The Extreme Light Infrastructure
European Project

INFLPR

Surse secundare de radiatie la sistemul Extreme Light Infrastructure

Prezentat de Daniel Ursescu

Laboratorul de laseri cu corp solid /

INFLPR

Cand tot ce ai e un ciocan,

toate in jur par cuie!

Contents

- Attosecond science
- Particle beams production
- Laser produced x-ray beams
- Laser interaction with plasma
- Nuclear physics with lasers
- “Exotic” physics
- Applications

Attosecond science

Attosecond Light Source (ALS)

Isolated attosecond pulse and electron bunch generation

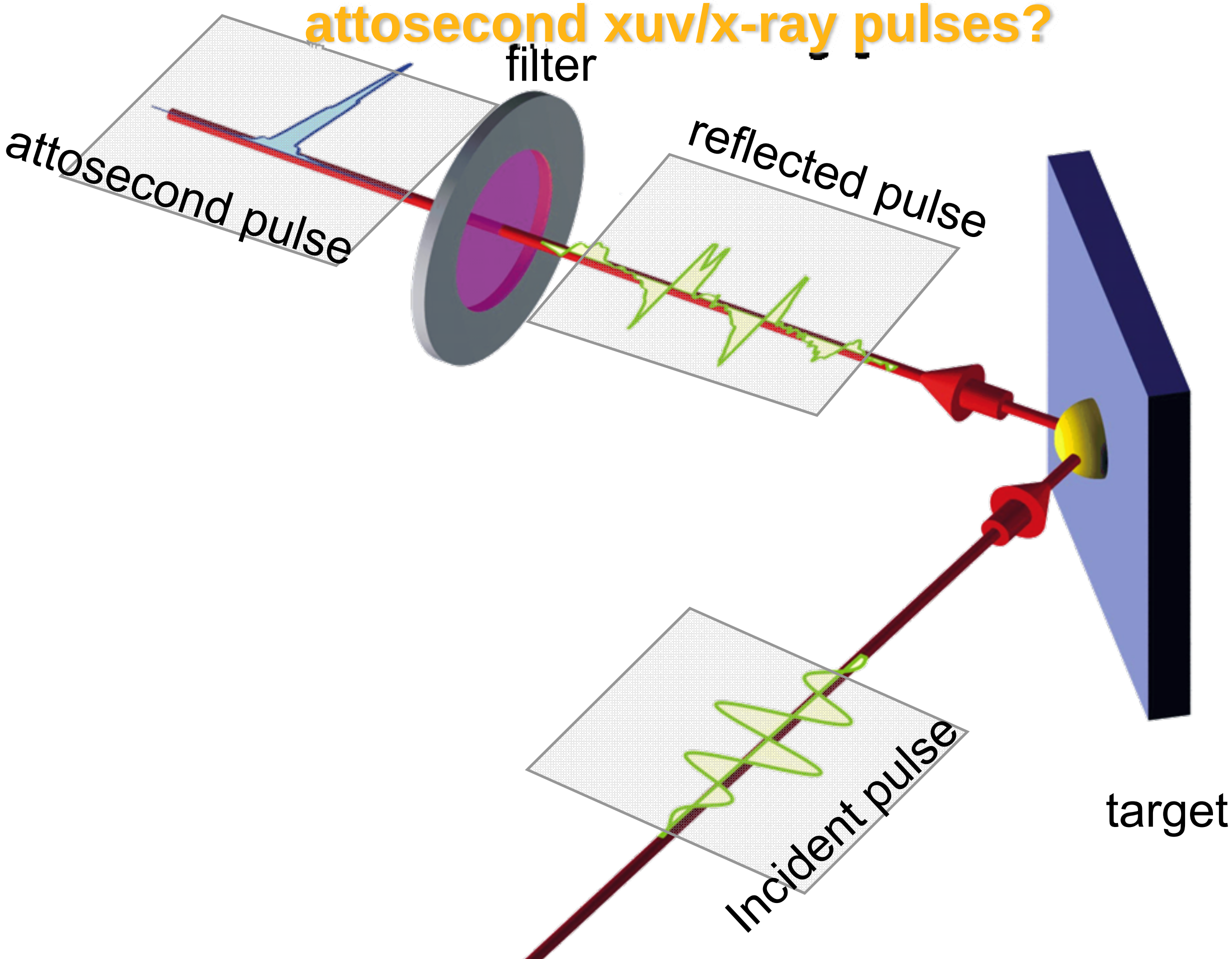
in the λ3 regime

Time-domain experiments

Attosecond Light Source (ALS)

driving electrons with controlled, relativistic, few-cycle fields:

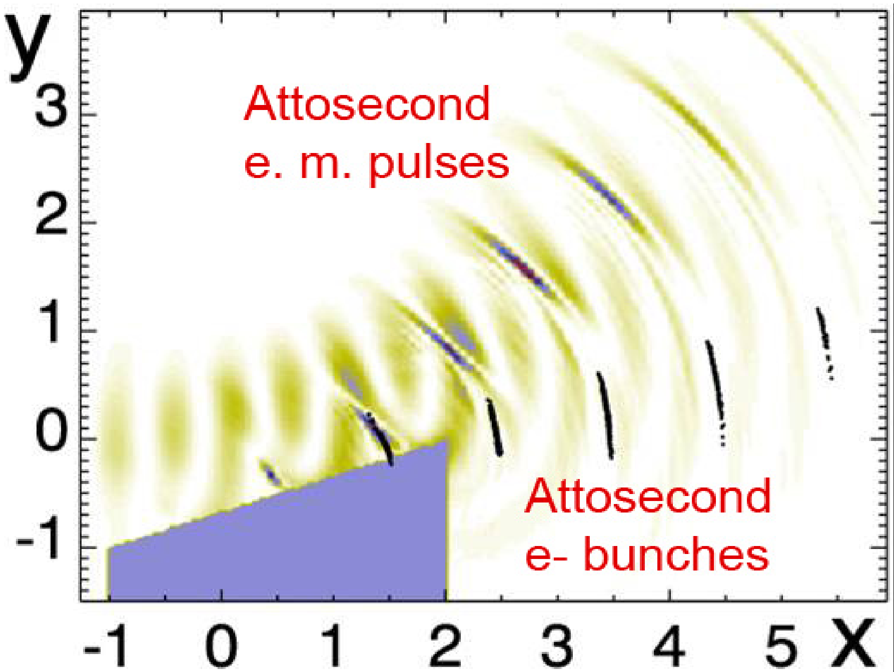
attosecond xuv/x-ray pulses?



