ELI
Attosecond Light Pulse Source

Karoly Osvay

Dept. Optics & Quantum Electronics
University of Szeged, Szeged, Hungary
and
ILE ENSTA, Palaiseau Cedex, France

extreme light infrastructure

ILE, France
Jean-Paul Chambaret, Gerard Mourou, Francois Mathieu

CLF RAL, UK
John Collier, Mike Dunne, Klaus Ertel, Cristina Hernandez-Gomez

MPQ, Garching, Gemany
Stephan Karsch, Georg Korn, Ferenc Krausz, Zsuzsanna Major, Thomas Metzger

FSU Jena, Germany
Joachim Hein

MBI, Germany
Peter Nickles, Ingo Will, Wolfgang Sandner

PALS, Czech Republic
Bedrich Rus

RISSPO, Hungary
Péter Dombi

U Pecs, Hungary
János Hebling
József Fülöp

U Szeged, Hungary
Gábor Szabó, Katalin Varjú

INFLPR, Romania
Razvan Dabu, Daniel Ursescu

Laserlab Europe

Outline

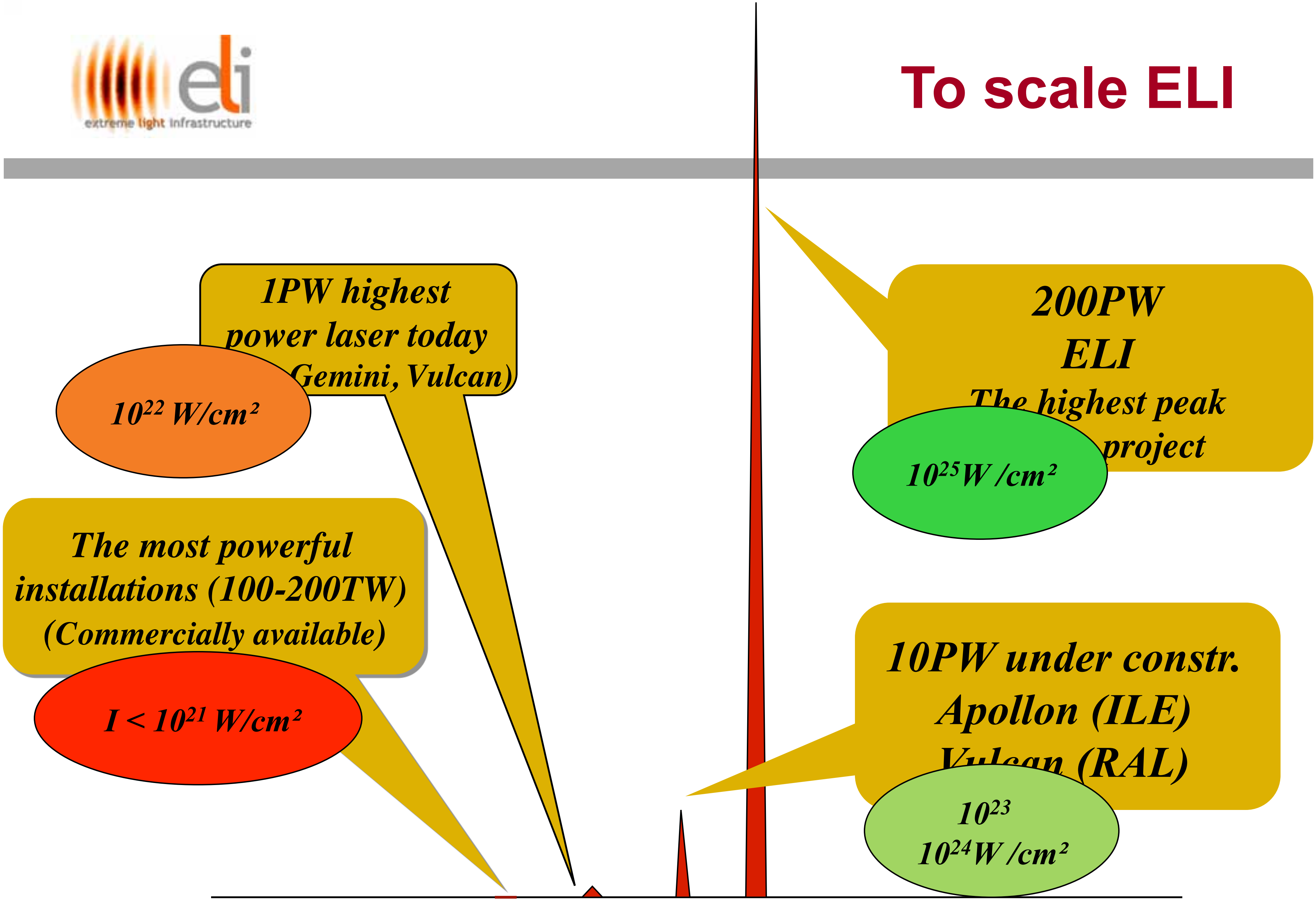
Vision of ELI

”Forerunner” lasers to ELI

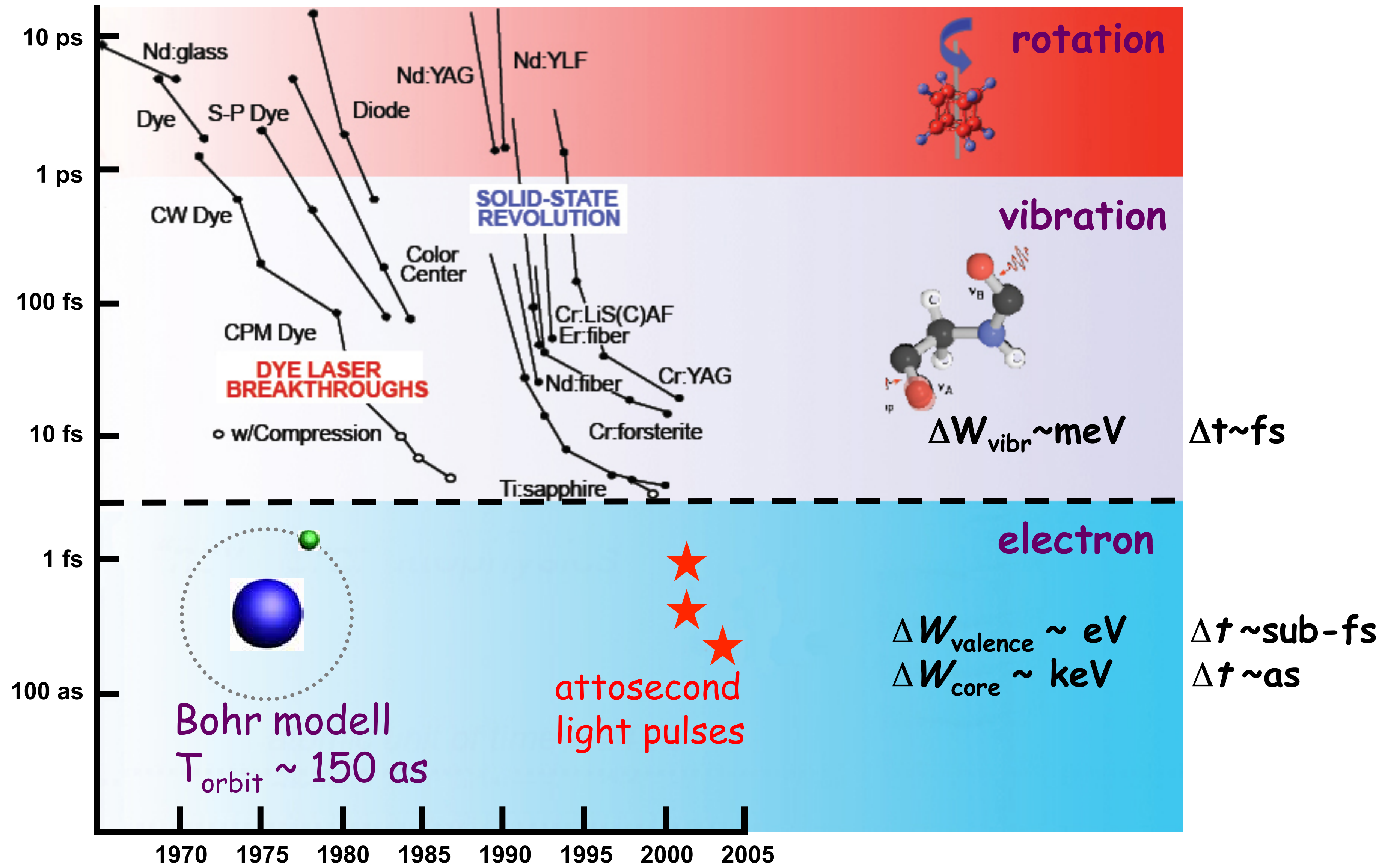
Implementation of ELI at the three sites

Major laser technologies and bottlenecks

To scale ELI


1PW highest
power laser today
(Gemini, Vulcan)
10^{22} W/cm²
The most powerful
installations (100-200TW)
(Commercially available)
I < 10^{21} W/cm²
200PW
ELI
The highest peak
project
10^{25}W /cm²
10PW under constr.
Apollon (ILE)
Vulcan (RAL)
10^{23}
10^{24}W /cm²

Duration of elementary processes



Mission of ELI

Main mission

An infrastructure that aspires to conduct *fundamental* and *applied* research at the highest intensity and the shortest duration level, through ultra intense laser beams and the particle and radiation beams that they will generate.

Applications

Use ELI technology to reduce the size of laser or photon sources and apply them to the environment, medical, material science, electronics…

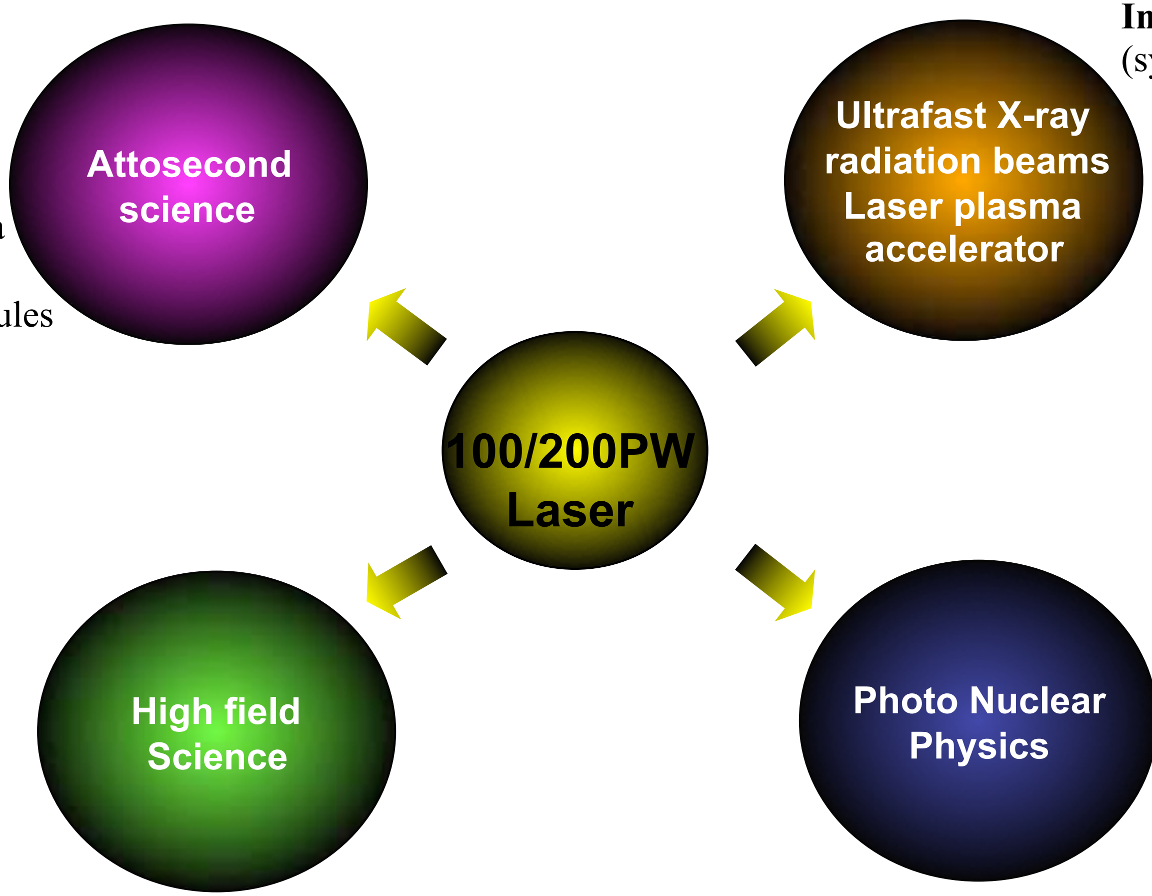
Scientific ”pillars” of ELI

Coherent (X,g)-rays
(FEL, HHG & plasma)
Incoherent (X,g)-rayBeams
(synchrotron-like, atomic)

