The Extreme Light Infrastructure ELI

Europe on its way to build the first international laser user facility

Wolfgang Sandner
Director General and CEO
ELI Delivery Consortium International Association (AISBL)

LLE Rochester, March 10, 2015, Rochester, NY

Project supported by:

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE

Executive summary

The vision

2006: Initiated as a bottom-up project by the EU scientific community:

"Let's have the world's most powerful scientific laser, exceeding the state-of-the-art by a factor of 100"

(G. Mourou)

The "business concept":

4 years later, after inclusion in the ESFRI Roadmap and EU funding for the Preparatory Phase (led by G.M.):

- Not one, but three (four) ELI; start with factor of 10
- Use "EU Structural Funds" for construction
- Aim for *international operation / sponsorship*
- Specifically, operate as "ERIC" after 2018 (European Research Infrastructure Consortium)
- Science case: the "ELI White Book"

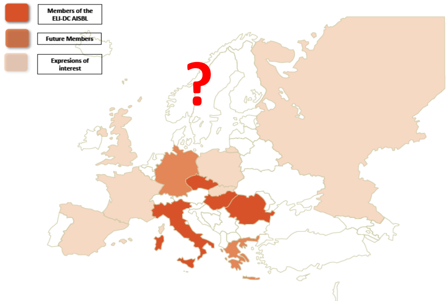
The product

Attosecond Laser Science, will capitalize on new regimes of time resolution (*ELI-ALPS*, Szeged, HU)

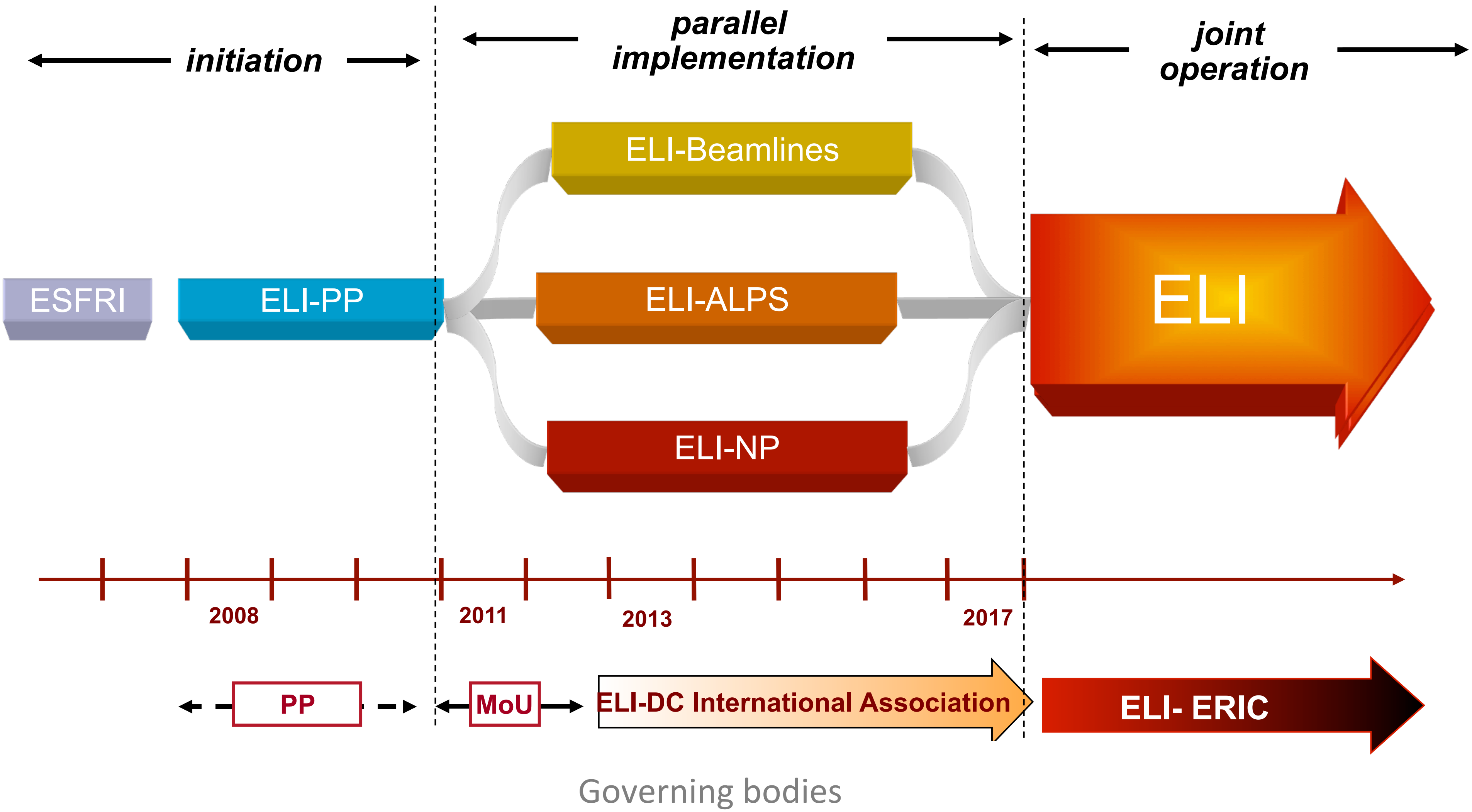
High-Energy Beam Facility, responsible for development and application of ultra-short pulses of high-energy particles and radiation (*ELI-Beamlines*, Prague, CZ)

Nuclear Physics Facility with ultra-intense laser and brilliant gamma beams (up to 19 MeV) enabling novel photonuclear studies (*ELI-NP*, Magurele, RO)

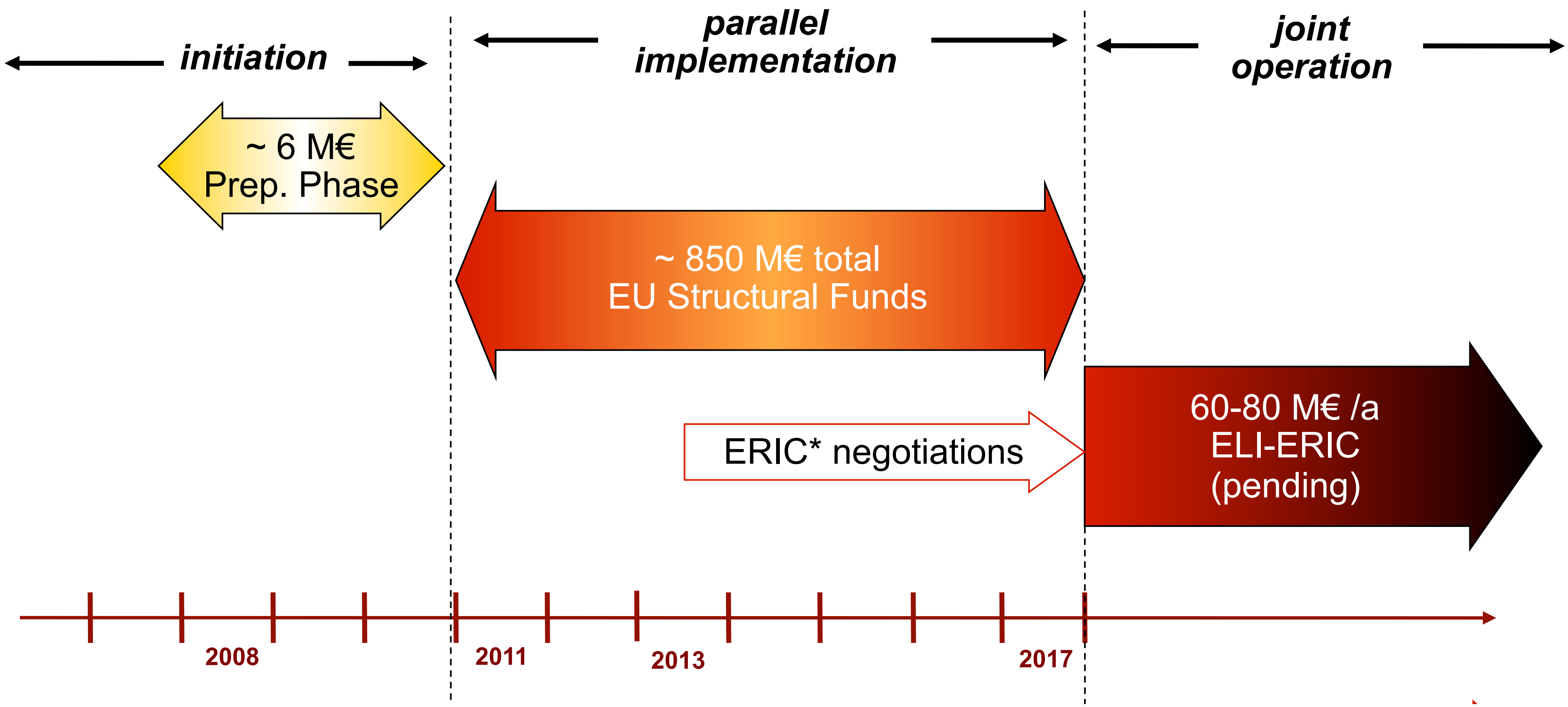
Ultra-High-Field Science centred on direct physics of the unprecedented laser field strength (*ELI 4*, to be decided)



The implementation plan



Financial plan



* ERIC = *European Research Infrastructure Consortium*, a new legal body after European law,

A good plan?

In principle yes! Fast & efficient implementation, easy EU construction money (almost 1 bn €) with only few strings attached, added value through regional development in Central Europe ⇔ using the full EU instrumentation.

In retrospect: one would have planned implementation with the end in mind: start with a business model for operation, shape the facilities after it, retain a steering body throughout.

It is still possible, but no time to waste - “before the concrete fully dries”.

Remaining challenges

ELI will be

- the *world's first international laser research infrastructure*, providing unique science and research opportunities for international users
- a *distributed research infrastructure* based initially on 3 facilities in CZ, HU and RO
- the first ESFRI project to *be implemented in the new EU Member States*
- *pioneering a novel funding model* combining structural funds (ERDF) for implementation and contributions to an ERIC for operation

What lies ahead?