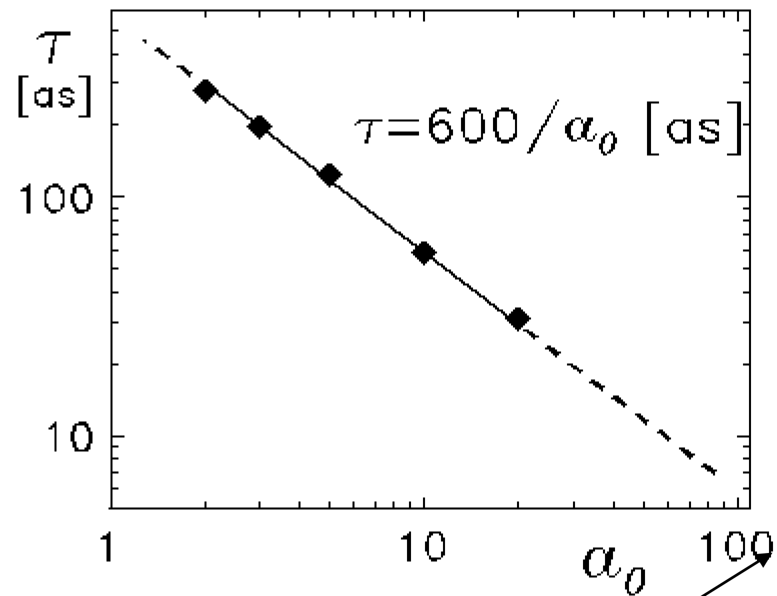
Attosecond Light Source (ALS):

sub-100-as, millijoule-microjoule pulses @ 10 – 1000 eV

Lambda cube regime



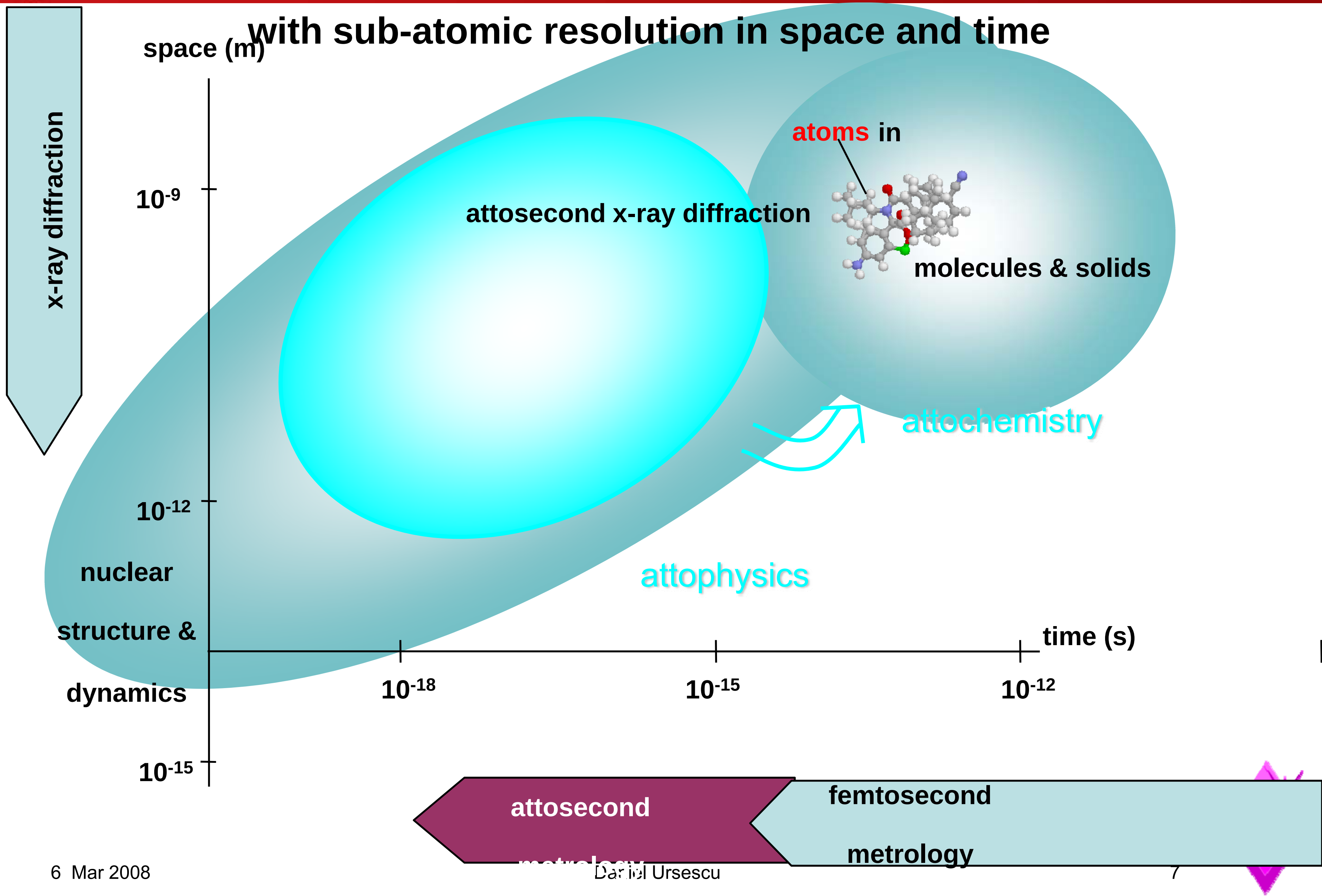
(Naumova 2005)



ELI

4-dimensional imaging

with sub-atomic resolution in space and time



1. Inner-shell nonlinear optics and coherent control, relativistic atomic and molecular physics

2. Real-time observation of intra-atomic electron dynamics

3. Control and real-time observation of electron dynamics in molecules and clusters

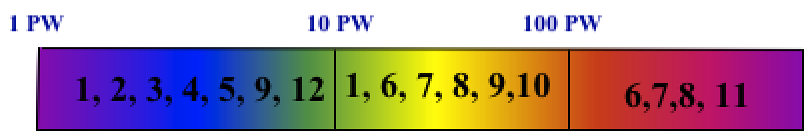
4. Real-time observation of electron transfer processes at interfaces

5. 4-dimensional microscopy of electron dynamics with nanometer - attosecond resolution

6. Laser generation of relativistic proton beams

7. Electron acceleration in wake field bubbles

8. Relativistic electron transport beyond the Alfven limit



9. Application to chemistry, radiolysis

10. Electron acceleration in wake field bubbles

11. Relativistic electron transport beyond the Alfven limit

12. Time-resolved defect creation with laser-produced ions

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Laser Produced Particle Beams Physics