Attosecond
to zeptosecond
Physics

Application
Ultrafast phenomena
Wave function
in atoms and molecules

Beam lines
Electrons beam
Gamma imaging
Protons beam
Muons beam
Beam lines

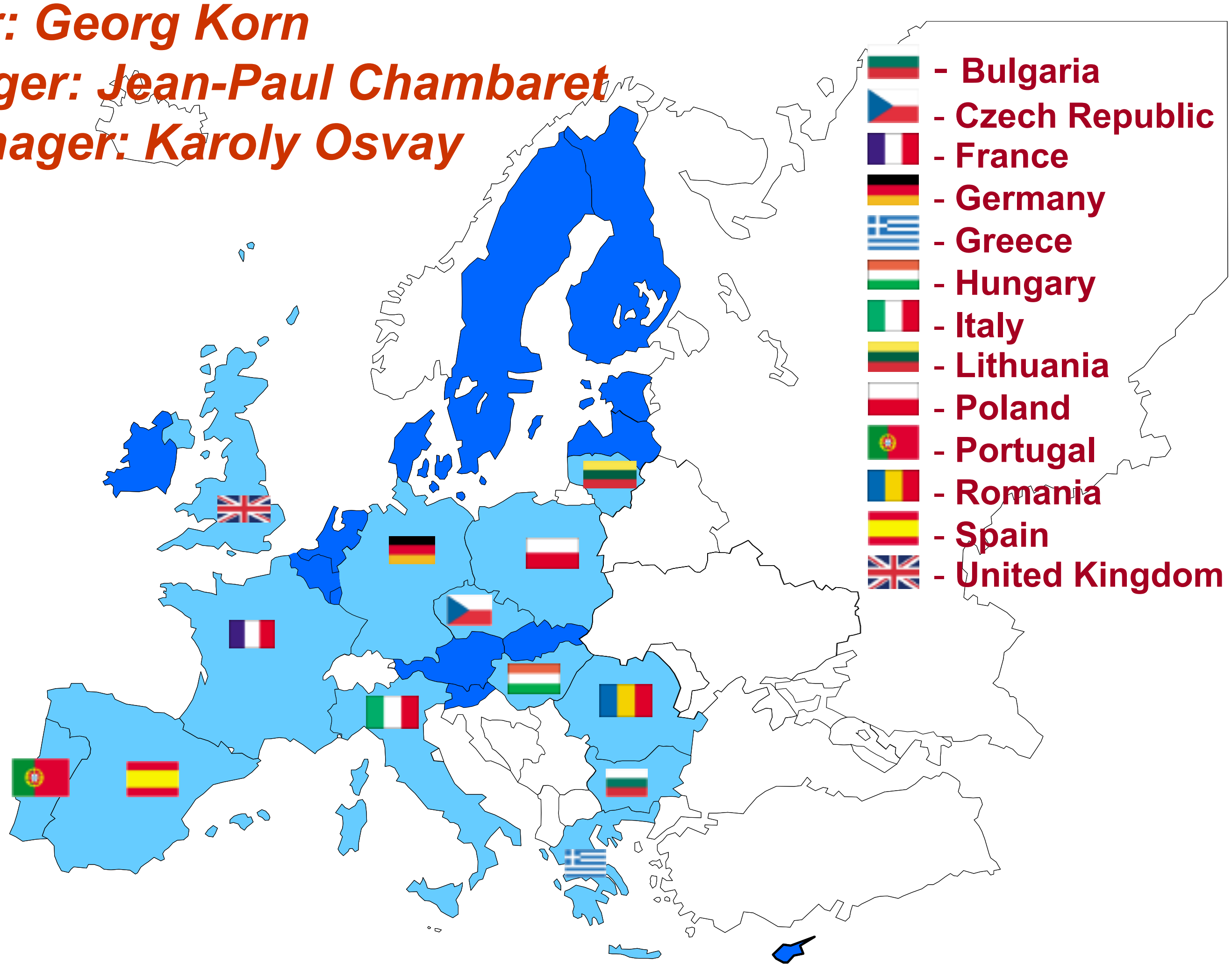


NLQED
Fundamental
physics
Exotic physics

Nuclear Physics
Transmutation

Preparatory phase: 2007-2010

Coordinator: Gerard Mourou
D.coordinator: Georg Korn
Project manager: Jean-Paul Chambaret
D.project manager: Karoly Osvay

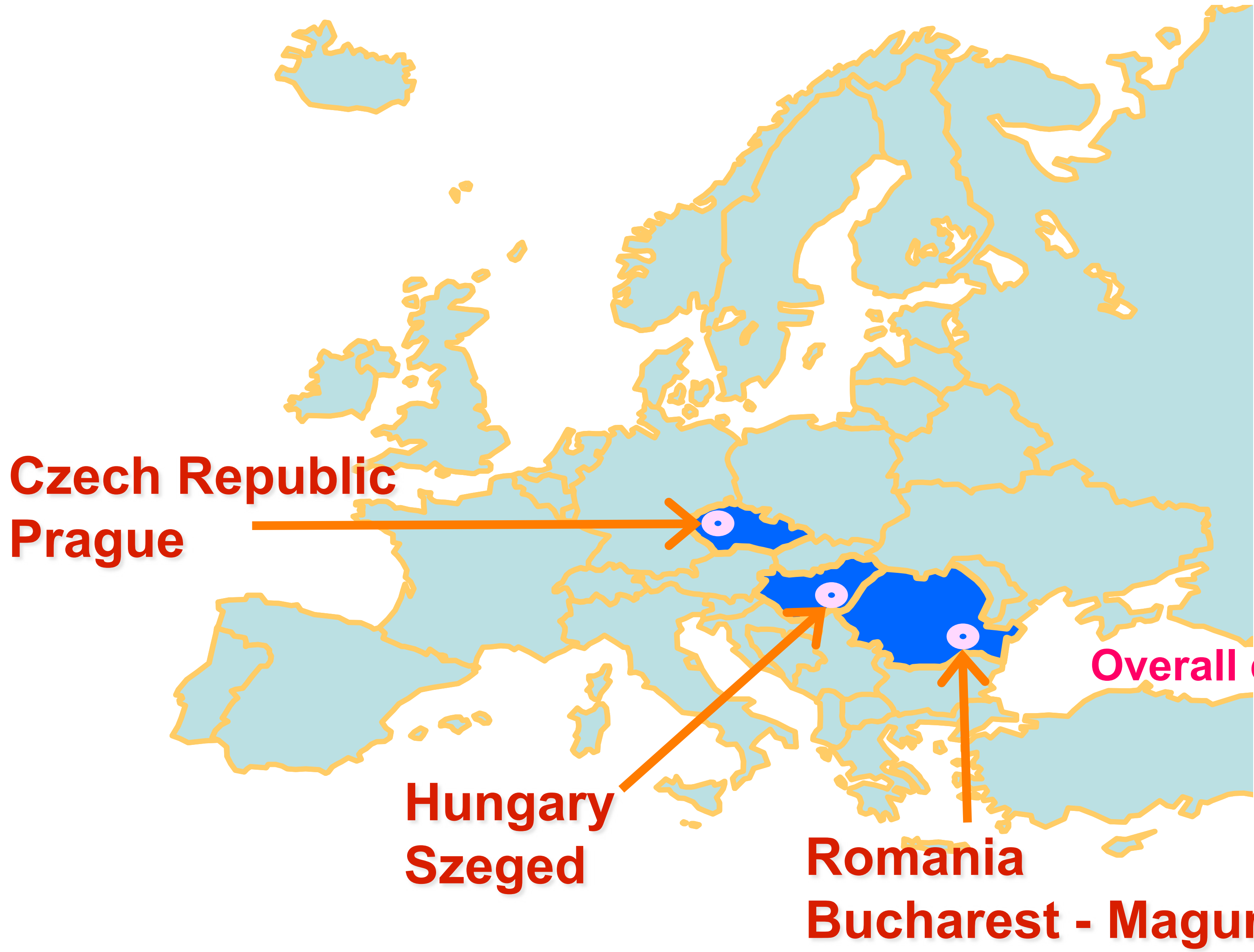


(Single-site) ELI in the ESFRI Roadmap

Construction costs 400M€

Operation costs 50M€/year

Site selection: decision on 1.10.2009



Overall cost: ≈800M€

Research Facilities of ELI

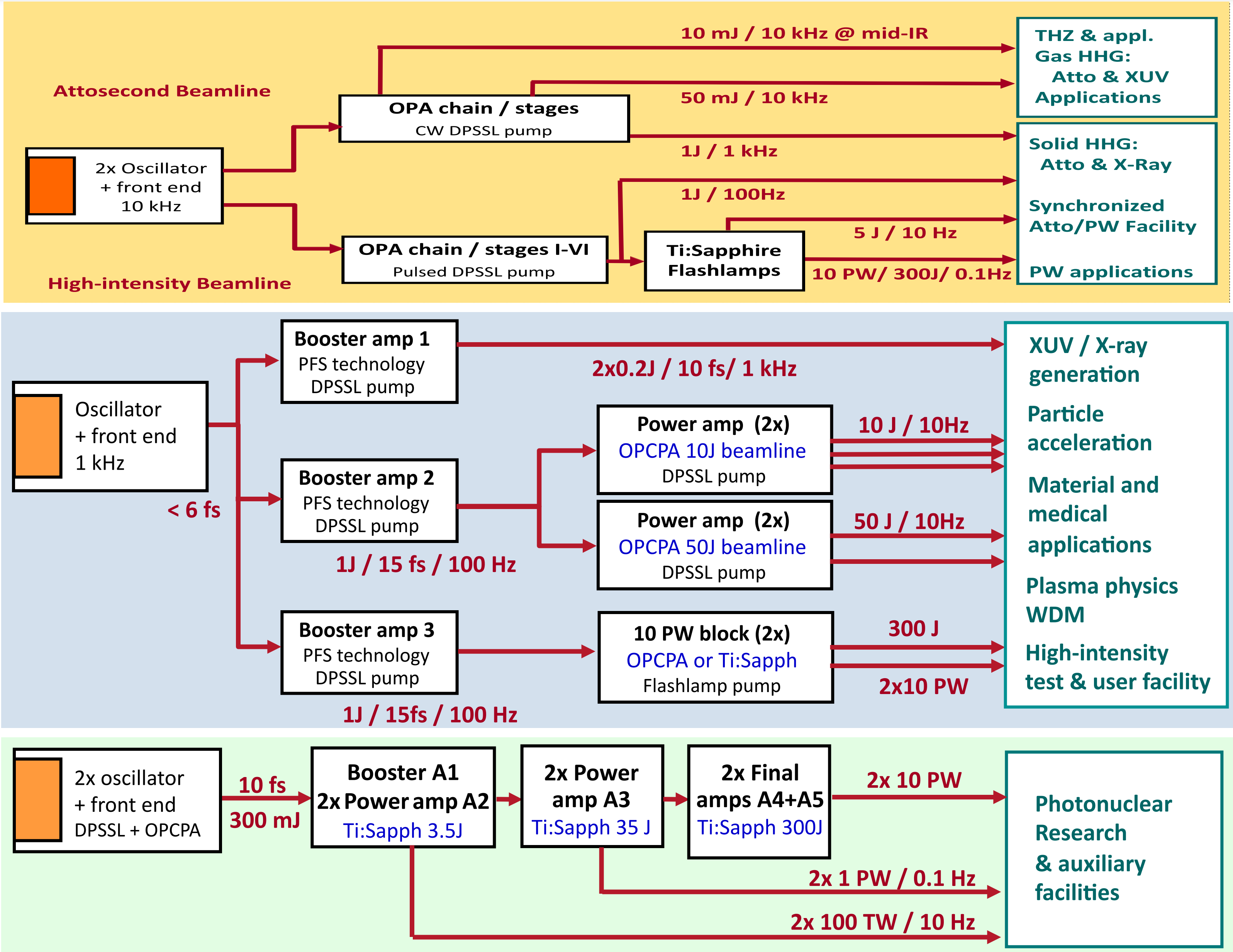
Attosecond Facility → Attosecond XUV/X-ray physics
Applications in material sciences and biology
Szeged HU

Beamlines Facility → High-brightness sources of X-rays & particles
Particle acceleration, dense plasma physics, exotic physics
Prague CZ

Nuclear Physics Facility → Laser-induced nuclear physics
Photonuclear science and applications
Magurele RO

Extreme-intensity development → Exawatt-class laser technology
High-intensity laser technologies for frontier physical research
Technology & site are to be determined after 2012

ELI laser: implementation layout (October 2010 update)



(Legal) Implementation of ELI

Single governance, three-site research infrastructure:

ELI-ERIC

(European Research Infrastructure Consortium)

… is to be formed around 2014

… from January 1, 2011 until ERIC:

ELI Delivery Consortium (ELI-DC)

Likely a non-for profit company under Belgian law.

