EUROPEAN UNION

Structural Instruments 2014-2020

Project co-financed by the European Regional Development Fund through the Competitiveness Operational Programme "Investing in Sustainable Development"

Introducere la Fizica de la ELI-NP

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Extreme Light Infrastructure – Nuclear Physics (ELI-NP) de la Institutul de Fizica și Inginerie Nucleară Horia Hulubei

Universitatea din Bucuresti

Sambata, 21 Septembrie 2019

Continut

1. Ce este fizica?
2. Cum functioneaza laserul?
3. Care sunt proprietatile luminii laser?
4. Ce e special la lumina extrema?
5. Cum arata un experiment?
6. Cum arata si cum functioneaza laserul de la ELI-NP?
7. La ce foloseste laserul de la ELI-NP?

Nuclear Physics

Ce e fizica?

IFIN-HH

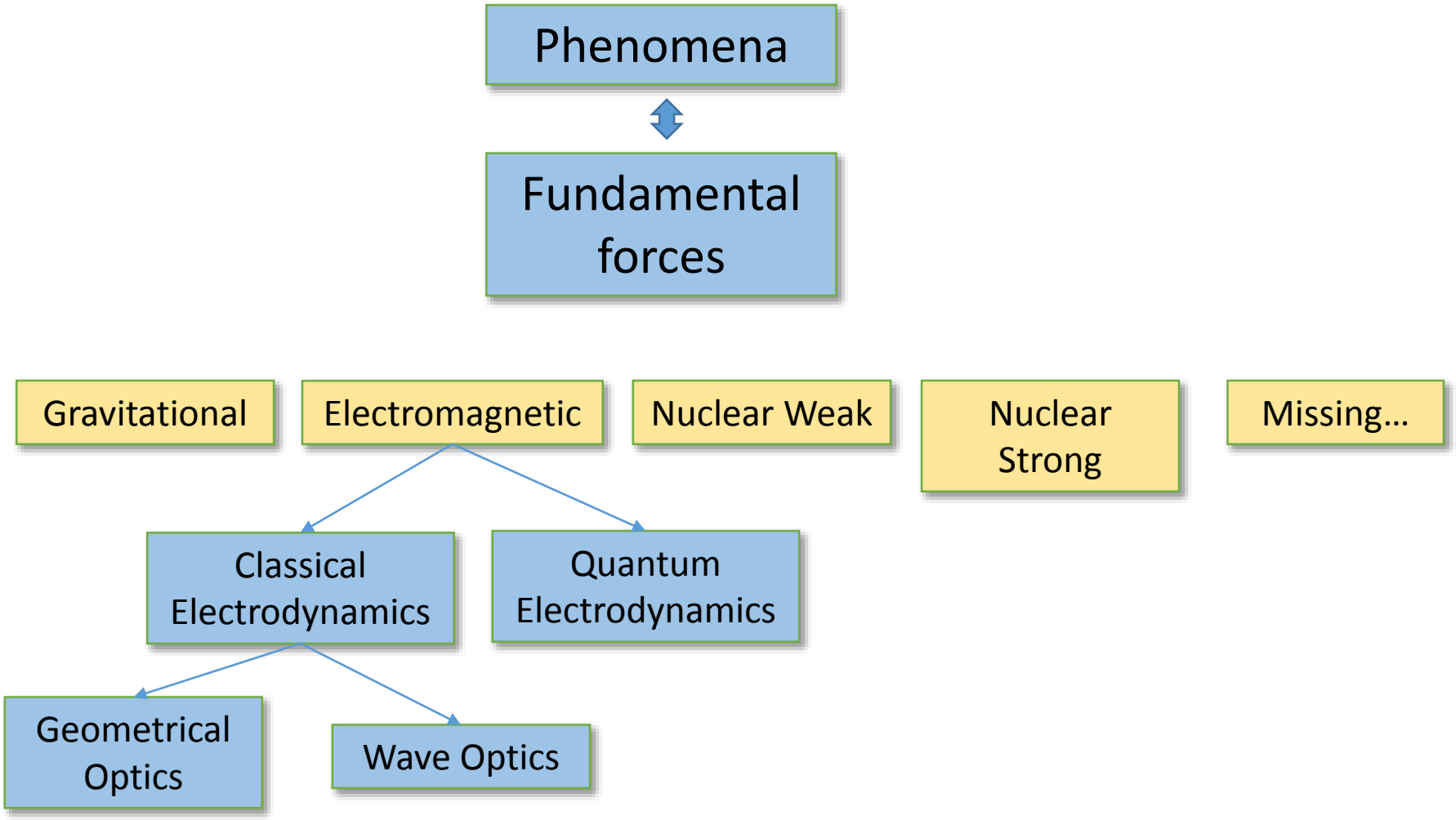
Nuclear Physics

Science is magic that works!

Kurt Vonnegut

IFIN-HH

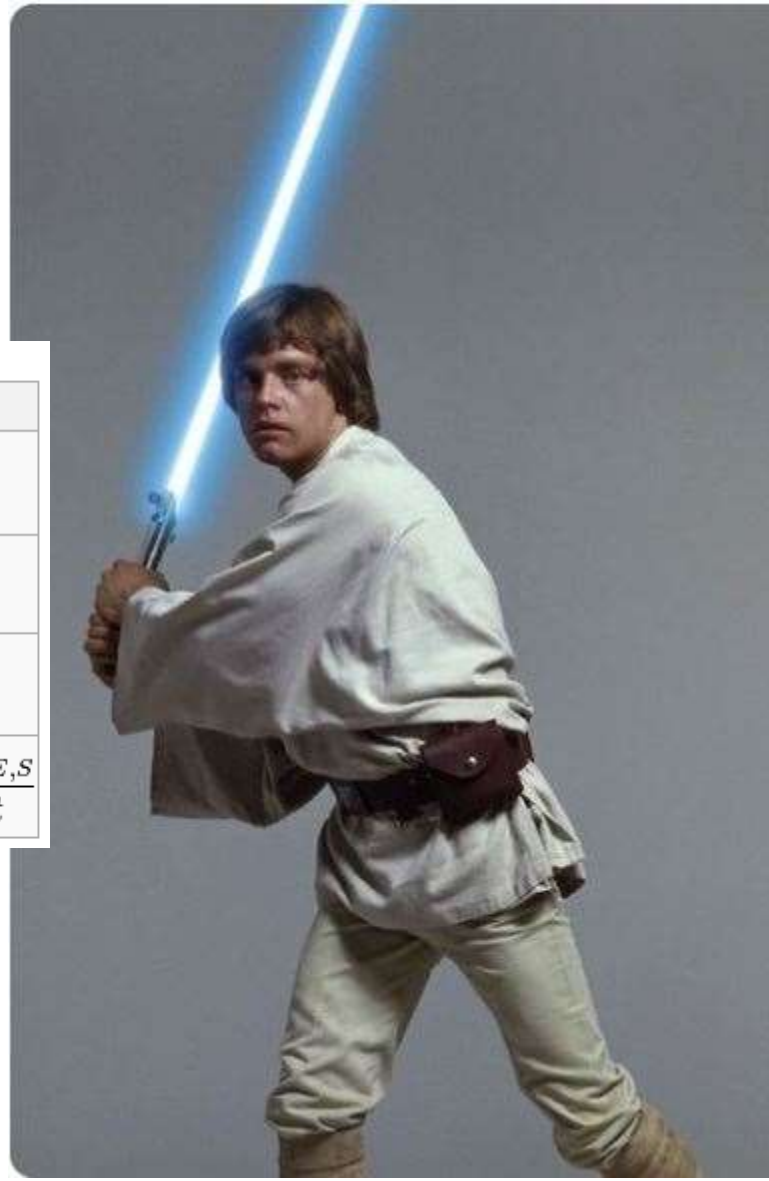
Imaginea de ansamblu



Nuclear Physics

Padawan incepator

$$\mathbf{F}_E = q\mathbf{E}$$
$$\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$$

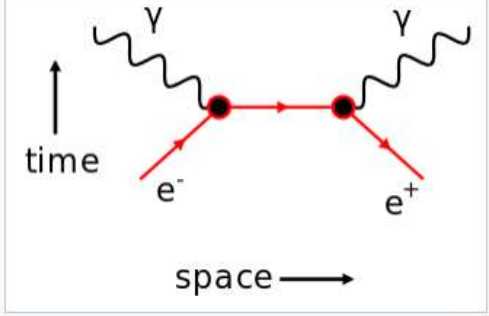


Padawan avansat

Formulation in terms of *total* charge and current[note 3]

Name	Differential form	Integral form
Gauss's law	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$	$\oiint_{\partial V} \mathbf{E} \cdot \mathrm{d}\mathbf{A} = \frac{Q(V)}{\varepsilon_0}$
Gauss's law for magnetism	$\nabla \cdot \mathbf{B} = 0$	$\oiint_{\partial V} \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint_{\partial S} \mathbf{E} \cdot \mathrm{d}\mathbf{l} = -\frac{\partial \Phi_{B,S}}{\partial t}$
Ampère's circuital law (with Maxwell's correction)	$\nabla \times \mathbf{B} = \mu_0\mathbf{J} + \mu_0\varepsilon_0\frac{\partial \mathbf{E}}{\partial t}$	$\oint_{\partial S} \mathbf{B} \cdot \mathrm{d}\mathbf{l} = \mu_0 I_S + \mu_0\varepsilon_0\frac{\partial \Phi_{E,S}}{\partial t}$

Cavaler Jedi avansat



Feynman diagram of electron/positron annihilation

IFIN-HH

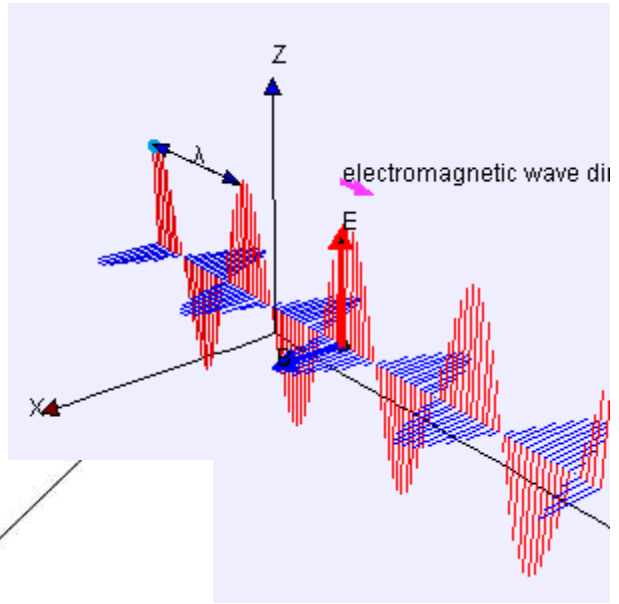
Nuclear Physics

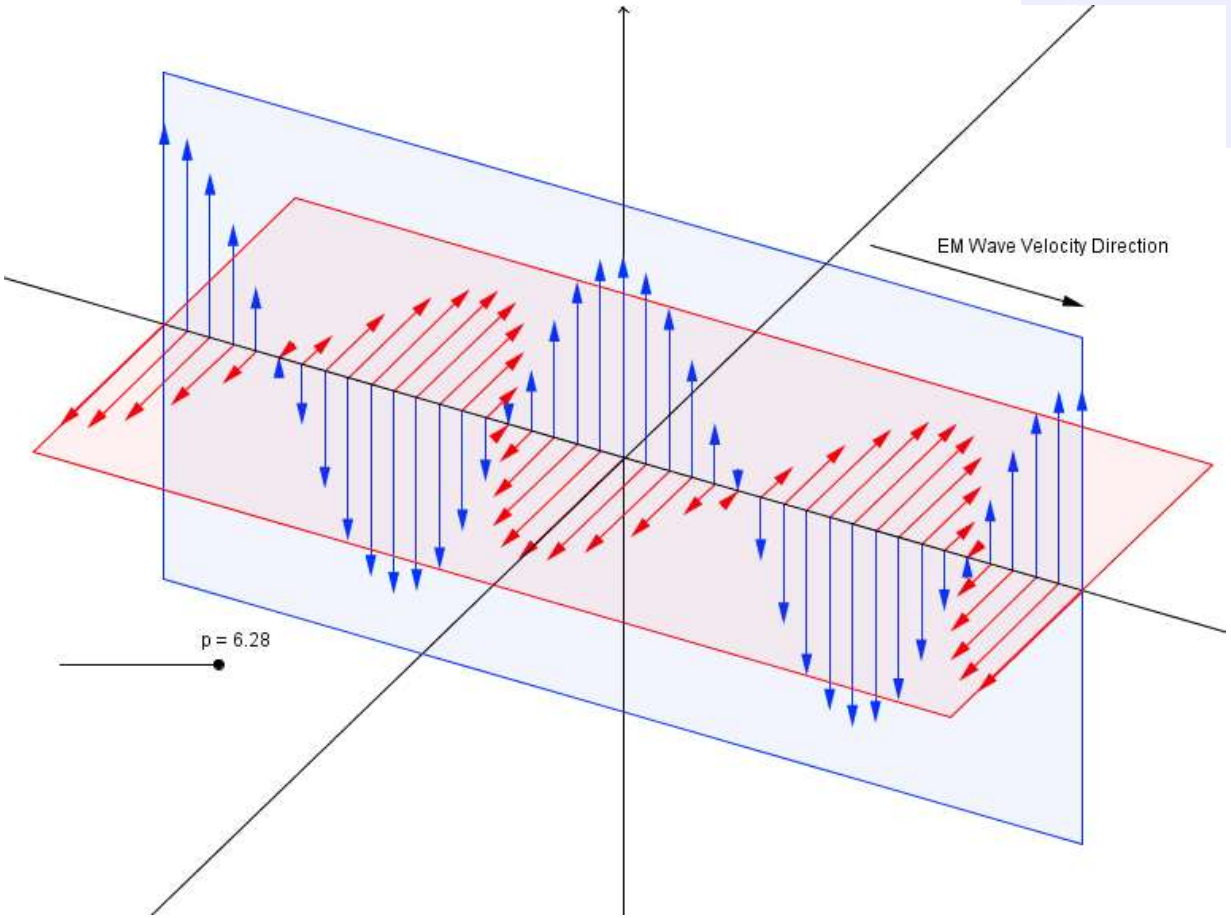
Lumina

Padawan avansat

$$\mathbf{E}(\mathbf{r},t) = \mathbf{E}_0 \cos(\omega t - \mathbf{k}\cdot\mathbf{r} + \phi_0)$$

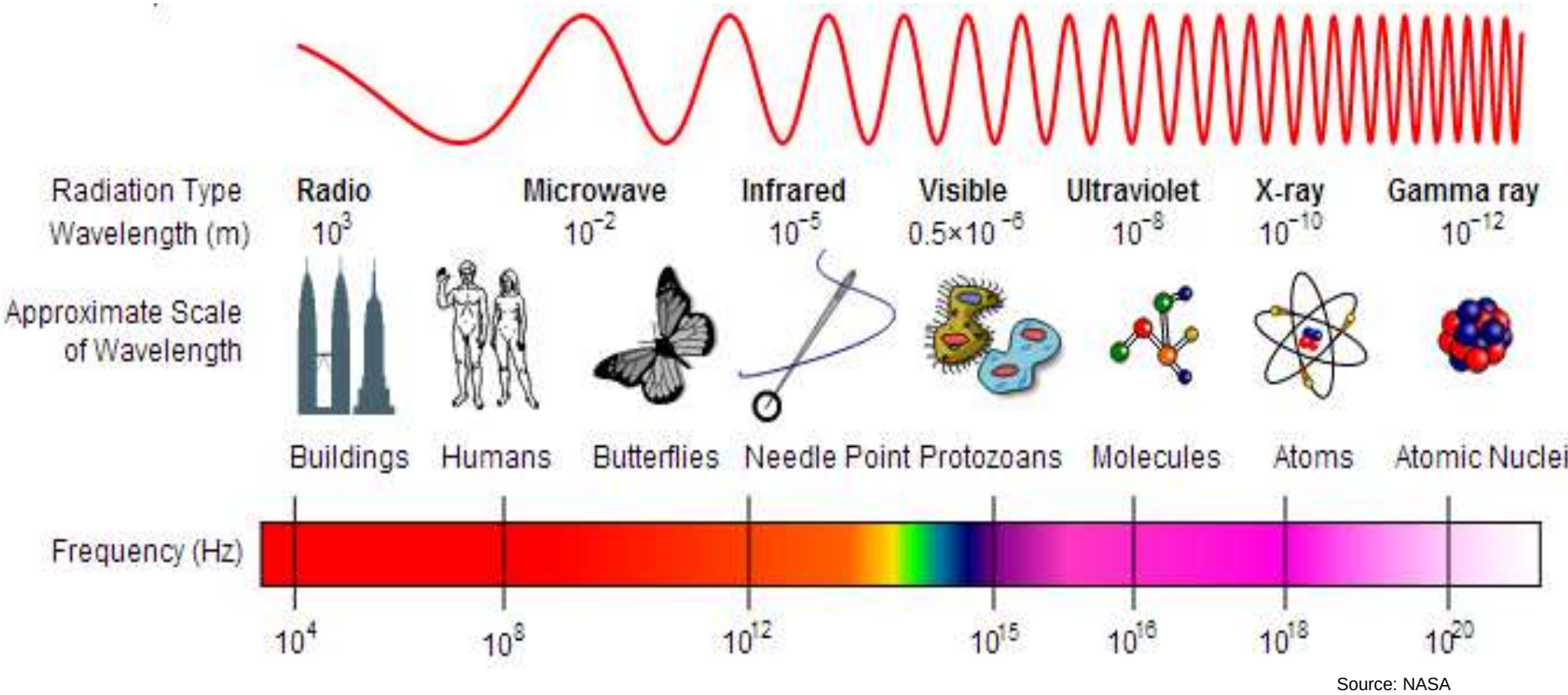
$$\mathbf{B}(\mathbf{r},t) = \mathbf{B}_0 \cos(\omega t - \mathbf{k}\cdot\mathbf{r} + \phi_0)$$





IFIN-HH

Particule & Radiatie

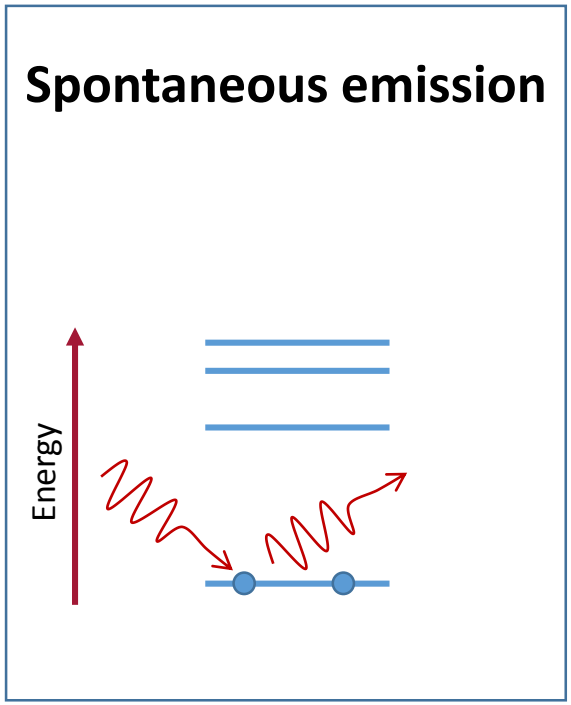


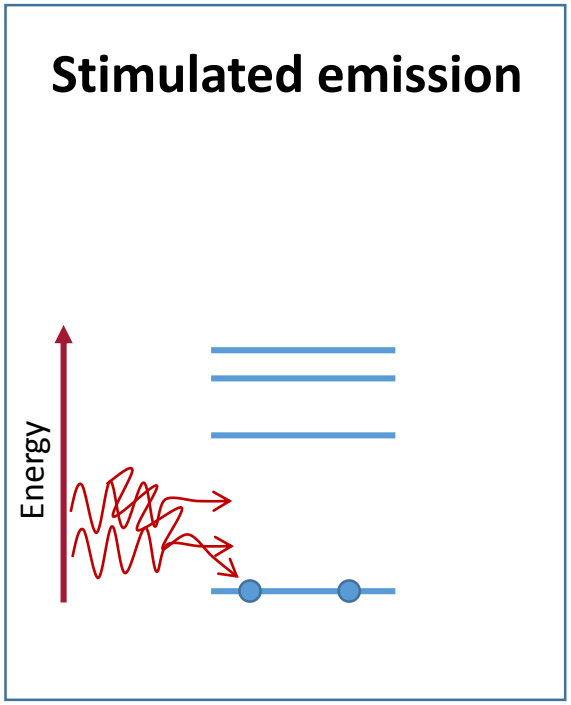
Source: NASA

Cum functioneaza laserul?