Electron beam produced by laser

Proton beam produced by laser

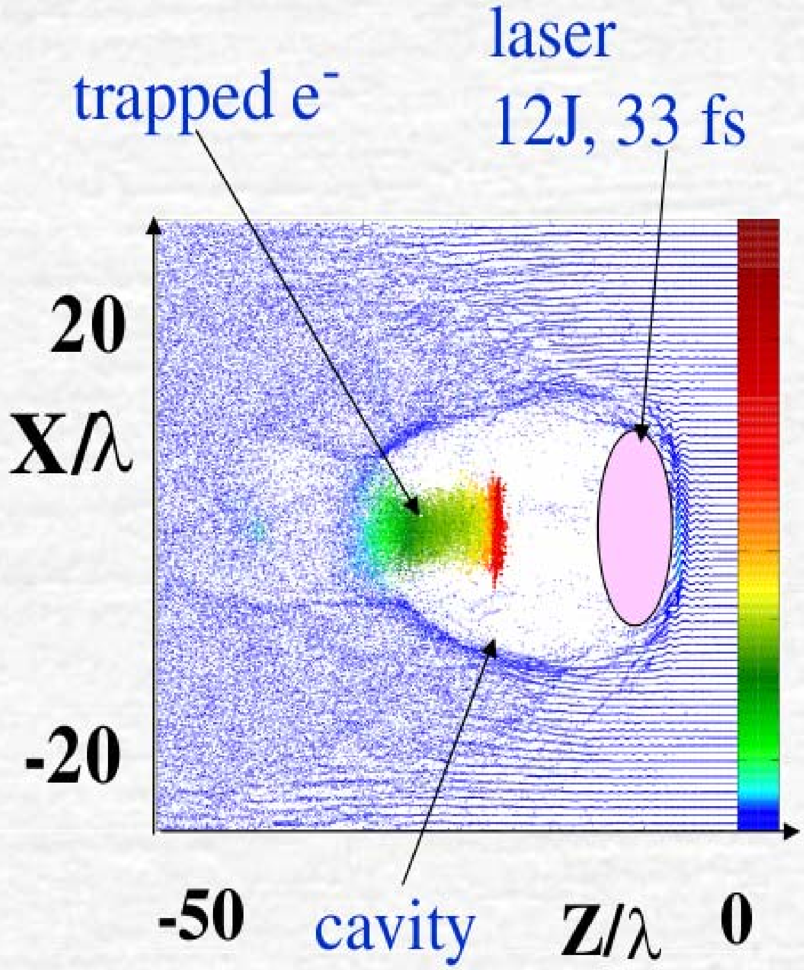
High-energy physics

1. Laser-produced pions, muons, neutrinos
2. Increasing the τ-lepton lifetime

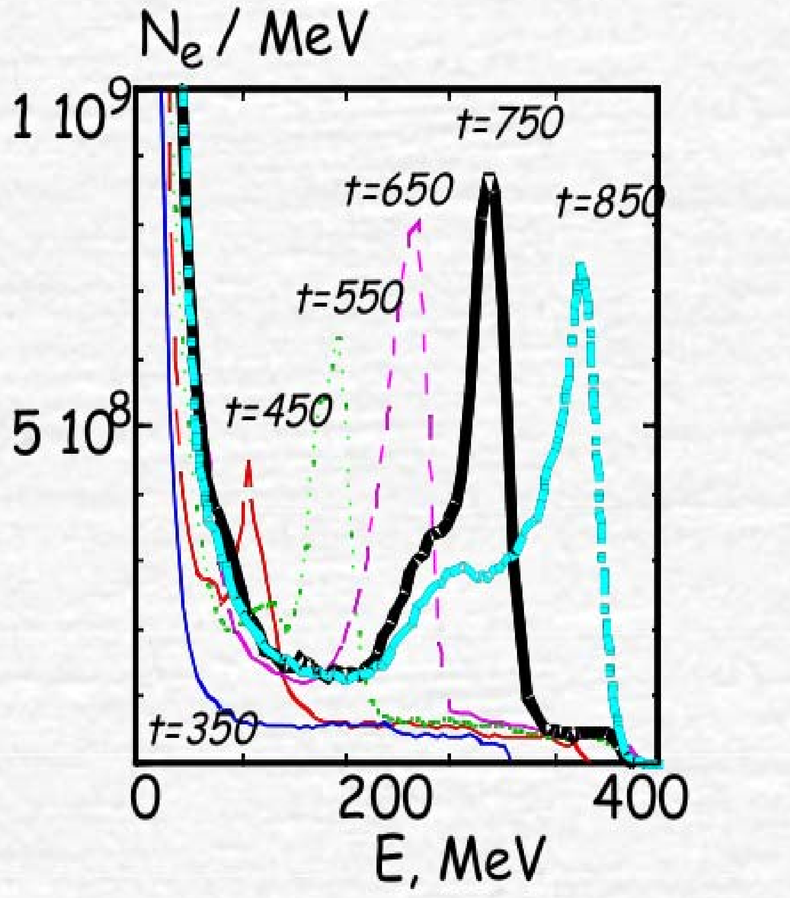
Ultra-relativistic case, $I=10^{20}$ W/cm^2: Bubble formation

VLPL

A.Pukhov & J.Meyer-ter-Vehn, *Appl. Phys. B*, **74,** *p.*355 (2002)



Time evolution of electron spectrum



Parameter designs Laser Plasma Accelerators

ELI : > 100 GeV

a_0=4

P(PW)	τ (fs)	n_e(cm^{-3})	W_0 (μm)	L(m)	E(J)	Q(nC)	E(Gev)
0.12	30	2e18	15	0.009	3.6	1.3	1.12
1.2	100	2e17	47	0.28	120	4	11.2
12	300	2e16	150	9	3.6k	13	112
120	1000	2e15	470	280	120k	40	1120