(SciTech) Implementation of ELI…

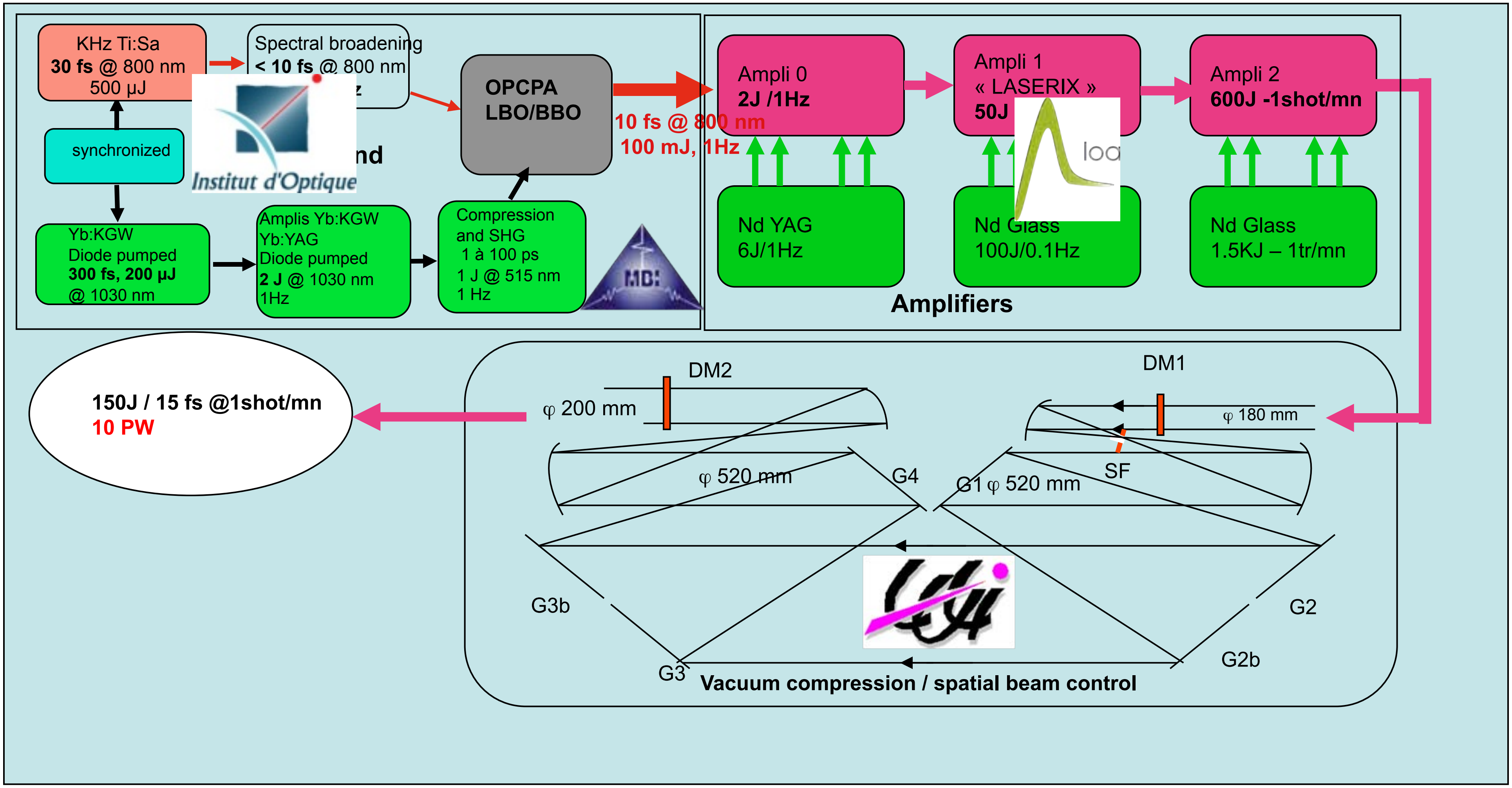
… strongly relies on the current national ”big forerunners”:

- **Apollon, ILE, Palaiseau, France**
  10PW: 150 J, 15 fs, 1 shot/min

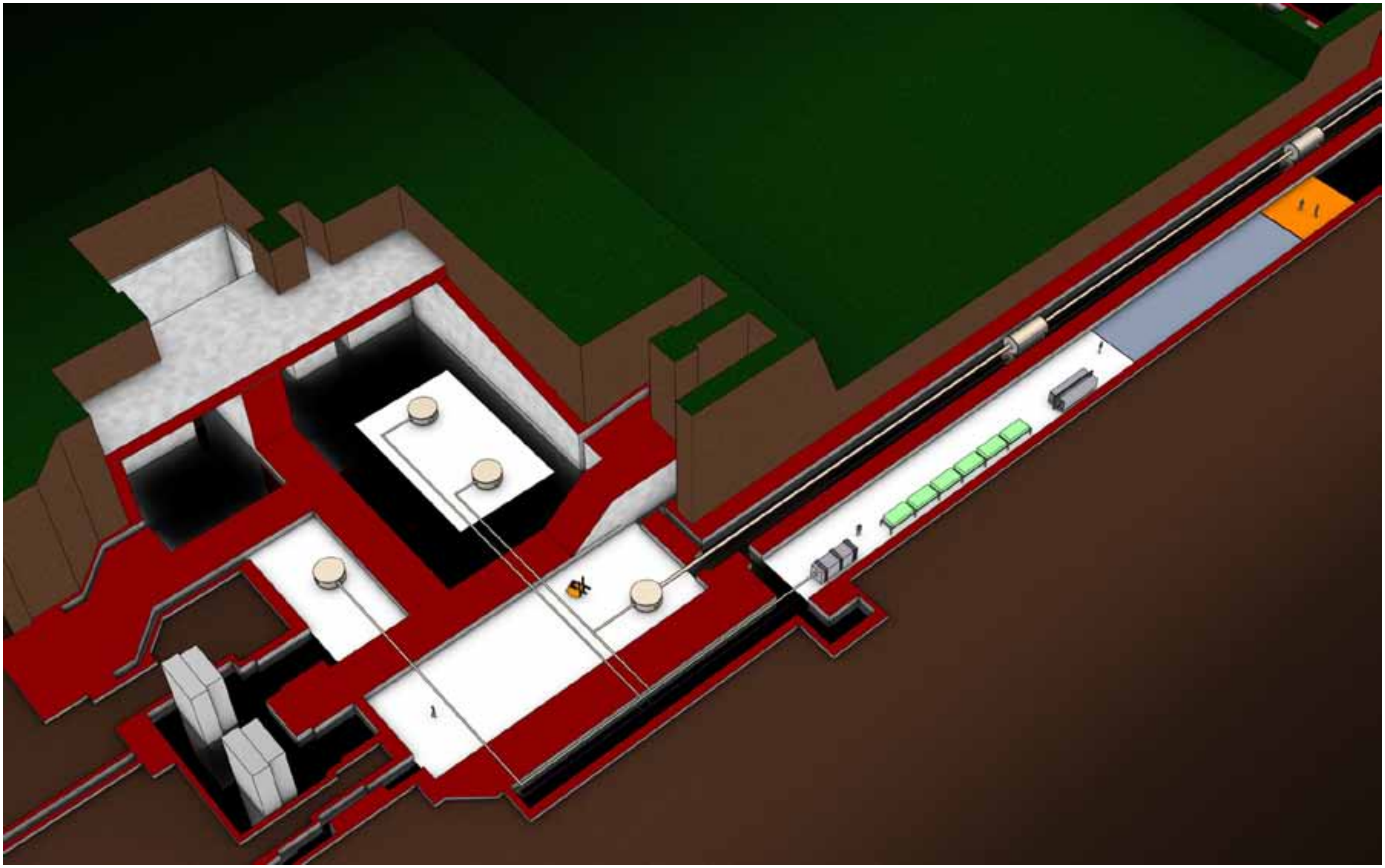
Under construction;
due by 2012-13

APOLLON,
a single beamline 10 PW laser

APOLLON, as a(n) (inter)national collaboration



APOLLON – Location



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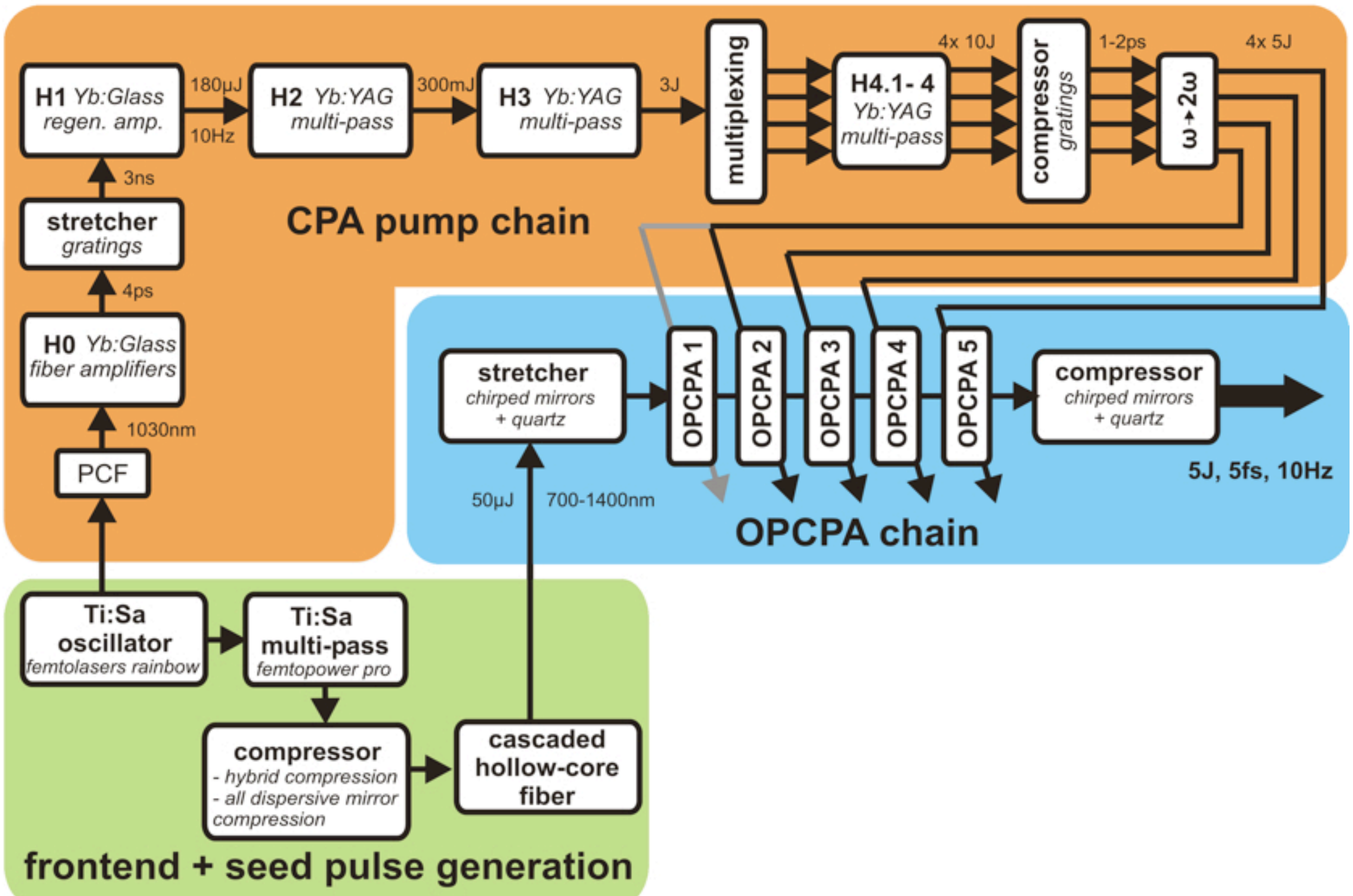
  10PW: 150 J, 15 fs, 1 shot/min

  Under construction; due by 2012-13

- **Petawatt Field Syntheser, MPQ, Garching, Germany**
  1PW: 5J, 5fs, 10Hz

  Under construction; due by 2010-11

PFS - Basic concept and layout



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  Under construction;
  due by 2012-13