Nuclear Physics

Padawan avansat





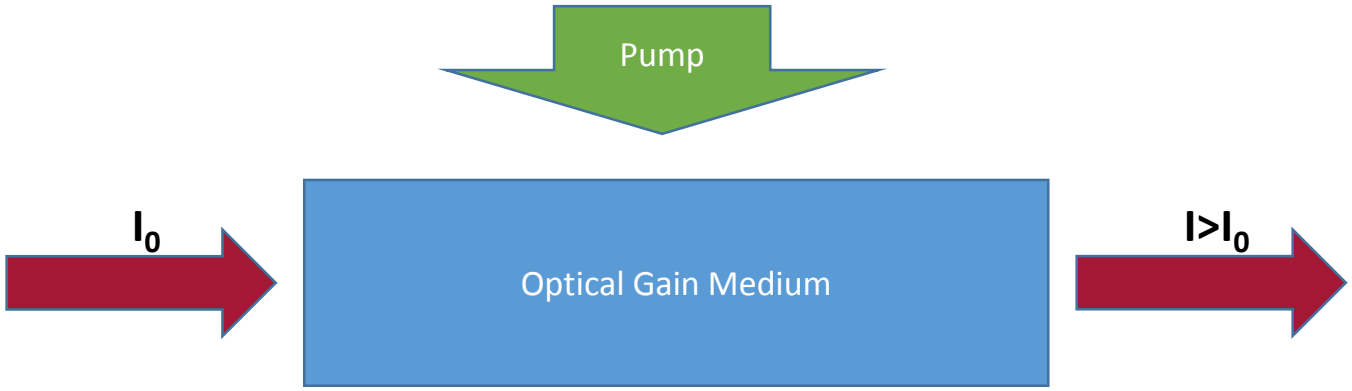
The stimulated emitted photon has:

Same Phase (coherent)
Same Energy (wavelength)
Same Polarisation
Same propagation direction

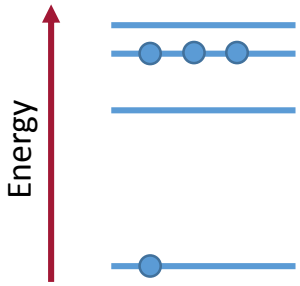
Teorie introdusa de Maestrul Jedi Albert Einstein

Nuclear Physics

LASER - *L*ight *A*mplification by Stimulated Emission of Radiation

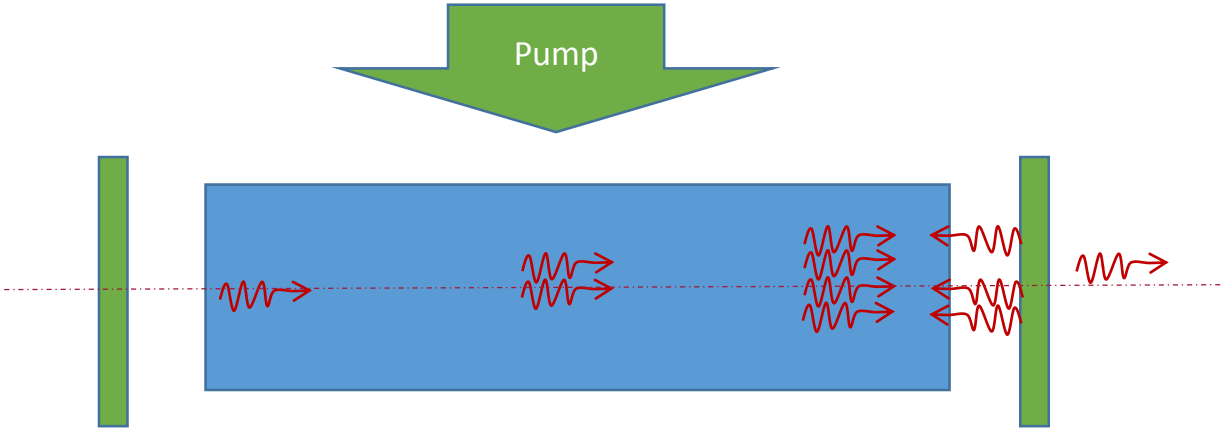


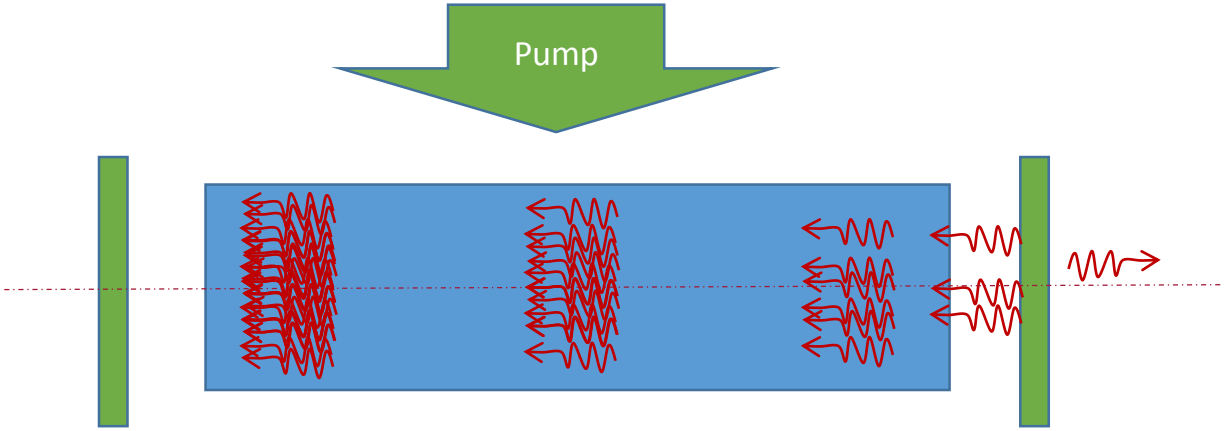
Population inversion



Competitive processes:

Absorption
Spontaneous emission
Stimulated emission


Pump
R=100%
R<100%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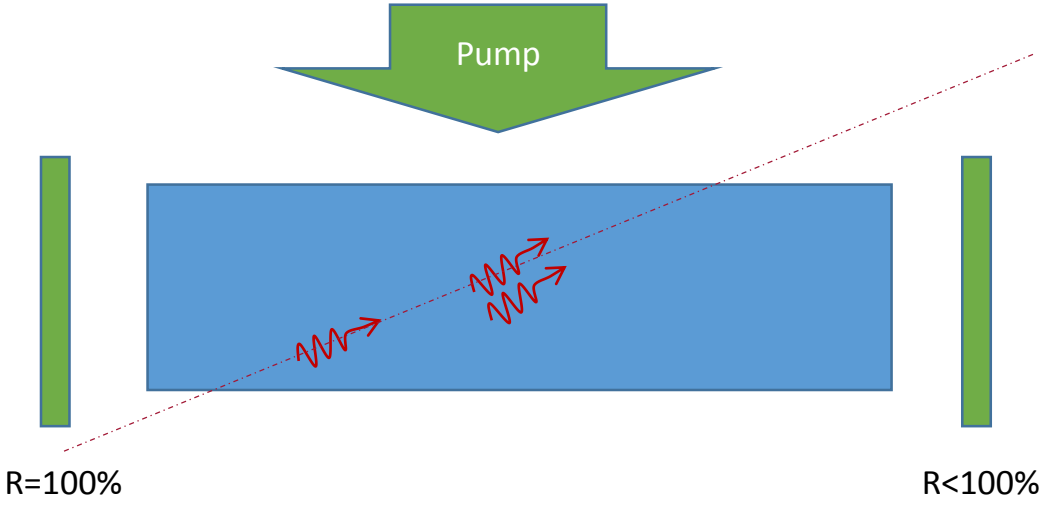
R<100%


Pump
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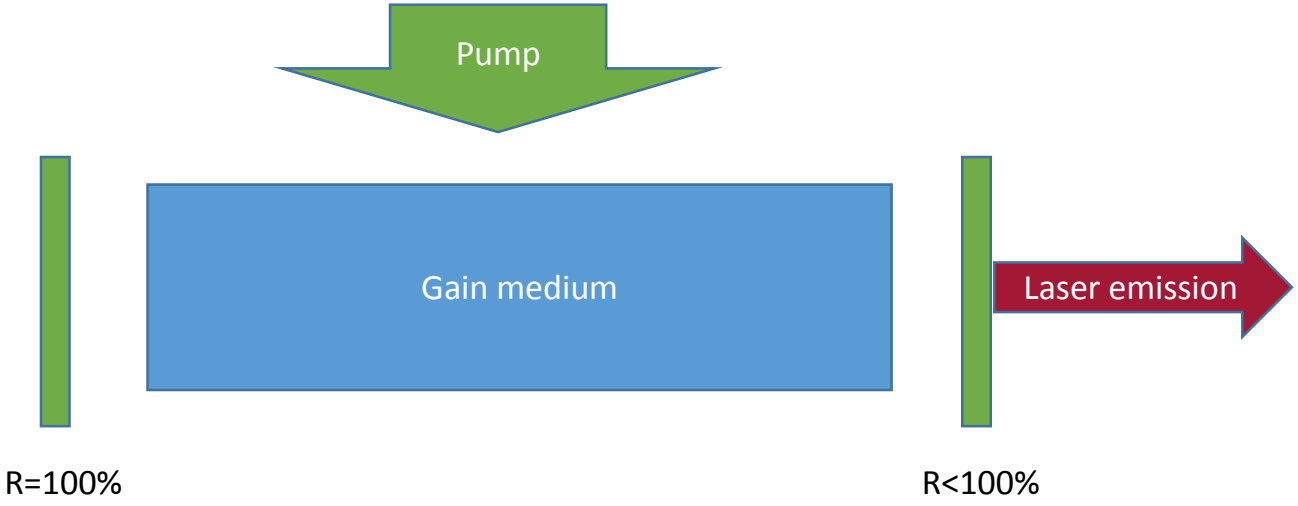

Laser radiation characteristics:

- Coherent
- Monochromatic
- Collimated

Nuclear Physics

Care sunt proprietatile luminii laser?

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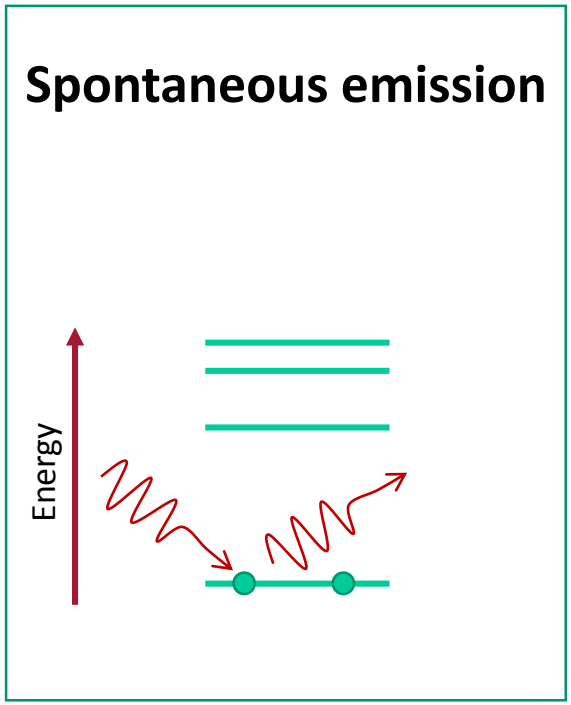

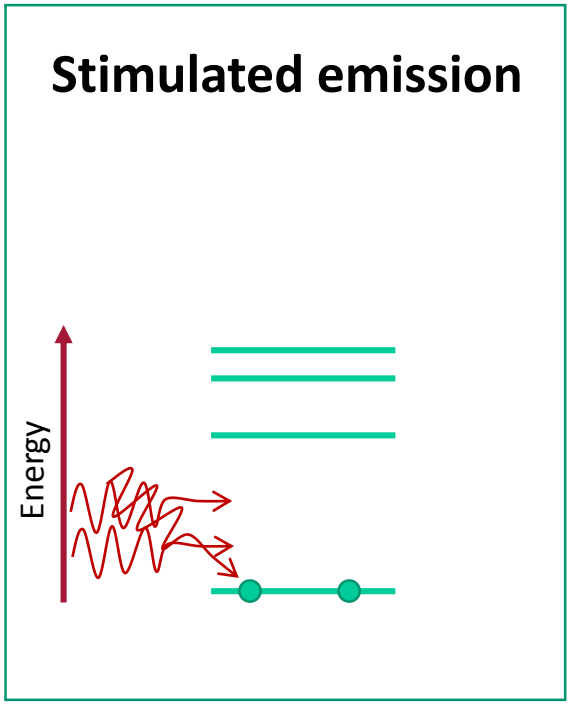

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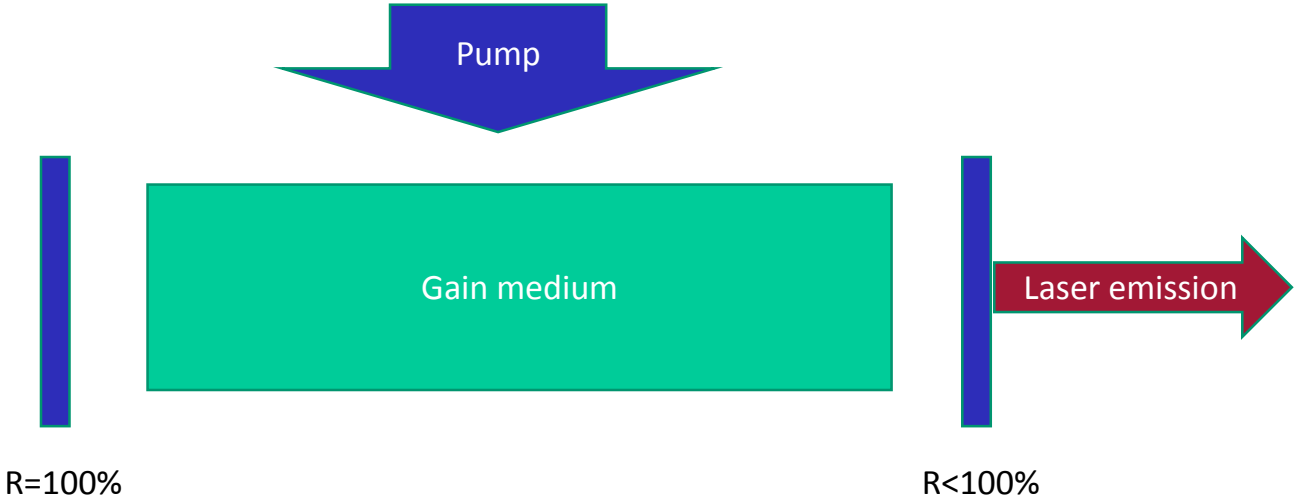


Laser radiation characteristics:

- Coherent
- Monochromatic
- Collimated

Revolutiile laser

CD, DVD, Blu-ray Disk…

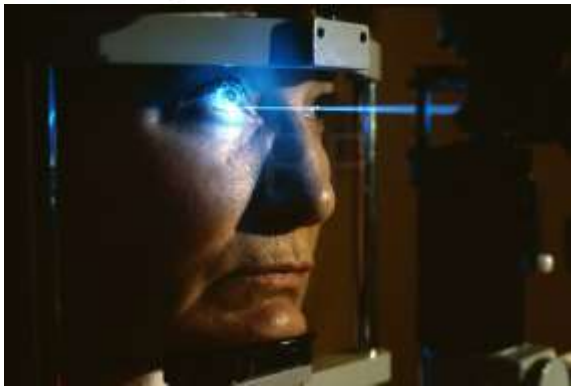
100Gb

Imprimanta laser

Printarea 3D cu
precizie micrometrica

Conexiuni prin satelit ~ 1%
Fibre optice pe fundul marii ~99% (2006)

Revolutiile laser



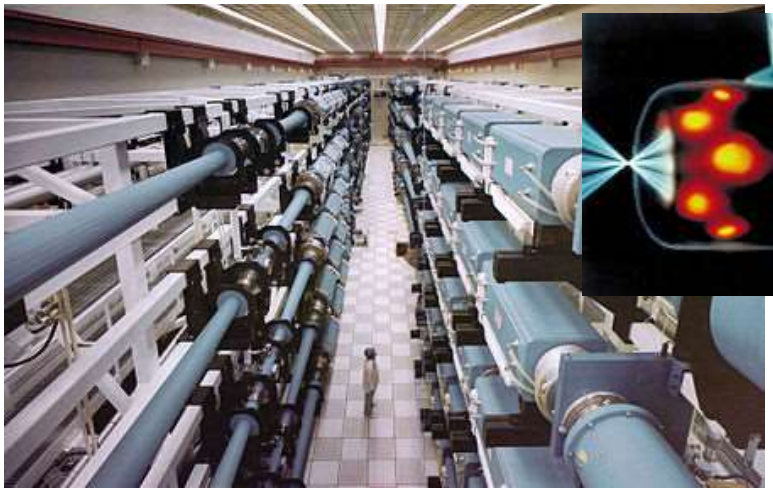
Chirurgie oculara

Sudura, taiere, intarirea suprafetelor…

Revolutiile laser: in pregatire

Bujia laser (la INFLPR!)