A **merger** of 3 legally autonomous construction projects, meanwhile having developed individual visions and cultures

Development of a sound **business model / business plan** for the ELI-ERIC operation as an **international user facility**

Selling the product to customers (sponsor countries) who may be scientific competitors, with no Cent to waste

ELI's window of opportunity

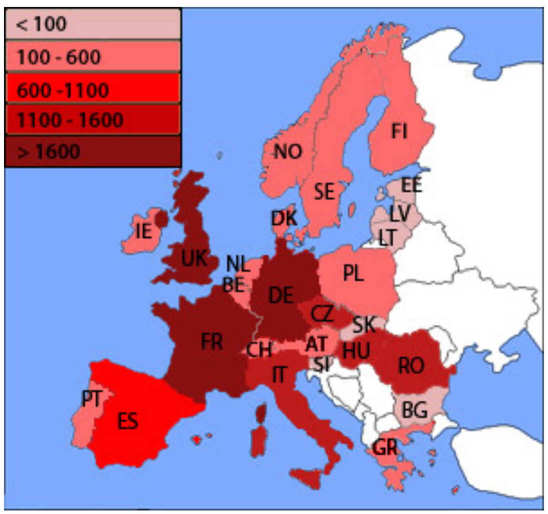
- why it could happen
- why in Europe
- why now

Note: In DoE terms (including operation cost) ELI is a 2bn € project, not counting the fourth pillar

Lasers in Europe

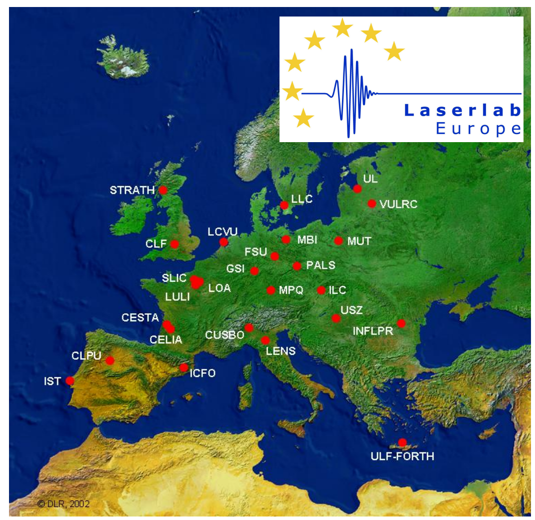
A structured research landscape to meet global challenges

European Laser Community



The basis

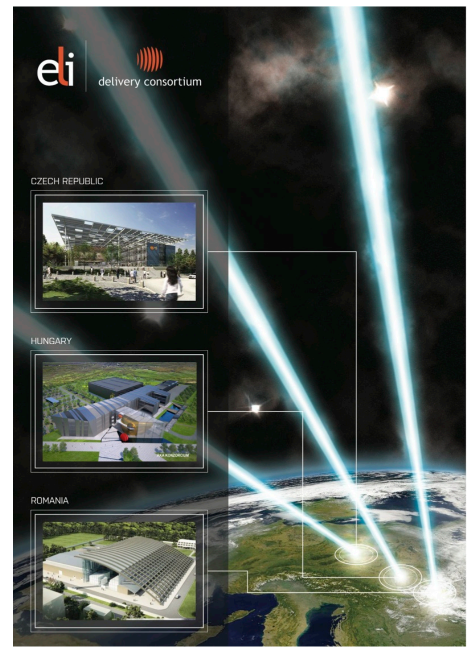
Infrastructure Network: Laserlab-Europe



Flexible instrument to perform and initiate new science beyond the national scale

ESFRI

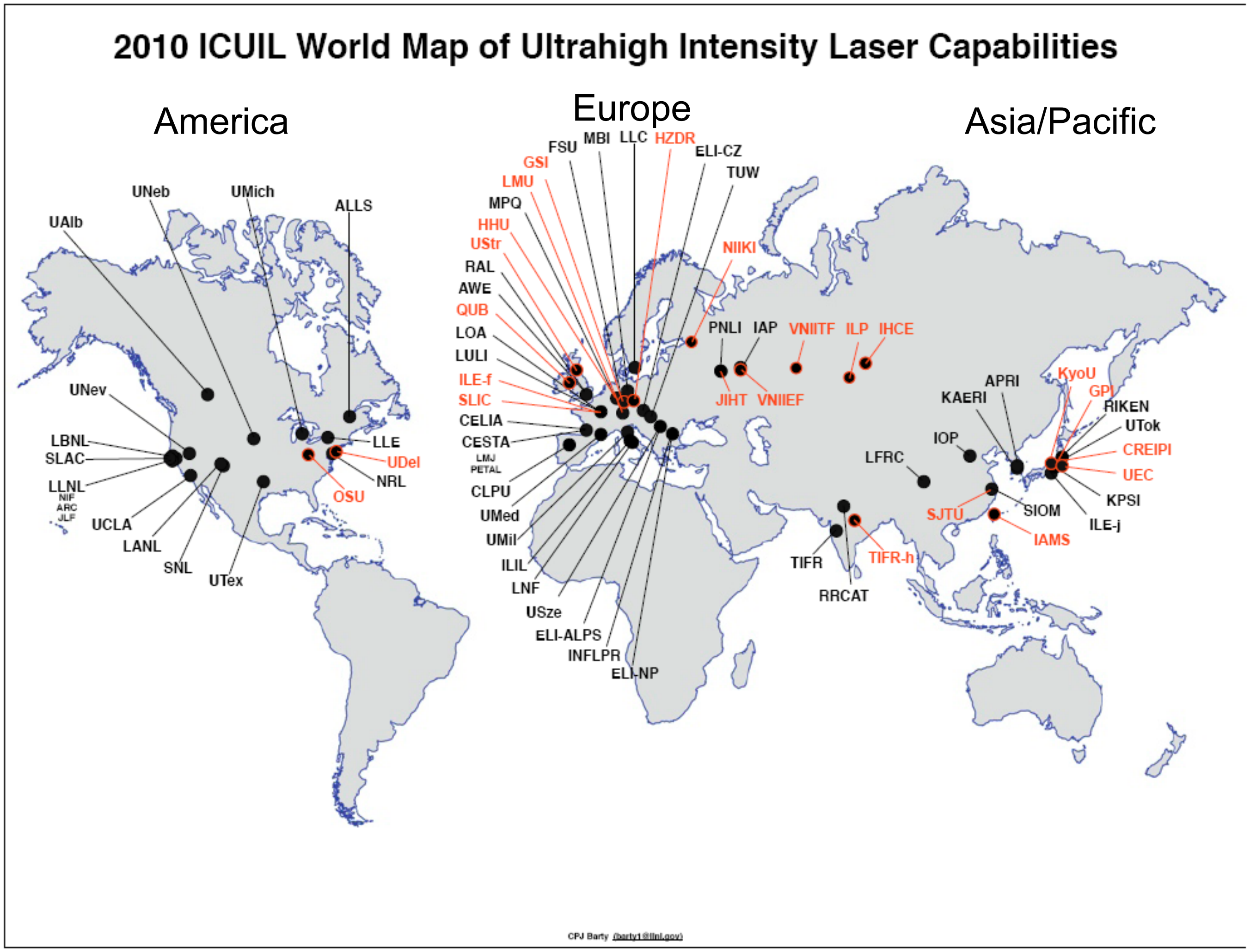
Pan - European Research Infrastructure ELI



Mission-oriented single entity to meet global challenges

The global scene: ***National Research Infrastructures***

High Power Lasers (P > 100TW)



2009
2010

Christopher P.J. Barty, 2011
http://www.icuil.org

ICUIL prediction of 2011

"The accumulated peak power of pulsed high-power laser systems world-wide was about 11.5 Petawatt (PW) in 2010

It is expected to grow to more than 120PW by the year 2015, representing an estimated 3.5 billion dollar effort by 1600 highly qualified experts."

Why?

One driver: science and the scientific community

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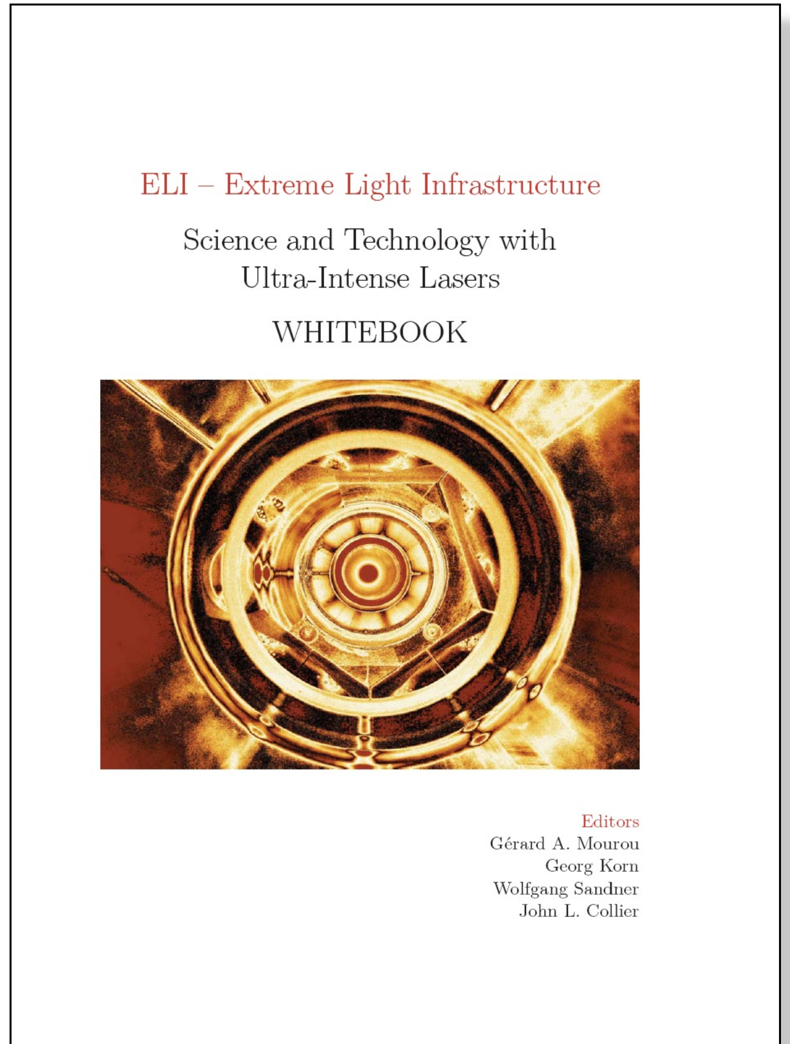
The ELI „White Book“

530 pages
172 authors
10 major interdisciplinary fields



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The quest for extreme light

- Investigation of Vacuum Structure
- Electron Acceleration
- Ion sources
- Neutron sources
- Terahertz sources
- Ultrafast-laser driven X-ray sources
- Attophysics
- ELI Nuclear Physics
- Physics of dense plasmas
- Laboratory Astrophysics

(from the “ELI White Book”)

Science alone is not enough

EC (DG Regio) on Research infrastructures

- ✓ *They must be integral part of strategies, not "cathedrals in the desert" & large-scale budget absorbers*
- ✓ *Identified in an entrepreneurial discovery process, not just desired by academia & researchers*
- ✓ *Research excellence* per se *is* *no* *objective for Cohesion Policy, but just a tool for competitiveness and growth*
- ✓ *Key RI should be designed / transformed into crystallisation points for economic change and growth: clusters, technology parks, incubators, firm cooperation*
- ✓ *Importance of international attractiveness & connectedness: private investors & brain-gain*
- ✓ *Evaluation, evaluation, evaluation!*

Katja Reppel
CC smart and sustainable growth
DG Regional and Urban Policy

Photonics – A EU Key Enabling Technology

- Total Photonics market € 350 bn (in 2011)
- Average annual growth 6,5% (= 2x GDP growth)
- Estimated market size in 2020 ~ € 615 bn
- **European Photonics market ~ € 64 bn**
- **European market share 18%** (in 2011)
- Many market-leading industrial players
- Market shares of European companies

Production technology	55%
Optical components & systems	40%
Measurement & automated vision	35%
Medical technology & life sciences	30%

- More than 5000 SMEs in Europe
- **~ 300,000 employees**

EUROPEAN UNION
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A strategic orientation of science policy

The European ESFRI Roadmap

ELI Science

What **usually** follows is a one-hour description of the exciting frontier science which has been developed by ELI pillars and the international scientific community - an impressive development culminating in new initiatives like IZEST and ICAN

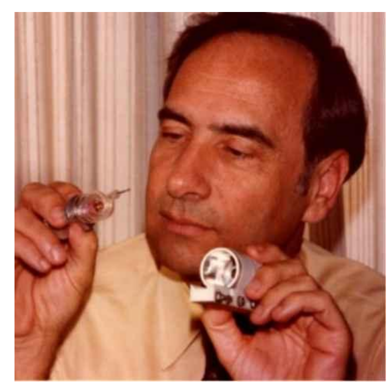
ELI science includes:

- **Creation** of laser pulses with highest power and intensity, at highest repetition rates
- **Interaction** of such pulses with matter: vacuum, nuclei, atoms, molecules, condensed matter and plasmas
- **Investigation and utilization of secondary radiation** of particles and photons from such interaction
- **Application** of all this in societally relevant areas through open access for an international user community