Golp and UCLA Group

Protons acceleration

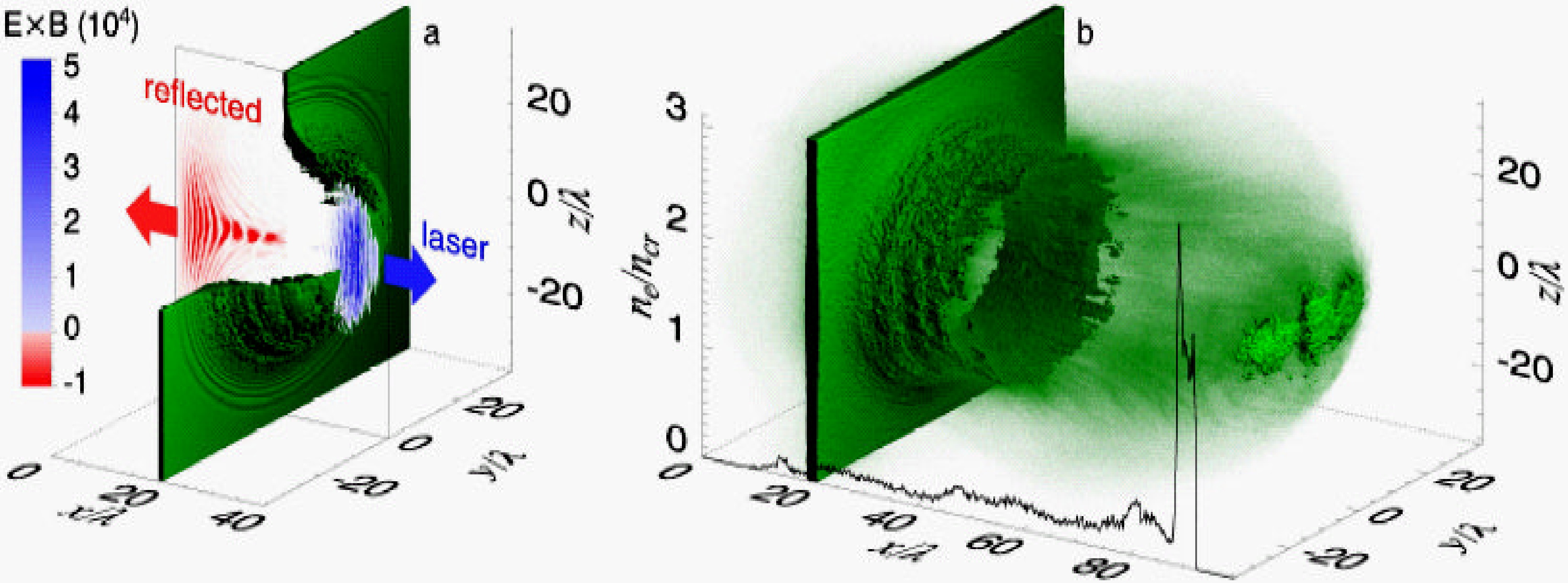
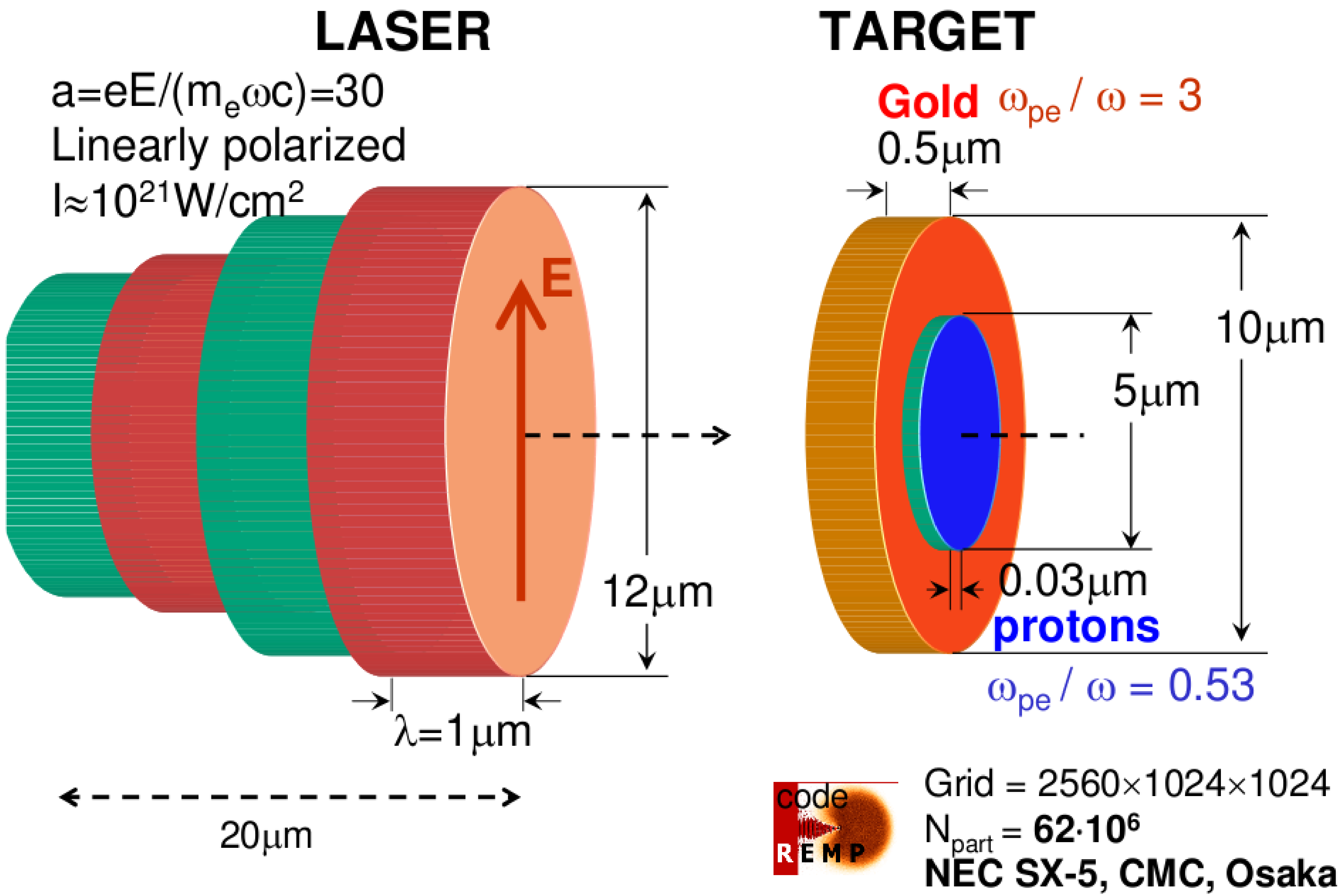
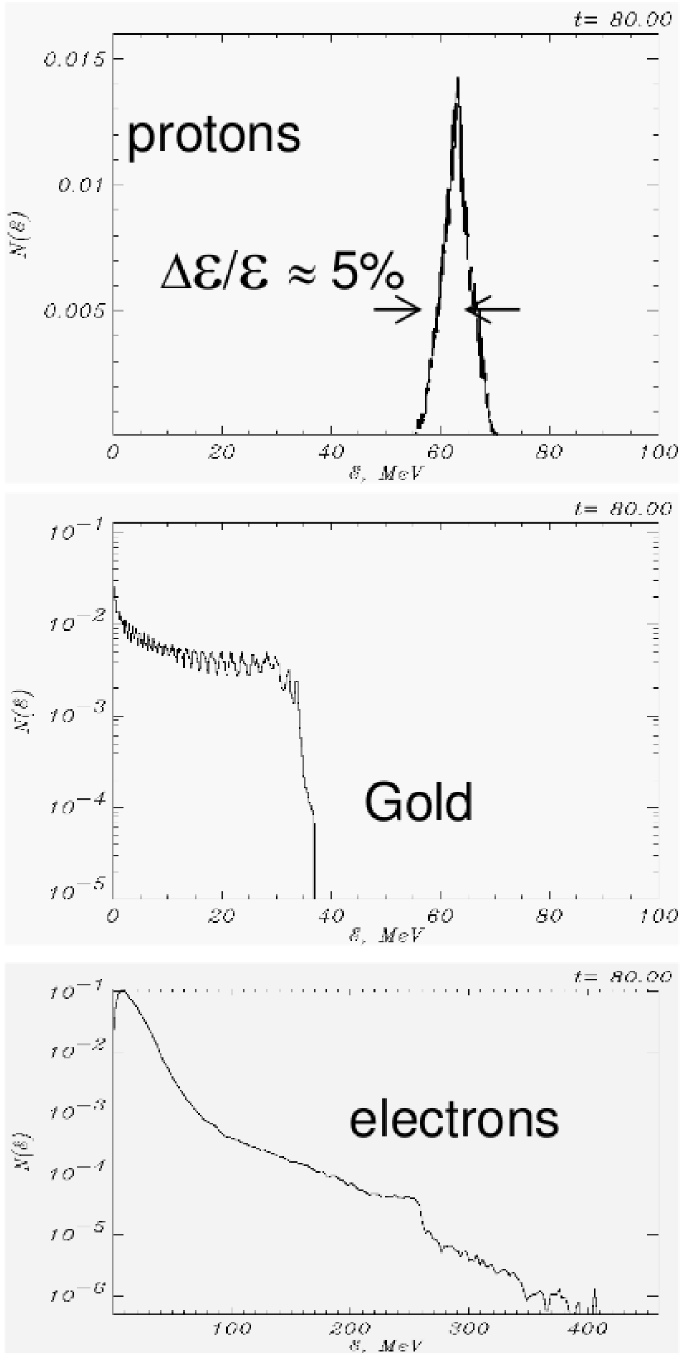


