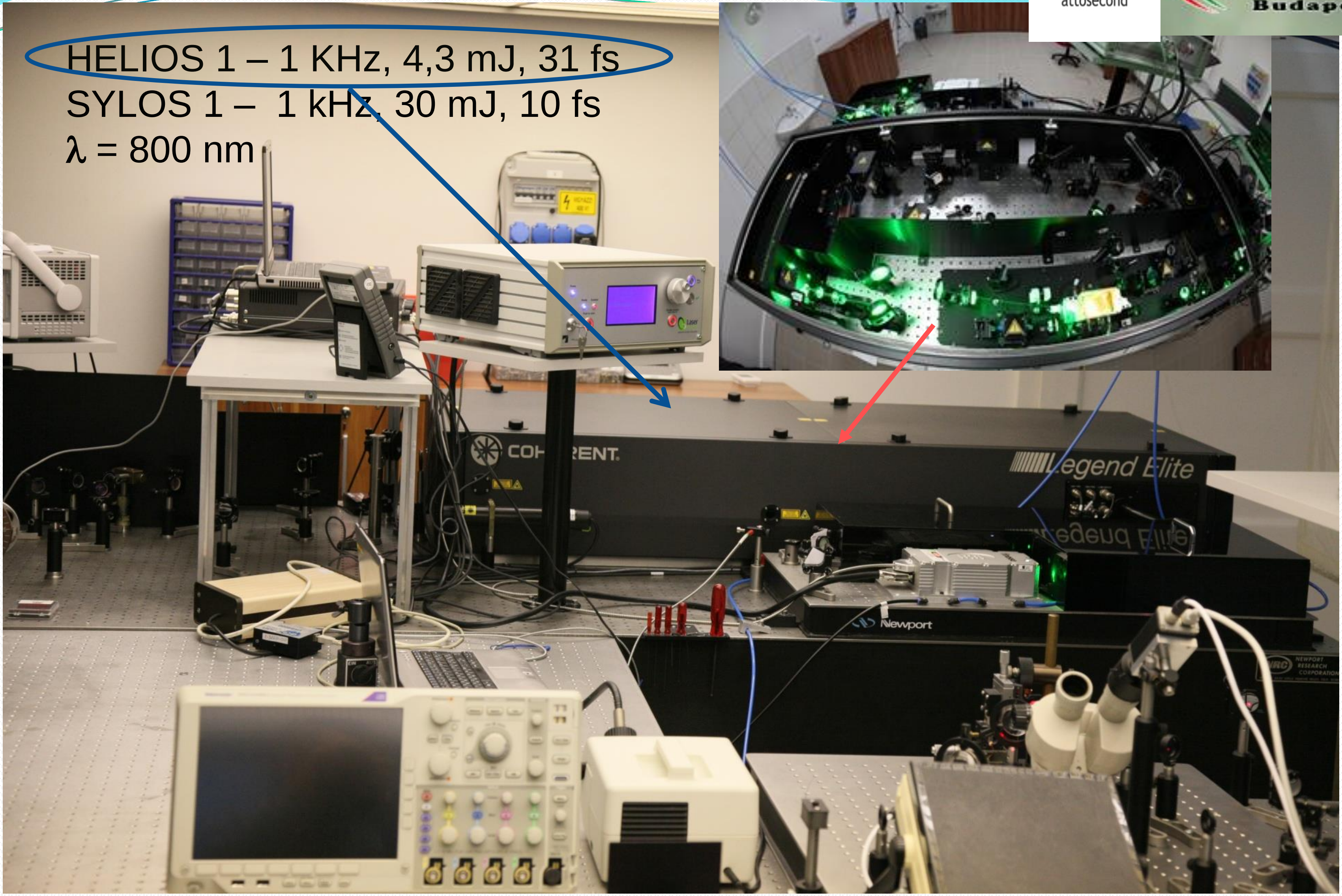
Helios program

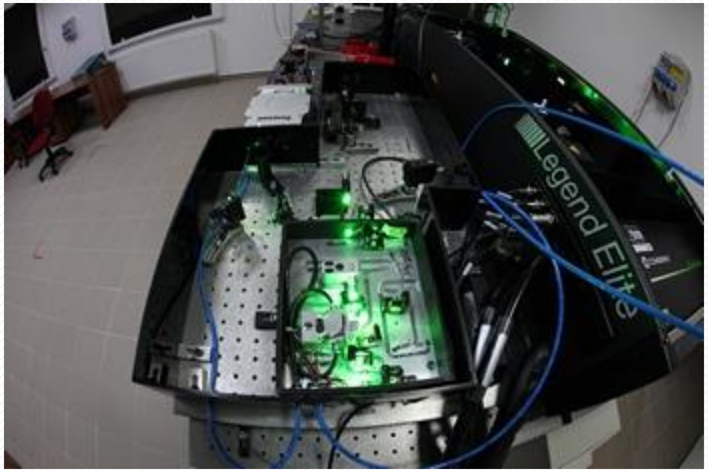