Creation of extreme light

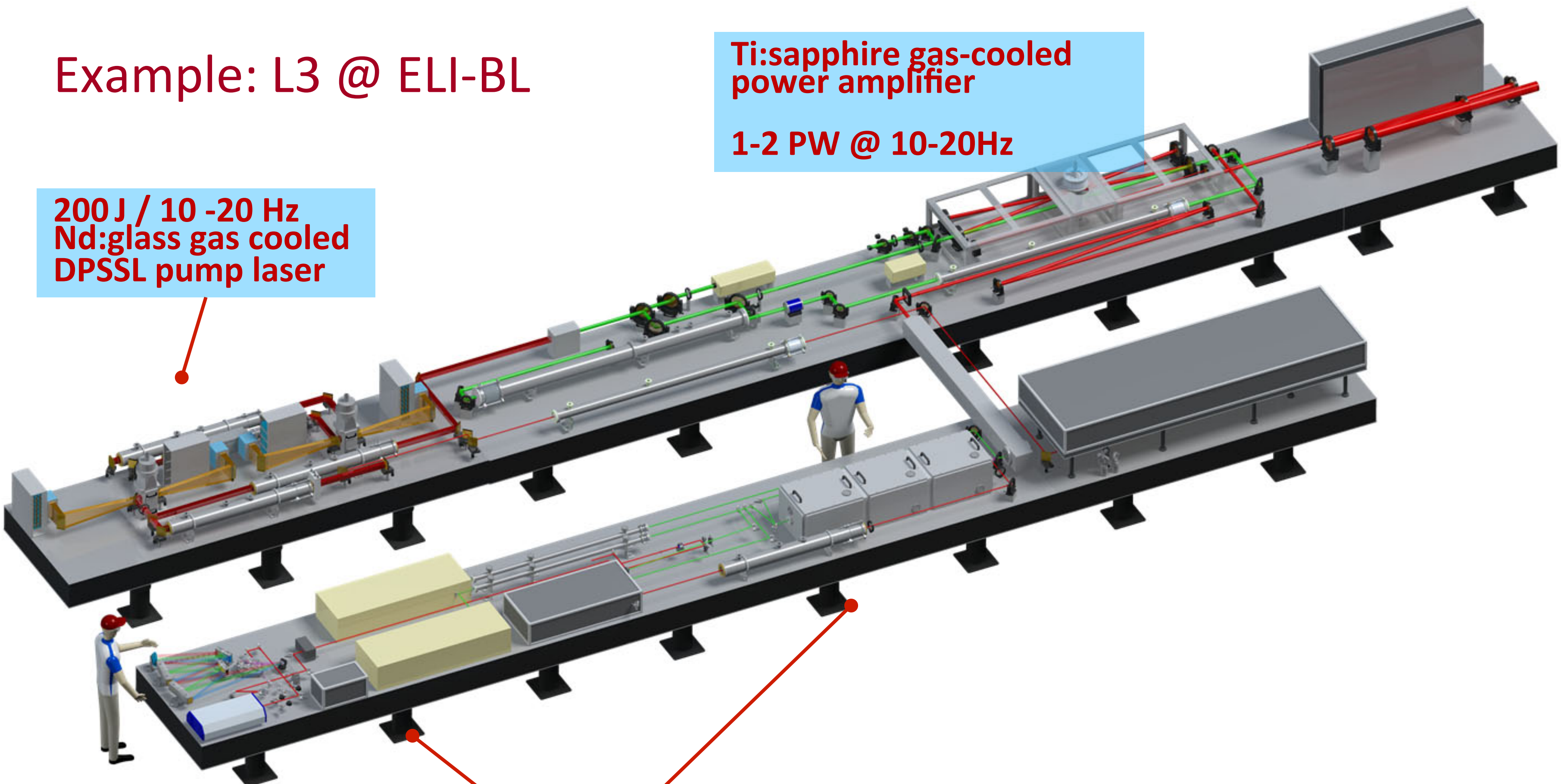
Taking Theodore Maiman's laser concept to today's extreme:

- Pulsed power at the 10 PW level
- Highest repetition rates (up to 10Hz @ 10PW)
- Focus on reliability and availability
- Extending the spectral range through nonlinear interactions (secondary sources)
- Combine many sources in one facility
- Provide the optimum environment for interdisciplinary research



High-repetition-rate diode pumping of high-power lasers

Example: L3 @ ELI-BL



Fyzikální ústav
Akademie věd ČR, v. v. i.
projekt podporovaný:
EVROPSKÁ UNIE
EVROPSKÝ FOND PRO REGIONÁLNÍ ROZVOJ
INVESTICE DO VAŠÍ BUDOUCNOSTI
OP Výzkum a vývoj pro inovace

Extreme power @ ELI

- Today's most powerful lasers achieve
  ~ 1PW (50J/50fs) @ 1Hz (BELLA laser, LBL)
- There exist a handful of PW-class lasers world-wide

- **ELI** will have by 2018

  - Two coupled 10PW lasers (ELI-NP)
  - One 1-2PW laser @ 10-20Hz (ELI-Beamlines)
  - One 1PW laser (OPCPA, <20fs) @ 10Hz (ELI-Beamlines)
  - One 10PW laser (1.5kJ, 150fs) (ELI Beamlines)
  - One multi-PW laser @ <10Hz (ELI-ALPS)

Each of these exceeds today's state-of-the-art by a factor of ~10

Reliability & availability must equally be improved!

New technologies => new physics

Three key phenomena for the interaction of extreme light with matter:

- Intensity => Electromagnetic peak fields
- Time-averaged „quiver energy“ of free electrons
- Light pressure on a reflecting plasma surface

„*LASER INTENSITY* I" = photon flux density

$\propto$ (electric field strength **F**)^2

$\propto$ (peak ***force*** on charged particles)^2

$$\mathbf{F}\,[\mathrm{V/cm}] = 27.4 \left(\mathbf{I}\ [\mathrm{W/cm^2}] \right)^{1/2}$$

10^{16} W/cm^2	→	breaking up atoms (**F**= 1 a.u.)
10^{18} W/cm^2	→	accelerating free electrons to relativistic energies (500keV)
10^{25} W/cm^2	→	naked Uranium ions
10^{29} W/cm^2	→	„breaking up the vacuum" (spontaneous pair creation)

Electromagnetic peak fields

@ 1µm

$$E_{max} = \left[\left(\frac{V}{cm}\right)\right] \cong 2.75\times10^{9}\left(\frac{I_L}{10^{16}W/cm^2}\right)^{1/2} \longrightarrow$$

$$B_{max} = [Gauss] \cong 9.2\times10^{6}\left(\frac{I_L}{10^{16}W/cm^2}\right)^{1/2} \longrightarrow$$

~ 1000

Gbar

Time-averaged „quiver energy“ of free electrons:

$$U_p[eV] = 9.33\times10^{-14}\underbrace{I[W/cm^2]\lambda^2[\mu m^2]}_{\text{time-averaged intensity !}} \longrightarrow$$

1 GeV @ 1µm

(@ R=30%)

Light pressure on a reflecting plasma surface:

$$P_L = \frac{I_L}{c}(1+R) \approx 3.3Mbar\left(\frac{I_L}{10^{16}W/cm^2}\right)(1+R) \longrightarrow$$

~ 1000 Gbar

(@ R=30%)

Sequence of light-matter interaction processes intensities ELI

1. Electromagnetic peak fields (10^{12} V/cm / 3G Gauss

$\Rightarrow$ Immediate ionization, => free electrons and ions

„quiver energy“ of free electrons (1 GeV):

- hot electrons + cold ions
- plasma heating processes
- electrons get expelled from the center of the laser pulse
  => charge separation between electrons and ions

3. Light pressure on a reflecting plasma surface (~1000 Gbar):

- electrons get pushed in forward
  charge separation may drag ions

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New physics => new technologies

Creating unprecendented secondary radiation of particles and photons

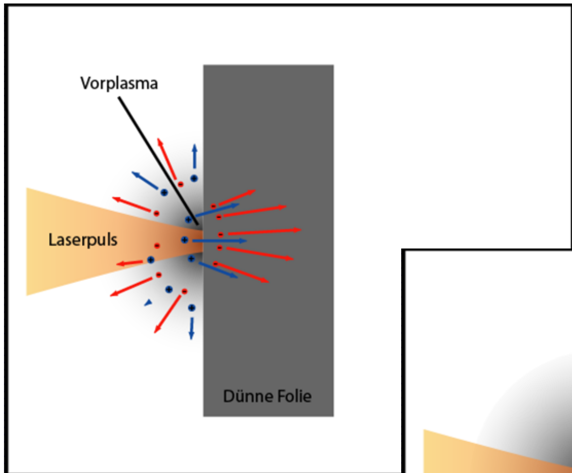
Particles: laser accelerated ions and electrons

Photons: from table-top XFELs to Gamma rays

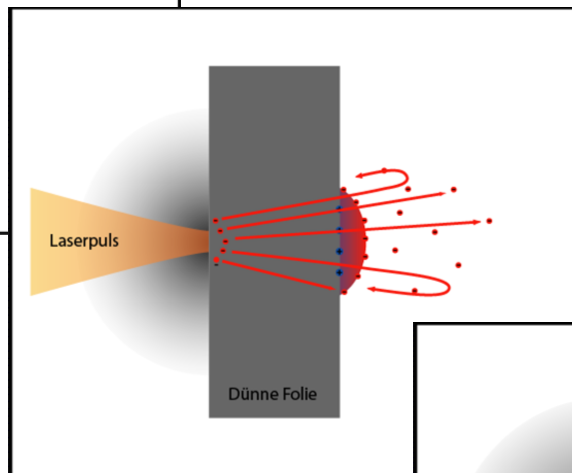
from meV (THz) to MeV

from pico- to attoseconds

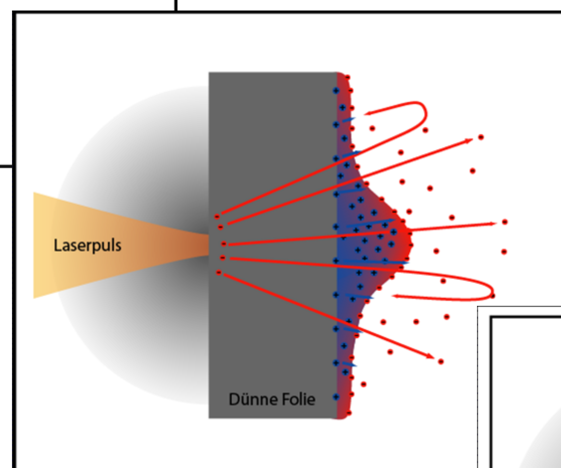
Ions: Target Normal Sheath Acceleration (TNSA)



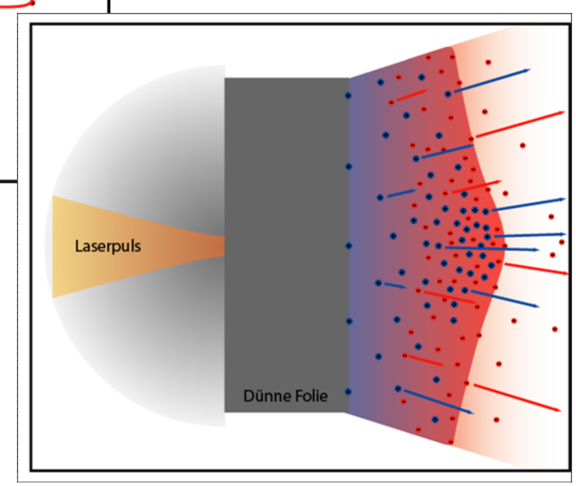
Pre-plasma creation on thin foil



Main pulse energy transferred to plasma electrons, electrons leave on the back

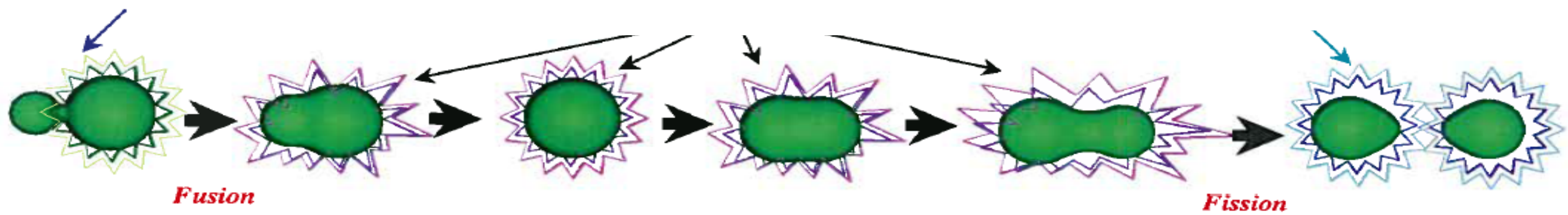


Formation of an electron sheath
=> quasi-equilibrium electric field (MV/µm)