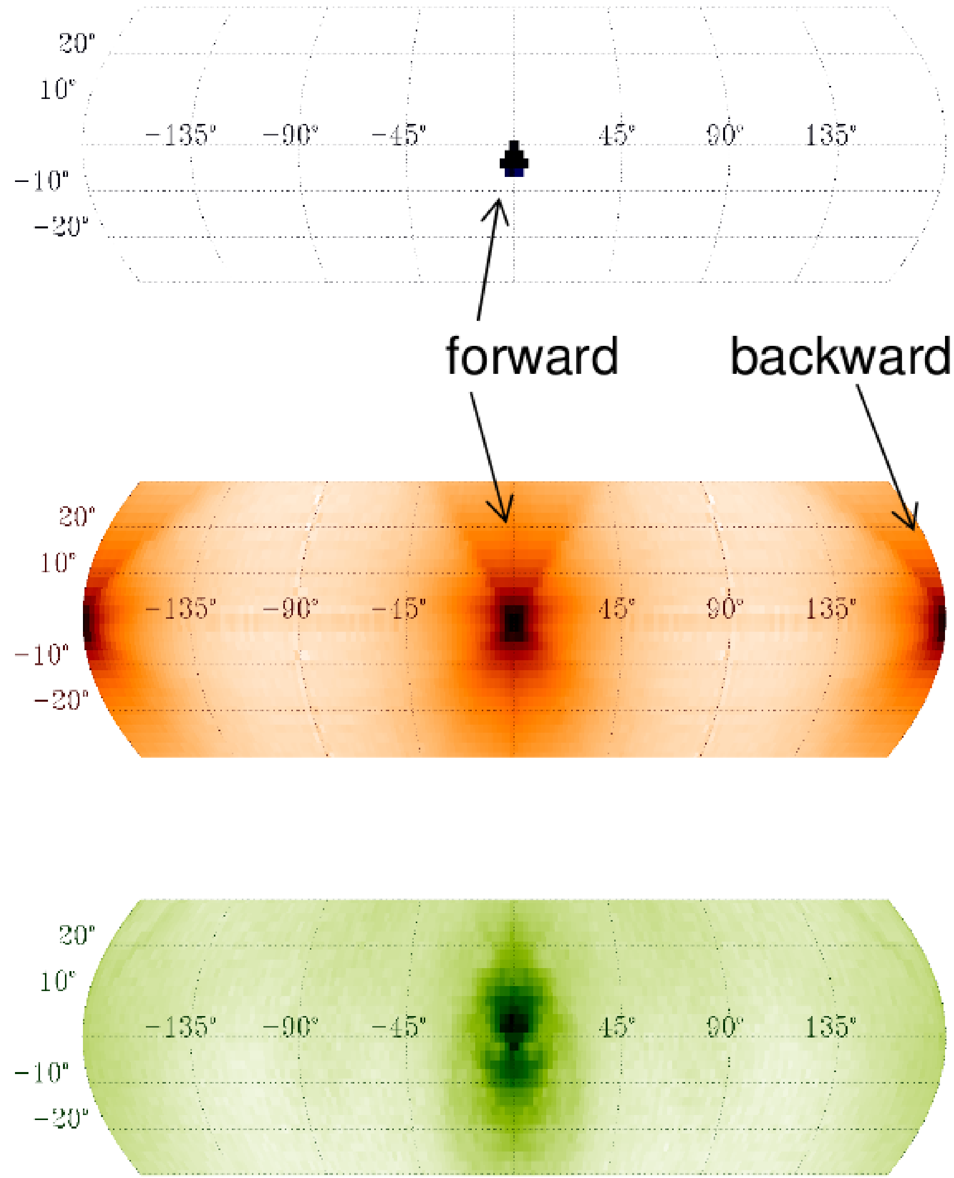
FIG. 1: (color). (a) The ion density isosurface for $n = 8n_{cr}$ (a quarter removed to reveal the interior) and the x-component of the normalized Poynting vector $(e/m_e\omega c)^2\,\mathbf{E}\times\mathbf{B}$ in the $(x, y = 0, z)$-plane at $t = 40 \times 2\pi/\omega$. (b) The isosurface for $n = 2n_{cr}$, green gas for lower density at $t = 100 \times 2\pi/\omega$; the black curve shows the ion density along the laser pulse axis.

3D Particle-in-Cell Simulation



<E> ≈ 63MeV


t= 80.00
protons
ΔƐ/Ɛ ≈ 5%
N(Ɛ)
Ɛ, MeV
t= 80.00
Gold
N(Ɛ)
Ɛ, MeV
t= 80.00
electrons
N(Ɛ)
Ɛ, MeV


forward
backward
20°
10°
−10°
−20°
−135°
−90°
−45°
45°
90°
135°

High-energy physics

Laser-produced pions, muons, neutrinos

The electric field reach 500 TeV/m at 10e23 W/cm2

Pion production yield according to 2D simulations has a treshold at 10e21 W/cm2

At high fields these can be accelerated up to 100 times their mass (140 MeV) during their lifetime (20 ns). So one could obtain collimated muon and neutrino beams.

Increasing the τ-lepton lifetime:

mass 1784 MeV; lifetime 300 fs, corresponds to about 100 microns and could be accelerated to several times its mass.

e1 quasi-monoenergetic 1-1.5 GeV

e2 two-stage generation and acceleration

e4 100GeV beam

p1 generation of 200 MeV protons

p2 generation of 1-10 GeV protons

High-energy physics questions:

E1. TeV accelerator, should linear or highly non-linear modes be used?

E2. Can we inject a beam in a plasma accelerator?

E3. What impact do very short electron bunches have on luminosity?

E4. How monochromatic can the beams be?

E5. What emittance can be obtained and what repetition rates?

E6. Is the power efficiency of a laser system acceptable?

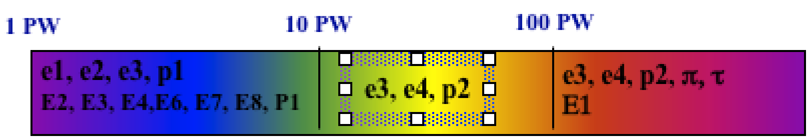
E7. What about producing and accelerating positrons?

E8. What about electron and positron polarization ?