Fuziunea cu laser => energia viitorului?



Nuclear Physics

Ce e special la lumina extrema?

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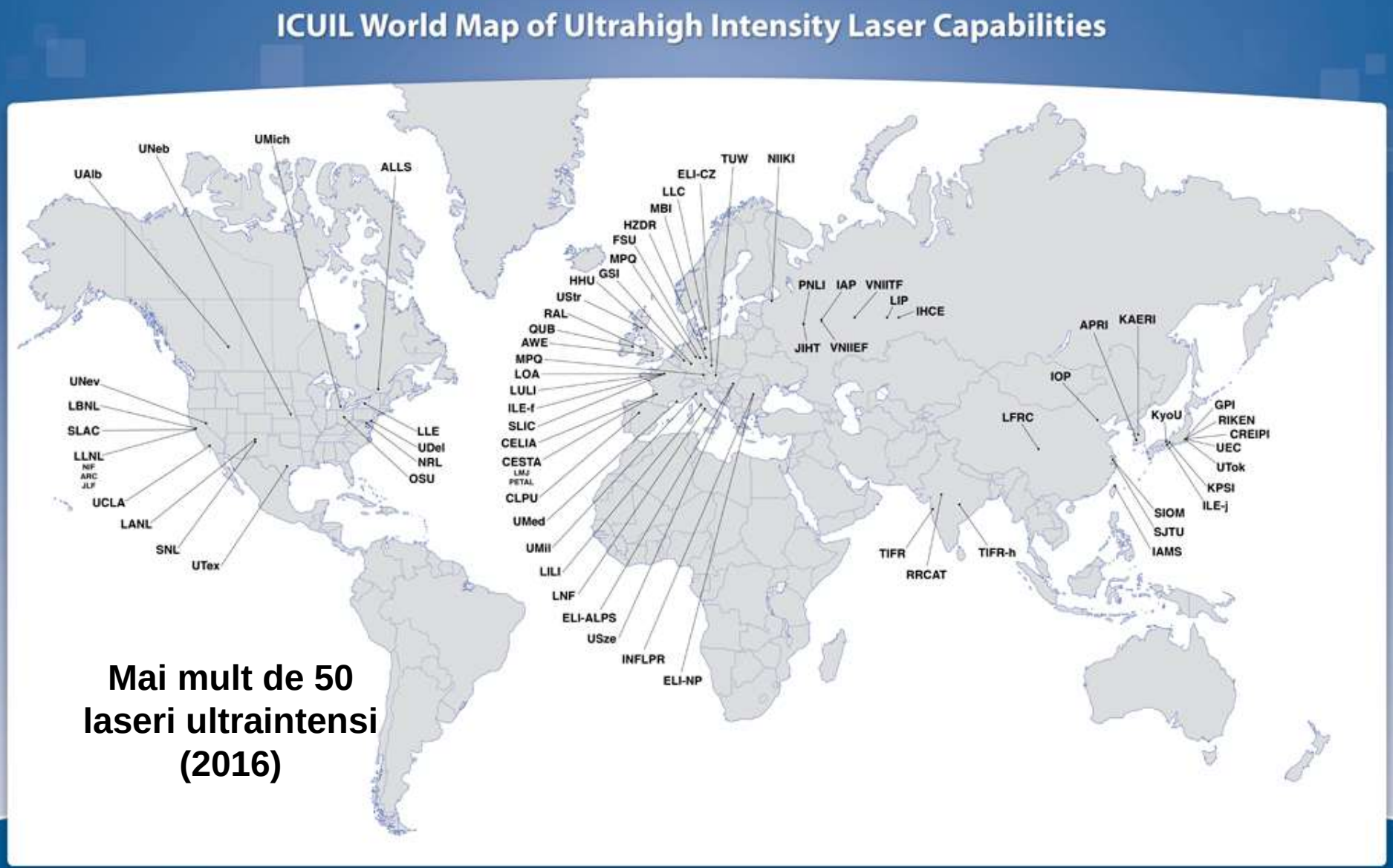
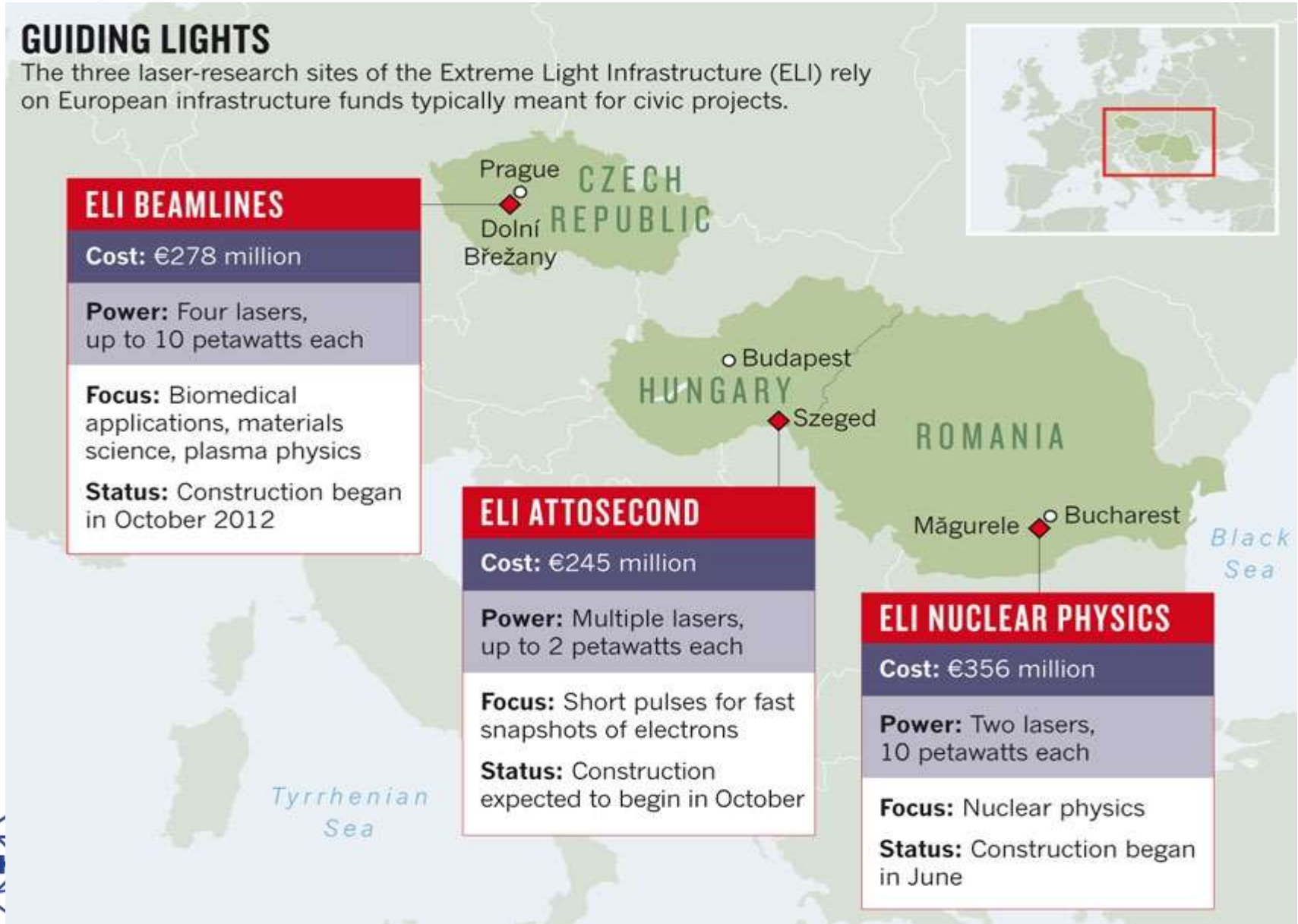
Urmatoarea revolutie stiintifica cu laserul: Extreme Light Infrastructure



Mai mult de 50 laseri ultraintensi (2016)

Extreme Light Infrastructure (ELI)



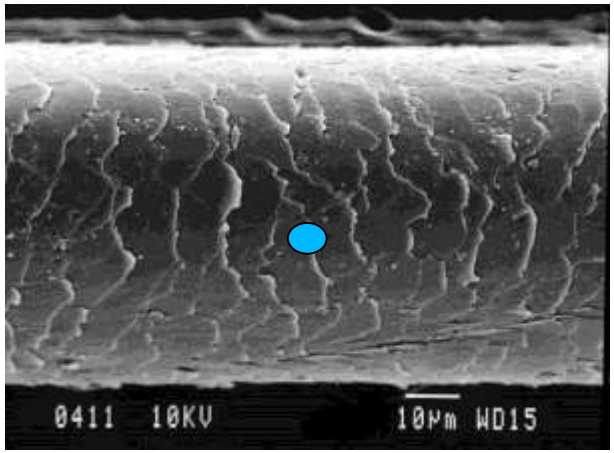
Laserul ELI-NP

Lumina ultraintensa la marginea spectrului vizibil

- 2 brate de 10 milioane de miliarde de Watt

100 000 000 000 000

- Concentrati intr-o zecime din grosimea unui fir de par



- In 20 de milionimi de miliardimi de secunda:
- 0.000 000 000 000 020 secunde

Echipament unic in lume!

Parametrii asociati pulsurilor laser

Camp electric $$E_L\,(\mathrm{V/cm}) = 2.75 \times 10^9 \left(\frac{I_L}{10^{16}\,\mathrm{W/cm^2}} \right)^{1/2}$$

Camp magnetic $$B_L\,(\mathrm{Gauss}) = 9.2 \times 10^6 \left(\frac{I_L}{10^{16}\,\mathrm{W/cm^2}} \right)^{1/2}$$

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

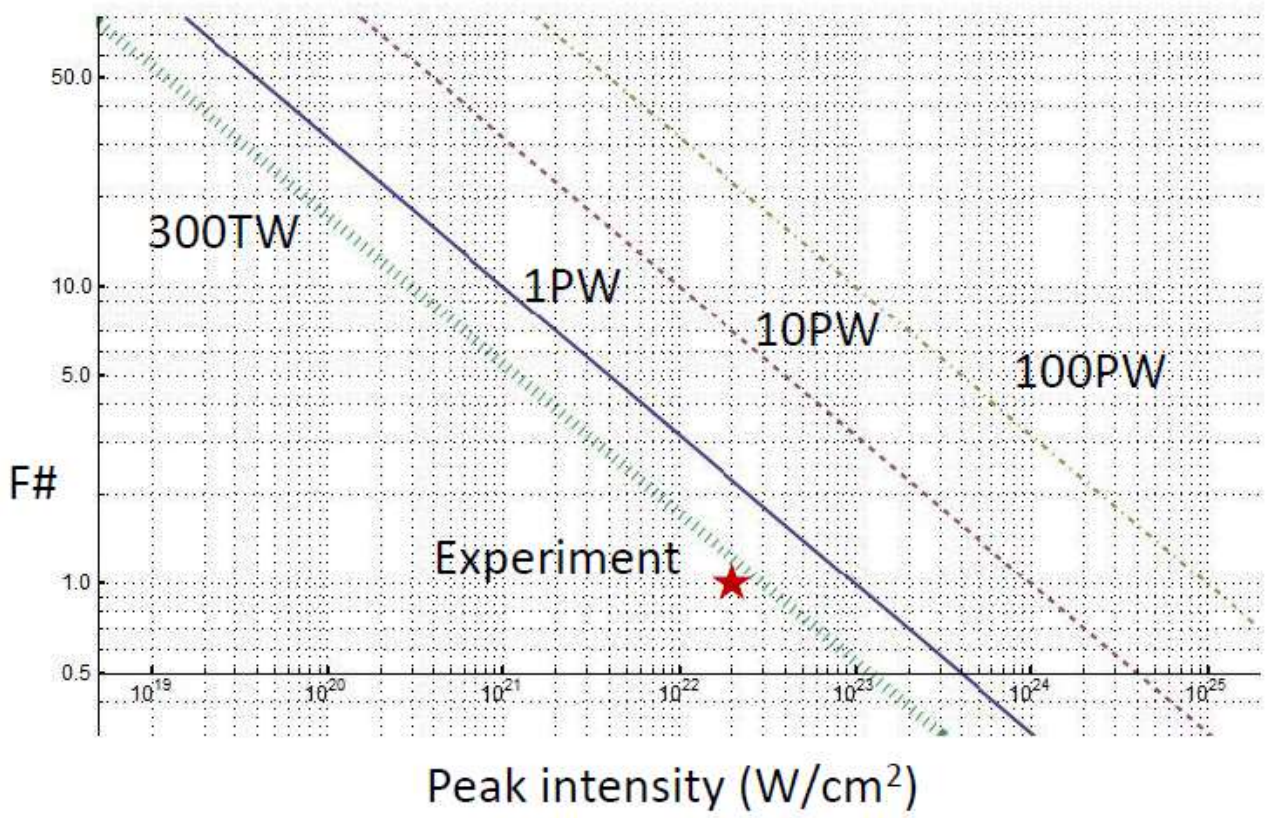
Spre intensitati extreme: puteri, intensitati si dimensiunea in focus

Intensitatea de varf:

$$I = 2P/\pi w_0^2$$

Talia fasciculului:

$$w_0 = f\#\lambda$$



Ionel L., Ursescu D., "*Spatial extension of the electromagnetic field from tightly focused ultra-short laser pulses***"** Laser and Particle Beams, 2014

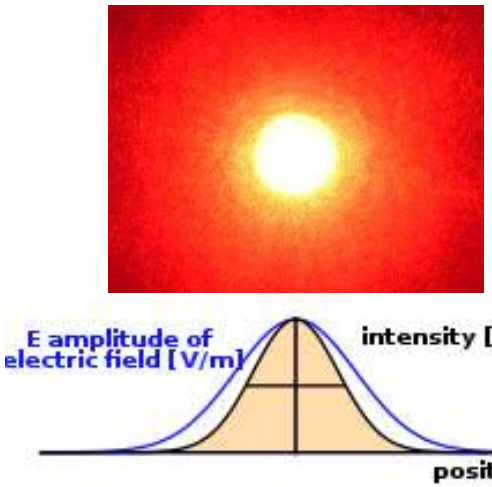
Fasciculul Gauss-ian

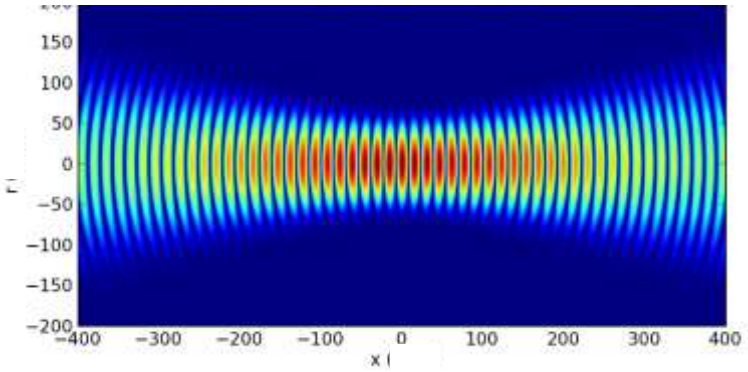
Padawan avansat

Functia matematica ce descrie fasciculul gaussian este o solutie a ecuatiei Helmholz paraxiale.

In acest caz, campul electric asociat este descries de:

$$E(r,z) = E_0 \frac{w_0}{w(z)} \exp\left(\frac{-r^2}{w^2(z)}\right) \exp\left(-ikz - ik\frac{r^2}{2R(z)} + i\zeta(z)\right) ,$$





Laser = “simplest” electromagnetic field distribution

Comparatii

Camp magnetic

- 1 MG Strongest pulsed non-destructive magnetic field produced in a laboratory, Pulsed Field Facility at National High Magnetic Field Laboratory's, Los Alamos National Laboratory, Los Alamos, NM, USA).[18]
- 12 MG Record for indoor pulsed magnetic field, (University of Tokyo, 2018) [19]
- 28 MG Record for human produced, pulsed magnetic field, (VNIIEF, 2001)[20]
- 10 GG - 1 TG Strength of a non-magnetar neutron star.[21]
- >9.2 GG in reach at ELI-NP

Presiune

- >600 GPa Pressure attainable with a diamond anvil cell[84]
- 5TPa Pressure generated by the National Ignition Facility fusion reactor
- 2.5 $x10^{11}$ bar Pressure inside Sun's core [88]
- >3.3 $x10^{12}$ bar in reach at ELI-NP

Comparatii

Padawan avansat

Camp electric

When the electric field is expressed in terms of Electromagnetic potentials, one can get:

$$\mathbf{E} = -\frac{\partial \mathbf{A}}{c\partial t}, \quad \mathbf{B} = \nabla \times \mathbf{A}$$

Define the normalized vector potential as $\mathbf{a} = \frac{e\mathbf{A}}{m_e c^2}$

This is non-dimensional factor. It can be connected to the intensity of the laser through:

$$a_0 = \left(\frac{2e^2\lambda_0^2 I}{\pi m_e^2 c^5}\right)^{1/2} \cong 0.855 \times 10^{-9} I^{1/2}\left[\mathrm{W/cm^2}\right]\lambda_0[\mu\mathrm{m}]$$

For Intensities of 10^{18}W/cm^2 and wavelength of μm, this becomes a_0=1.
=> The electron dynamics needs relativistic description.