Ion acceleration by the static electric field

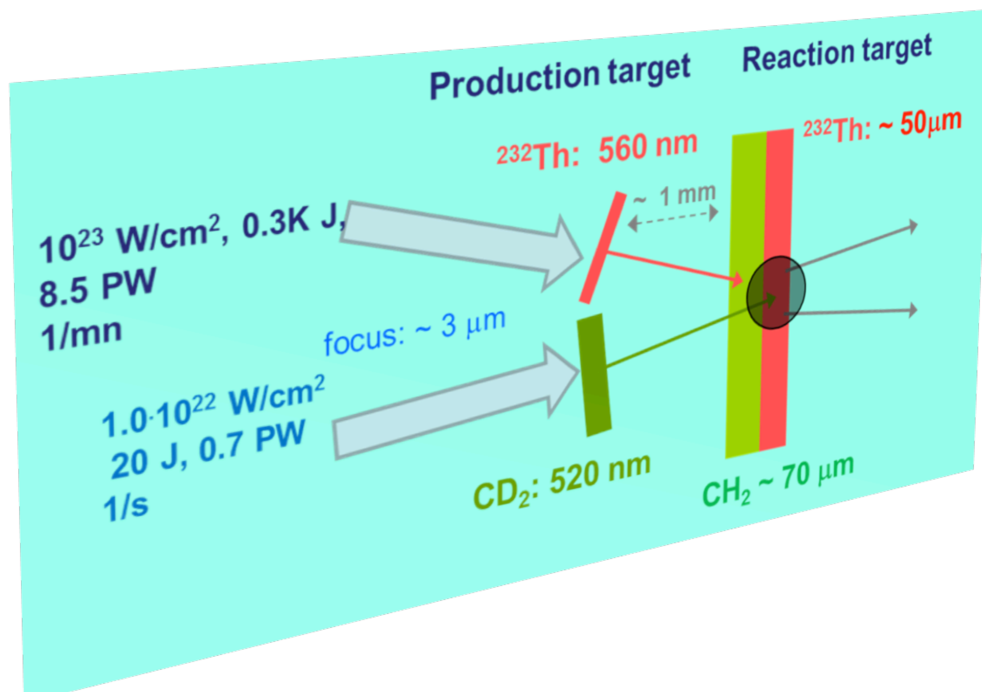
Example: Nuclear Astrophysics
How the elements are made in the cosmos



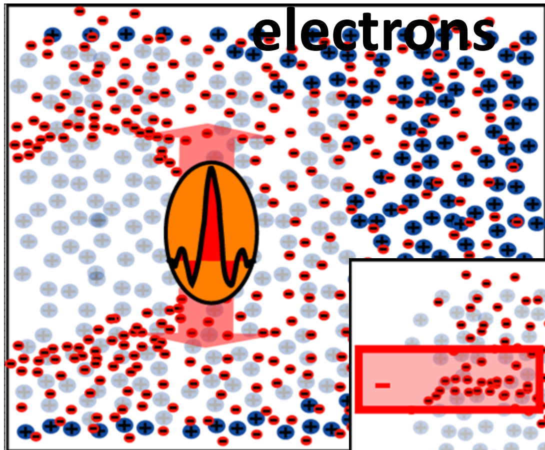
Fusion –Fission Process induced by HP Lasers

n–rich nuclei around N = 126 waiting point

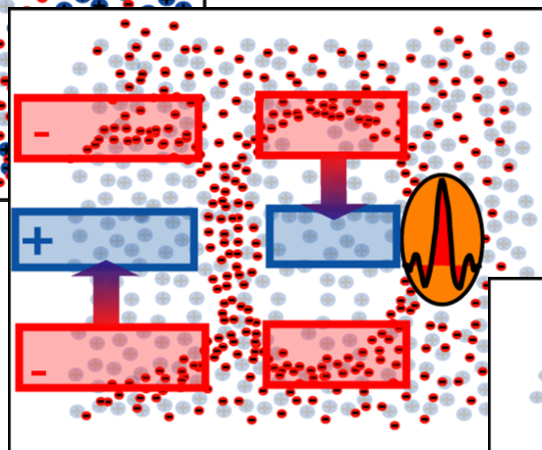
Laser-driven dense ion beams for nuclear physics Experiments at ELI-NP in Magurele



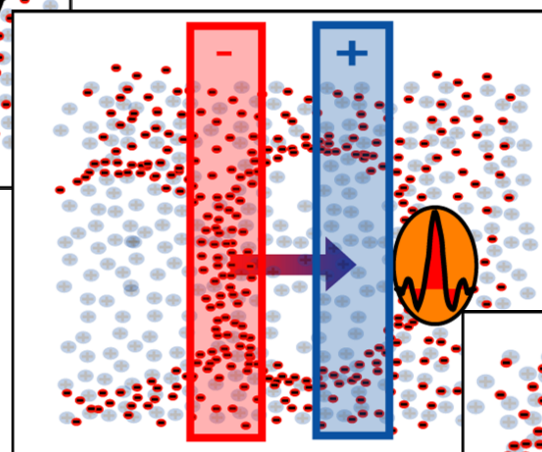
Electrons: Laser Wakefield Acceleration (LWA)



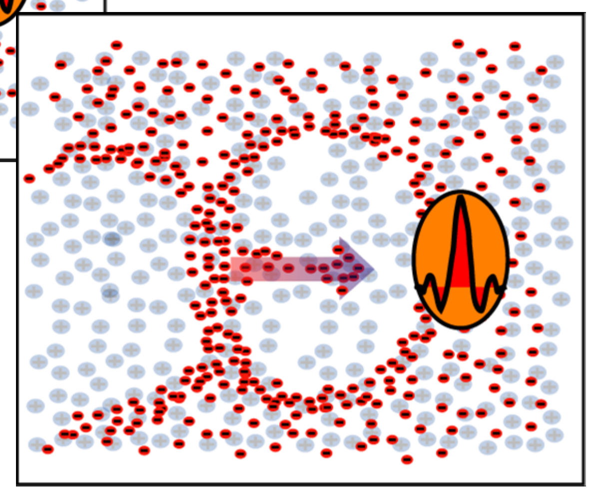
Laser in gas:
Atoms are ionized
Electrons expelled from the laser path through ponderomotive forces



Electrons are driven back to the center after the pulse „bubble creation“



Acceleration field in laser direction, wake structure follows the laser pulse (GV/m)

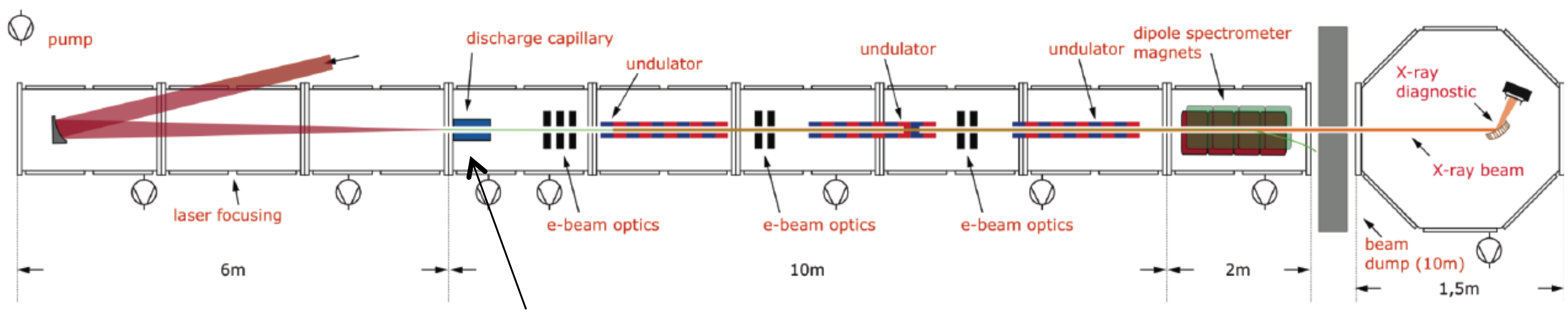


Some electrons get trapped and accelerated

VUV Photons: Towards "table-top" X-ray FEL (ELI-BL)

The LUX beamline:

Photon yield:	10^{12} photons per shot	
Photon energy	up to 5 keV	
Pulse width:	general:	few fs
	advanced:	below 1 fs