Pion π pion generation

Tau τ generation, increasing its lifetime

Positron P1 positron generation



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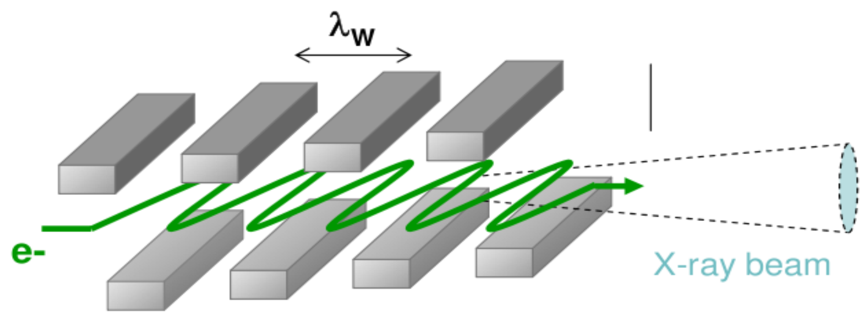
Laser produced x-ray beams

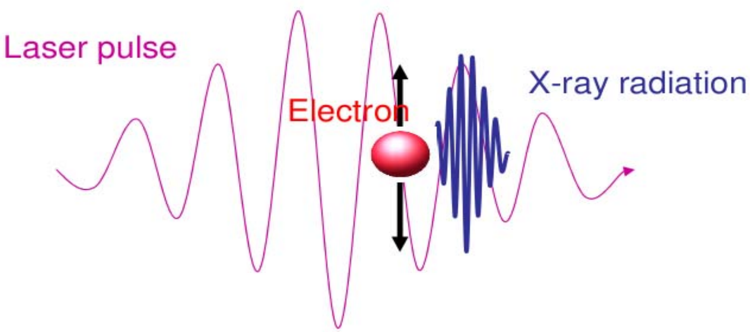
- Laser-assisted synchrotrons

- Free-Electron Laser (FEL)