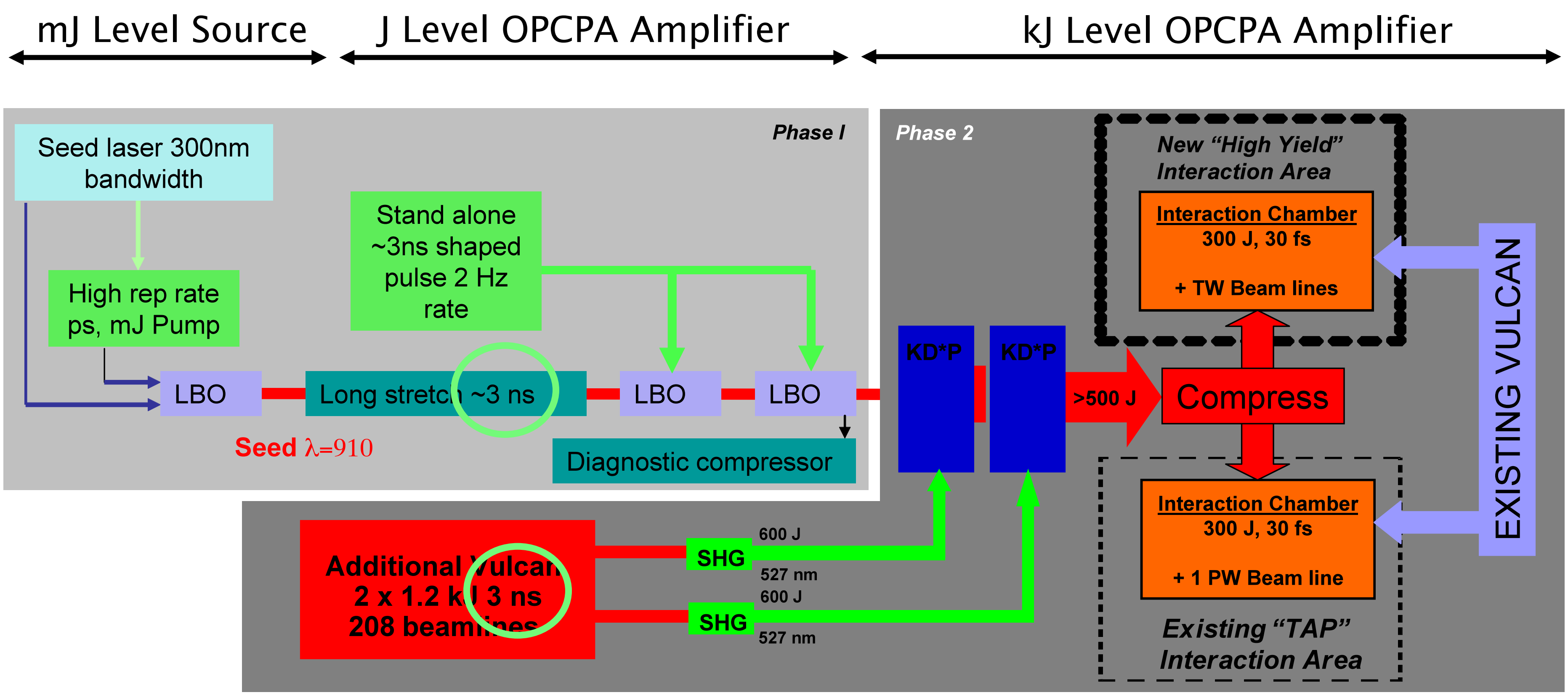
- Petawatt Field Syntheser, MPQ, Garching, Germany
  1PW: 5J, 5fs, 10Hz

  Under construction;
  due by 2010-11

- VULCAN 10PW project, CLF, Chilton, UK
  10PW: 300J, 30fs, 1 shot/15min

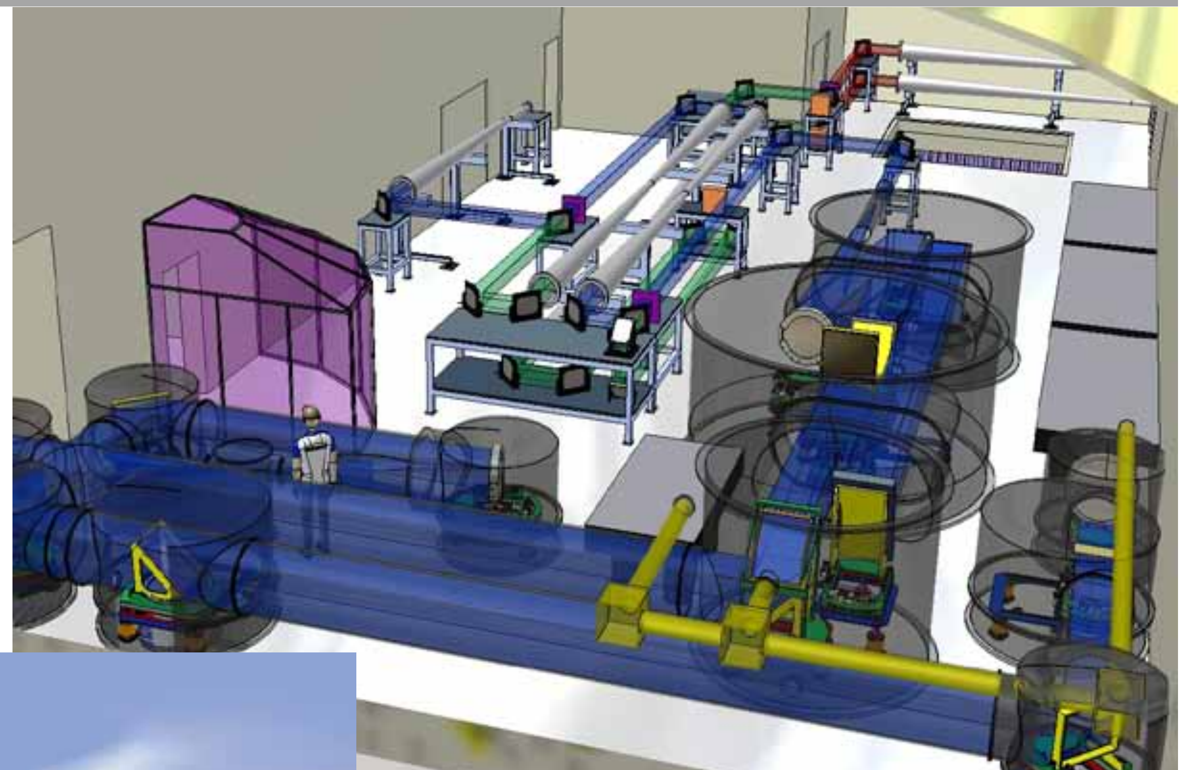
  First phase completed;
  due by 2014-15

VULCAN - Overall 10PW Schematic



- Will be based on a combination of LBO and KD*P
- 3 stages of amplification (some old Nova !)
- Optical Efficiency 10-15%

VULCAN 10PW – Designs



(SciTech) Implementation of ELI…

… strongly relies on the three national ”big forerunners”, and quite a few ”smaller” ones:

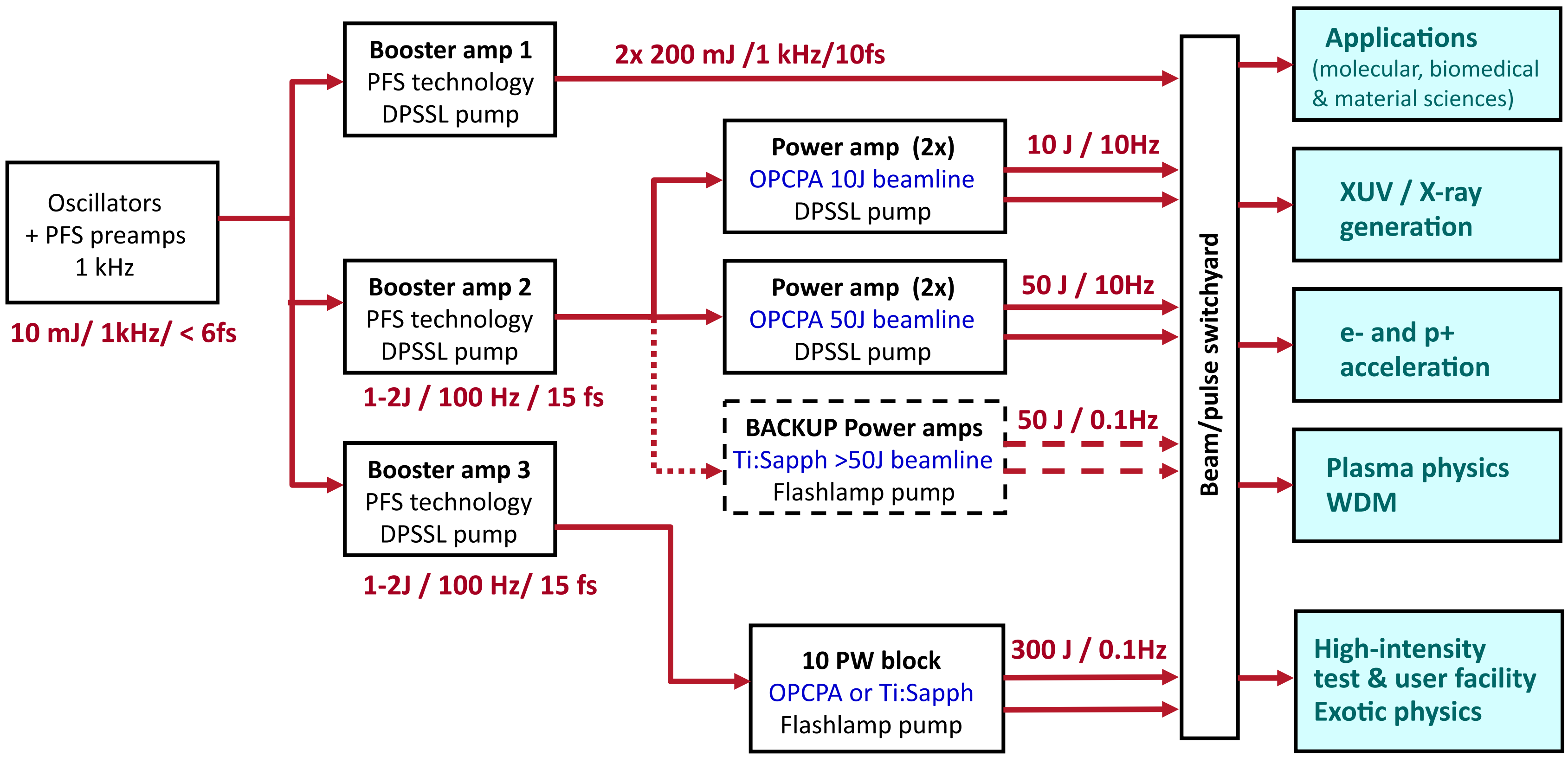
- **Gemini, CLF, Chilton, UK**
  2×0.5PW: 2×(15J, 30fs), 0.05Hz
- **MBI, Berlin, Germany**
  50TW+200TW: (3J+6J, 30fs) 10Hz
- **DASY, Hamburg, Germany**
  mJ, 7fs, 100kHz
- **ICFO, Barcelona, Spain**
  10μJ, 2cycle, 100kHz, mid-IR
- **POLARIS, FSU/HI, Jena, Germany**
- **…**