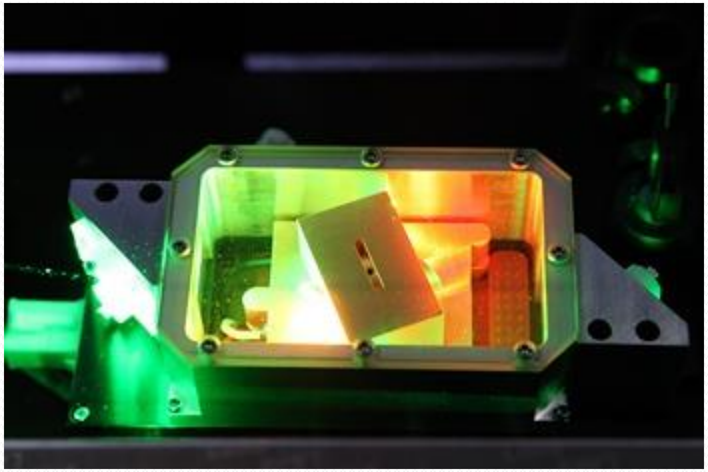
HELIOS 1 – 1 KHz, 4,3 mJ, 31 fs

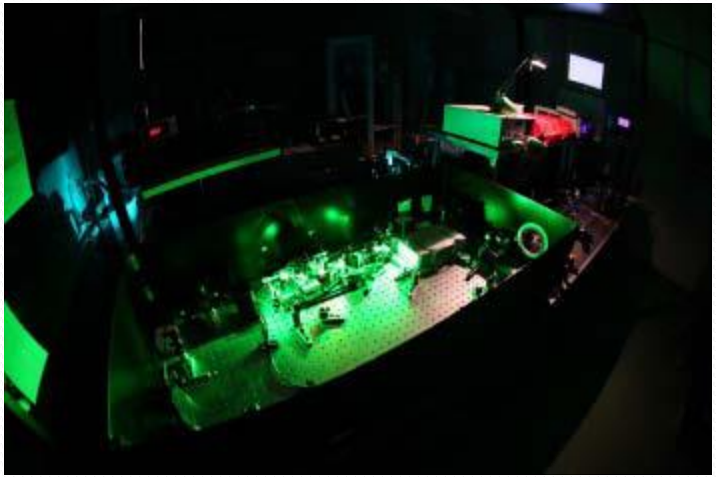