ELI electron beam

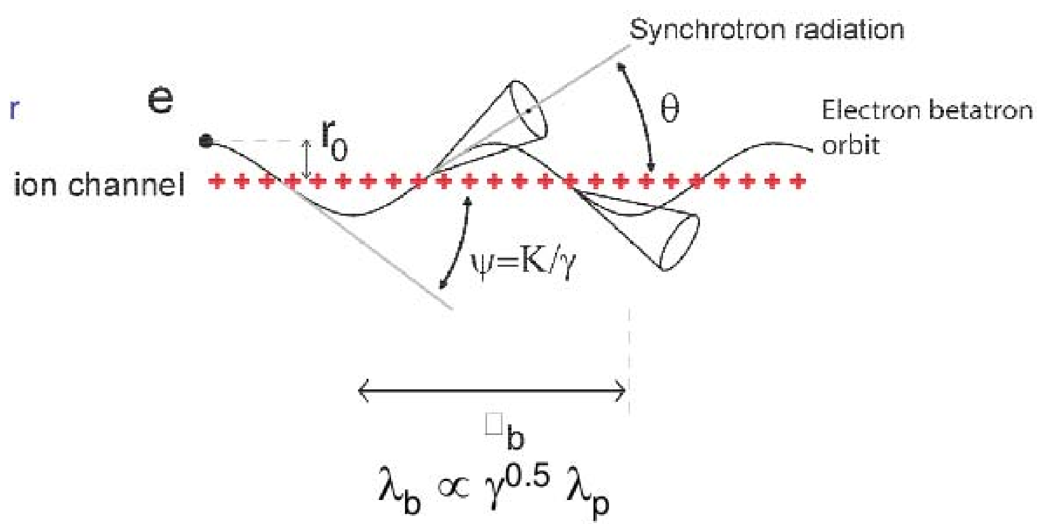


Static undulator



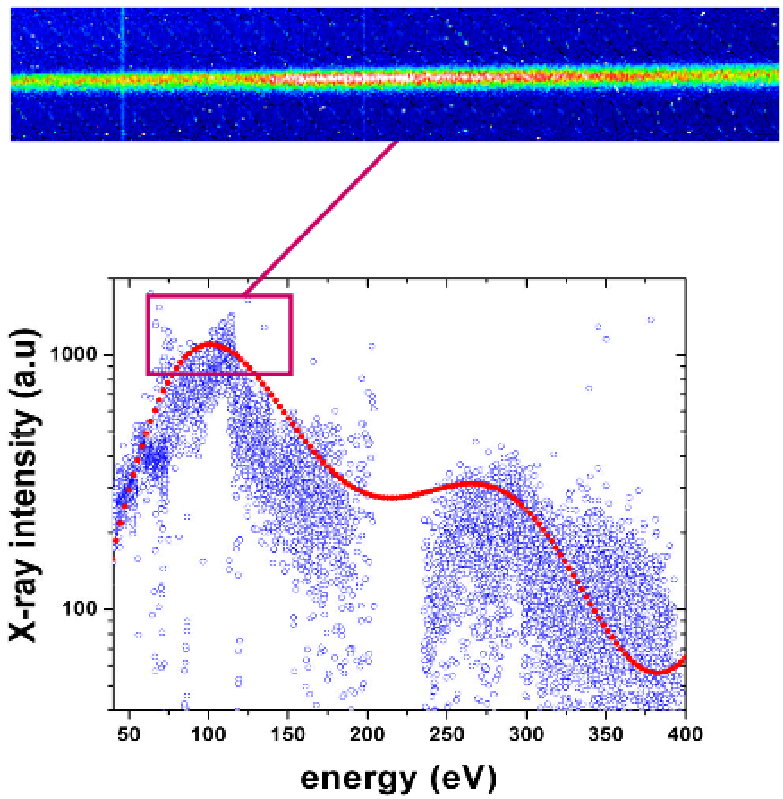
Compton scattering

Betatron



Non linear Thomson scattering

Now



a_0=5

~ 100 eV – broad band
~ 20°
~ 10^8 photons / shot/1keV bw
Femtosecond

ELI

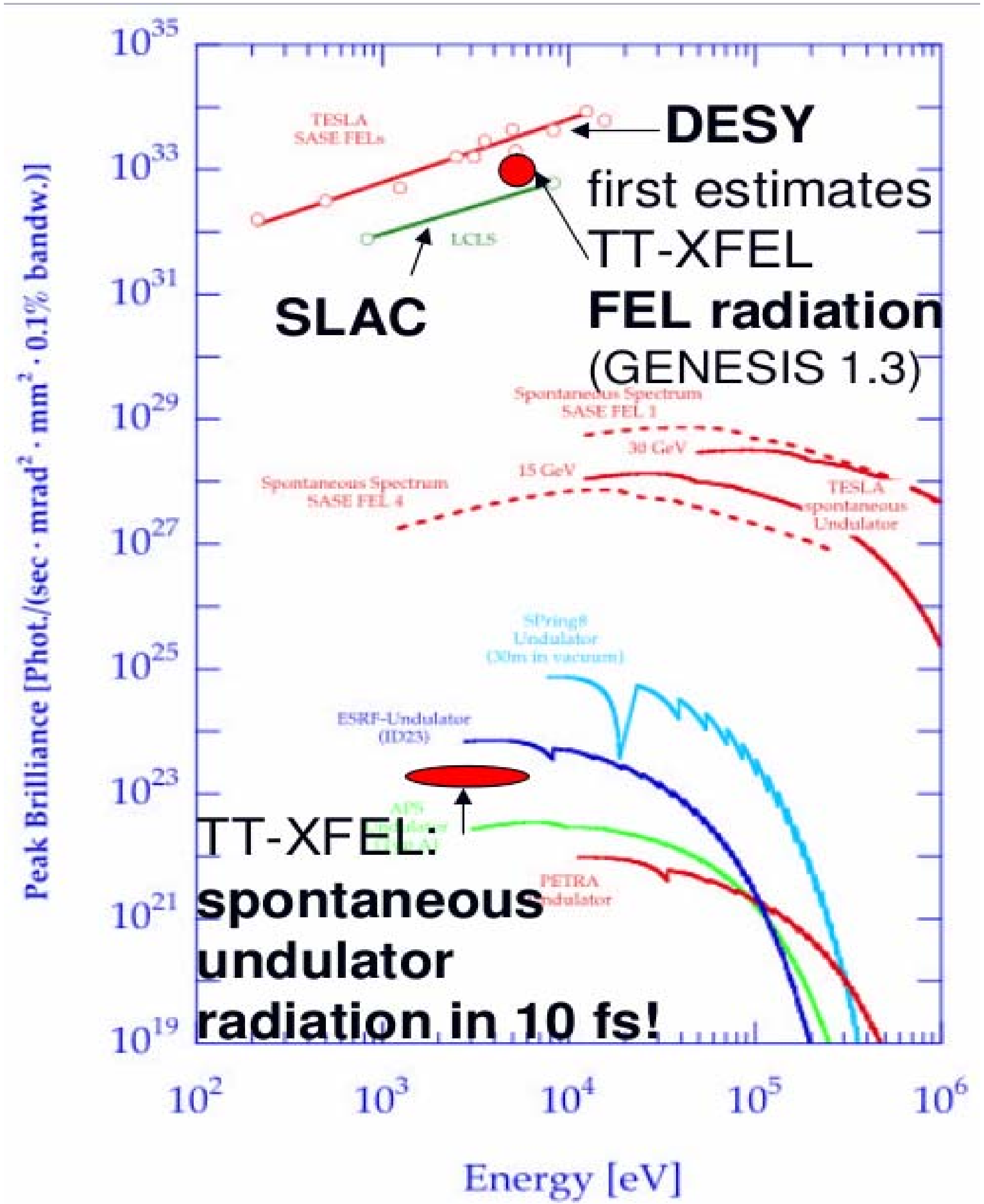
λ_x ~ 10 MeV

θ_x ~ 0.3 ° (6 mrad)

N_x ~ 10^{11} ph/shot/0.1%BW

τ_x < 10 fs

Comparison


Peak Brilliance [Phot./(sec · mrad² · mm² · 0.1% bandw.)]
Energy [eV]
TESLA
SASE FELs
LCLS
DESY
first estimates
TT-XFEL
FEL radiation
(GENESIS 1.3)
SLAC
Spontaneous Spectrum
SASE FEL 1
30 GeV
15 GeV
Spontaneous Spectrum
SASE FEL 4
TESLA
spontaneous
Undulator
SPring8
Undulator
(30m in vacuum)
ESRF-Undulator
(ID23)
PETRA
TT-XFEL:
spontaneous
undulator
radiation in 10 fs!

Laser assisted synchrotron

XFEL

Betatron

Efficient ultrafast beams of x-rays

...10-100 keV

...10 fs

...10e6 to 10e9 ph/shot/0.1%BW

...50 microrad to 5 mrad

...1 Hz

Multidisciplinary applications

Pump-probe at fs time scales,

ultrafast zooming on the atomic landscape

Compton scattering

gammaFEL (above 50 GeV electrons)

Efficient ultrafast beams of Gamma-rays

...MeV to 100 MeVs

...10 fs

...10e9 to 10e11 ph/shot/0.1%BW

...50 microrad to 5 mrad

...1 Hz

Particle physics

(gamma-gamma colliders, neutron production)

Plasma physics (probing dense matter)

Laser produced x-ray beams

- Laser-assisted synchrotron
- Compton scattering
- Betatron
- Free-Electron Laser (FEL)

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Laser-Plasma interaction

Propagation of intense laser pulses in dense matter

chanel formation relevant to ICF

Electromagnetic solitons

stationary, long lived (tens of ps) electromagnetic fields for study of nuclei in strong EM fields

Limited-mass targets, multiple ion species acceleration

acceleration from clusters

High-current electron beam transport

relevant to ICF, and possibly

positron production (e- with Z=80)

High-energy-density matter

relevant to ICF and astrophysics

(phase transitions in planet cores)

Time-resolved relativistic plasma physics with ELI

relevant to ICF and understanding of the acceleration mechanism

Nuclear Physics and Astrophysics

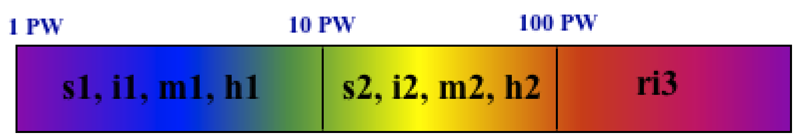
-s1, s2 electromagnetic soliton

-m1, m2 limited mass target

-ri3 relativistic ions

-i1, i2, i3 high-current electron beam transport

-h1, h2, h3 high energy density matter interaction



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Nuclear Physics and Astrophysics

Direct interaction of nuclei with EM fields (at 10e26 W/cm2, each proton would get up to 100eV)

Changing the nuclear level lifetimes (at 10e22-24 W/cm2, internal conversion would be affected)

Neutron-rich nuclei (based on coherent harmonic focusing... producing harmonics on U nuclei)

Decay of neutron-rich nuclei (study of the elongation of the nucleus in E field until it fissions; ELI might provide up to 10e12 T magnetic fields, relevant to white dwarves and neutron stars as laboratory astrophysics)

Developing new detector technology (needed ultrafast detection; EM field devices to control the particle beams)

Electron-positron pair production (counter propagating beams on high-Z targets or in vacuum)