ELI Beamlines Facility – Prague, CZ

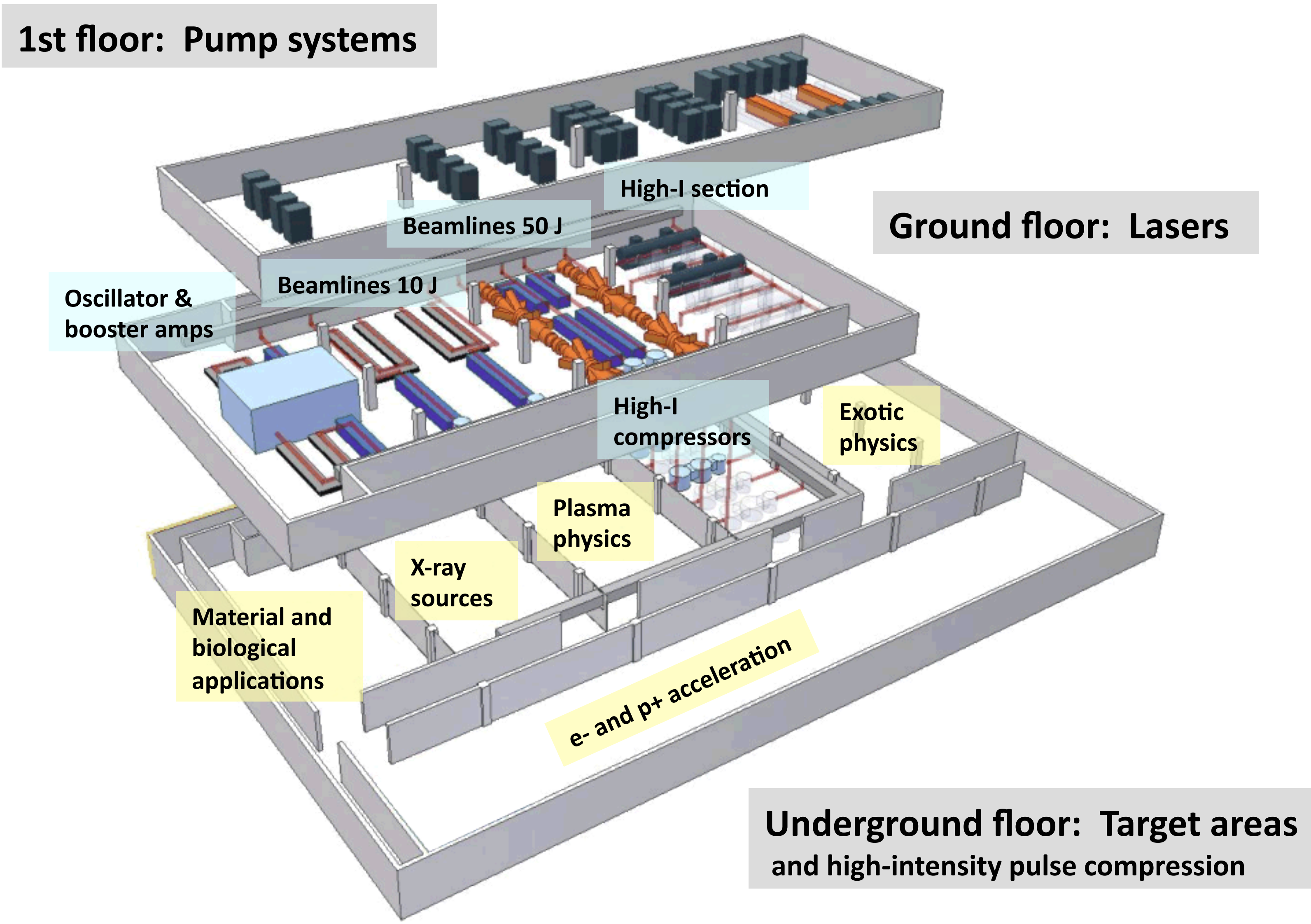
ELI Beamline Mission

- Plasma-based XUV and X-ray sources (not attosecond)
  Seeded high-energy XUV lasers, HHGs, plasma betatron, laser-plasma based FEL
- Electron, proton and ion acceleration
  Generation of 10-50 GeV electrons, >1 GeV protons
- Programmatic applications in molecular, biomedical, and material sciences
  Time-resolved X-ray diffraction, fast pulse radiolysis, probing early events in interaction of ionizing radiation with matter, probing of diluted systems, femtochemistry, proton therapy
- Physics of dense plasma, high-energy-density-in-matter (HEDM) physics
  Laboratory astrophysics, WDM, energy transport in high $I\lambda^2$ systems
- Exotic physics
  Experiments with focused intensities 10^{23}-10^{24} Wcm^{-2}
- Prototyping technologies for the high-intensity pillar
  10 PW and multi-10-PW chains, compression & coherent superposition of multi-10-PW ultrashort pulse

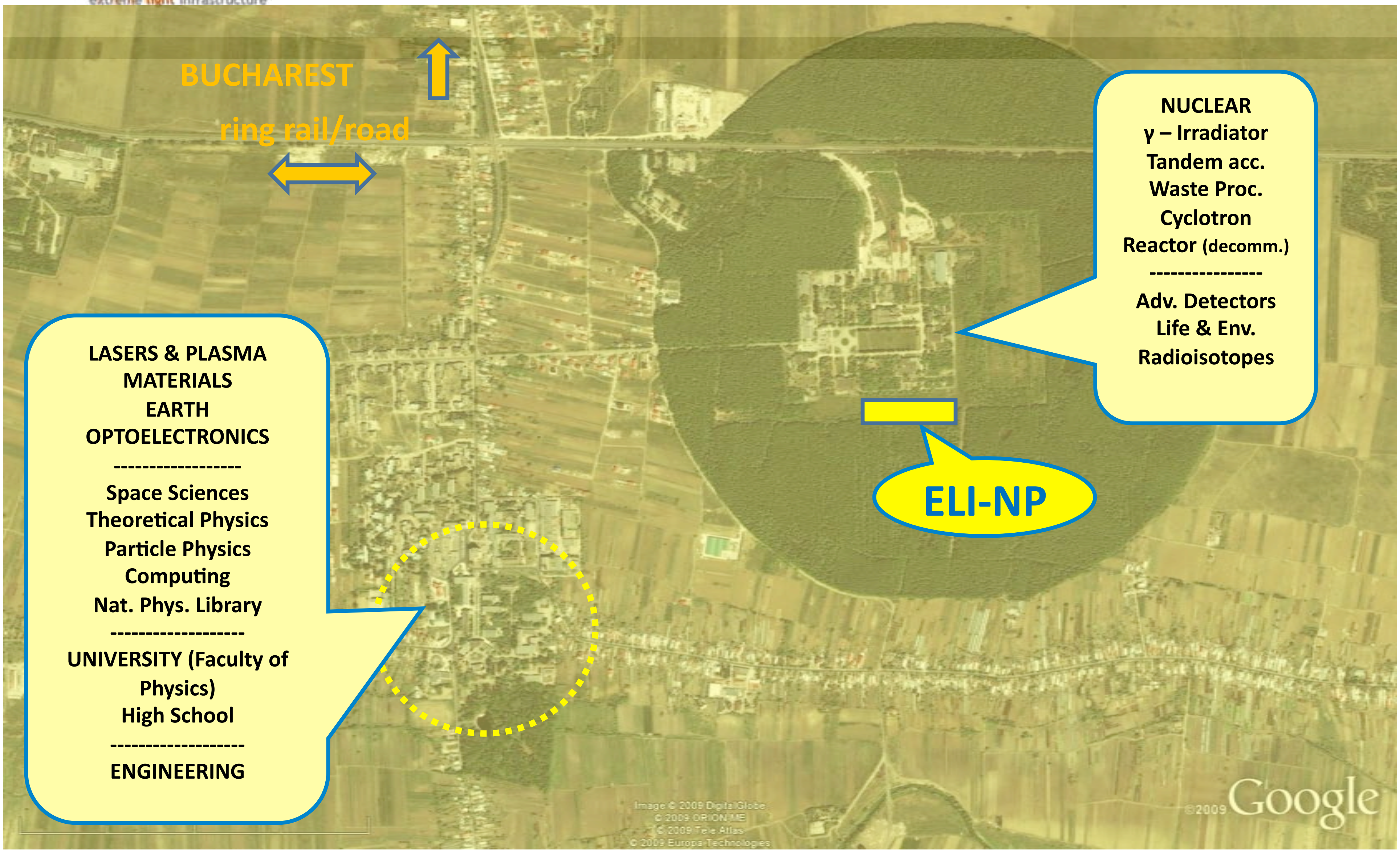
ELI Beamlines Laser



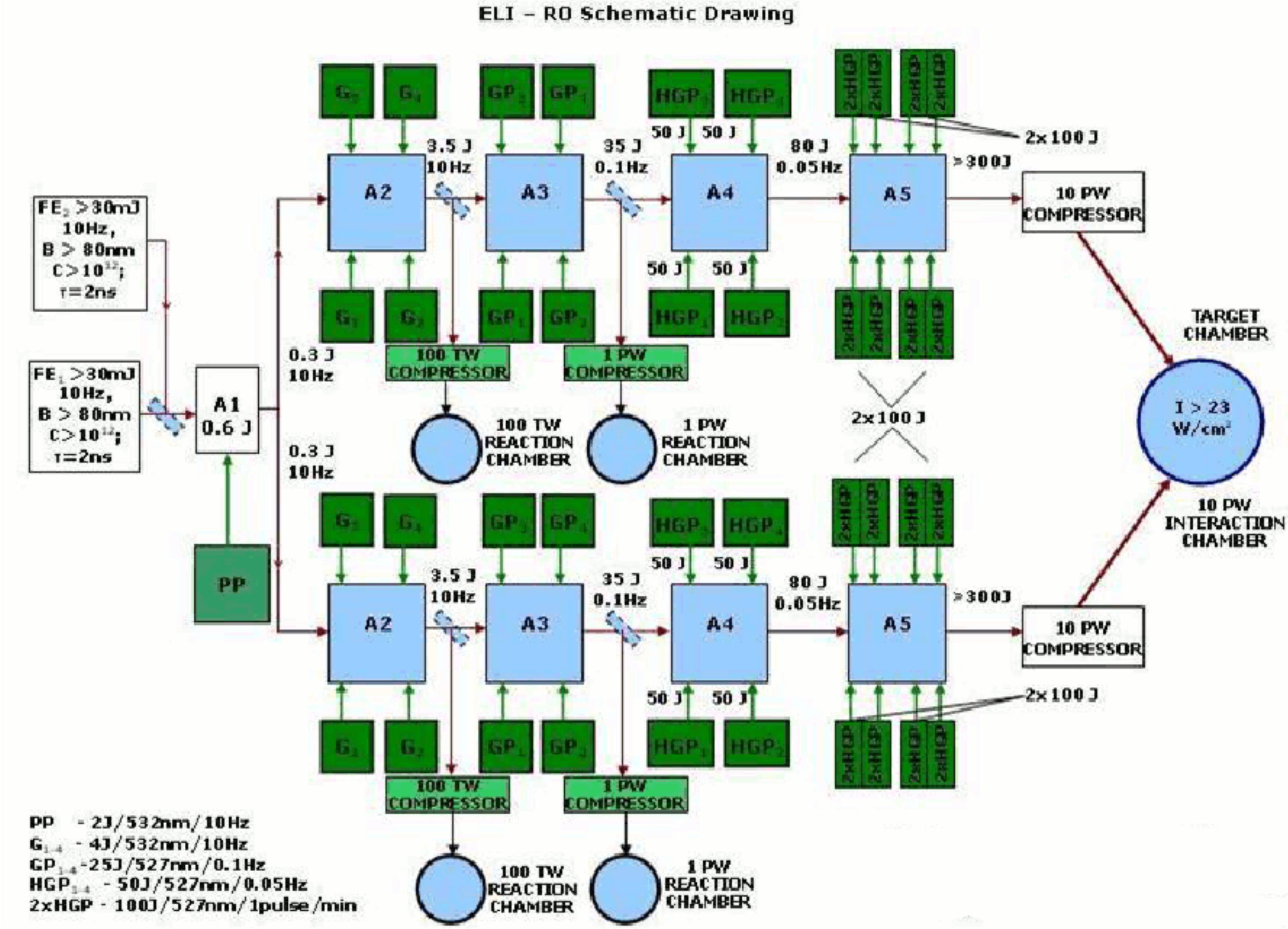
ELI Beamline Facility Infrastructure



Măgurele – The Romanian Pole of Physics

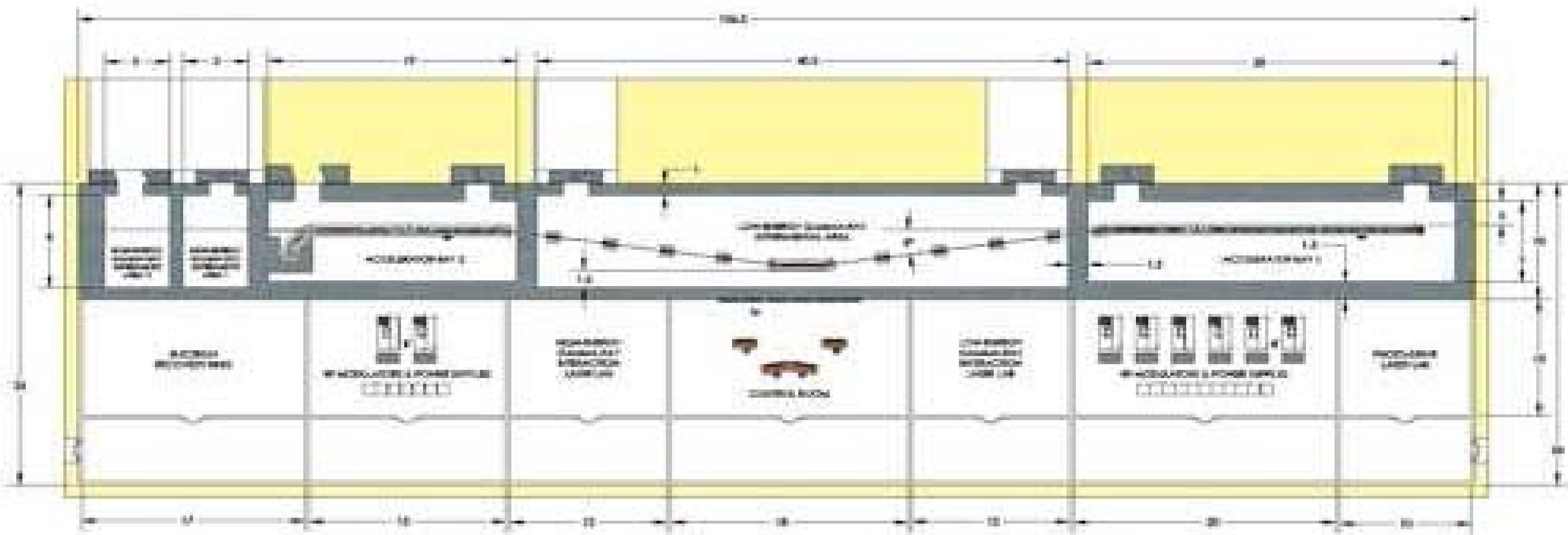


Laser Architecture – 2x APOLLON



High brilliance γ-source

X-band linac technology (based on LLNL machine)
Rep.rate: 12kHz
γ: up to 19MeV
Peak brilliance: 10^{21} photons/sec/mm2/mrad2/0.1%BW