Driver Laser

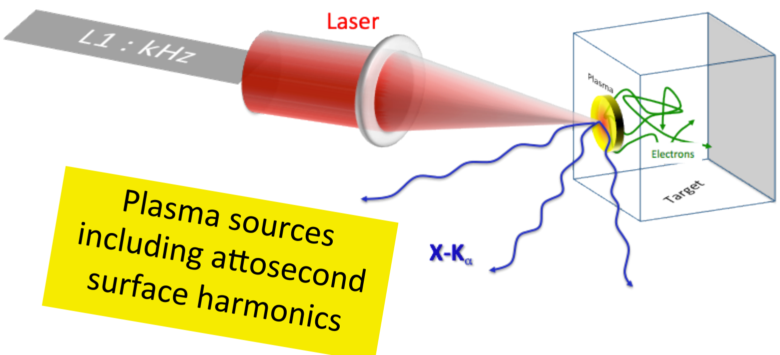
Wakefield electron accelerator

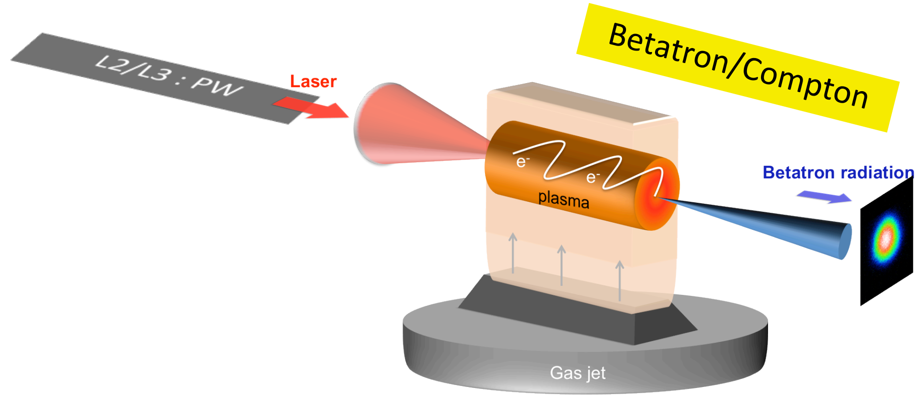
Undulators

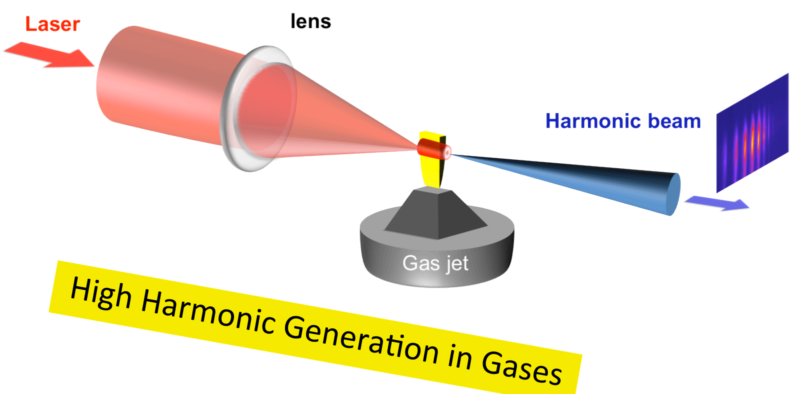
Experiments

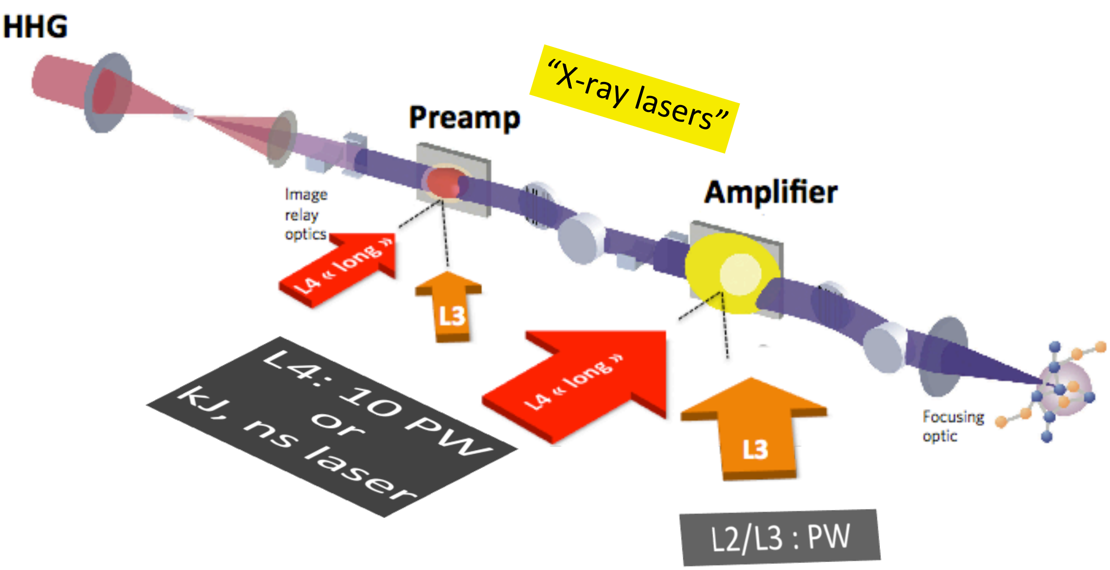
LAOLA Laboratory for Laser- and beam-driven plasma Acceleration

VUV and x-rays: short pulse, intense laser driven sources (ELI-BL & ELI-ALPS)





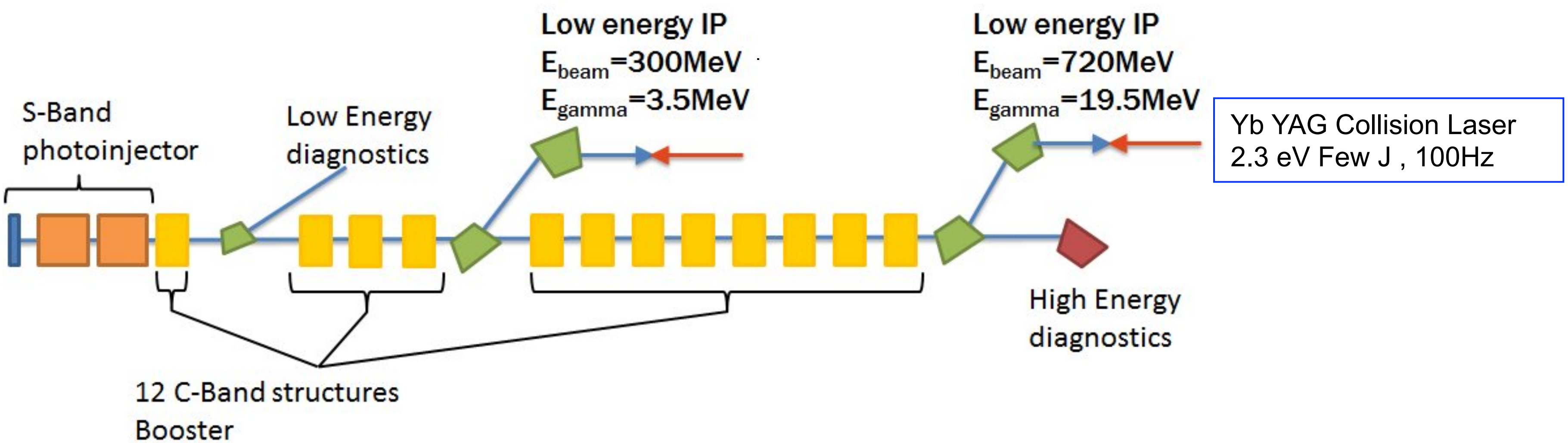




Gamma rays: Compton backscattering source (ELI-NP)

Unique in the world:

- *photon energy tunable in the range* — *1–20 MeV,*
- *Rms bandwidth* — *0.3 %*
- *spectral density* — *>10^4 photons/s/eV,*
- *source spot sizes smaller than* — *10–30 microns at 100Hz ,*



The Eurogammas Consortium

delivery consortium

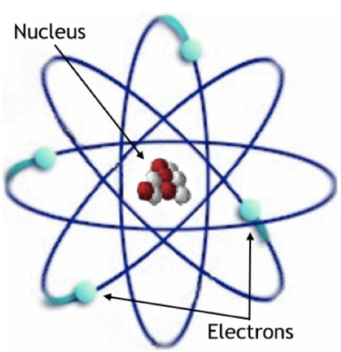
The pillars and their scientific missions

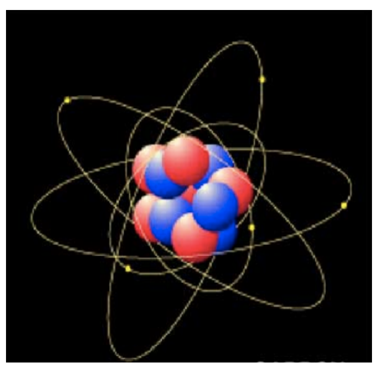
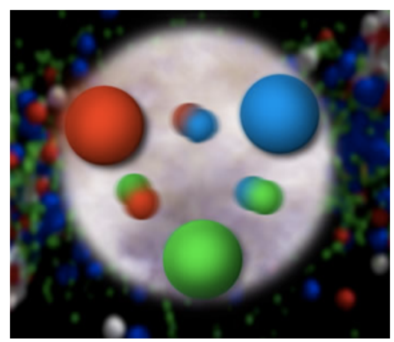
ELI-NP in Magurele, Romania: Nuclear Science and applications with the next generation of High Power Laser and Gamma beams

Mission:

Study matter from atom to vacuum

Fundamental Research & Applications of Laser & Ion beams




S. Gales for the ELI-NP team, Brussels 07-03-2014

Example: Nuclear Photonics

Electromagnetic dipole response of nuclei

Nuclear structure

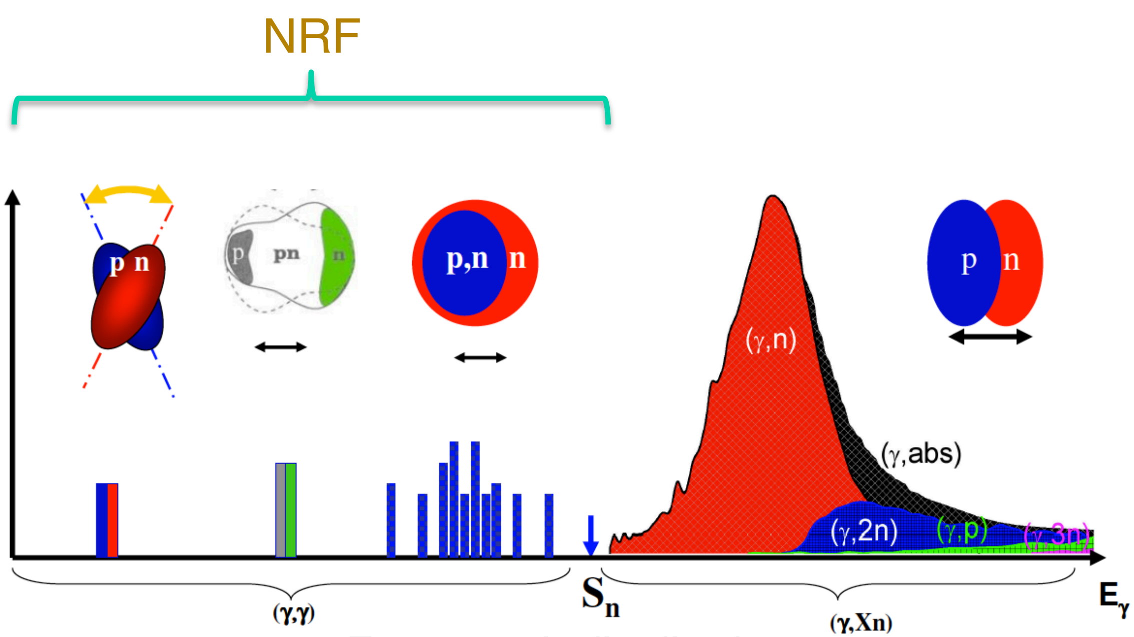
•Modes of excitation below the GDR

Impact on nucleosynthesis

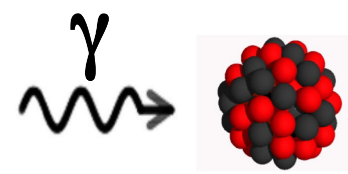
•Gamow window for photo–induced reactions in explosive stellar events

Understanding exotic nuclei

•E1 strength will be shifted to lower energies in neutron rich system



E1 strength distribution



ELI–NP NRF Working group

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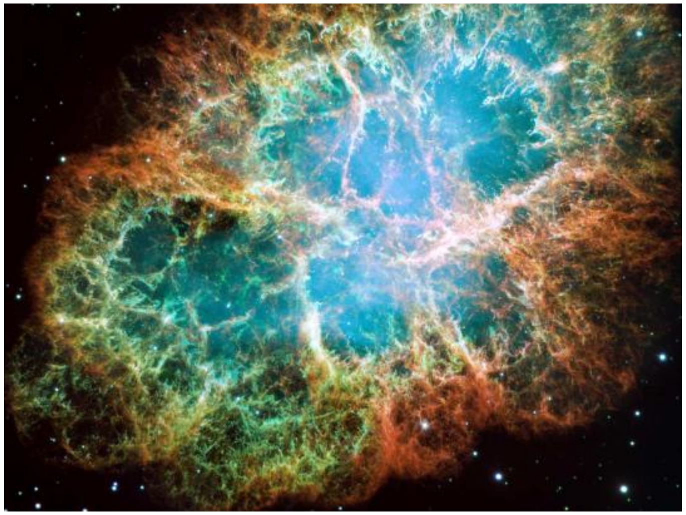
Vera Derya	IKP, Universitat zu Koeln
Bastian Loehner	EMMI, GSI Darmstadt
Norbert Pietralla	TU Darmstadt
Cristopher Romig	IKP, TU Darmstadt
Andreas Zilges	IKP, Universitat zu Koeln

Example: Astrophysics again

Production of heavy elements in the Universe –a central question for Astrophysics