SYLOS 1 – 1 kHz, 30 mJ, 10 fs

λ = 800 nm

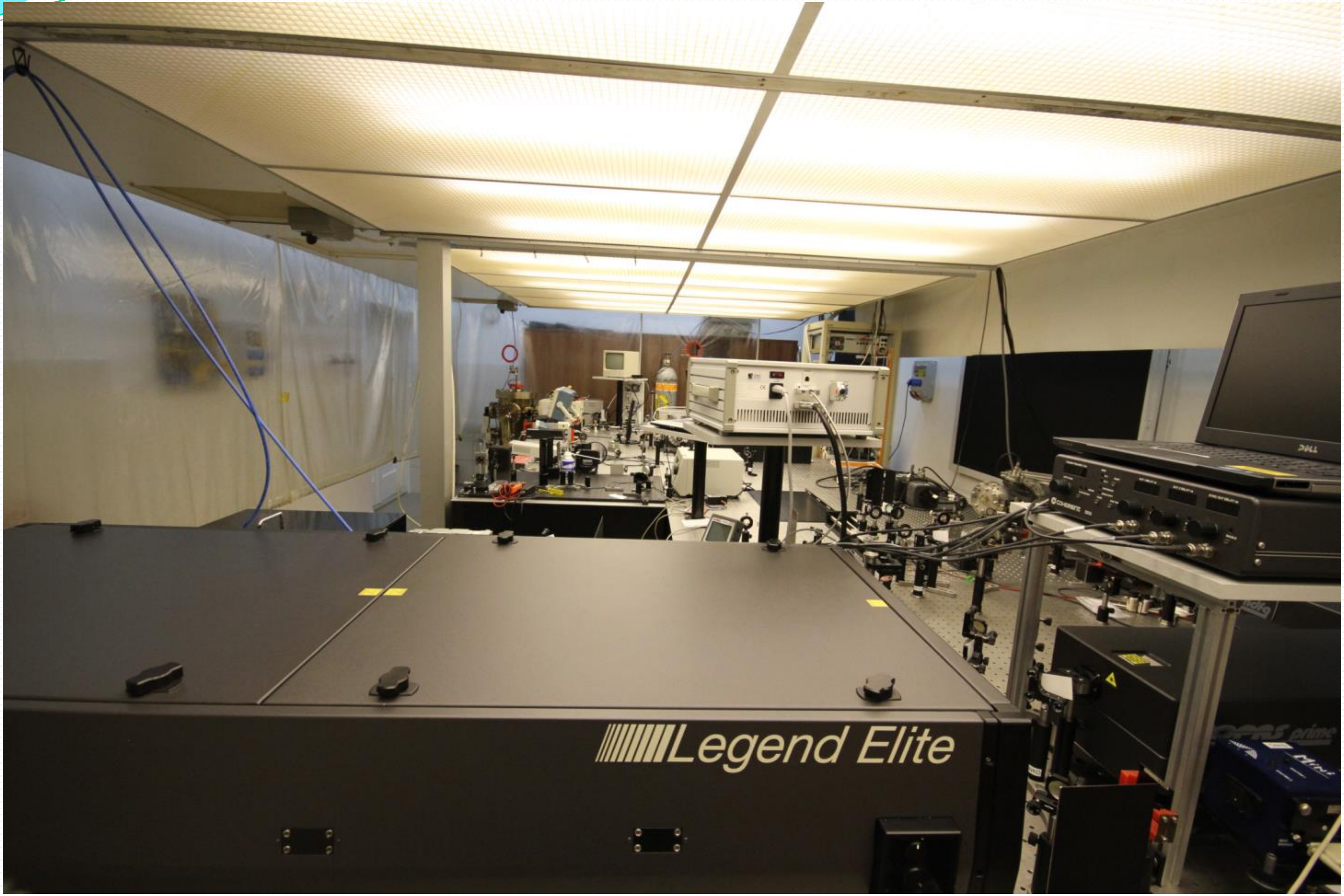