Putem fierbe ceaiul cu 2x10PW de la ELI-NP?

10PW

+

10PW

versus

Q=460J

c=4186 J / (kg °C)
m=0,1 kg

$Q = m\,c\,\Delta T \rightarrow \Delta T = Q/(m\,c) = 460/418{,}6\ ^\circ C = 1{,}1\ ^\circ C$

Nuclear Physics

Cum arata un experiment cu laserul?

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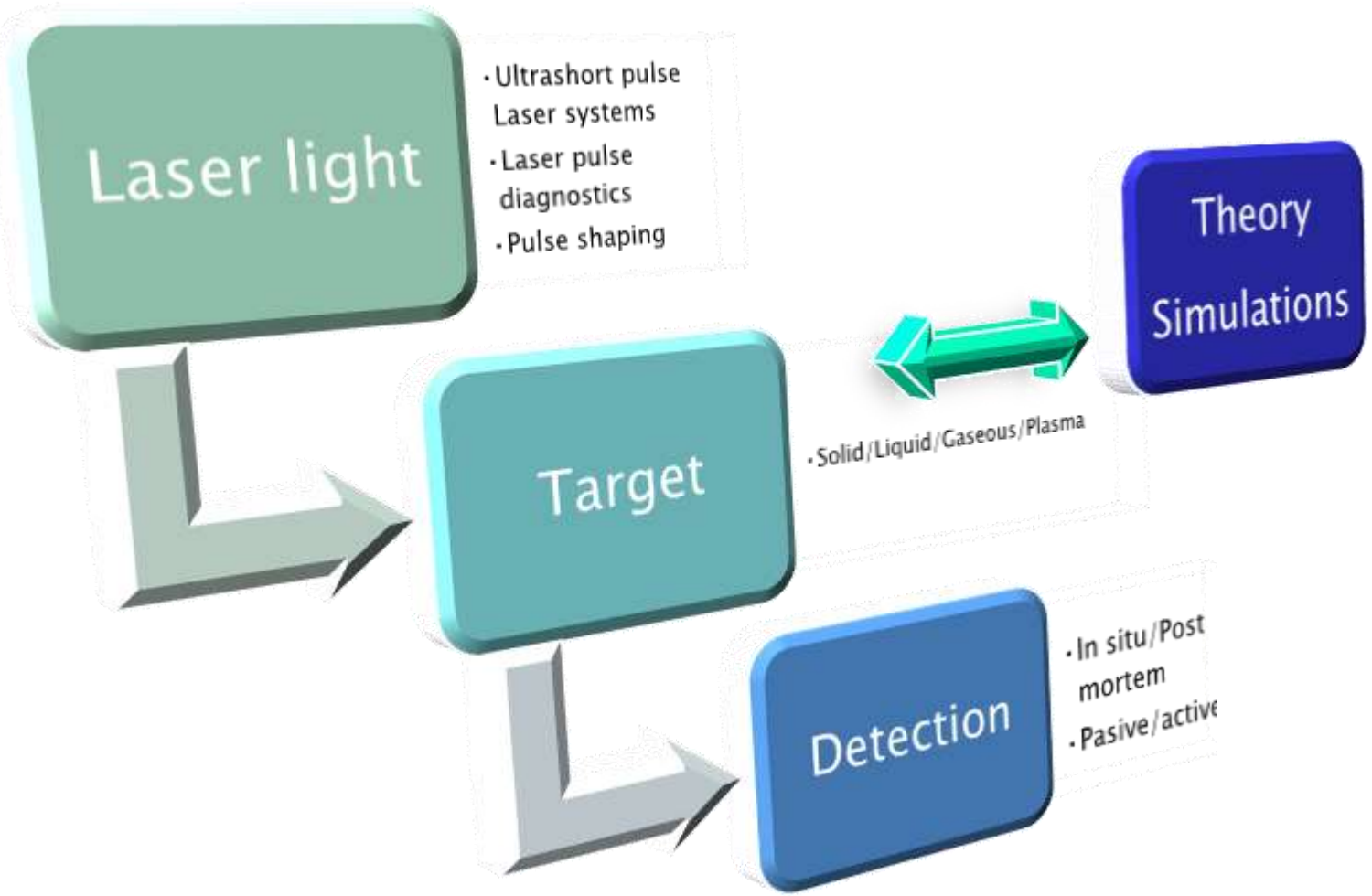
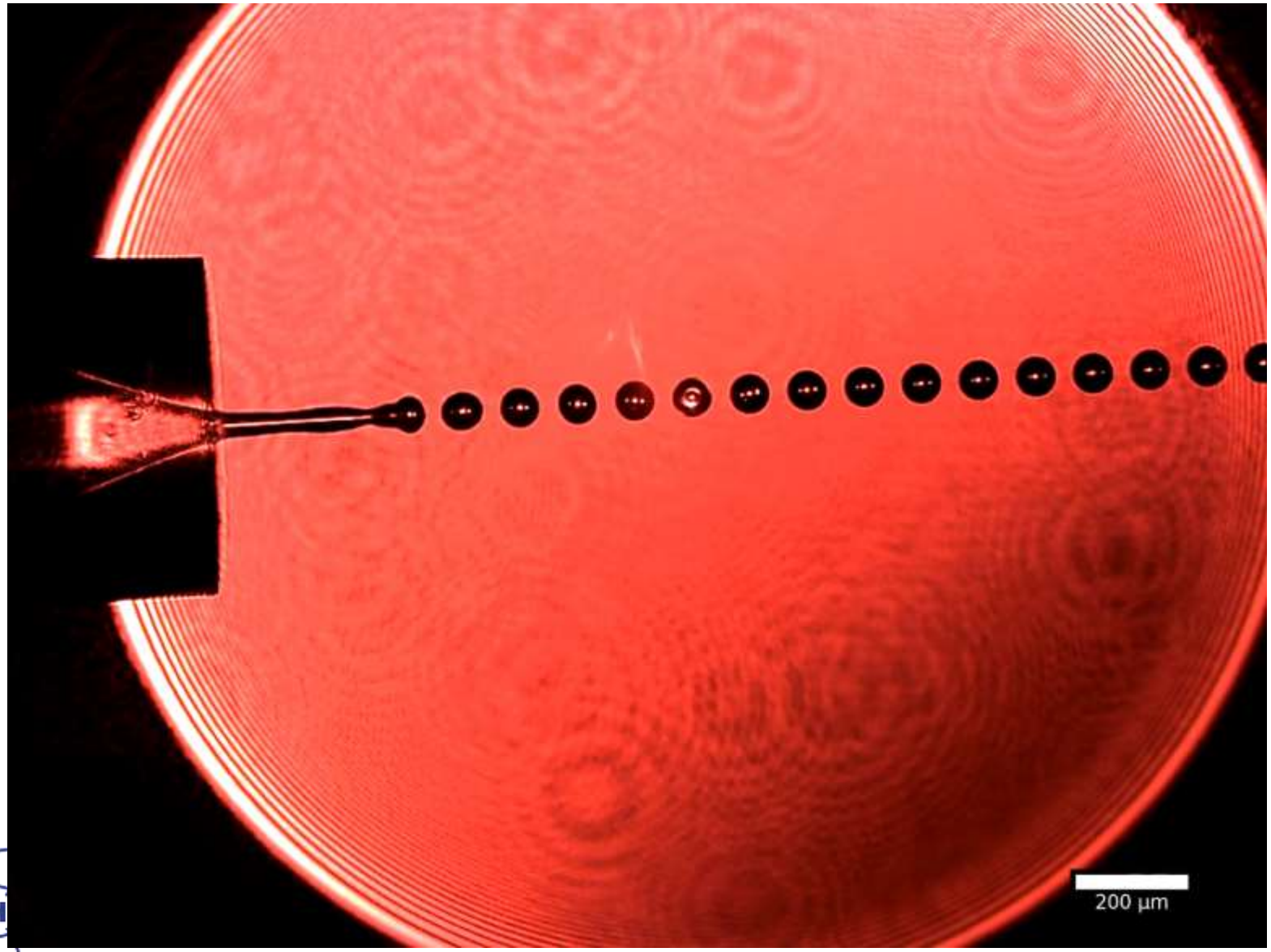
Experimente cu laserul



Micropicaturi



Nuclear Physics

Cum arata si cum functioneaza laserul de la ELI-NP?

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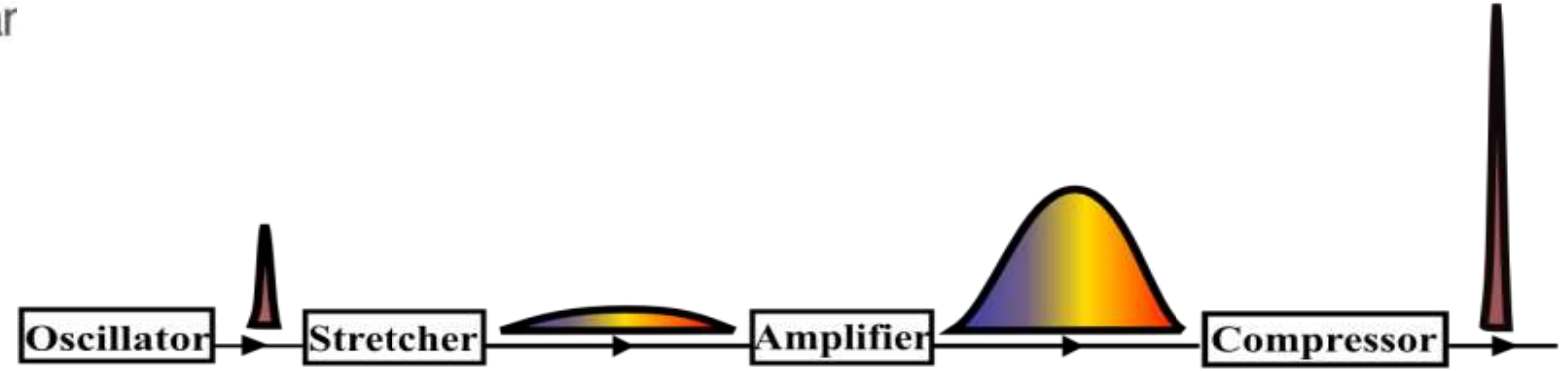
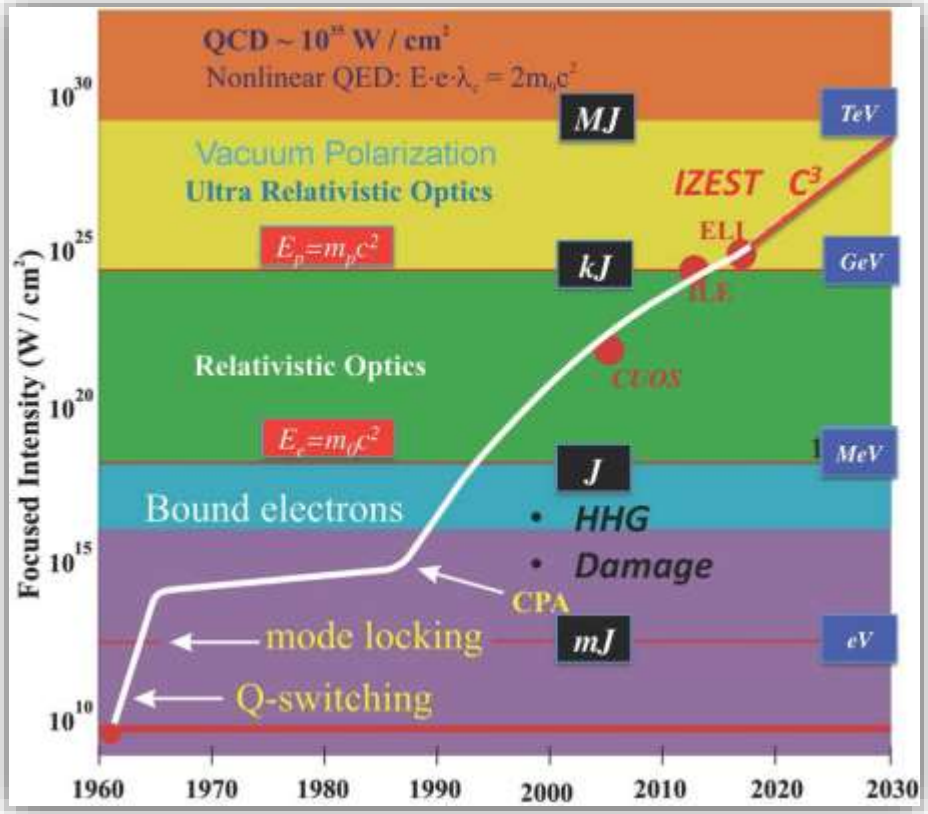
Nobel 2018: Chirped Pulse Amplification

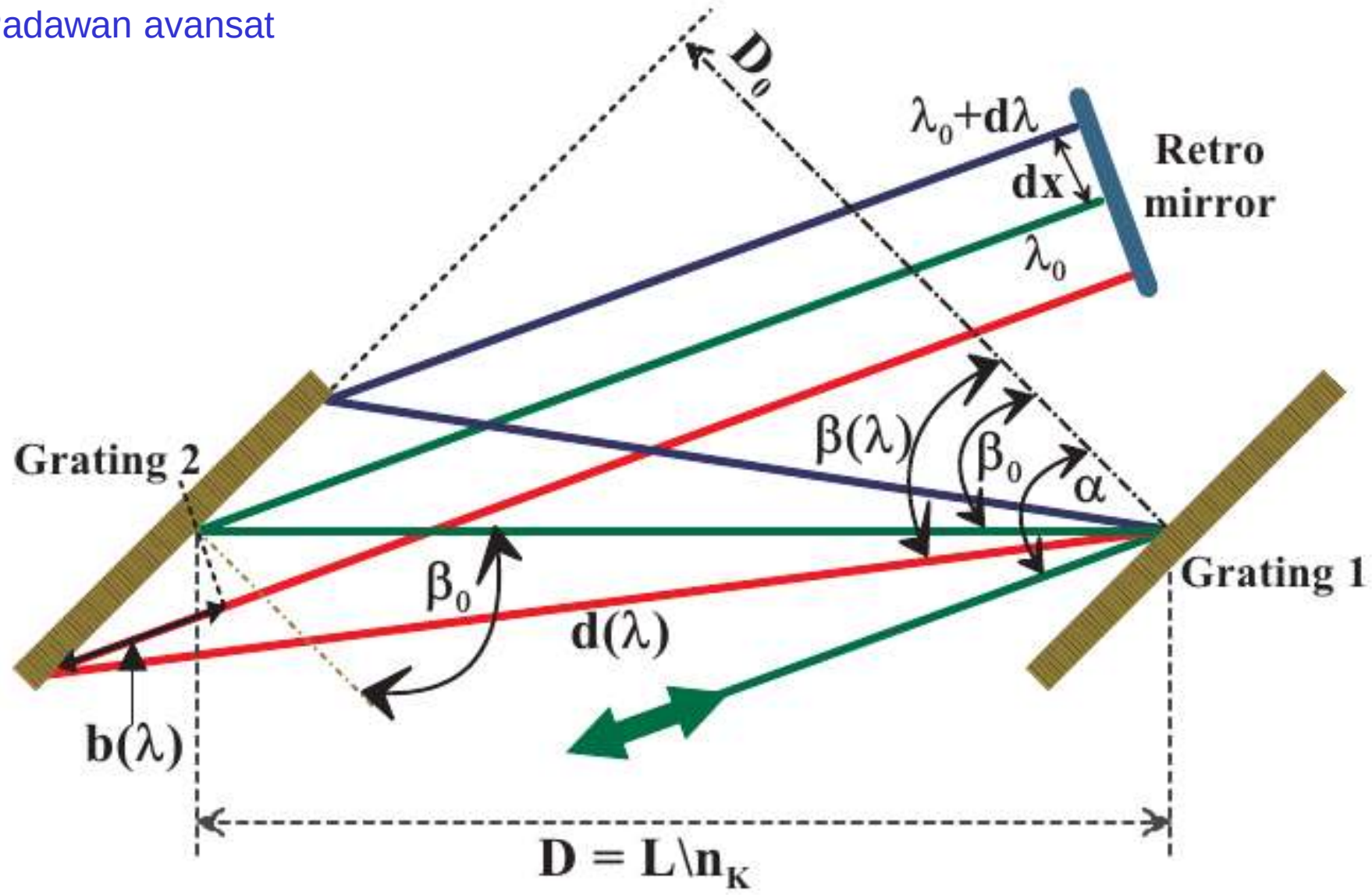




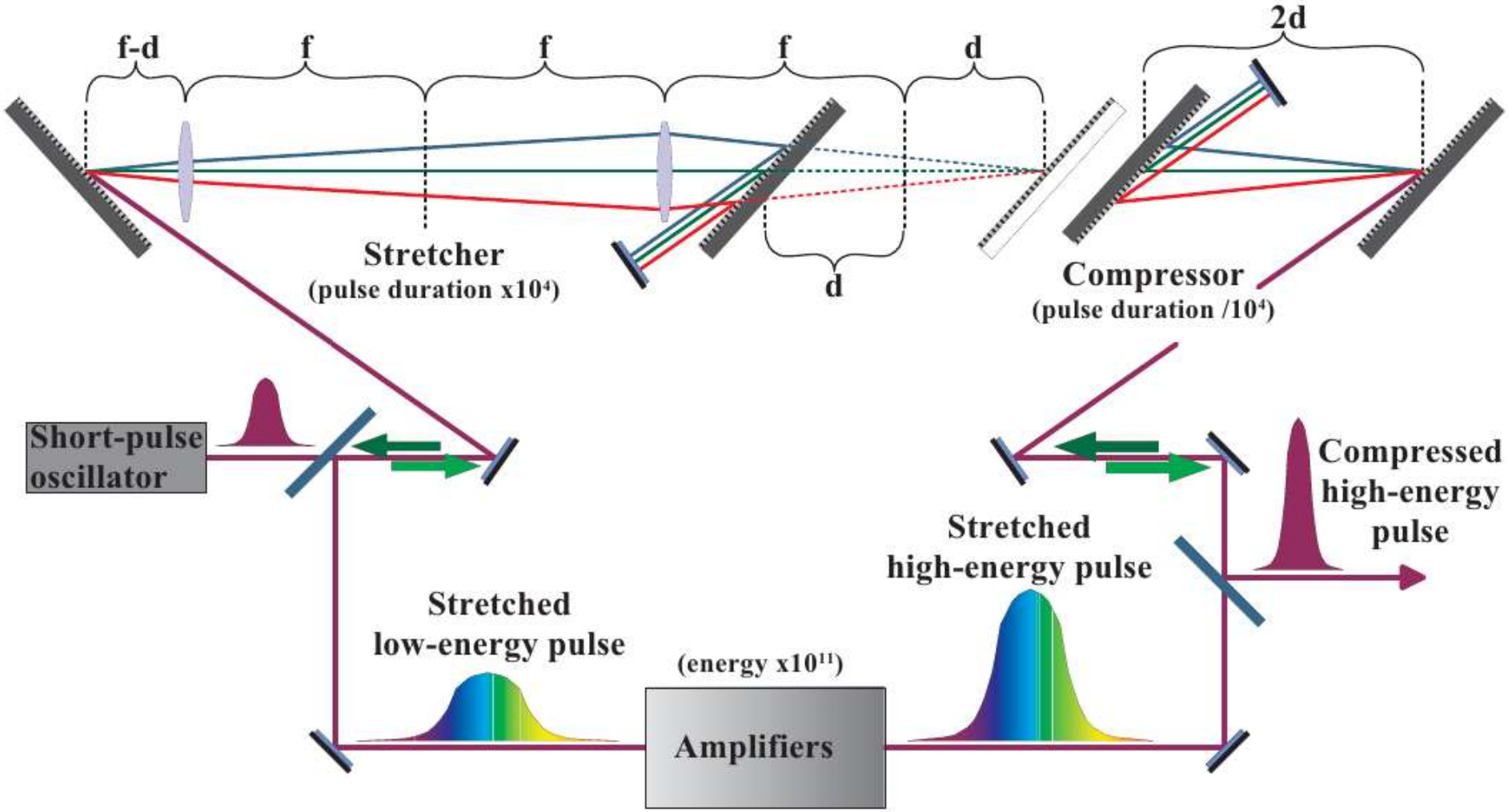
GERARD MOUROU
& DONA STRICKLAND
(Nobel 2018)