Neutron Capture Cross Section of s-Process Branch

Measurements of (γ, p) and (γ, α) Reaction Cross Sections for p –Process-Nucleosynthesis :

Key reaction $\gamma + {}^{16}O \rightarrow {}^{12}C + \alpha$

Tremendous advance to measure these rates directly

- very high intense γ beam needed

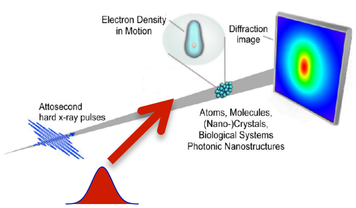
ELI Attosecond Light Pulse Source

Scientific mission

To provide the international scientific community with unique ultrafast coherent light sources,

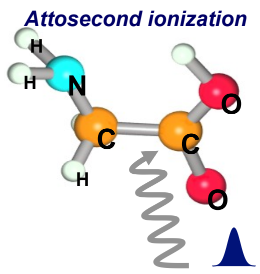
with special emphasis on attosecond pulses in the XUV- and X-ray spectral range

1) 4D attosecond imaging

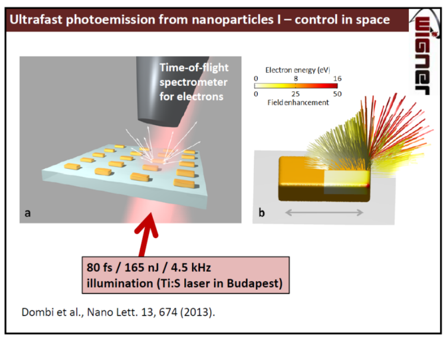


4D (space+time) attosecond/Å scale imaging of atoms and molecules

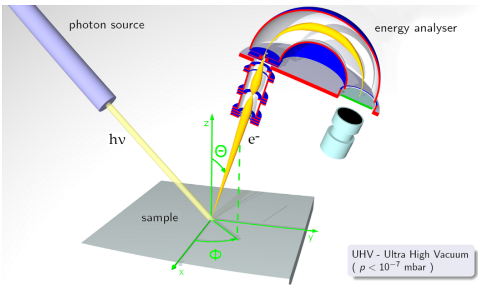
2) New directions in chemistry



3) Nano-plasmonics

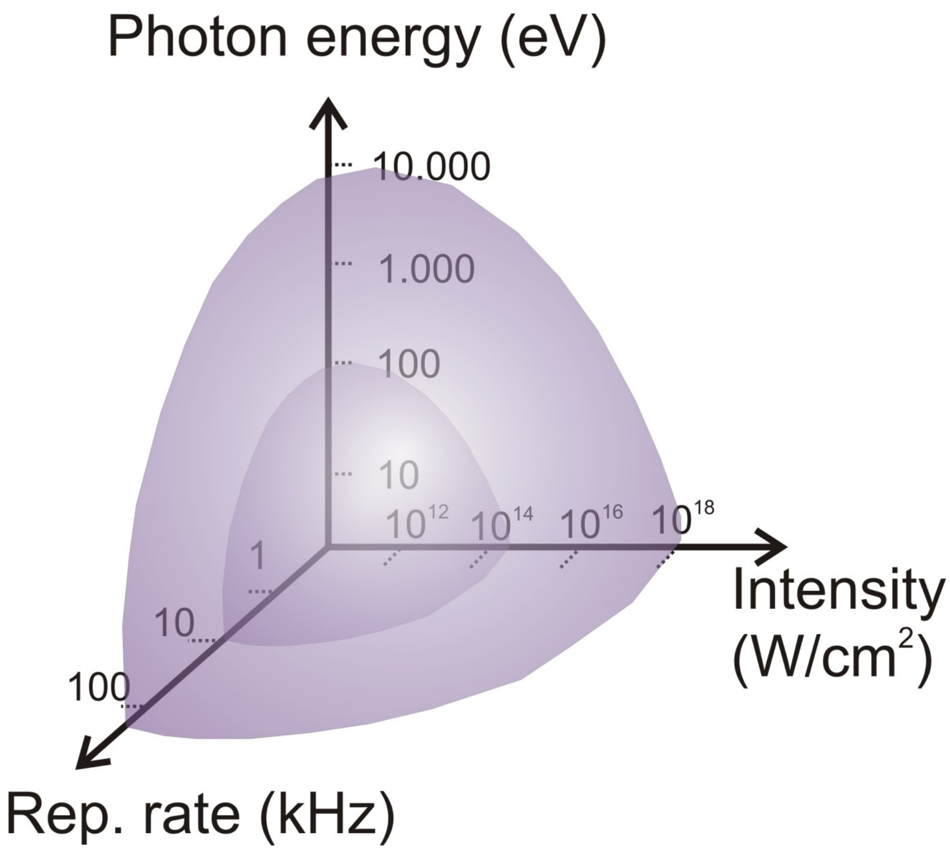


4) Interface processes (charge dynamics)



NEW SZÉCHENYI PLAN

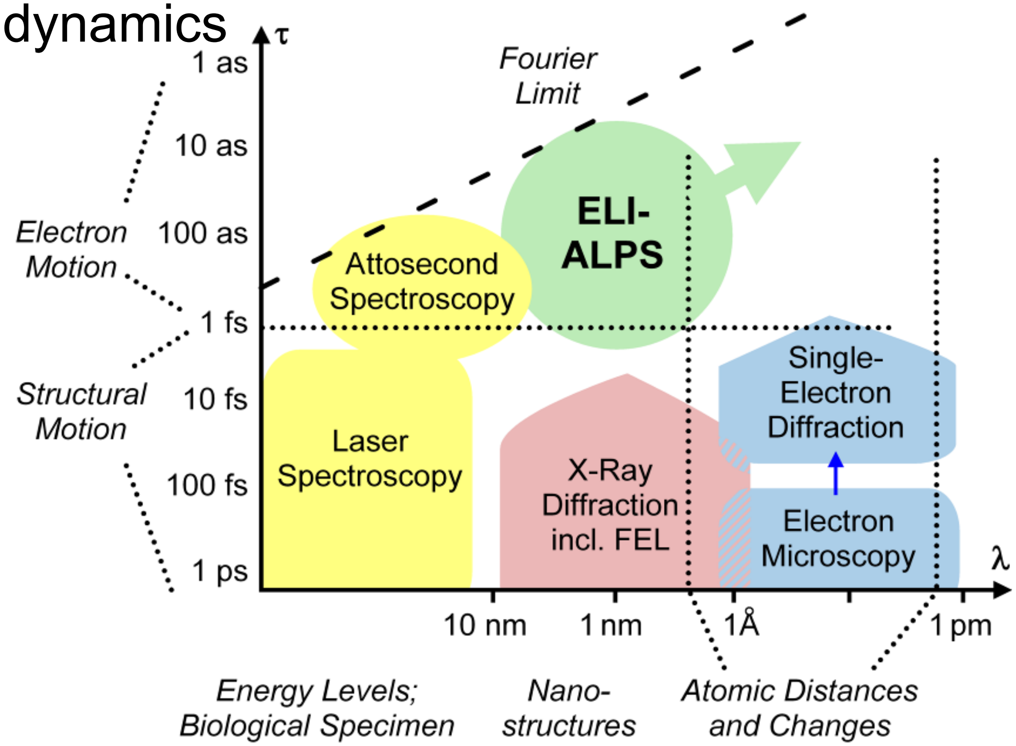
ELI-ALPS: beyond the state-of-the-art

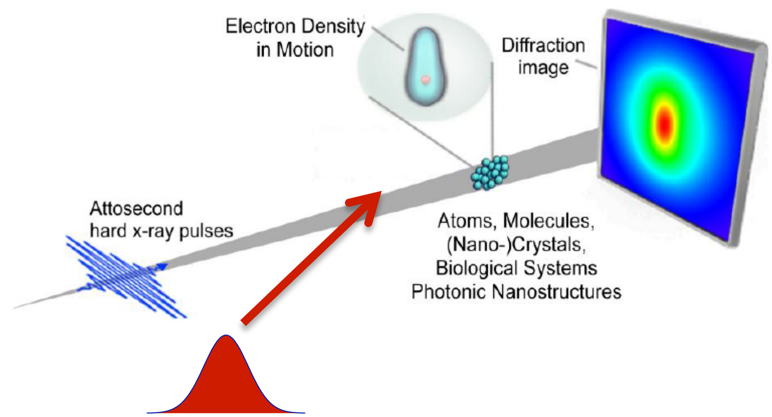


- **Repetition rate** (1 kHz ->**100 kHz**)
- **XUV Intensity** (10^9 **-> 10^{18} W/cm^2**
- **Photon energygy** (100-> -**10.000 eV**