Financing & Building

Item	Budget (M€)
Planning/Design fees	2,7
Land purchase	0,0
Building and construction	62,8
Plant and machinery	169,3
Laser systems	*80,2*
Gamma beam	*59,6*
Experimental equipments	*23,3*
Workshops and laboratories	*4,3*
Furniture and Fixtures	*0,8*
Intangibles	*1,0*
Contingences	14,0
Technical Assistance – Start-up Grant	30,6
Consultancy	*1,0*
Commissions, taxes	*0,8*
Payroll	*23,0*
Travels	*2,9*
Invited researchers	*0,9*
Others	*0,6*
Overheads	*1,4*
Publicity	0,2
Supervision during construction	0,4
TOTAL excl. VAT	**280,0**

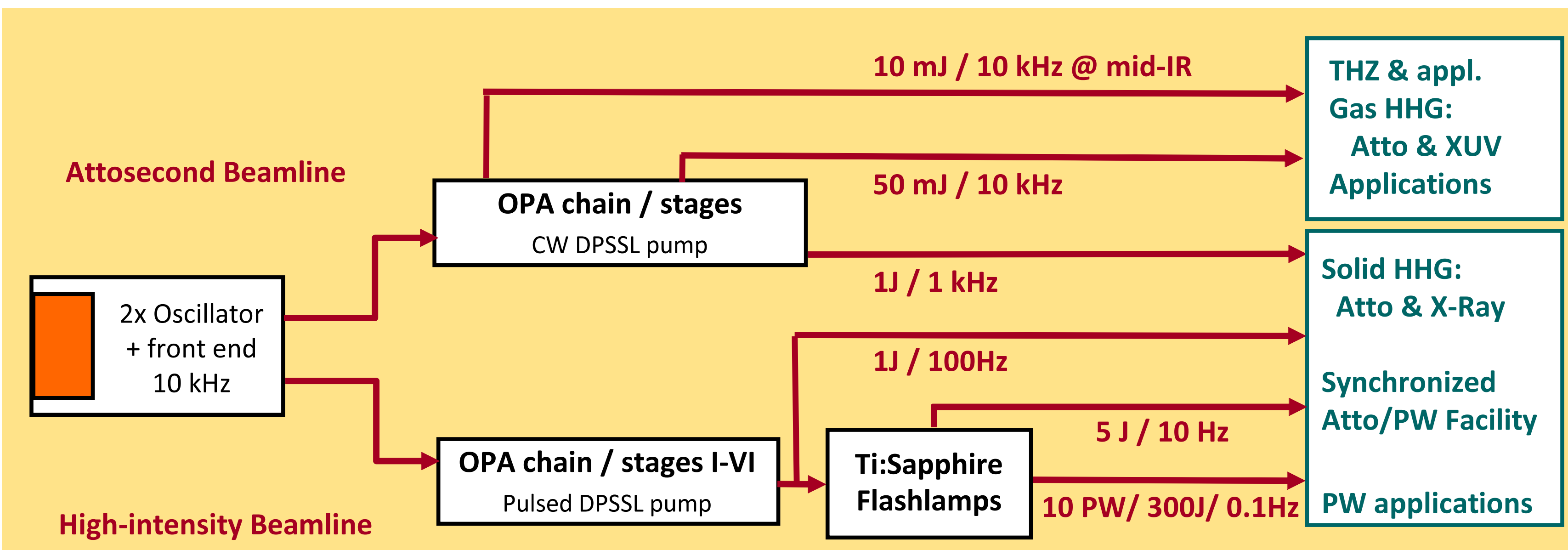
ELI-ALPS Facility, Szeged, HU

Budapest
165 km (motorway)

Aims and current schematics

1) To generate X-UV and X-ray fs and atto pulses, …
   ATTOSECOND section

2) To contribute to the technological development towards 200PW…
   High-intensity section



A unique combination of photon beams

Few-cycle NIR + PW beamline

Fs UV (VIS) excimer + PW beamline

As X-UV + Few cycle NIR

As XUV + PW beamline (?)

As XUV + THz

Applications of the attosecond branch

- time-resolved studies of electronic transitions in atoms and molecules (also X-ray-pump/X-ray-probe possible)

- time-resolved pump-probe studies in condensed matter, ultrafast nanoplasmonics etc.

- time-resolved structural studies with X-ray (with 1 keV source)

- X-ray imaging of macromolecules and cells with <10 fs X-ray pulses (before Coulomb explosion takes place)

- steering chemical reactions with tailored XUV pulses (5-15 eV)

- THz-assisted atto pulse generation and time-resolved THz imaging

- etc.

Applications of the PW branch

Technology tests for ELI / 200 PW project:

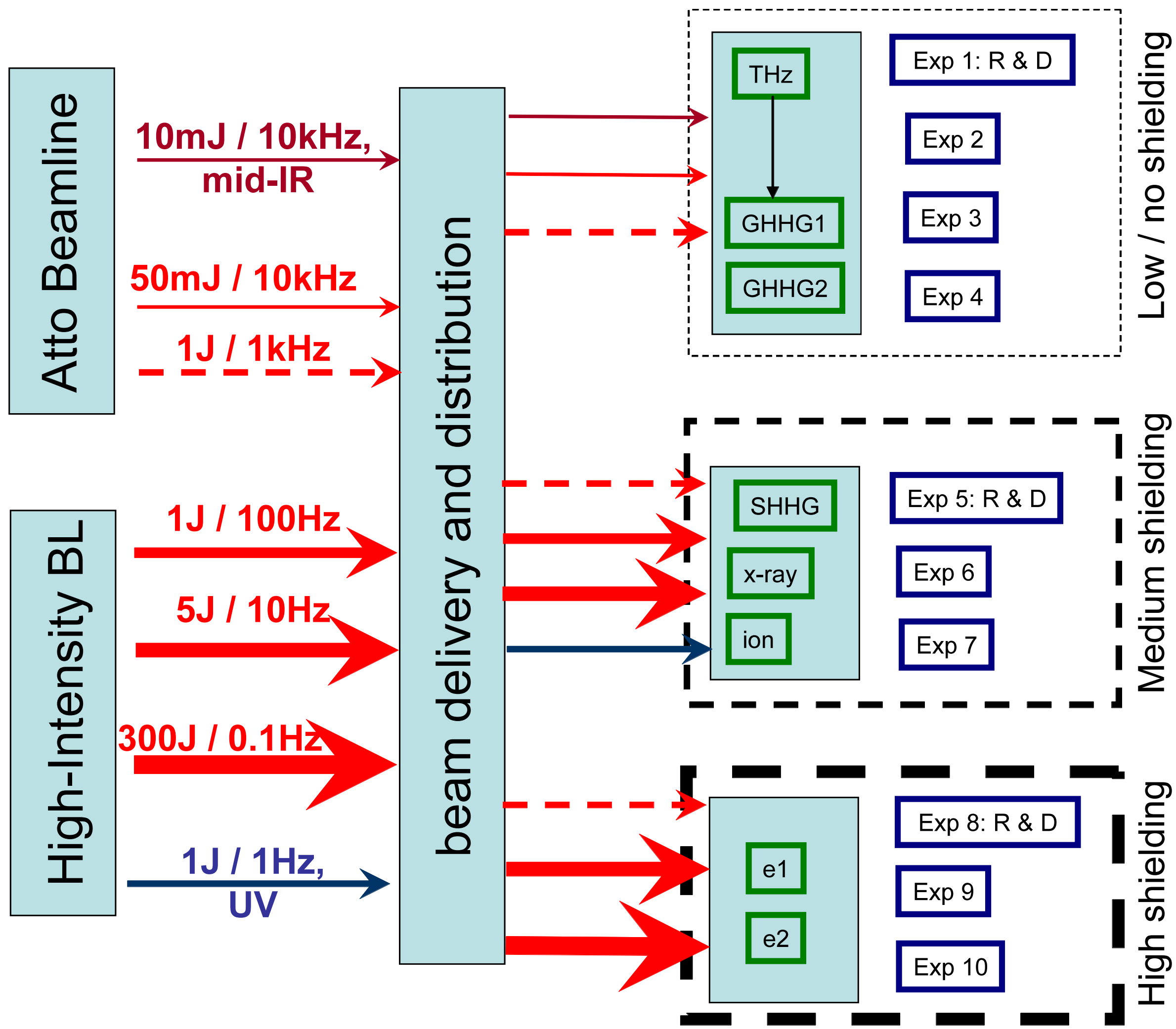
- synchronization between IR beams of atto driver and high-int. beamlines
- measurement methods and optical testing techniques

Science and applications:

- plasma physics and diagnostics (synchronized IR/X-ray target area)
- particle acceleration (electron and proton beams)
- hadron therapy of cancer
- tabletop FEL tests
- exotic/high-intensity physics etc.

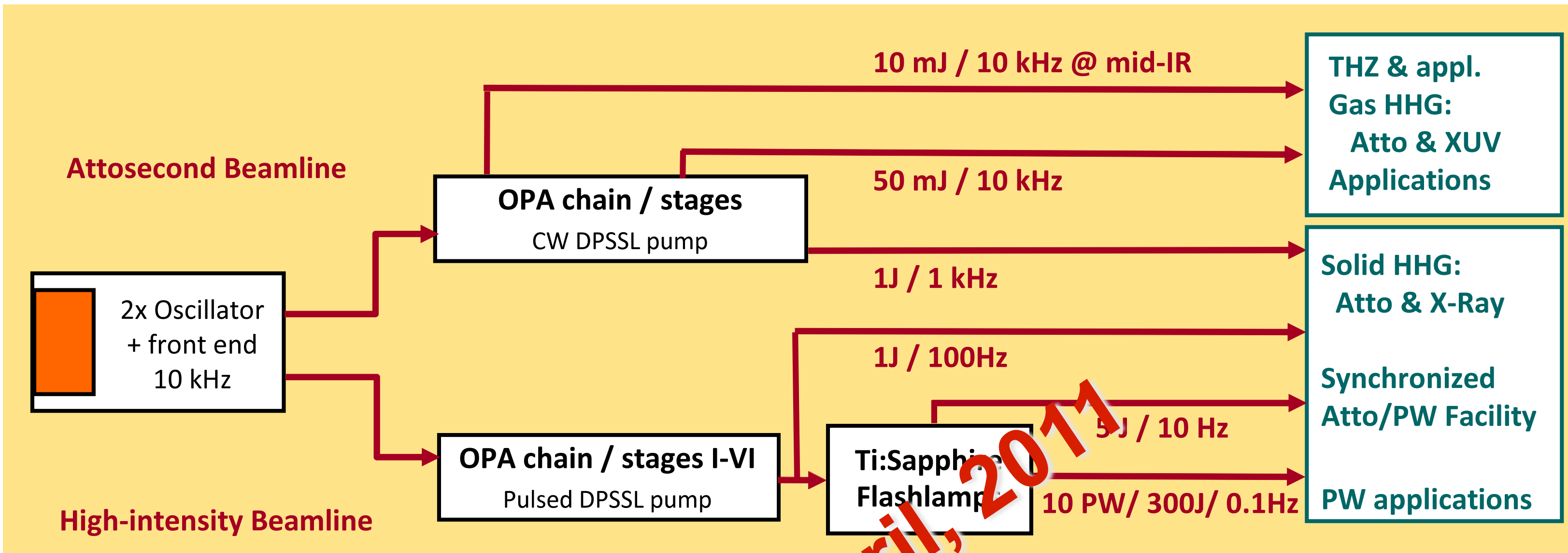
Collaboration with LBNL (MBI)?