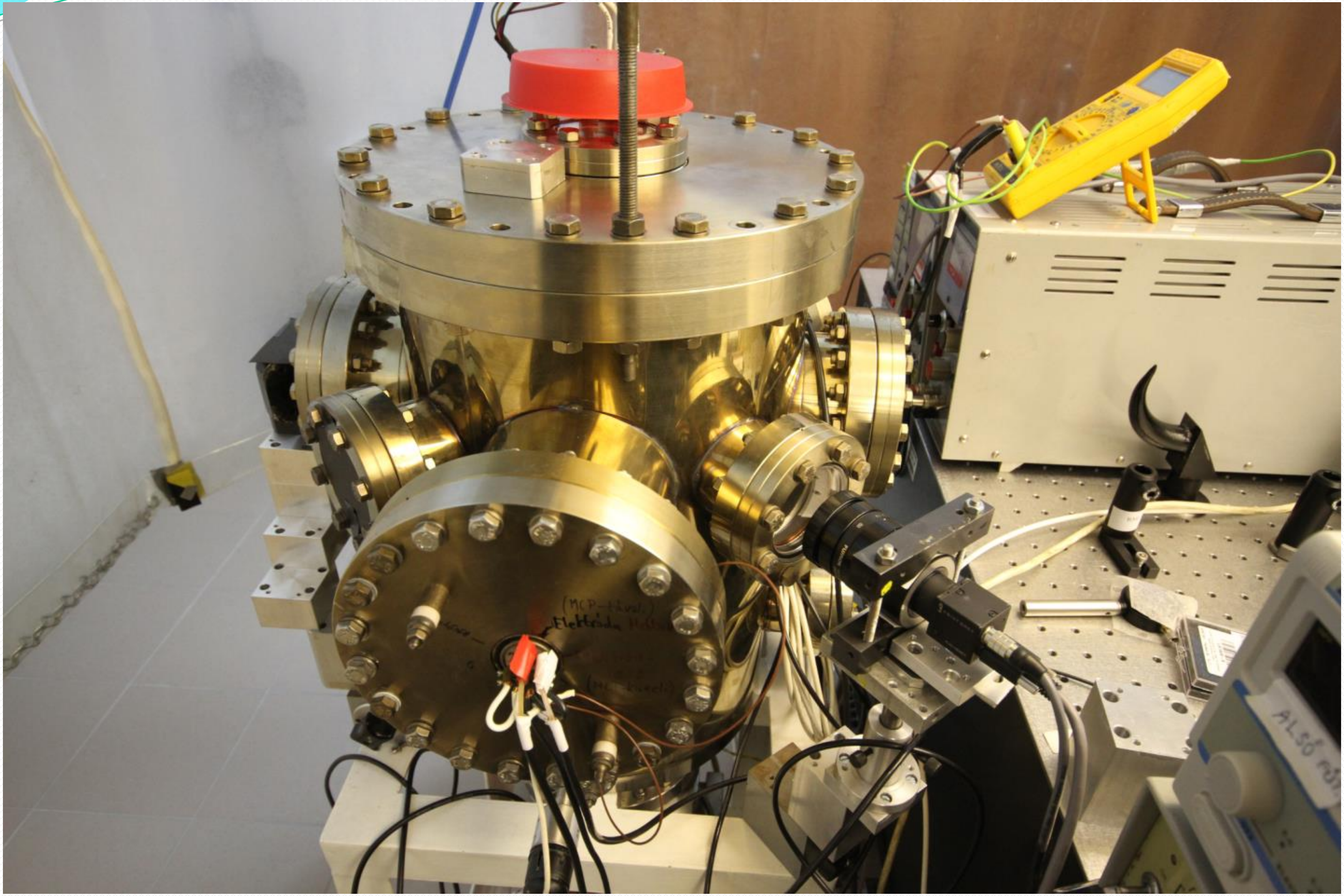




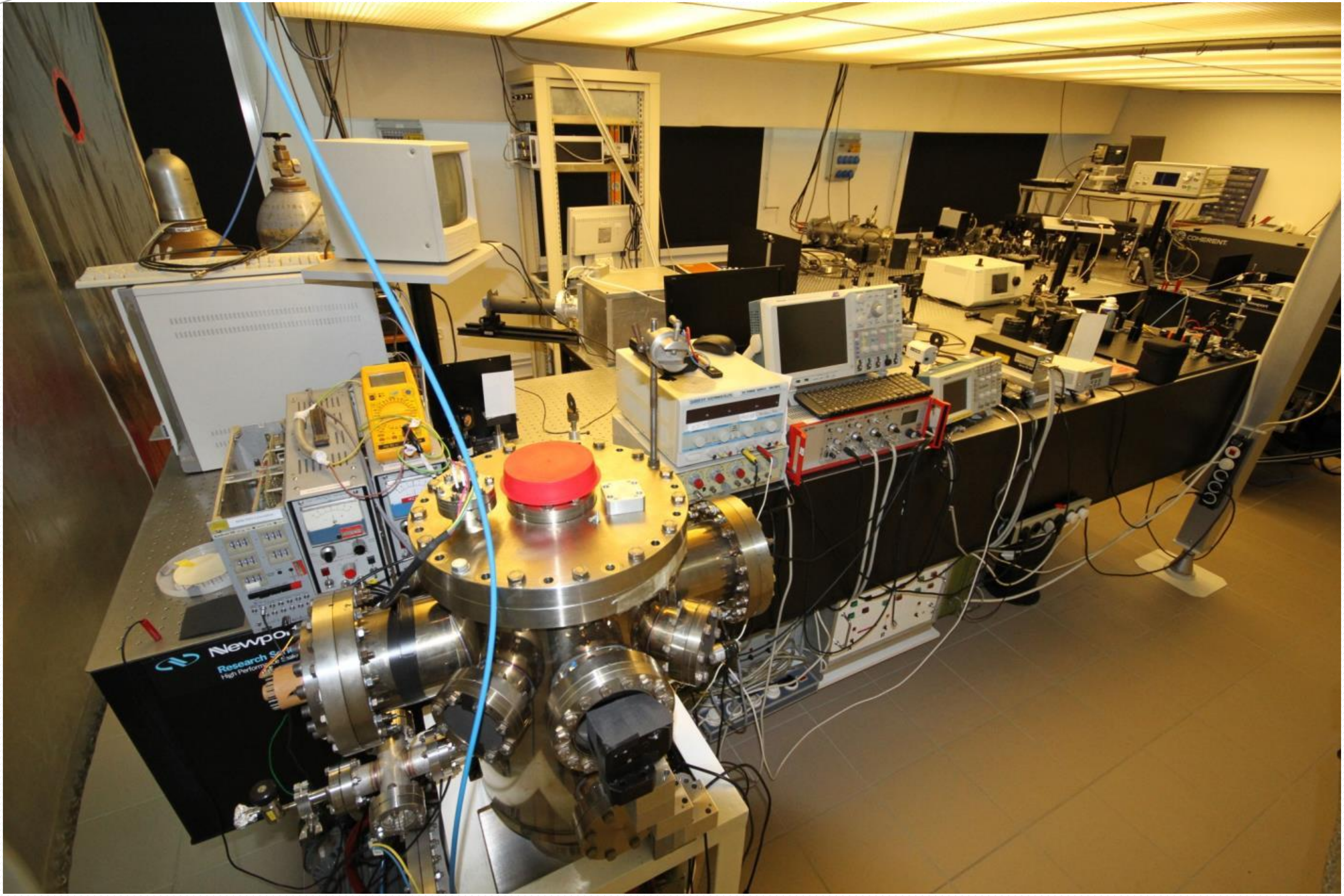
HELIOS 1 – 1 KHz, 4,3 mJ, 31 fs