4D attosecond imaging

Current status of visualizing structural dynamics

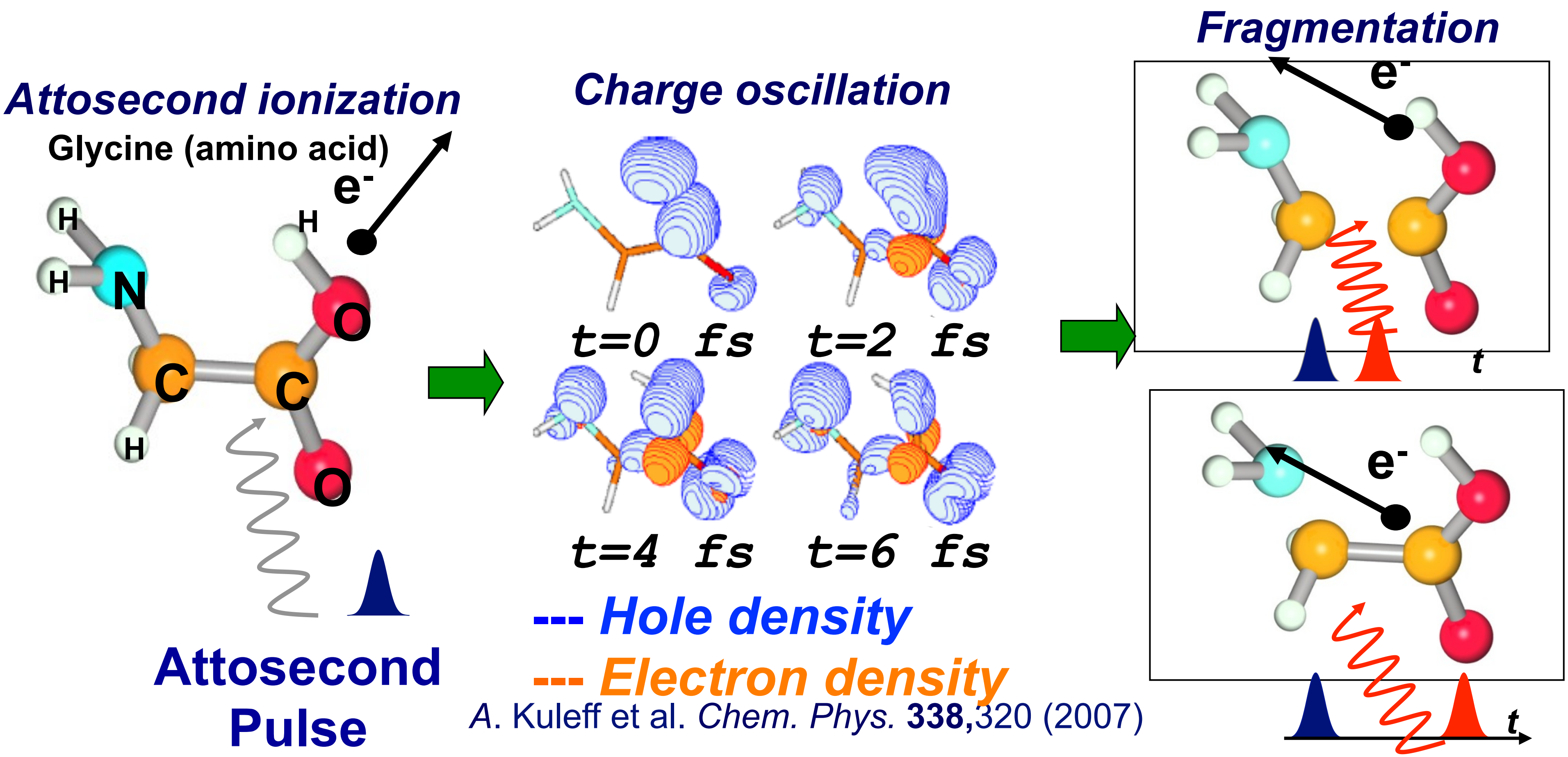




4D (space+time) attosecond/Å scale imaging of atoms and molecules

Time-resolved structural dynamics with unprecedented temporal/spatial resolution

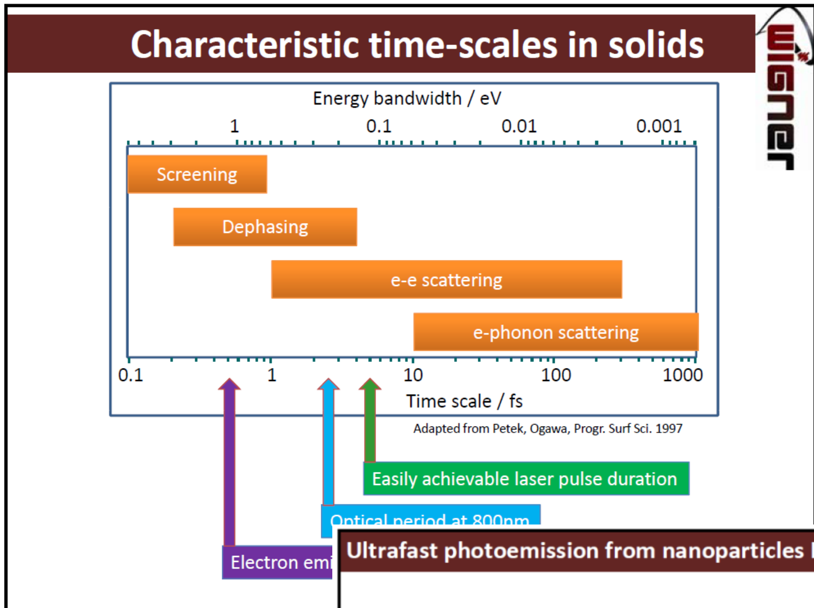
New directions in chemistry: capturing charges motion in molecules

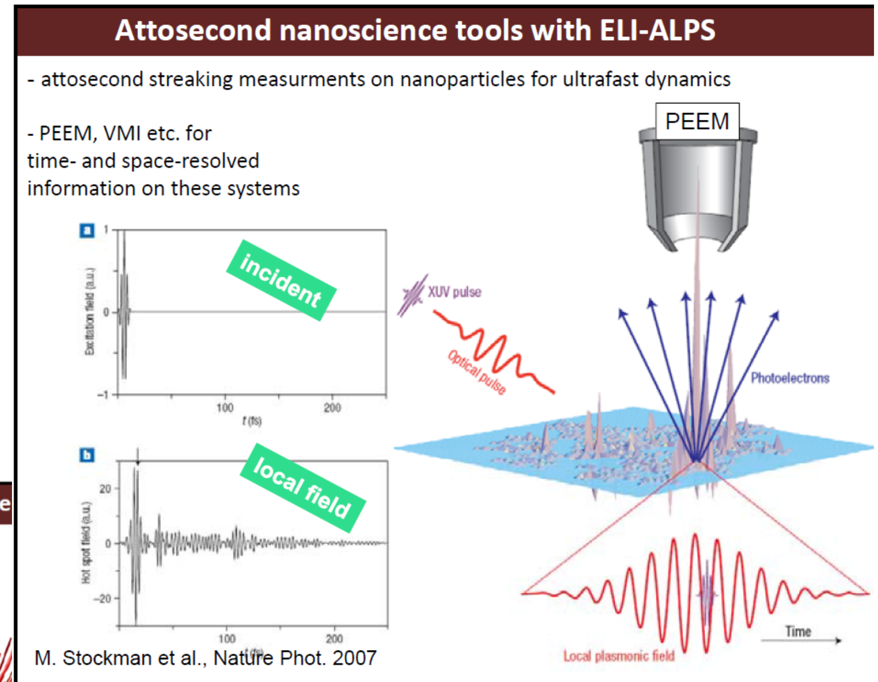


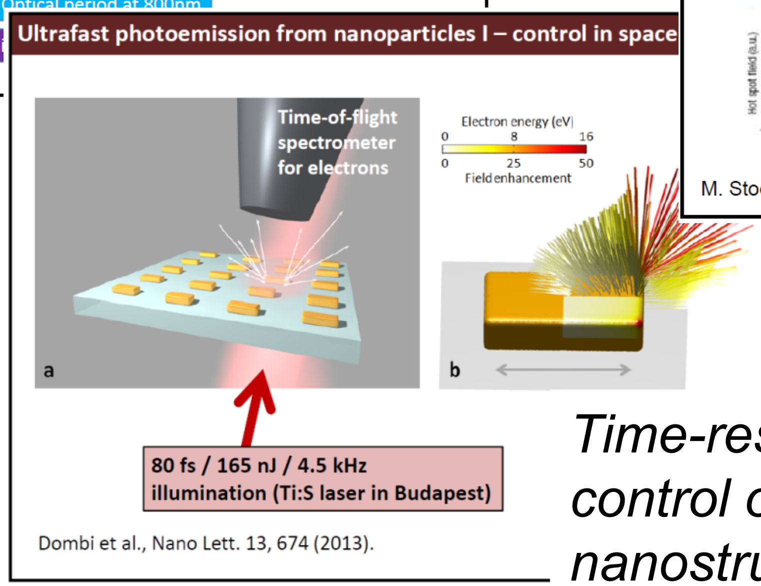
A. Kuleff et al. *Chem. Phys.* **338,**320 (2007)

The very-first steps leading to bond-breaking in biological molecules could be related to electronic dynamics

Nanoplasmonics







Time-resolved observation and control of plasmonic fields in nanostructures

ELI-Beamlines project mission: fundamental & applied research

1. **Generation of rep-rated femtosecond secondary sources of**
2. **radiation and particles**

- XUV and X-ray sources (monochromatic and broadband)
- Accelerated electrons (2 GeV 10 Hz rep-rate, 100 GeV low rep-rate),
  protons (200-400 MeV 10 Hz rep-rate, >3 GeV low-rep-rate)
- Gamma-ray sources (broadband)

2. Programmatic applications of rep-rated femtosecond secondary sources

- Medical research including proton therapy
- Molecular, biomedical and material sciences
- Physics of dense plasmas, laser fusion, laboratory astrophysics

3. High-field physics experiments with focused intensities 10^{23}-10^{24} Wcm^{-2}

- "Exotic" physics, non-linear QED: sophisticated pump-probe capabilities

4. Development & testing new technologies for multi-PW laser systems

- Generation and compression of 10-PW ultrashort pulses, coherent superposition, etc.

Science Case at ELI-Beamlines

Research Program 1

Lasers generating rep-rate ultrashort pulses & multi-petawatt peak powers, B. Rus

Research Program 2

X-ray sources driven by rep-rate ultrashort laser pulses, S. Sebban

Research Program 3

Particle acceleration by lasers, D. Margarone

Research Program 4

Applications in molecular, biomedical, and material sciences, J. Andreasson

Research Program 5

Laser plasma and high-energy-density physics, S. Weber

Research Program 6

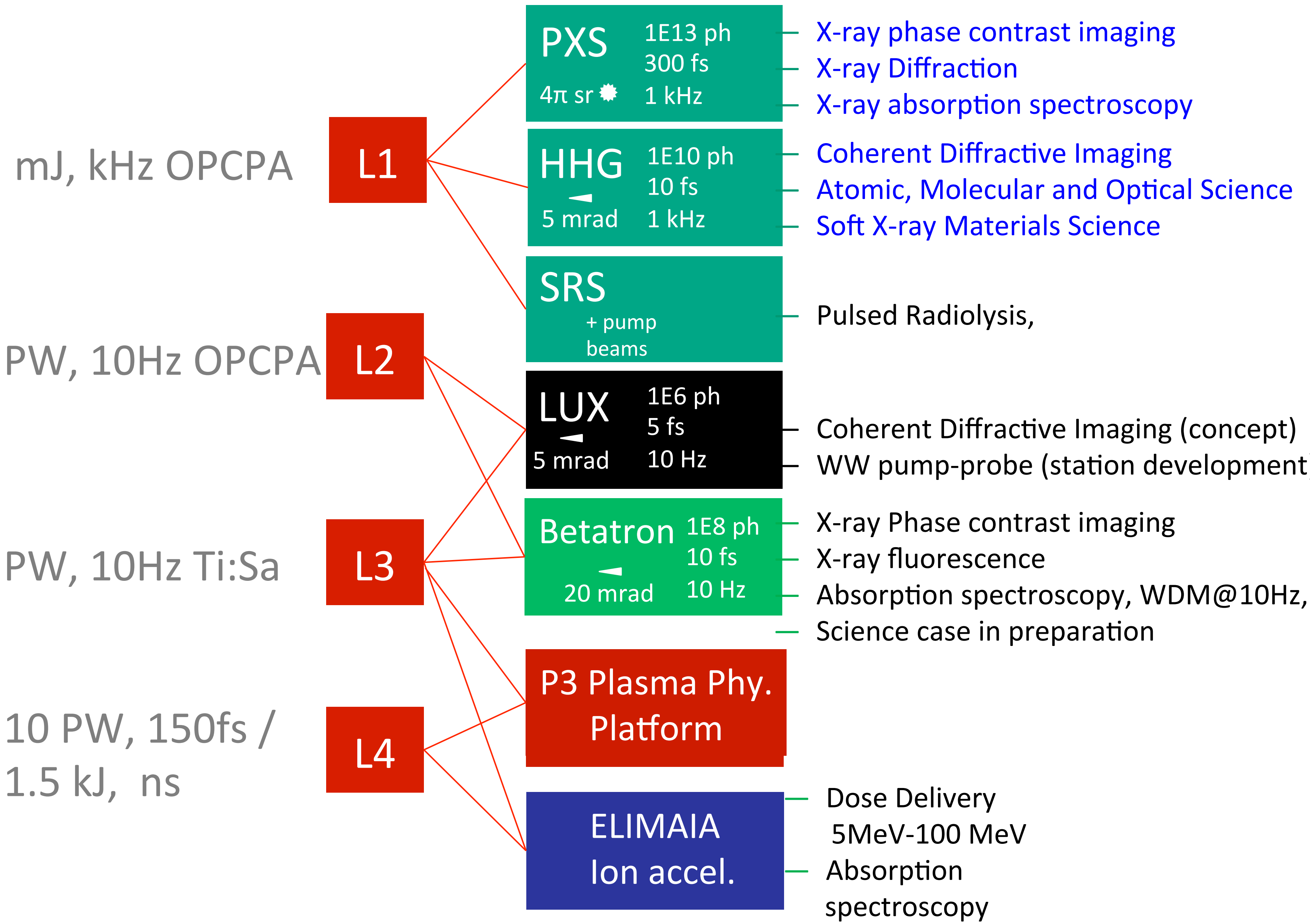
High-field physics and theory (steps to 10^{23}W/cm^2, radiation reaction) eli beamlines

ELI Beamlines
Scientific mission

User facility for fundamental & applied research

- Generation of high repetition-rate laser-driven sources of radiation and particles
- Programmatic applications of laser-driven femtosecond secondary sources of X-rays and accelerated particles: medical and biomolecular research, material research
- High-field physics using unique combination of synchronized laser pulses and laser-generated secondary sources
- Development of high-repetition rate laser technologies

ELI-BL: What users get



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Where do we stand?