Tipuri de compresoare

Padawan avansat



Diferenta intre alungitoare si compresoare

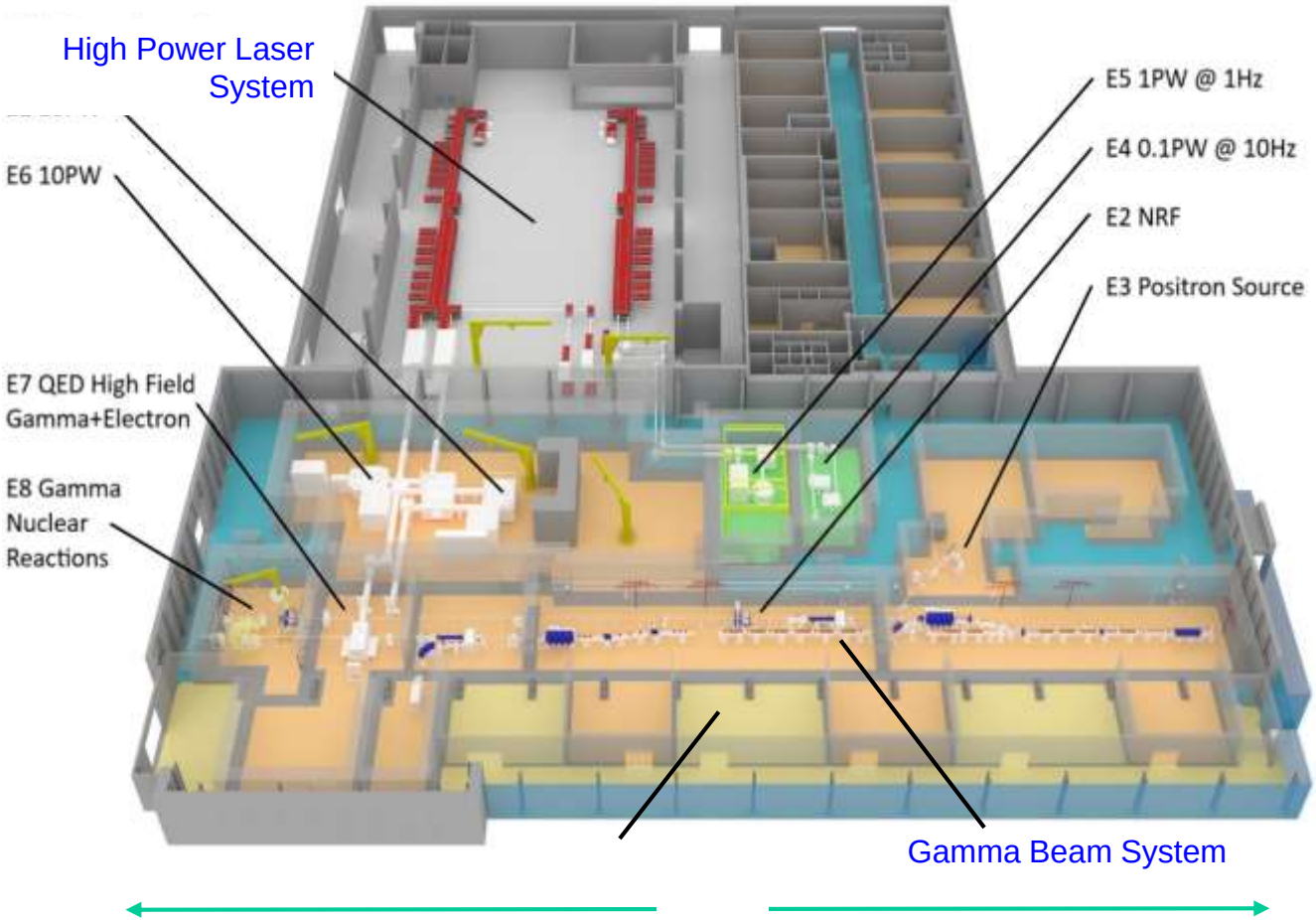


Faza de ordinul 2 >0 (stretcher)
Sau <0 (compresor)

Nuclear Physics

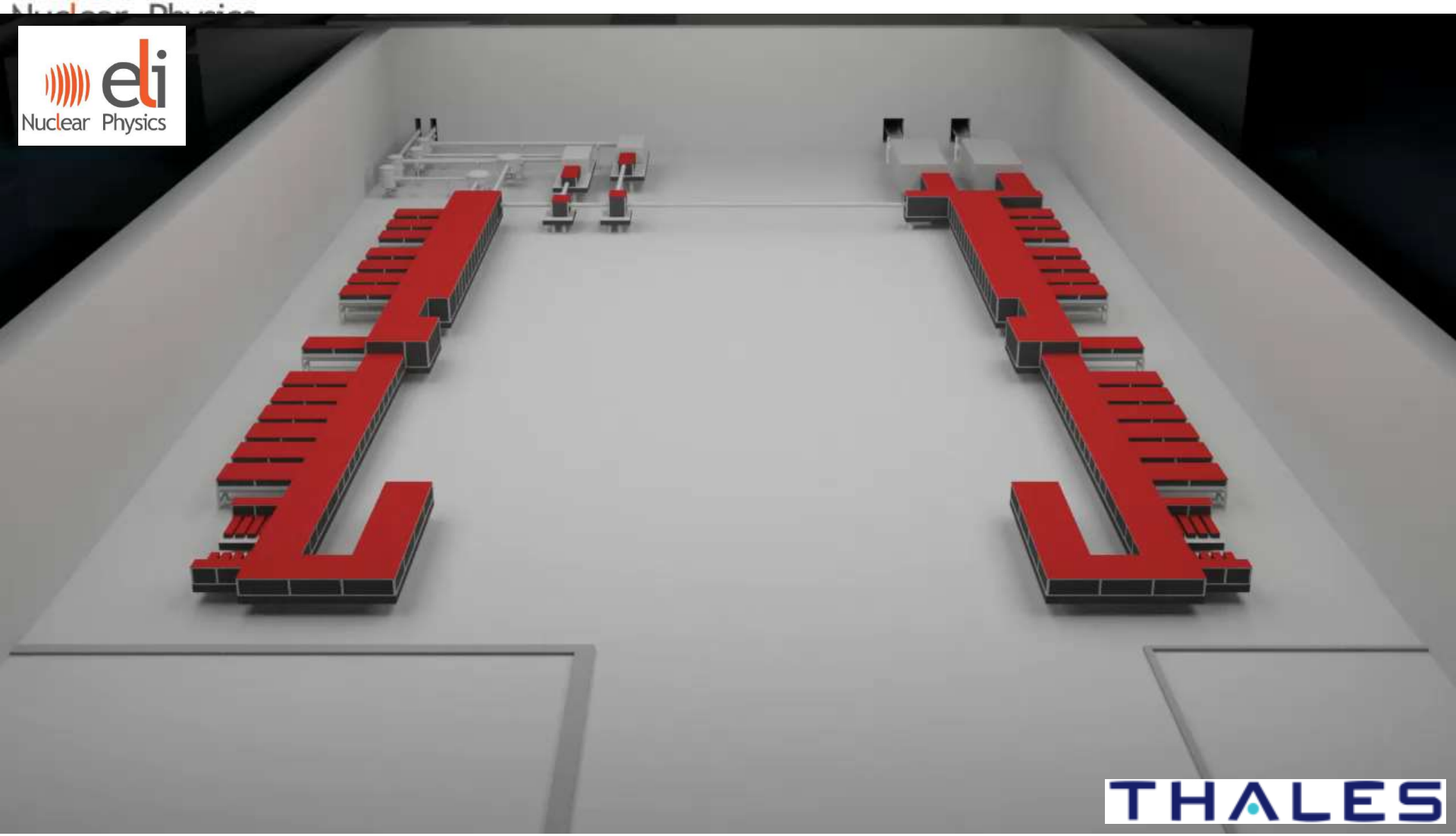
Rom. Rep. Phys. 68 (2016)

www.rrp.infim.ro



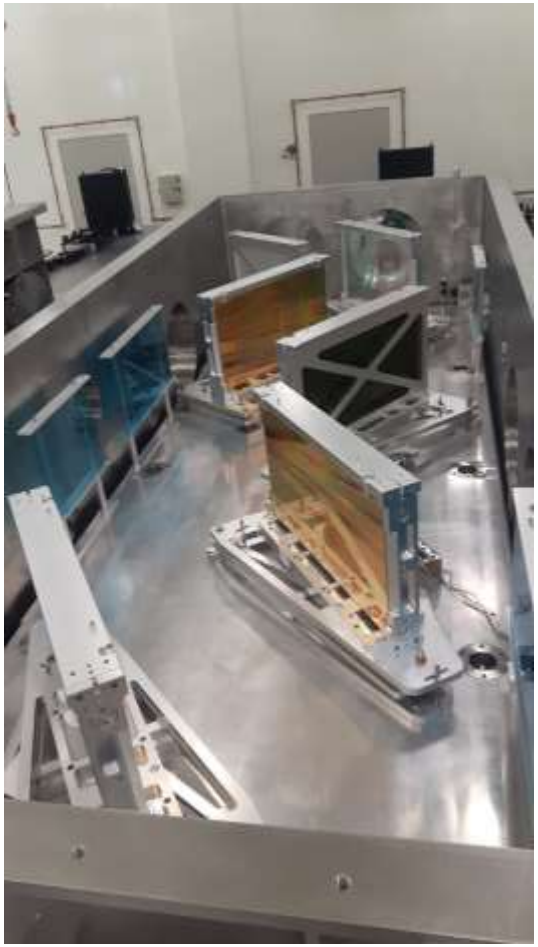
Nuclear Physics

IFIN-HH



IFIN-HH

Nuclear Physics



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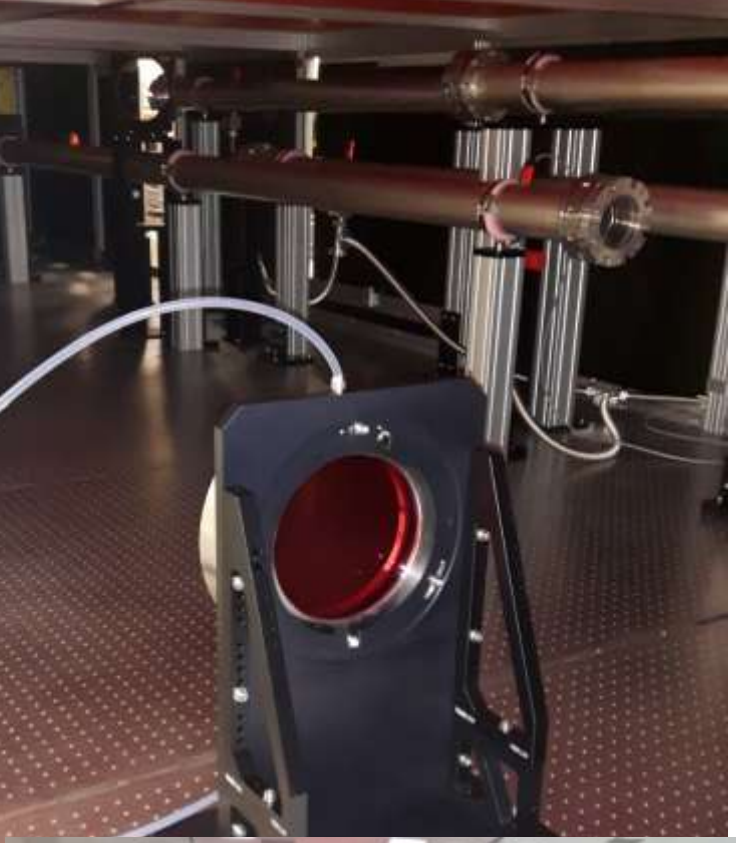
10 PW - compresoarele