Legend Elite
COHERENT
DELL

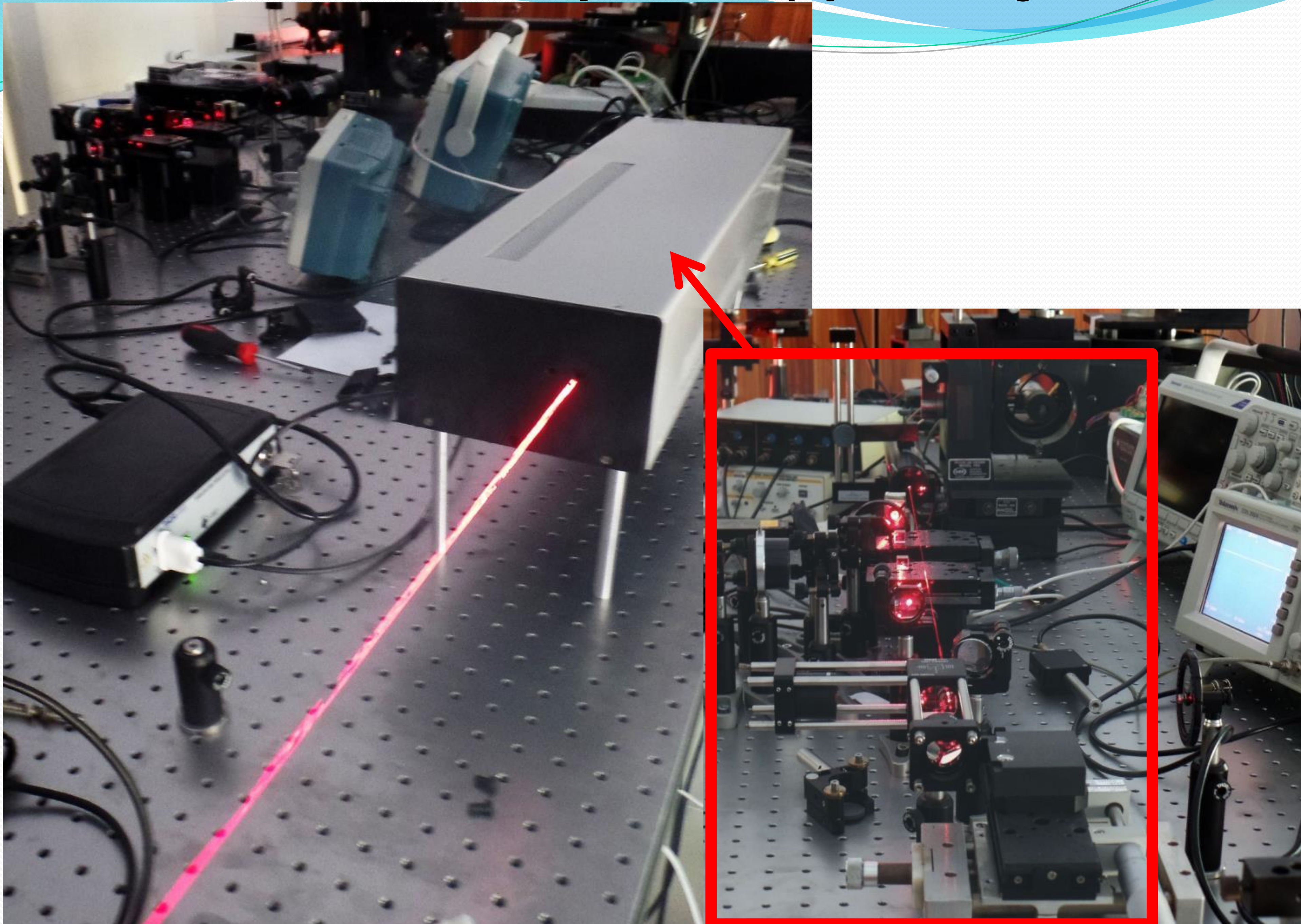
Plasma diagnostics