Beam distribution and target areas



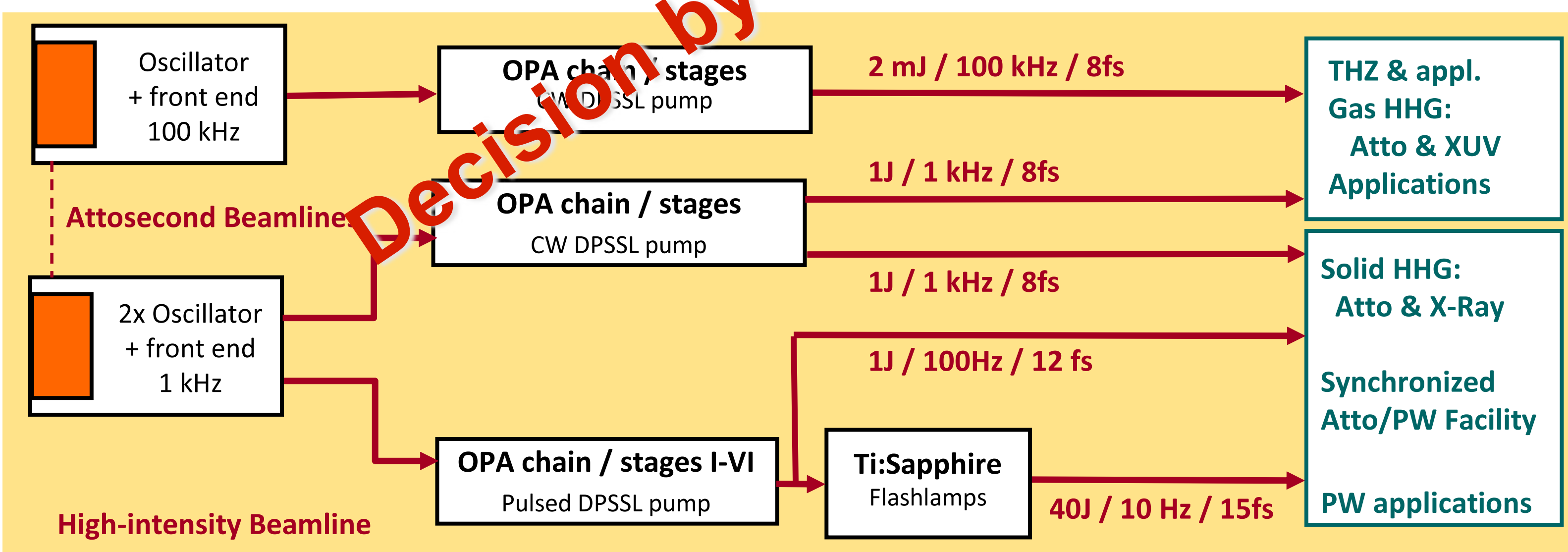
New alternatives

Current design

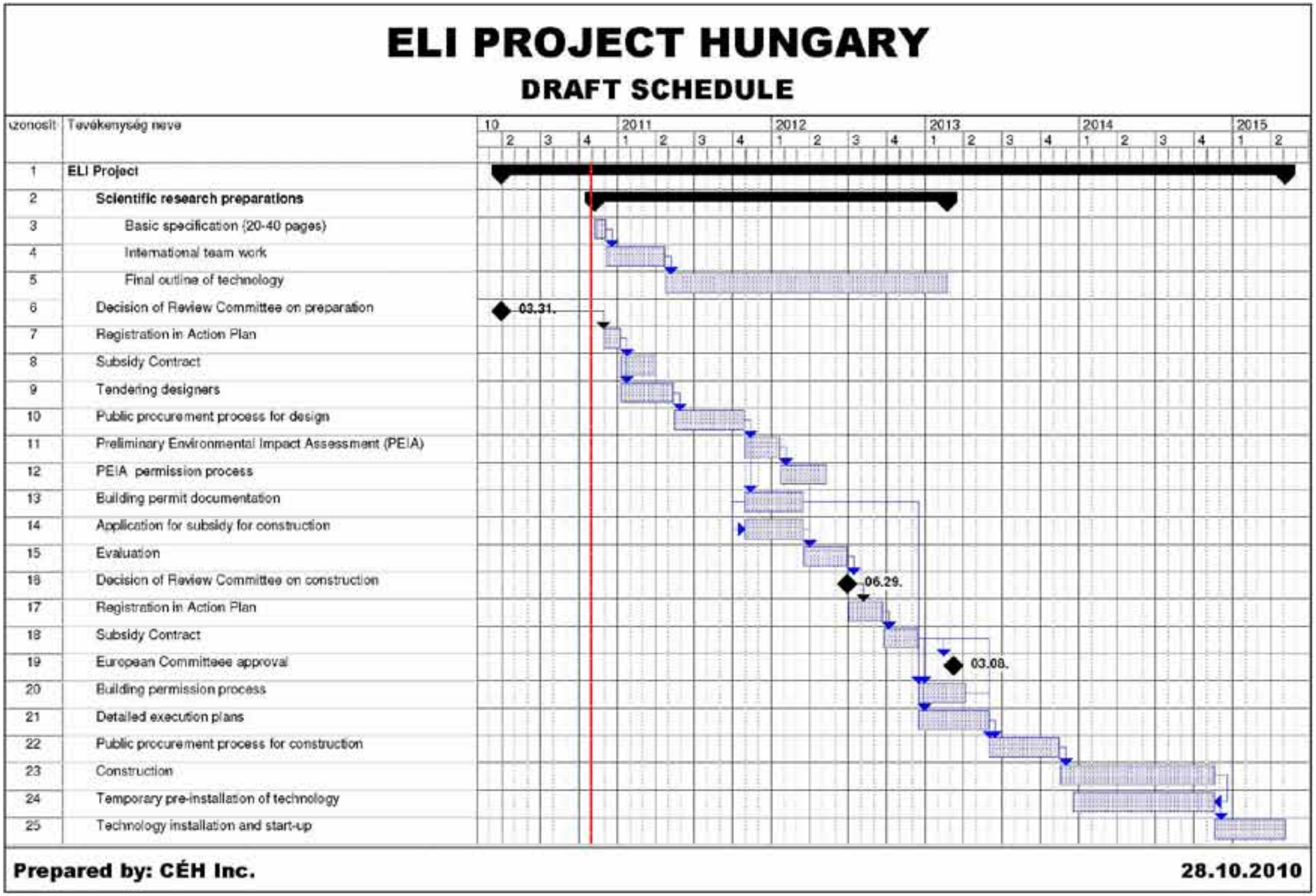


Decision by April, 2011

New alternative



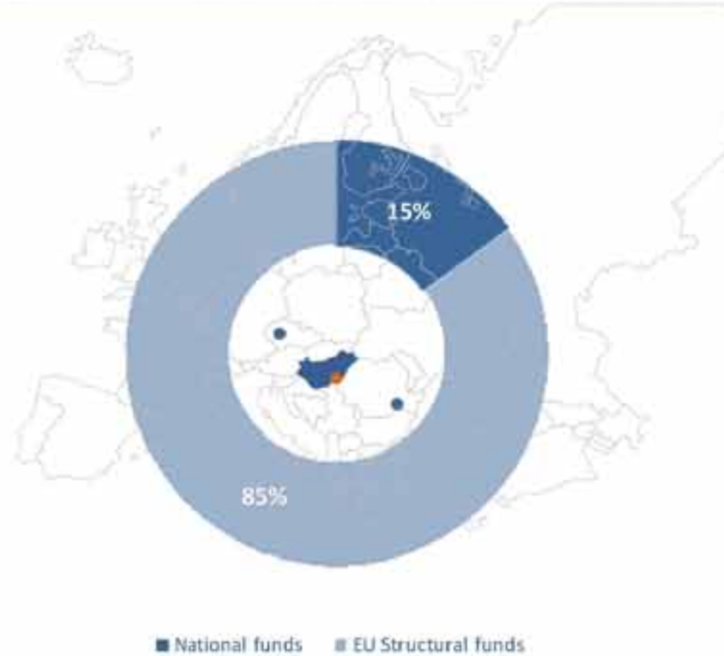
Schedule



ELI PROJECT HUNGARY
DRAFT SCHEDULE
Azonosít
Tevékenység neve
10
2011
2012
2013
2014
2015
1 ELI Project
2 Scientific research preparations
3 Basic specification (20-40 pages)
4 International team work
5 Final outline of technology
6 Decision of Review Committee on preparation
7 Registration in Action Plan
8 Subsidy Contract
9 Tendering designers
10 Public procurement process for design
11 Preliminary Environmental Impact Assessment (PEIA)
12 PEIA permission process
13 Building permit documentation
14 Application for subsidy for construction
15 Evaluation
16 Decision of Review Committee on construction
17 Registration in Action Plan
18 Subsidy Contract
19 European Committeee approval
20 Building permission process
21 Detailed execution plans
22 Public procurement process for construction
23 Construction
24 Temporary pre-installation of technology
25 Technology installation and start-up
03.31.
06.29.
03.08.
Prepared by: CÉH Inc.
28.10.2010

Financing

Implementation	€m
Site acquisition	1,8
Building cost	57,0
Oscillators and front-end	2,5
Boosters and final amplifiers	35,0
High-intensity systems	83,2
Beam delivery and diagnostics	7,5
Experimental facilities, prototyping	26,7
Services	7,2
Personnel	20,0
Others, Overheads	2,8
TOTAL	**244,7**

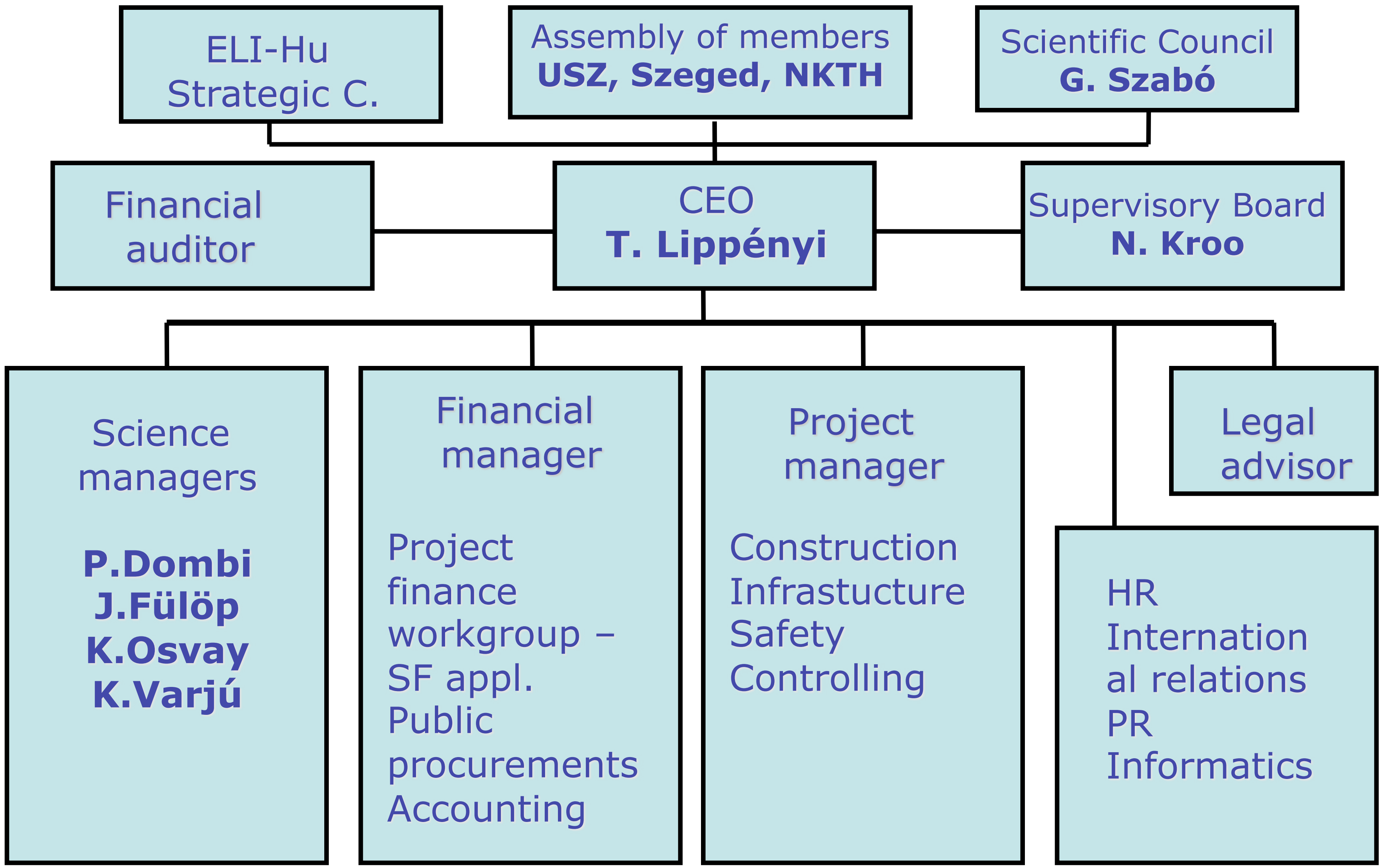


Running Costs	€m
Salaries	12,5
Consumables	5,5
Maintenance Costs	4,0
Travel expenses	1,5
Services	0,5
Utilities, Overheads	1,5
TOTAL	**25,5**

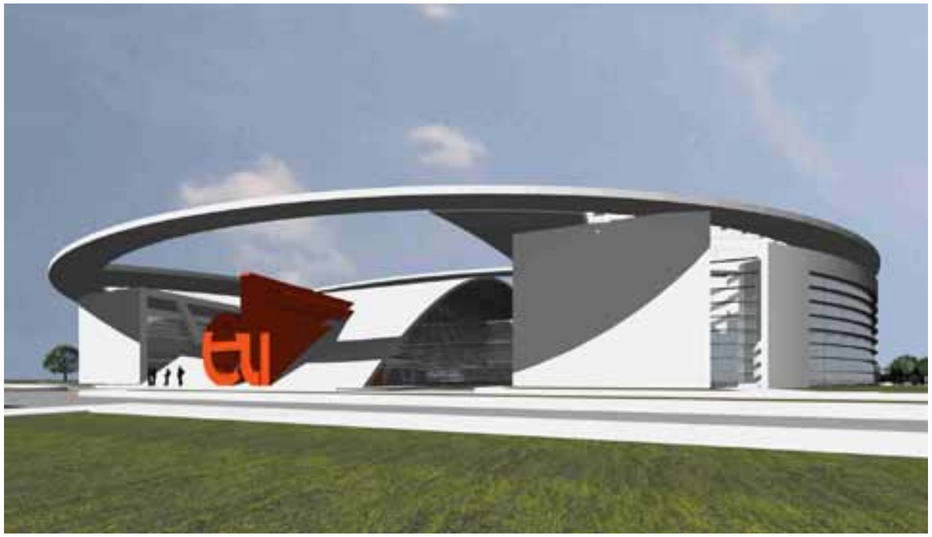
Financial sustainability	
National public funds	30%
Contributions from internat. partners	30%
Project funds	40%

Staff	FTEs
Employees	250-300

ELI-Hu Non-Profit Kft.