2017 January 20th

2018 February 25

Nuclear Physics

IFIN-HH



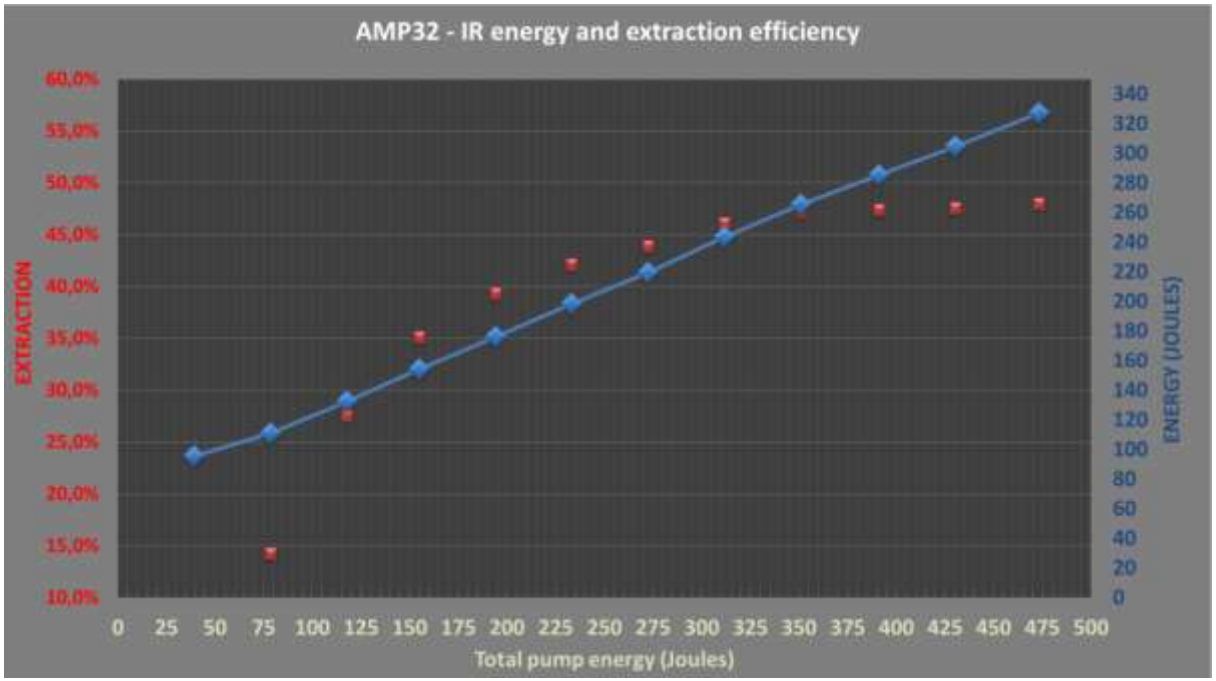

THALES

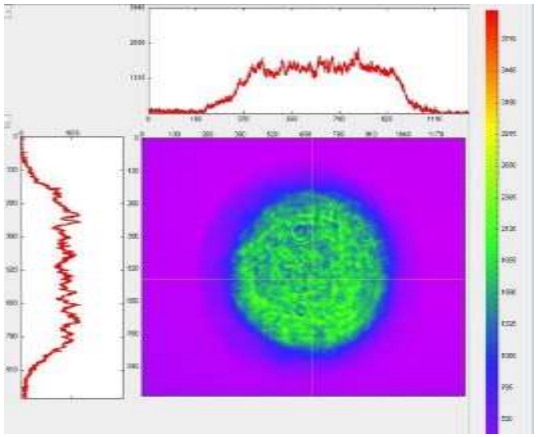
Nuclear Physics

IFIN-HH

Martie 2019 – demonstratia de 10PW

Amplificarea cu energie E > 300J

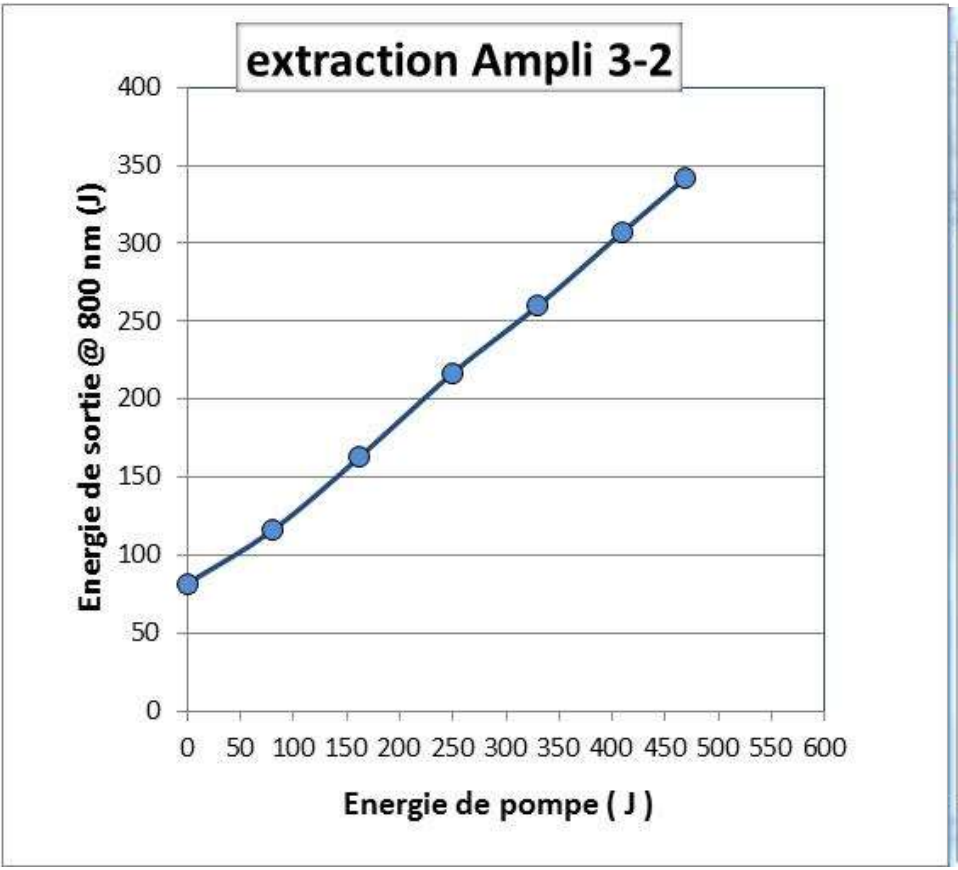


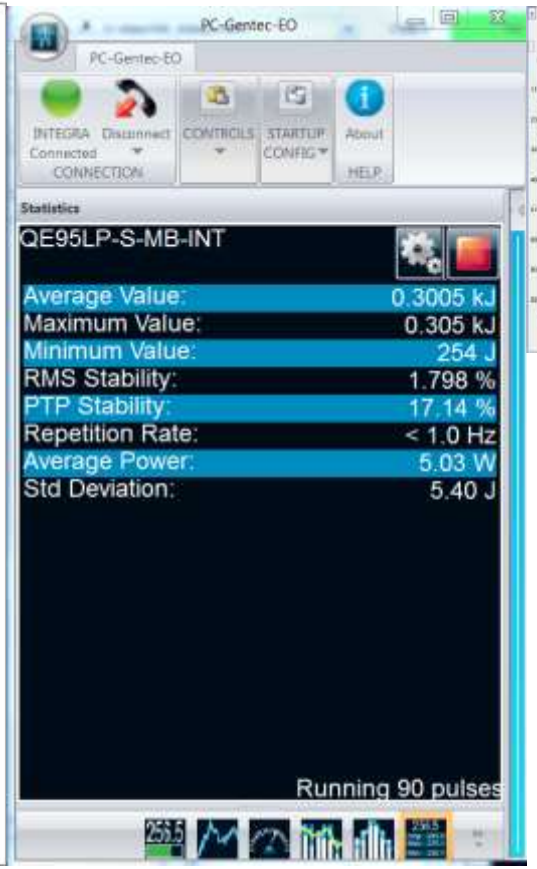


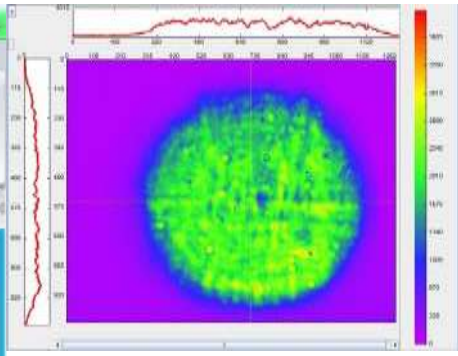
Profilul laserului dupa amplificare la 327J

Pompajul limitat la 80% din total

Aprilie 2019 – Amplificare la energie E ~ 340J pe al doilea brat



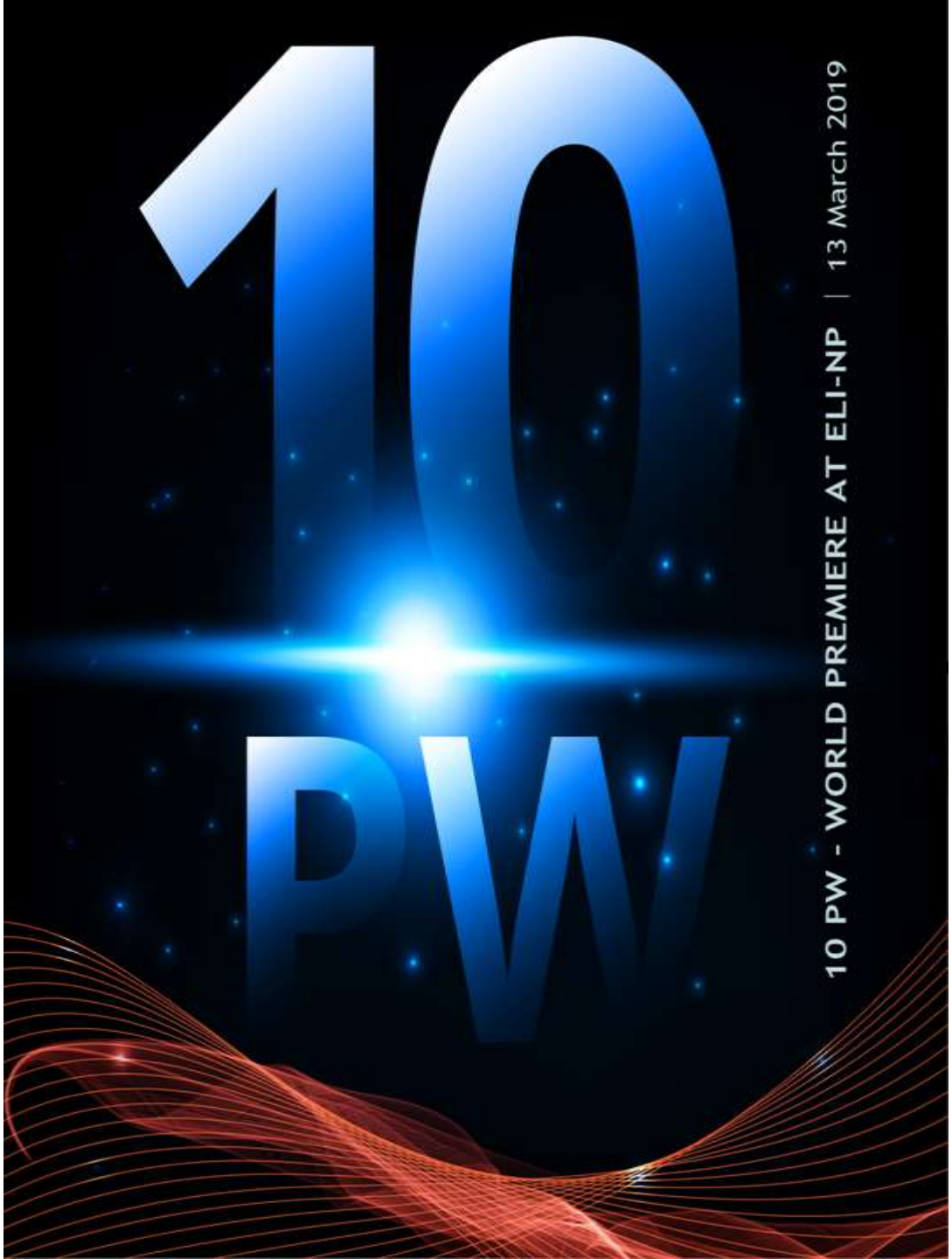




Near field beam profile recorded during long term test over 90 minutes:

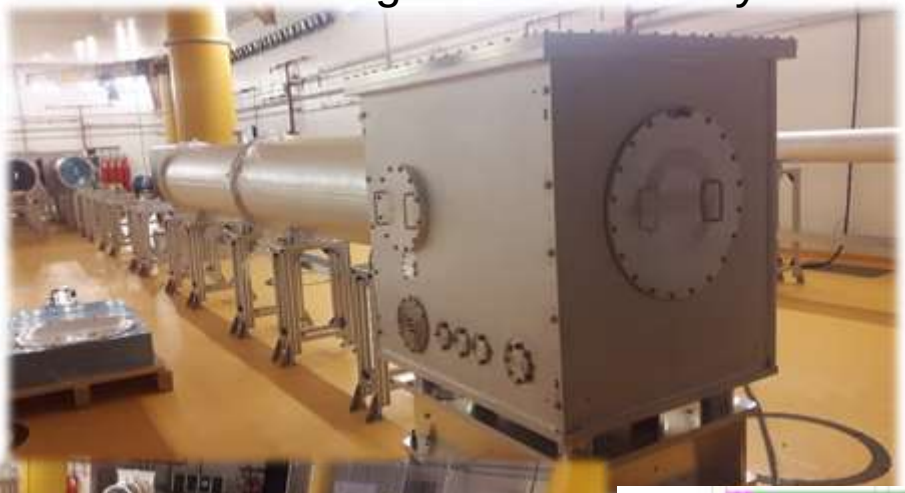
- Average energy 300J
- RMS stability < 2%

2x

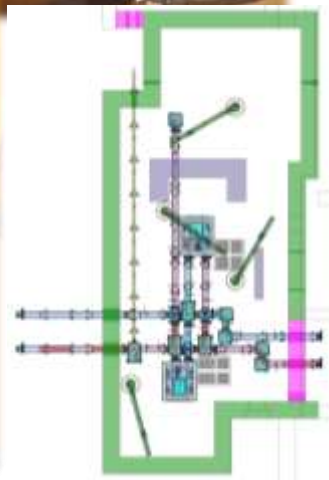


Linia de transport pentru pulsurile de 10PW (LBTS)

10PW long focal vacuum system to E

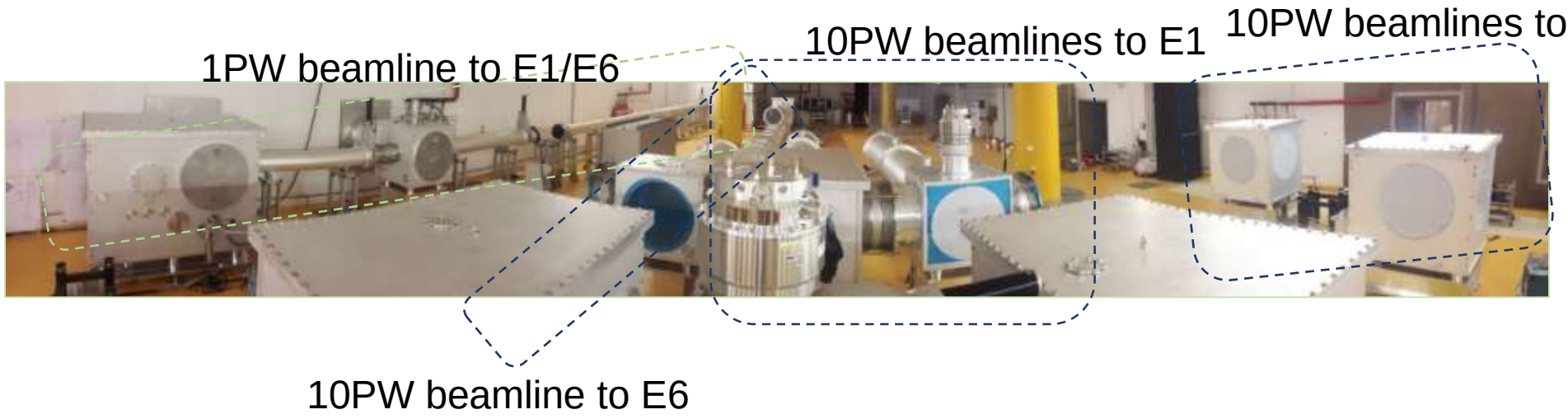


1PW beamline to E1-E6
Under vacuum leak tests.



10PW two beams vacuum system to E1

LBTS imagine de ansamblu

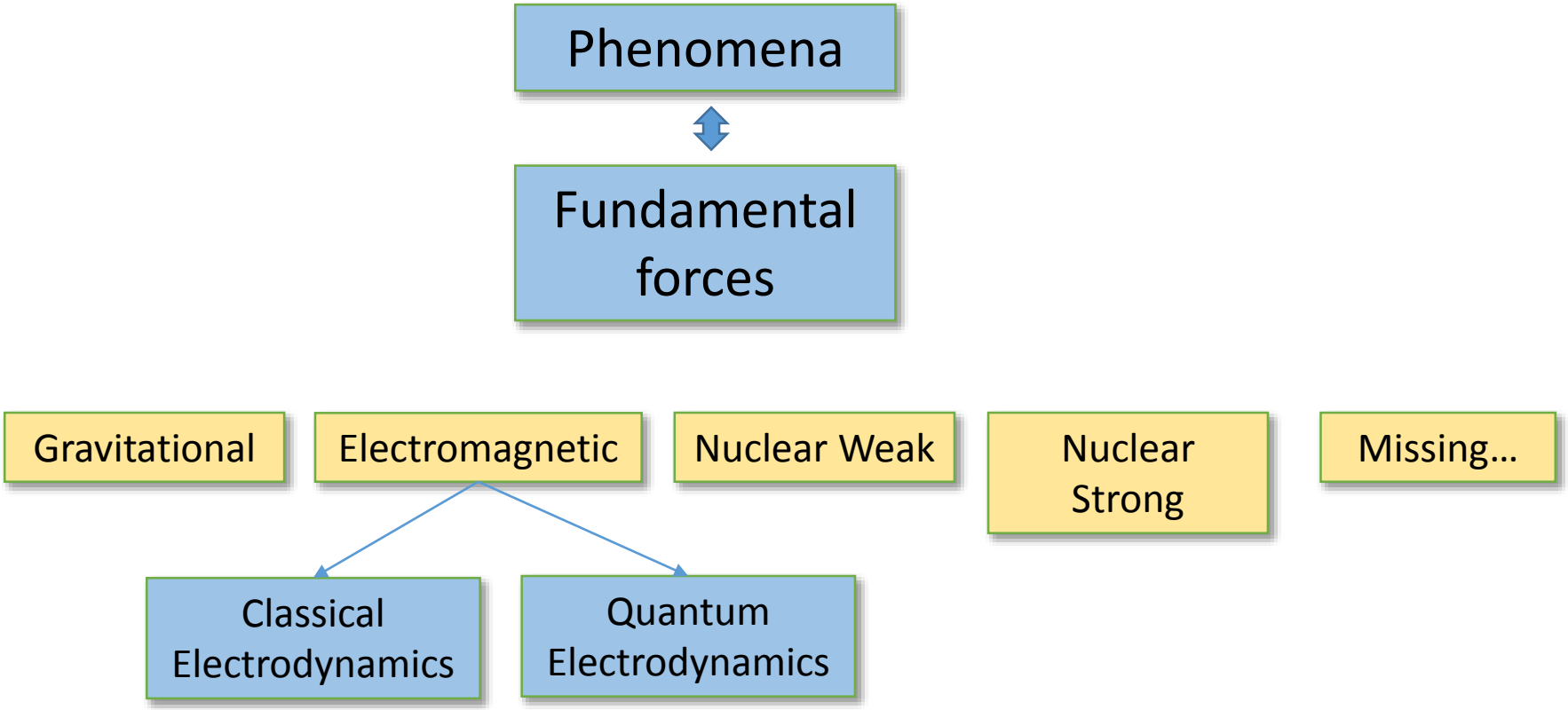


Nuclear Physics

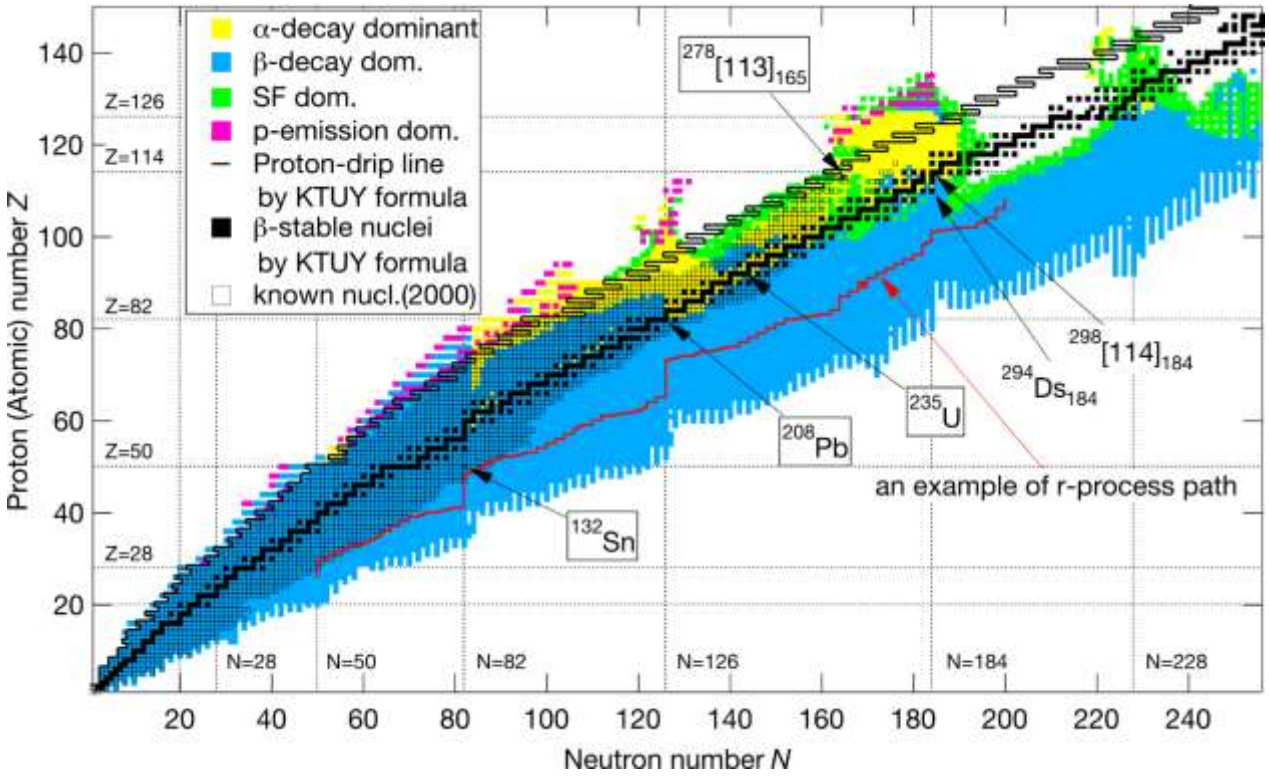
La ce foloseste laserul de la ELI-NP?