Plasma diagnostics

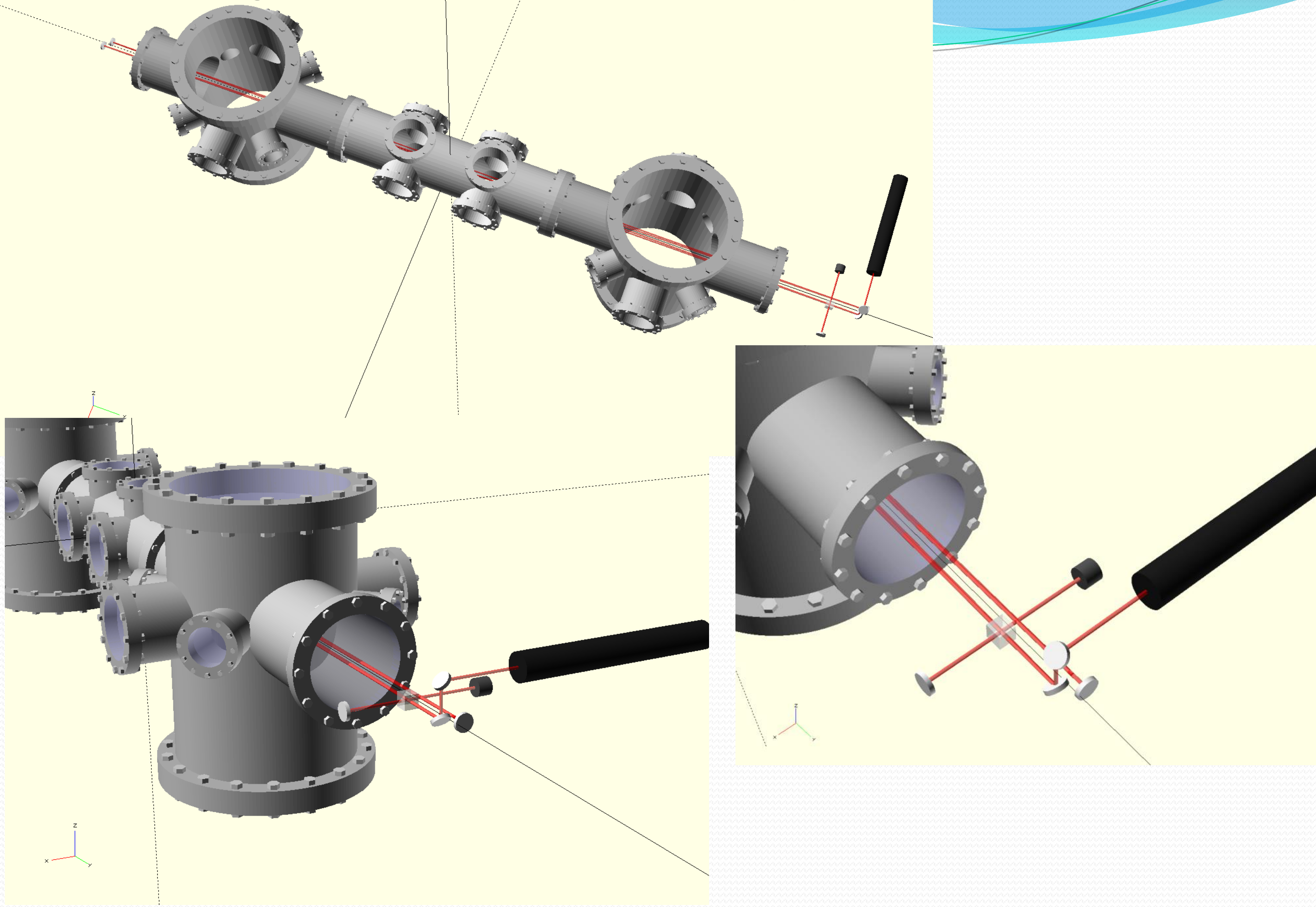


New interferometric system for plyama diagnostics