Artist’s impression of the building



ELI-HU site and science park

SZEGED: regional scientific, educational and cultural center

163 000 inhabitants

30 000 students

2300 researchers in USZ, Biological Research Center,
Institute for Cereal Research

Departments of Physics University of Szeged

4 departments + research group of the Academy

>30 PhD students

Industrial partners

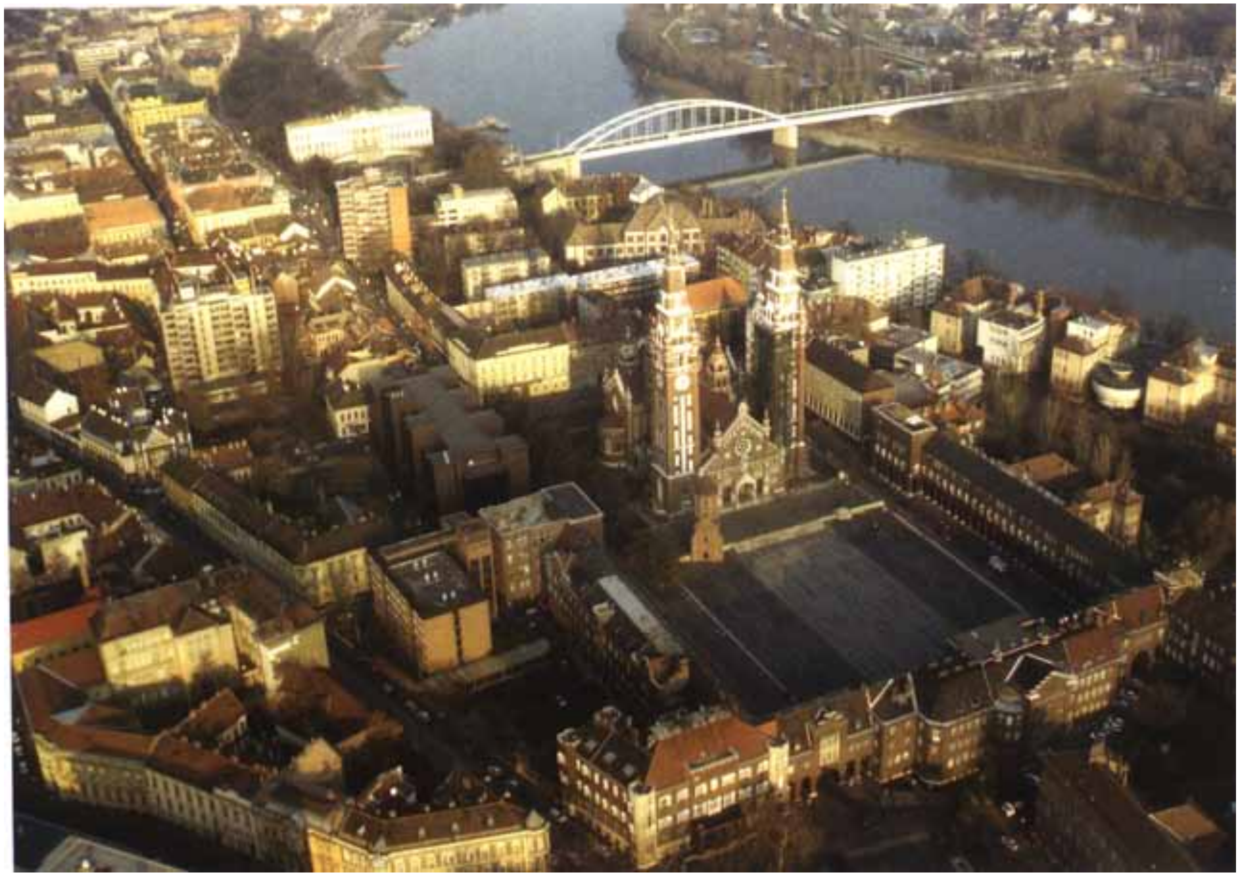
(MOL, Videoton, GE, Continental, Knorr-Bremse, Semilab)

Spin-off companies

(CE Optics, HiLASE, Laserskills)

1 M€/Y R&D budget

(grants, contracts)



Dept. Experimental Physics

High Intensity Laser Laboratory (HILL)

S. Szatmari

http://exp.physx.u-szeged.hu/hill/

Sub-ps, terawatt excimer laser
80 mJ, 600 fs (100 fs), @ 248 nm

VUV, XUV generation
100 μJ, < 500 fs, @ 83 nm

Dept. Experimental Physics

High Intensity Laser Laboratory (HILL)
S. Szatmari
http://exp.physx.u-szeged.hu/hill/

An operational, user-facility based on a hybrid dye-excimer laser system which uses an excimer-laser-pumped dye laser, whose frequency-converted pulses are amplified in a discharge-pumped KrF excimer system.

- **Uniqueness of the system is**
  - the availability of synchronized femtosecond pulses at exotic wavelengths,
  - excellent focusability (brightness) of the pulses and
  - the availability of high-brightness VUV pulses at 83 nm.

- **Pulse parameters:**

Rep. rate	**2 Hz**			
Wavelength	**496 nm**	**248 nm**		**83 nm**
Pulse duration	**300 fs**	**600 fs**	**150 fs**	**-**
Energy	**100 μJ**	**80 mJ**	**40 mJ**	**> 10 μJ**
Contrast	**-**	**> 10^9**	**-**	**-**
Peak power	**-**	**> 0.1 TW**		**-**
Brightness	**-**	**> 10^{19} W/cm^2 sterad**		**-**
Available intensity	**-**	**> 10^{18} W/cm^2**		

Main applications:

- plasma physics experiments,
- micro material's processing,
- solid-state physics.

Dept. Optics and Quantum Electronics

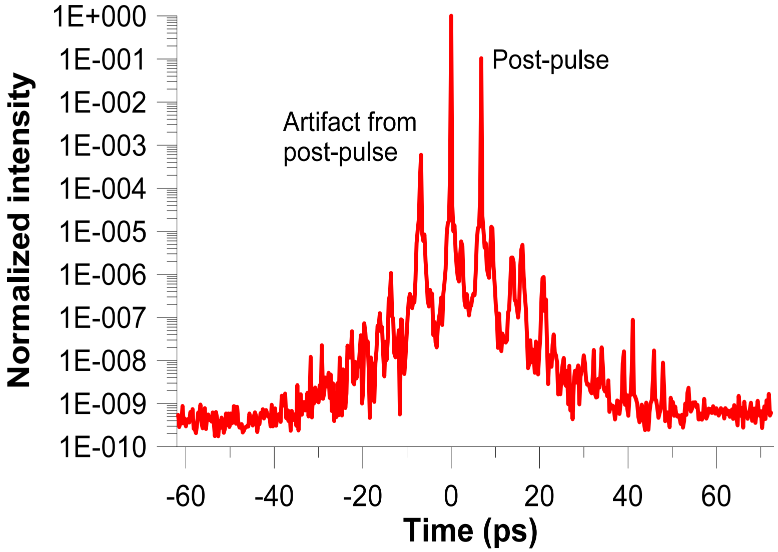
TEWATI Laser and Laboratory

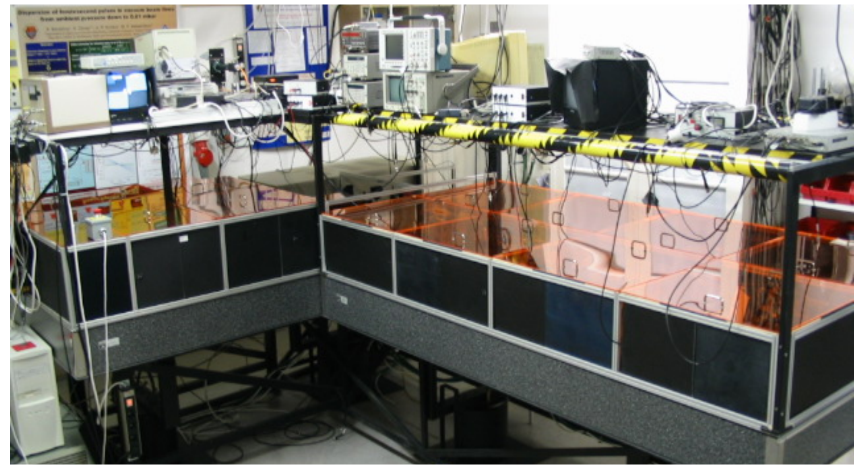
Group leader: Karoly OSVAY

www.tewati.hu

2 TW 10 Hz laser system
Hybrid: OPCPA + Ti:S
Home designed and made

Temporal contrast
w/o contrast enhancing elements





Available pulses

800 nm: 6 nJ, 12 fs, 70 MHz
35 mJ, 20 fs, 10 Hz
530 nm: 0.2 mJ, 25 fs, 10 Hz New
532 nm: 360 mJ, 3 ns, 10 Hz
400 nm: 2 mJ, 25 fs, 10 Hz
266 nm: 140 mJ, 3 ns, 10 Hz

Dept. Optics and Quantum Electronics

TEWATI Laser and Laboratory

Group leader: Karoly OSVAY
www.tewati.hu

Research directions and recent results

Development and applications of all-linear measurement technique for material and angular dispersion

Pressure dependent dispersion of air and inert gases
Nonlinear refractive indices of inert gases
Ultrafast dispersion of bacteriorhodopsin

*Osvay et al., APB **87**, 457 (2007)*
*Börzsönyi et al., OC **281,** 3051 (2008)*
*Heiner, et al., AO **48**, 4610 (2009)*
Börzsönyi et al., Opt.Exp. In press
Fabian et al., submitted

Development of techniques for control of higher-order dispersion of femtosecond pulses

Thermal slab
Non-linear crystal based cubic compressor
Wedge assemblies for CEP and dispersion control

*Osvay et al., APB **89**, 565 (2007)*
*Görbe et al., OL **33**, 2704 (2008)*
*Grebing et al., APB **97**, 575 (2009)*

Atto-physics

Generation and measurement of attosecond pulse trains
Linear measurement of carrier envelope offset phase

*Osvay et al., OL **32**, 3095 (2007)*
*Ruchon et al., NJP **10**, 25027 (2008)*
*Görbe et al., APB **95**, 273 (2009)*

Surface processing with pulsed lasers

Generation of submicron period gratings on bulk surfaces
Investigation of plasmonic behaviours

*Csete et al., ASS **253,** 7662 (2007)*
*Vass et al., APA **87**, 611 (2007)*
*Vass et al., APA **93**, 69 (2008)*
*Sipos et al., ASS **255**, 5135 (2009)*

Major laser technologies

	Beamline Cz	Attosource Hu	NuclearPhys. Ro
Ps OPCPA frontend	✔	✔	✔
Ps OPCPA power		✔	
Ns OPCPA power	✔		
Ns Ti:S power		✔	✔
DPSSL pump kHz	✔	✔	✔
DPSSL pump 10Hz	✔		
Flashlamp pump 10Hz		✔	✔
Flashlamp pump shot/min		✔	✔
CEP stabilization		✔	
Coherent beam comb.	✔	✔	✔
XPW cleaing	✔	✔	✔
Plasma mirror cleaning	✔		✔

Technology towards 200PW?
Hybrid?

Major industrial bottlenecks…

- **Pump lasers:** flashlamp based: 200J, 1shot/min
  DPSSL: 10kW: 10J, 1kHz … (≈kJ, 10Hz) - Cz
- **Large size crystals:** Ti:S: ∅ ≥ 20 cm
  LBO: ∅ ≥ 6 cm
- **Compressor gratings:** η>95% over a bandwidth >200nm
  and LDT≈0.5J/cm^2 @ 15 fs
- **Coatings:** Low dispersion, bandwidth >300nm,
  and LDT≈1J/cm^2 @ 15 fs, large size

… and further challenges

Dispersion management

Compensation for the residual chirp up to 5th order
Compensation for angular dispersion / spectral chirp

Temporal contrast

10^{10}-10^{14} on target
Optics size / tiled gratings

Coherent beam combination

8-12 beams on target: timing, phasing incl. CEP

Radio protection / shielding

extreme light infrastructure

Thanks for your attention!

www.eli-laser.eu