Nuclear Physics

Intrebari fundamentale

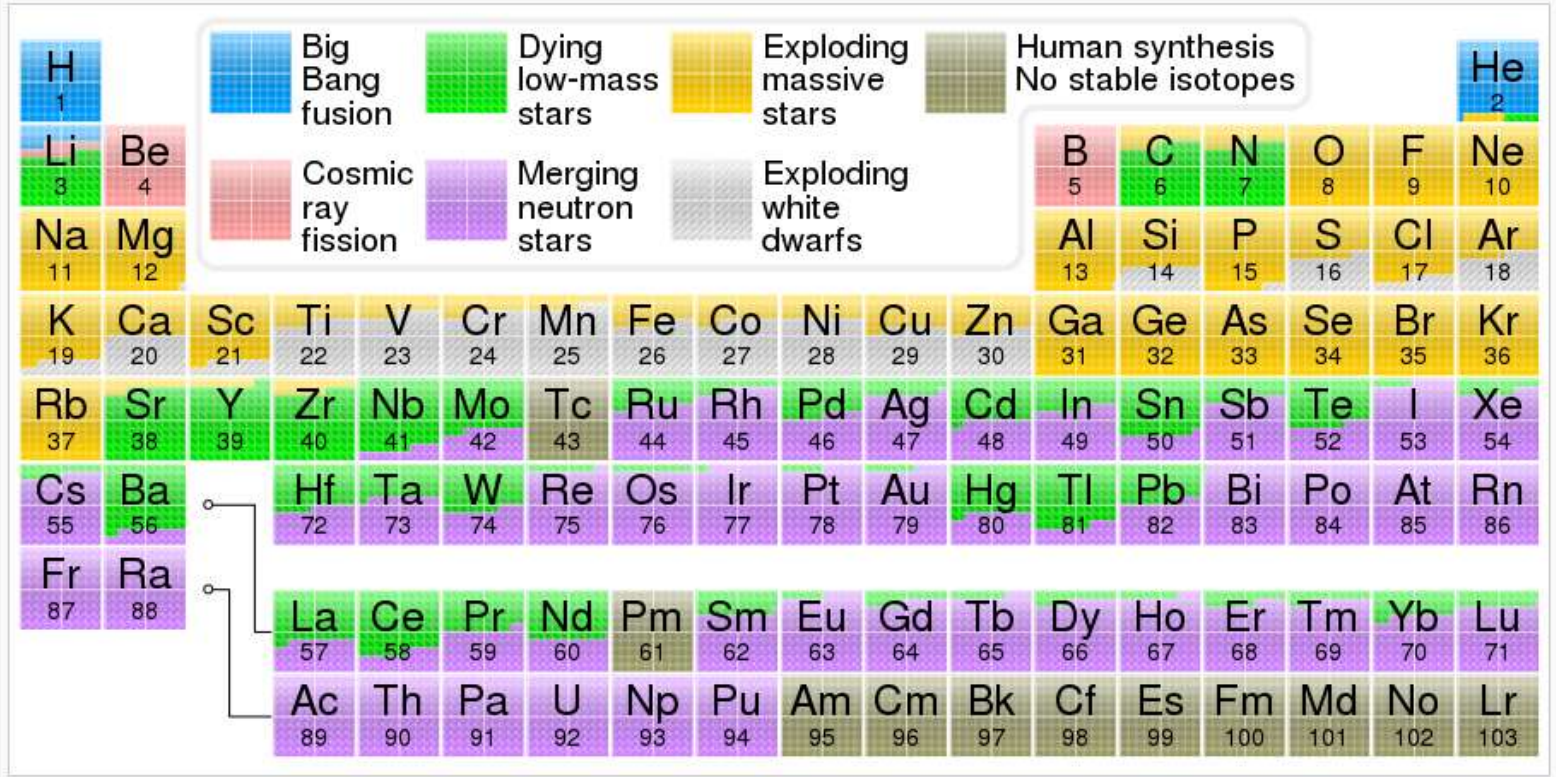


Se cauta un model nuclear general



Shell model
Droplet model
…

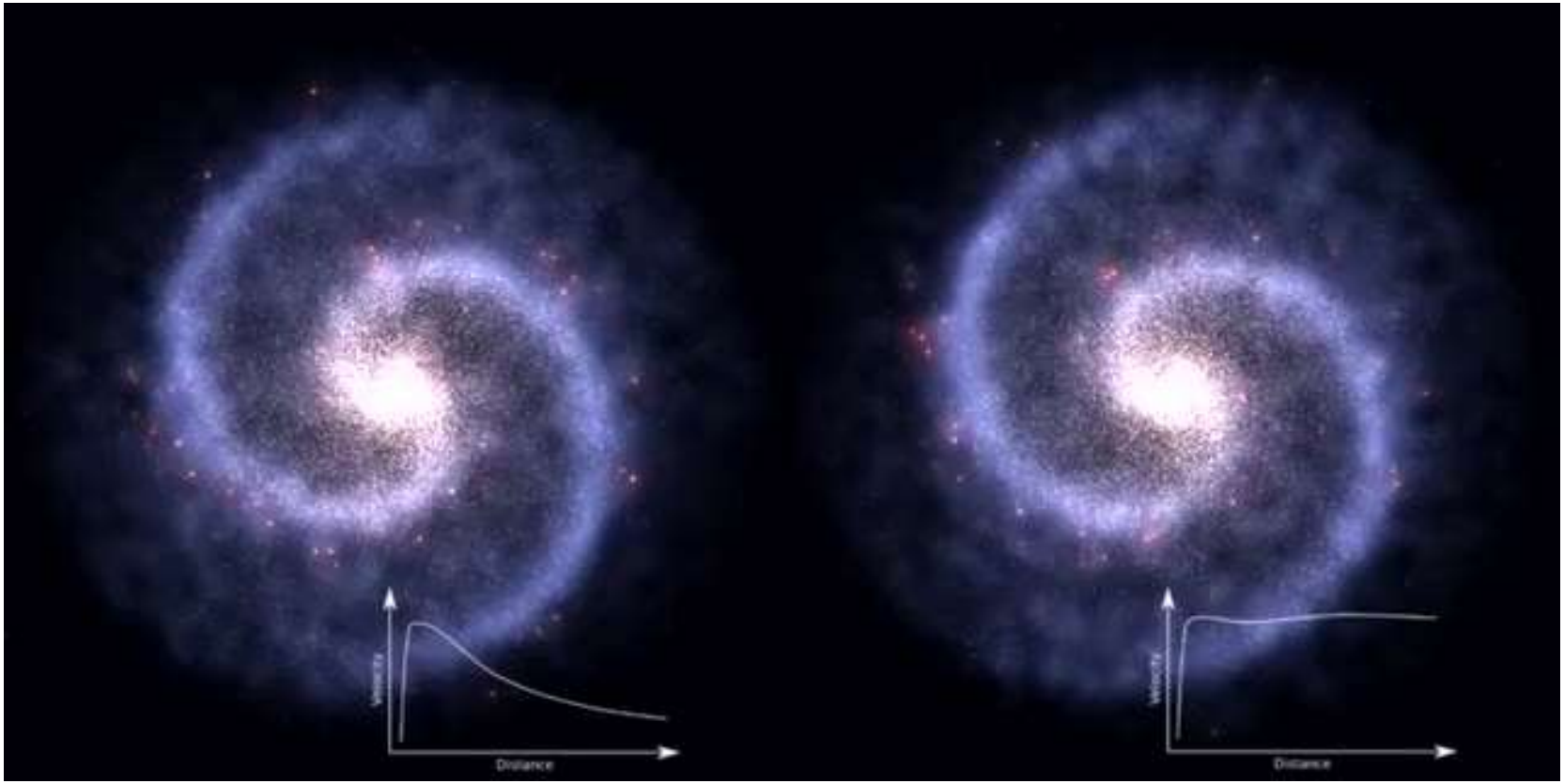
Astrofizica si sinteza de nuclee



Periodic table showing the origin of each element. Elements from carbon up to sulfur may be made in small stars by the alpha process. Elements beyond iron are made in large stars with slow neutron capture (s-process). Elements heavier than iron may be made in neutron star mergers or supernovae after the r-process.

Sursa: Wikipedia: Nucleosynthesis

Gravitatie si materie intunecata



Sursa: Wikipedia: **Galaxy rotation curve**

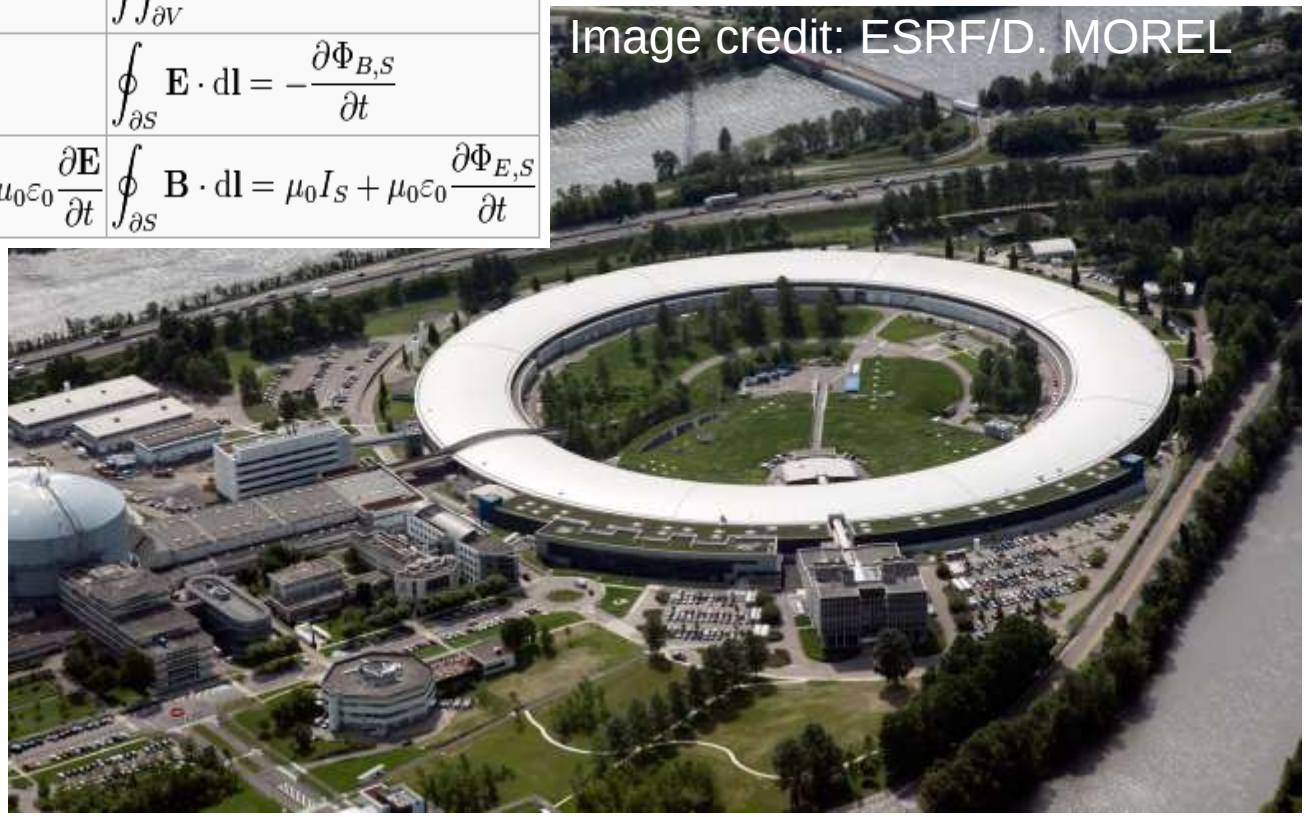
Radiatia emisa de o particula incarcata electric la acceleratii violente

Padawan avansat

Formulation in terms of *total* charge and current[note 3]

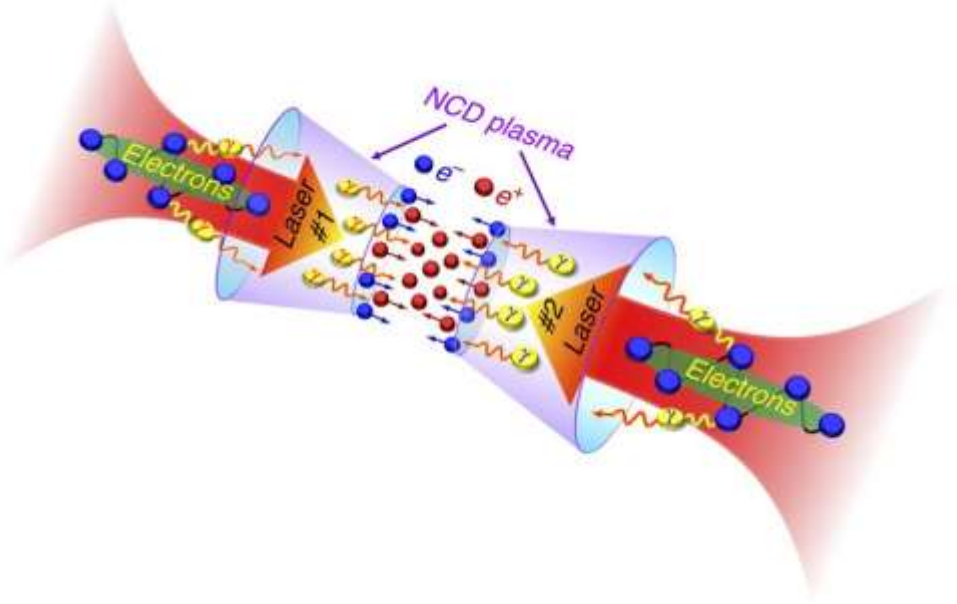
Name	Differential form	Integral form
Gauss's law	$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$	$\oiint_{\partial V} \mathbf{E} \cdot \mathrm{d}\mathbf{A} = \frac{Q(V)}{\varepsilon_0}$
Gauss's law for magnetism	$\nabla \cdot \mathbf{B} = 0$	$\oiint_{\partial V} \mathbf{B} \cdot \mathrm{d}\mathbf{A} = 0$
Maxwell–Faraday equation (Faraday's law of induction)	$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$	$\oint_{\partial S} \mathbf{E} \cdot \mathrm{d}\mathbf{l} = -\frac{\partial \Phi_{B,S}}{\partial t}$
Ampère's circuital law (with Maxwell's correction)	$\nabla \times \mathbf{B} = \mu_0\mathbf{J} + \mu_0\varepsilon_0\frac{\partial \mathbf{E}}{\partial t}$	$\oint_{\partial S} \mathbf{B} \cdot \mathrm{d}\mathbf{l} = \mu_0 I_S + \mu_0\varepsilon_0\frac{\partial \Phi_{E,S}}{\partial t}$