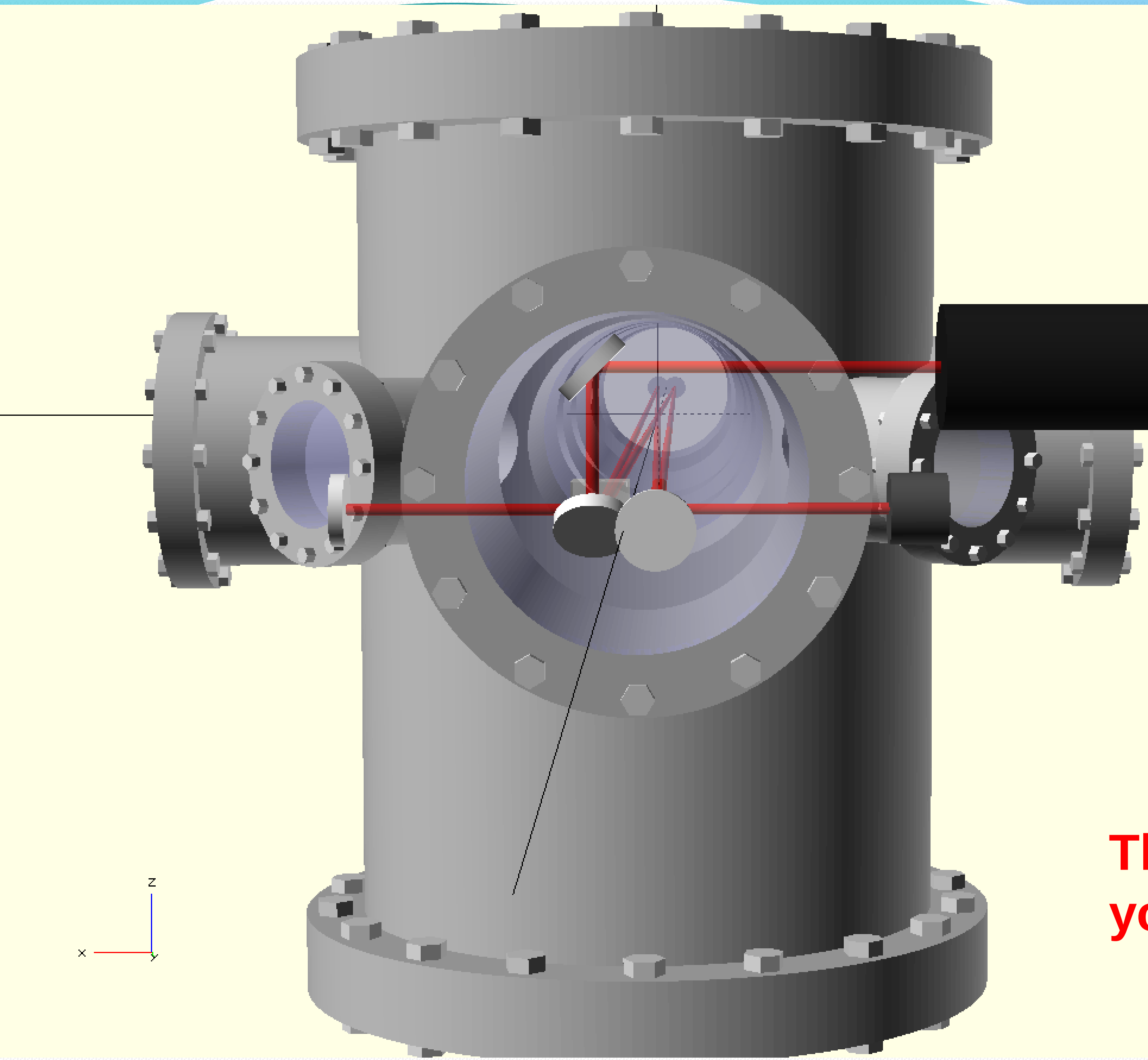


New interferometric system for plasma diagnostics

Design of the interferometric system



Design of the interferometric system



Thank you for your attention!