Project supported by:

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
INVESTING IN YOUR FUTURE

Construction in Szeged (HU)

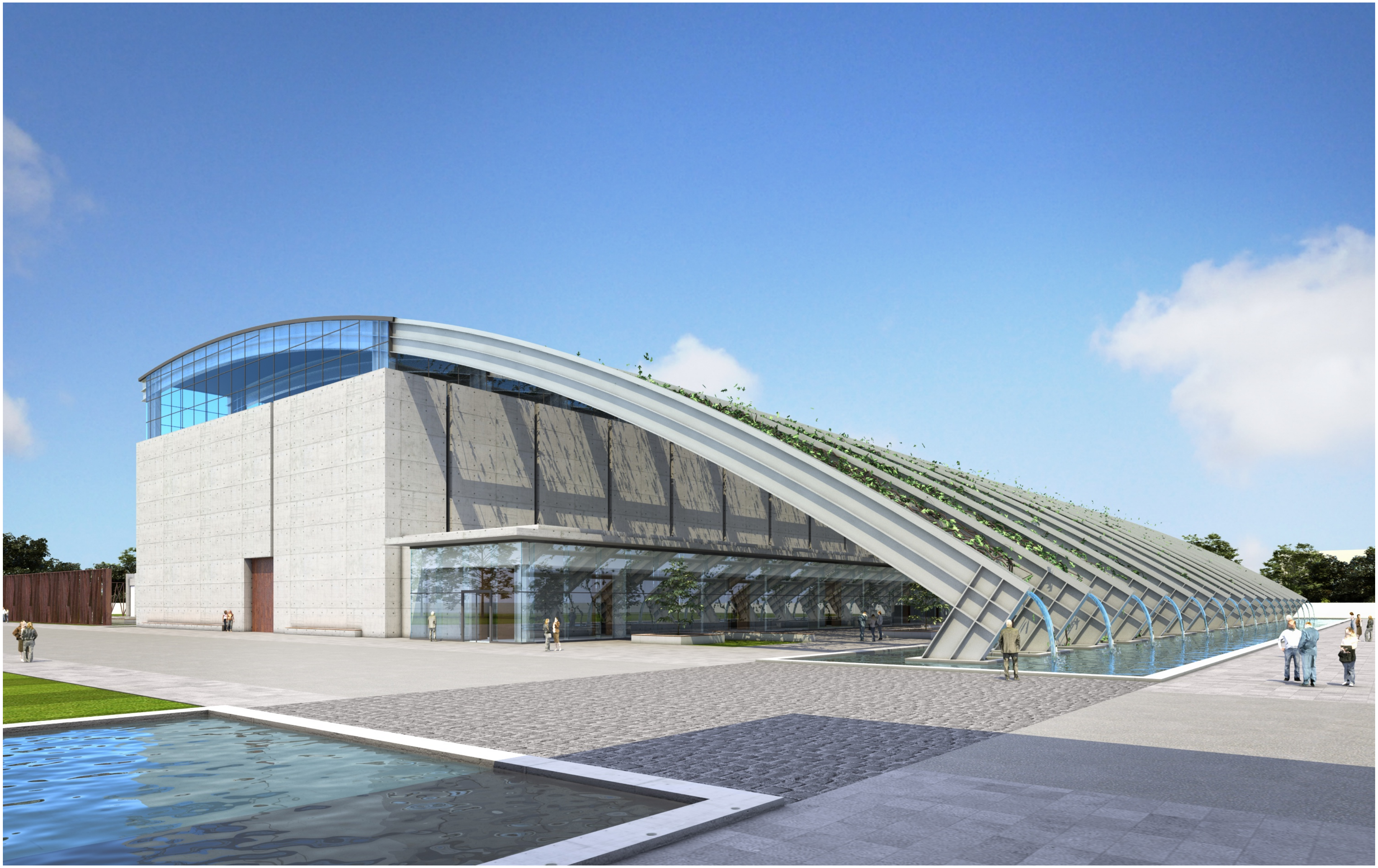
National Development Agency
www.ujszechenyiterv.gov.hu
06 40 638 638

HUNGARY'S RENEWAL

The projects are supported by the European Union and co-financed by the European Regional Development Fund.

Construction in Dolny Brezany (CZ)

Construction in Magurele (RO)



ELI's fourth pillar?

ELI's „fourth pillar" will be a sub-exawatt (~200PW) laser facility, again by a factor of 10 more powerful than the present state-of-the-art (ELI)

- Strategy:
  - **Implement** the present three pillars, already having world-leading specifications
  - **Gain experience** with new technologies (10 PW Ti:Sa, OPCPA, phase-correct beam superposition etc.)
  - **develop funding model** for construction and operation
  - **then decide** on fourth pillar technology and site

The remaining challenge:

Creating the international ERIC Consortium for sponsoring and operating ELI-ERIC after the implementation phase (after 2018)

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EUROPEAN REGIONAL DEVELOPMENT FUND
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The governance model

ERIC:

A model treaty after European law to govern and operate large scale research facilities

ERIC legal status

- **ERICs are considered as international bodies/ organisations**
  - ERICs may set their own procurement rules
  - ERICs will be exempted from paying VAT and excise duty.

- **Statutory seat in a Member State or Associated Country; research locations anywhere**

- **Mandatory bodies:**
  - **members' assembly;**
  - **director/board of directors**

- **Members' liability**
  - ✓ limited to committed contribution, no capital requirement (unless specified otherwise in the Statutes)

ERIC Members

The following entities may become members of an ERIC:

(a) EU Member States;
(b) EU associated countries;
(c) third countries other than associated countries;
(d) intergovernmental organisations.

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ERIC statutes

The statutes (*ELI-ERIC's business model*) shall contain basic principles on

- Legal constitution, political dimension, management
- scientific profile, operations and user research opportunities, internal and external evaluation policy
- access policy for users
- intellectual property rights & dissemination policy
- employment & procurement policy,
- upgrade strategy and decommissioning
- data policy
- …….

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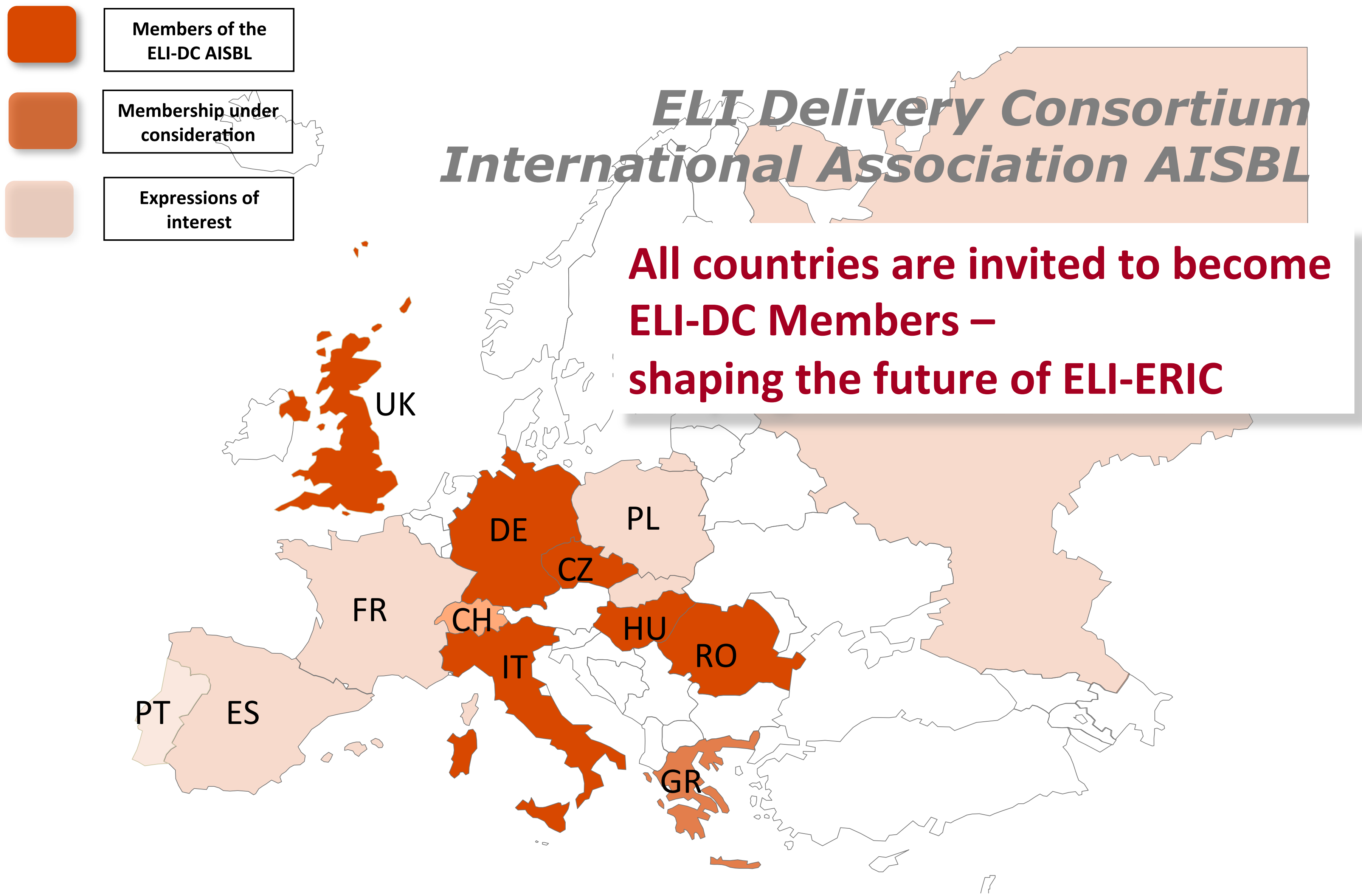
Shaping the future: developing the ELI-ERIC



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Developing the ELI-ERIC

INTERNAL / CONFIDENTIAL

ELITRANS

Enabling ELI's transformation
from ERDF - funded distributed implementation
towards ERIC - governed unified operation

DRAFT PROPOSAL OUTLINE
(version 3.1, 2014-11-10)

in response to the Call
INFRADEV-3-2015: Individual implementation and operation of ESFRI projects[1]

1 HORIZON 2020, WORK PROGRAMME 2014 – 2015, 4. European research infrastructures (including e-Infrastructures) Revised; (European Commission Decision C (2014) 4995 of 22 July 2014)

- ELI-ERIC's ***"business model"*** (Work Packages ERIC, ACCESS, PARTNERS)
- ELI-ERIC's ***"business plan"*** as world-leading user facility (WPs QUALITY, COMPUTING, VMRE, ACCESS, IDENTITY)
- ELI-ERIC's "***Corporate ID"***: Internal structure, international relations, scientific image, and future evolution (WPs IDENTITY, QUALITY, ACCESS, PARTNERS)

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Summary

ELI will be

- a distributed research infrastructure based initially on 3 facilities in CZ, HU and RO
- the first ESFRI project to be implemented in the new EU Member States
- pioneering a novel funding model combining structural funds (ERDF) for the implementation and contributions to an ERIC for the operation

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ELI's new sources, science and applications…

… are essentially based on three key phenomena for the interaction of extreme light with matter:

- Electromagnetic peak fields: 1000 GV/cm / 3 G Gauss
- Time-averaged „quiver energy" of free electrons: ~GeV
- „Light pressure" on a plasma surface: ~1000 Gbar

With all this, ELI will be **the world‘s first international laser user facility,** providing unique research opportunities for the future:

“*The CERN of laser research*”