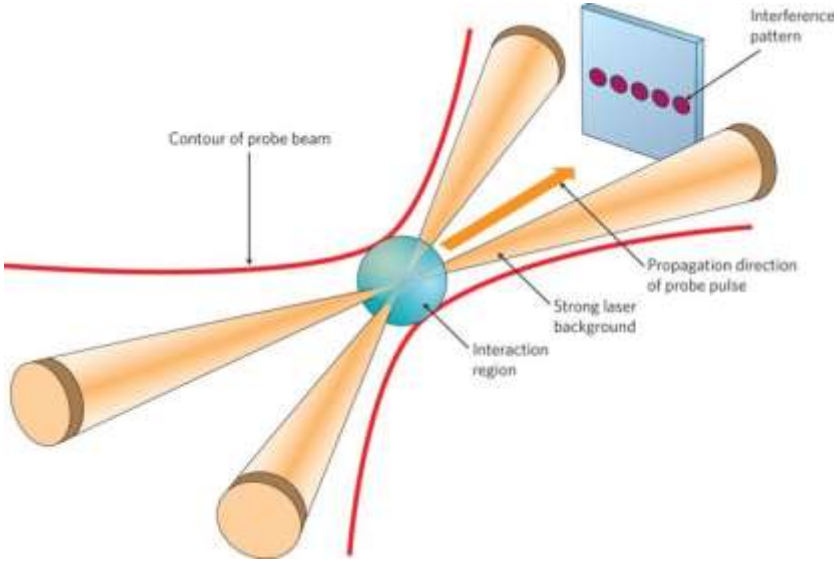
ESRF :844 m electron accelerator



https://www.compadre.org/osp/EJSS/4126/154.htm

Convertirea luminii in materie si modificarea proprietatilor vidului



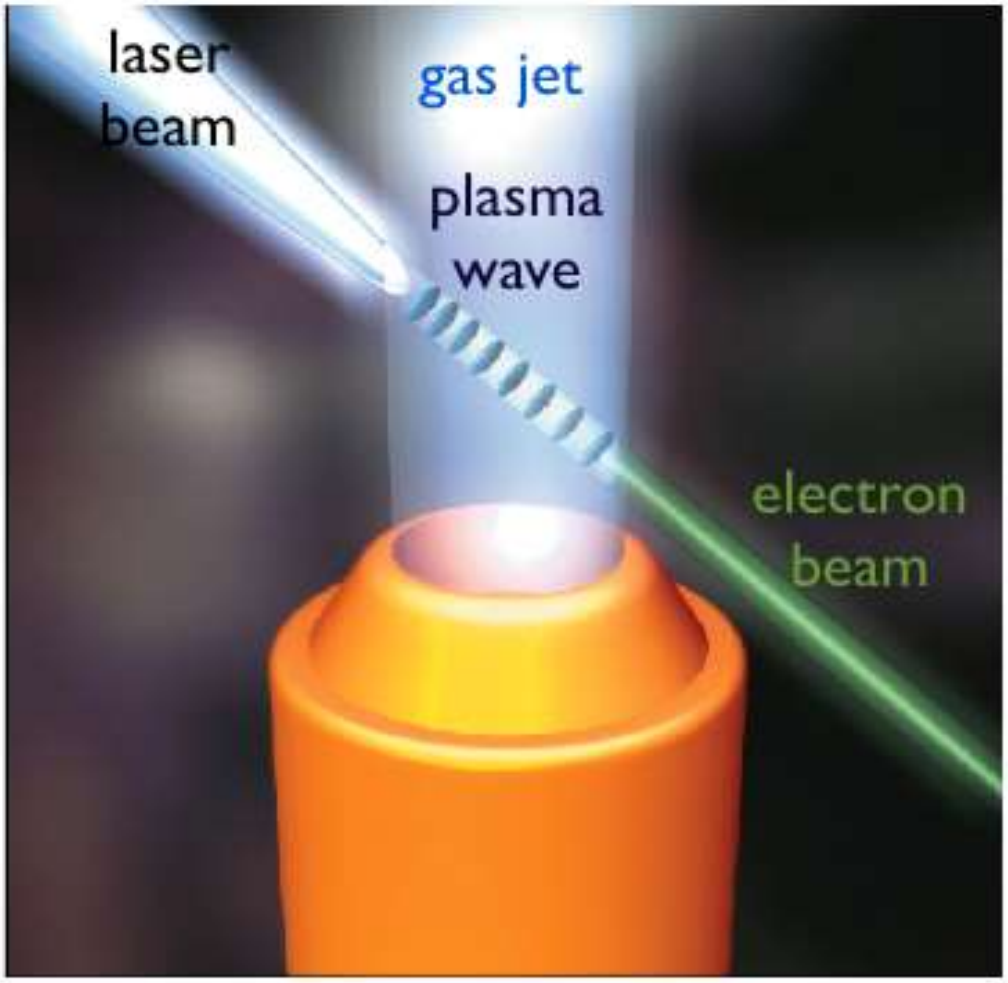


A matterless double slit
Ben King, Antonino Di Piazza & Christoph H. Keitel
Nature Photonics **volume 4**, pages92–94 (2010)

Dense GeV electron–positron pairs generated by lasers in near-critical-density plasmas
Xing-Long Zhu, Tong-Pu Yu, Zheng-Ming Sheng, Yan Yin, Ion Cristian Edmond Turcu & Alexander Pukhov
Nature Communications **volume 7**, Article number: 13686 (2016)

Aplicatii: lampa lui Aladin

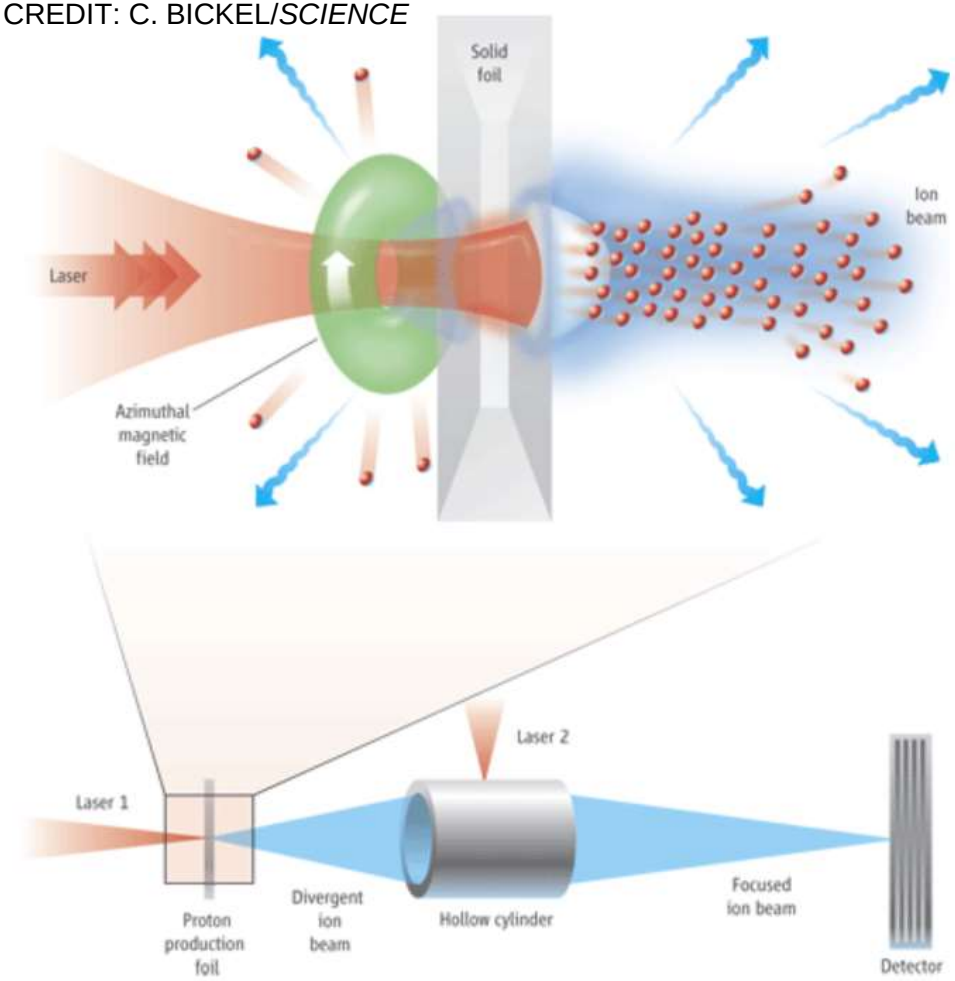
Accelerarea in plasma



Accelerarea in plasma

Spre terapia cancerului si spre fuziune nucleara

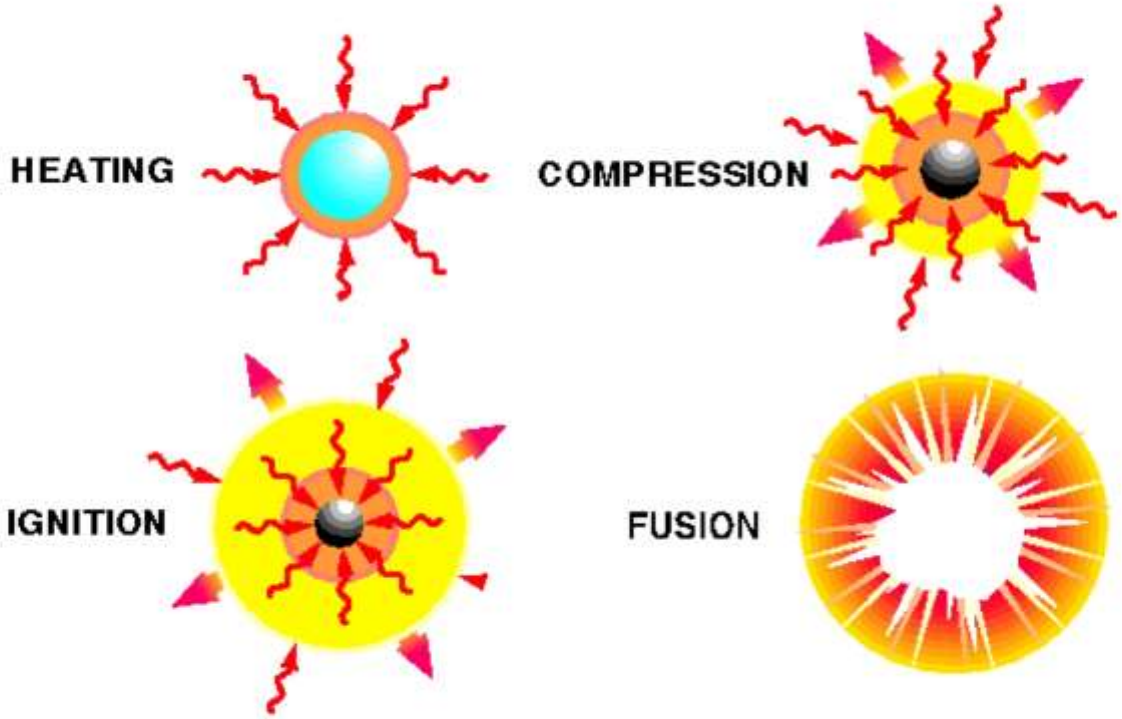
CREDIT: C. BICKEL/*SCIENCE*



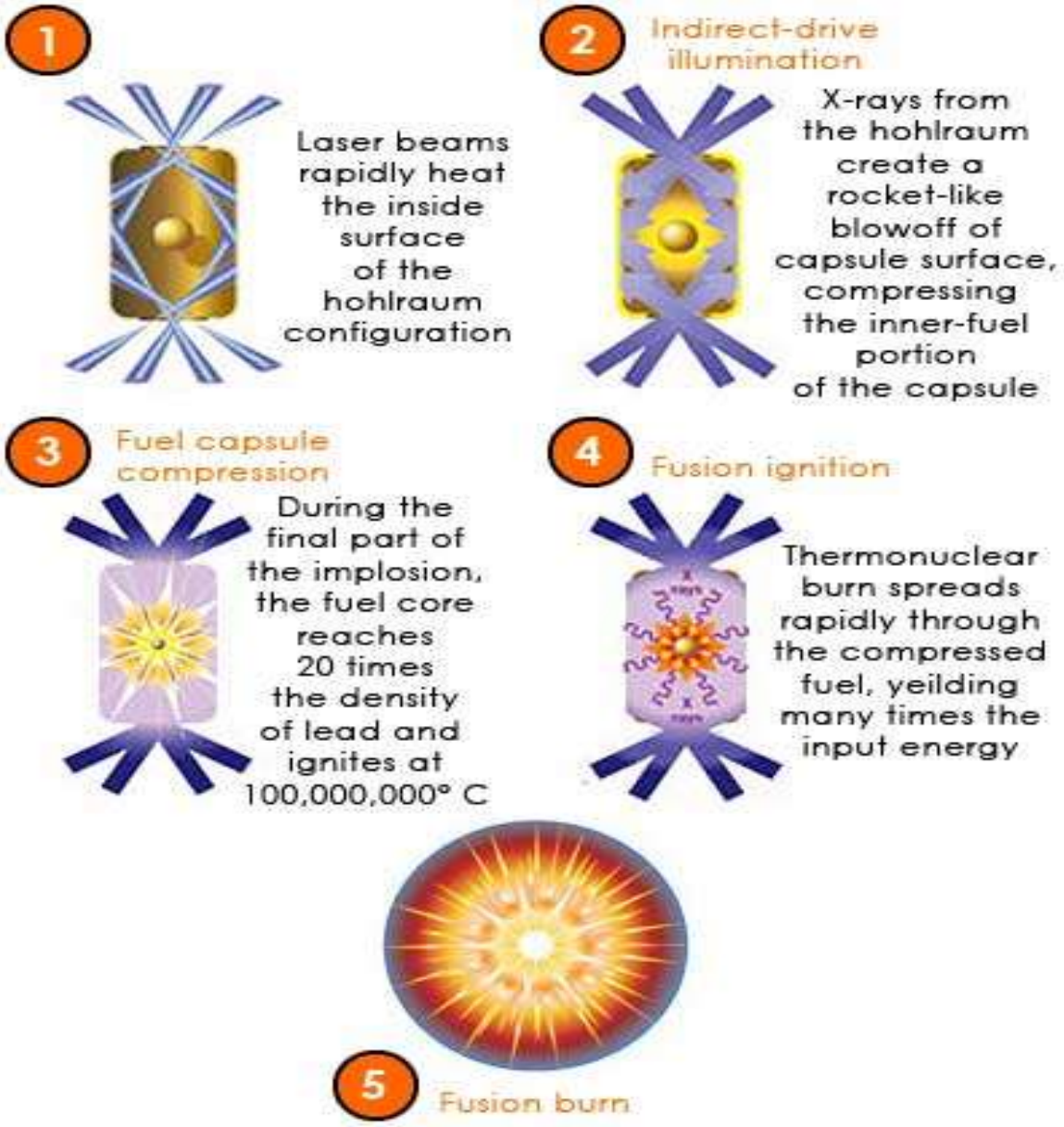
Ultrafast Laser-Driven Microlens to Focus and Energy-Select Mega-Electron Volt Protons
Toma Toncian, Marco Borghesi, Julien Fuchs, Emmanuel d'Humières, Patrizio Antici, Patrick Audebert, Erik Brambrink, Carlo Alberto Cecchetti, Ariane Pipahl, Lorenzo Romagnani, Oswald Willi
Science 21 Apr 2006:
Vol. 312, Issue 5772, pp. 410-413

Spre terapia cancerului si spre fuziune nucleara

Fuziune nucleara



Fuziune nucleara



GPS si Google Maps

Texas, on September 12, 1962

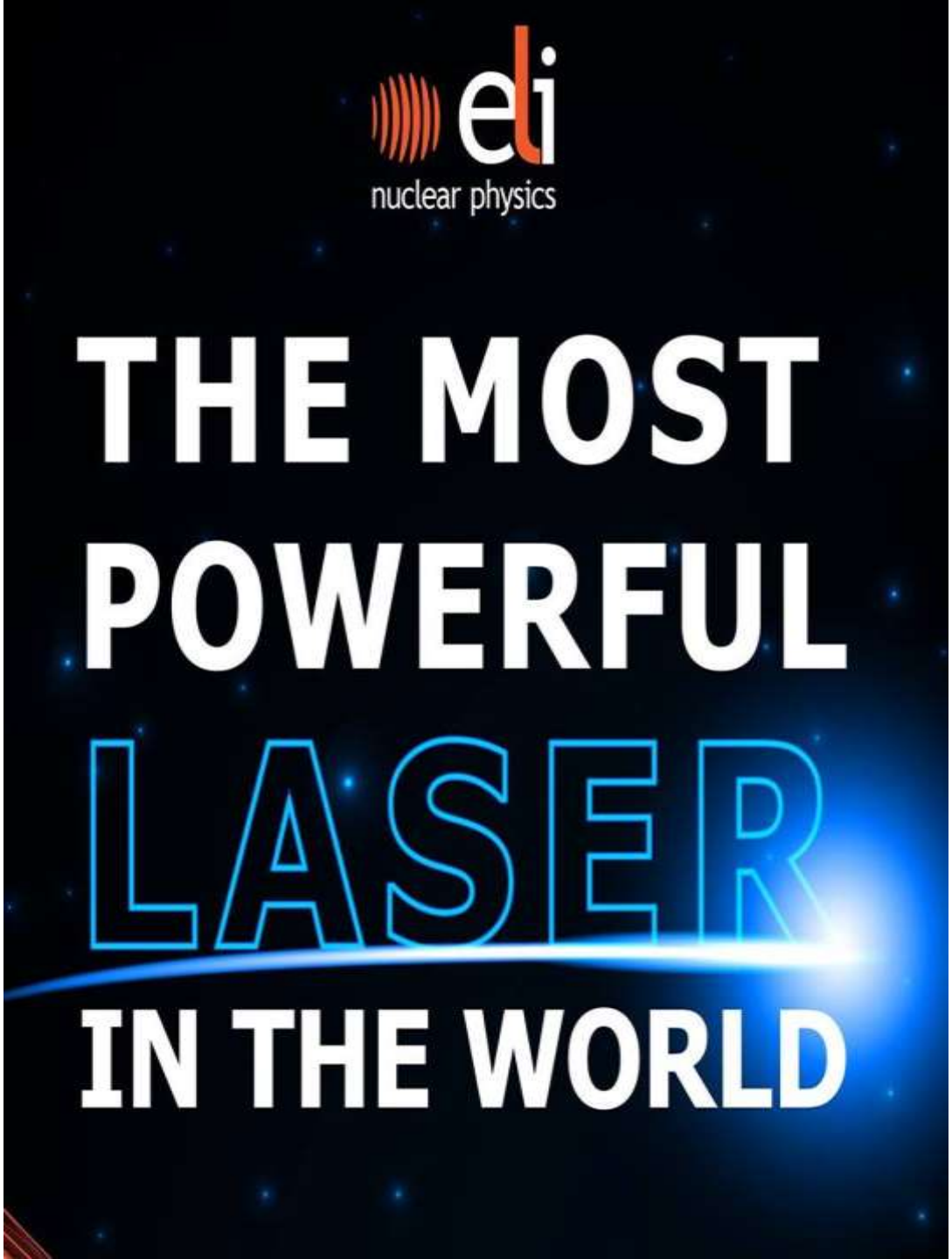
We choose to go to the Moon! We choose to go to the Moon...We choose to go to the Moon in this decade […], ***not because they are easy, but because they are hard***; because ***that goal will serve to organize and measure the best of our energies and skills***, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one we intend to win […].

July 21,1969

Concluzii

1. Ce este fizica? **Magic that works!**
2. Cum functioneaza laserul? **Ca o avalansa de lumina.**
3. Care sunt proprietatile luminii laser? **Ultimate control.**
4. Ce e special la lumina extrema? **Forte electrice, magnetice si presiuni uriase in volume micrometrice si timpi extrem de scurti.**
5. Cum arata un experiment? **Laser+ tinta+ detector+ concept de investigat**
6. Cum arata si cum functioneaza laserul de la ELI-NP? **Fain tare!**
7. La ce foloseste laserul de la ELI-NP? **Sa intelegem si sa facem mai buna viata de zi cu zi prin real magic**

eli Nuclear Physics



EUROPEAN UNION

GOVERNMENT OF ROMANIA

Structural Instruments 2007-2013

Extreme Light Infrastructure - Nuclear Physics (ELI-NP) - Phase II

Project Co-financed by the European Regional Development Fund

Document edited by
Horia Hulubei National Institute for Research and Development in Physics and Nuclear Engineering
Publication date of the document: February 2013