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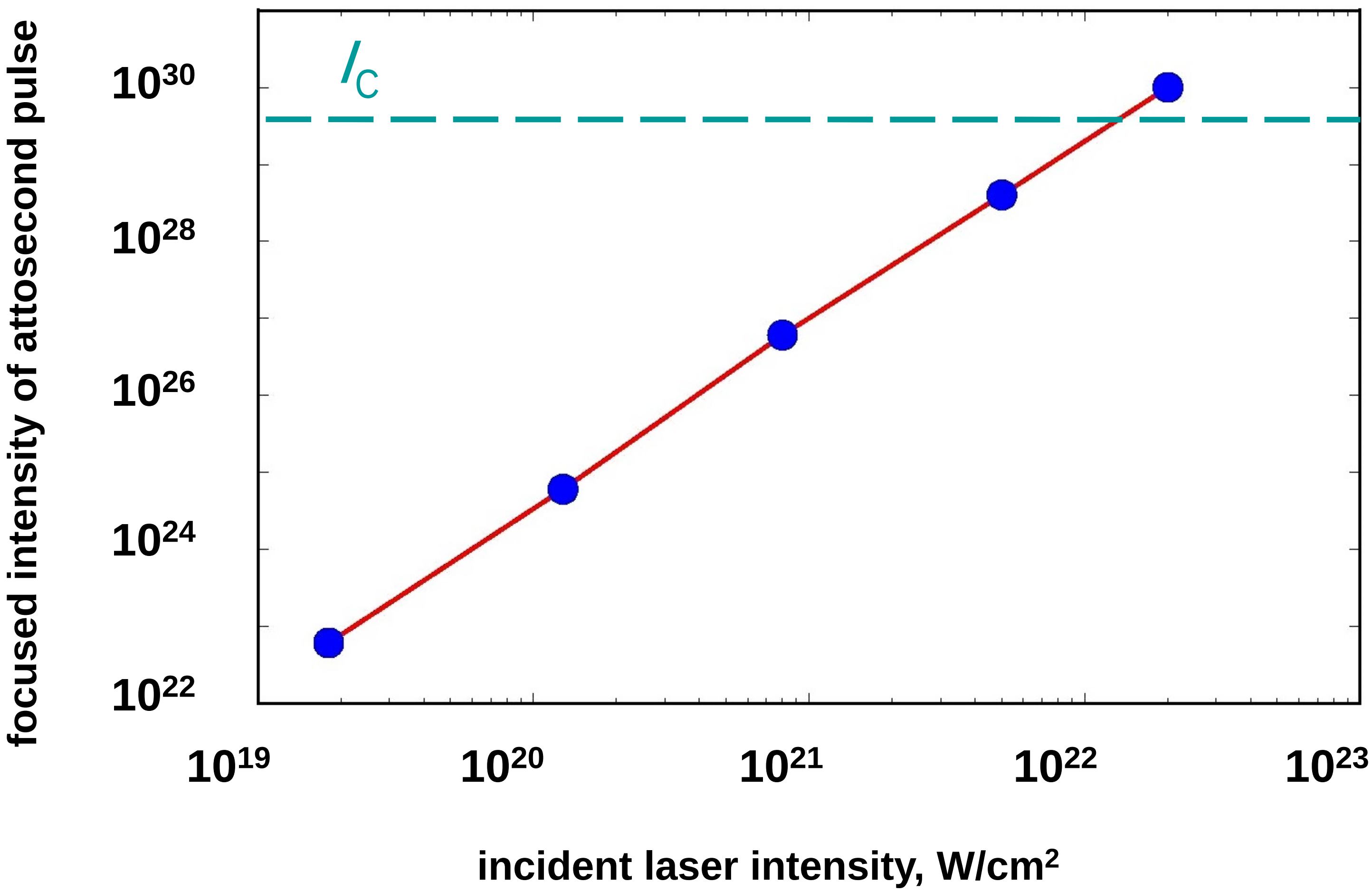
"Exotic Physics"

nonlinear vacuum, nonperturbative quantum electrodynamics?



S. Gordienko, A. Pukhov, O. Shorokhov, T. Baeva, *Phys. Rev. Lett.* 94, 103903 (2005)

“Exotic Physics”

Exploring the fundamental properties of vacuum (breakdown is a fundamental QED process : e-/e+ creation at high fields needs 10e26 W/cm2 at least)

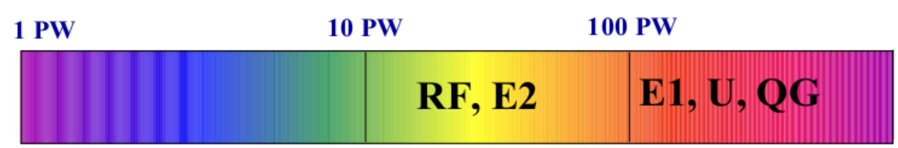
Observing vacuum polarization (10e22 W/cm2)

e+e- annihilation and the evolution of the universe (mater-field as in early universe)

Observing Unruh radiation (high acceleration for e- => interplay of GR and QFT)

Extra dimensions

Quark-gluon and neutrino oscillations (at 100 GeV/nucleon, maybe)



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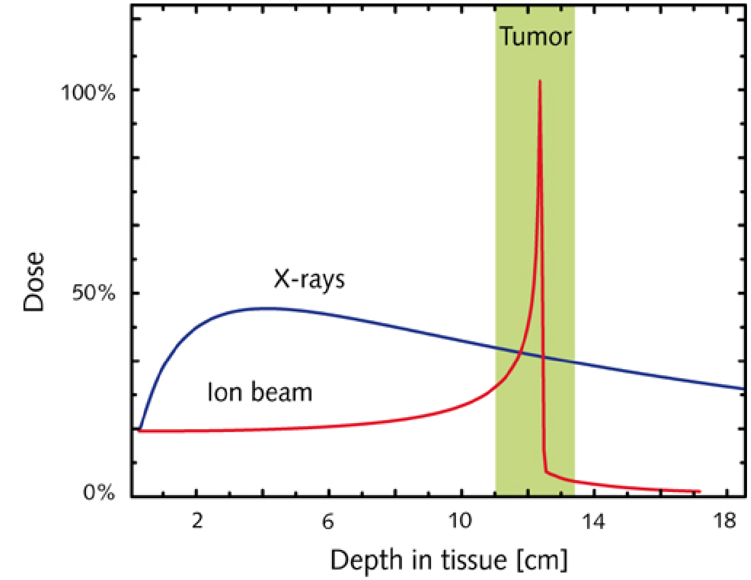
Applications

Medicine:

1 Application to Hadron Therapy



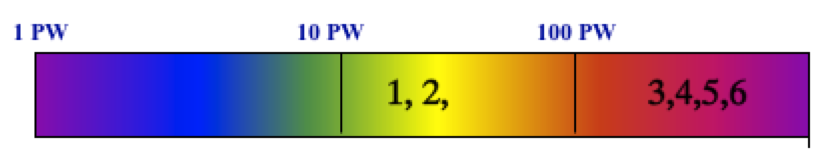
Secondary Sources for Material Science Studies

2 Understanding fundamental aging processes in nuclear power plant material (ion-pump – laser-probe experiments at sub ps scale)

3 Positron microscope

4 Positron sources for Bose-Einstein Positronium condensate

5-6 Improving environment: transmutation and nuclear waste treatment via laser induced photo transmutation or via hot plasma production with gama radiation emission on Ta target and subsequent nuclear reaction



Scientific Case - Review

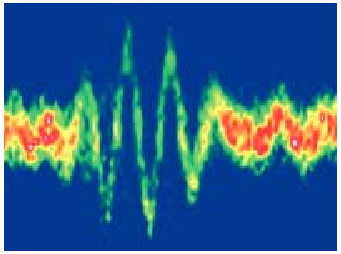
An outstanding tool for plasma and high-field physics

ELI will be the only infrastructure dedicated to the fundamental study of laser-matter interactions in the new ultra-relativistic regime ($I_L > 10^{23}$ W/cm²).

Relativistic compression will offer the opportunity to exceed intensities of 10^{25} W/cm², which would challenge the vacuum critical field as well as provide a new avenue for studying ultrafast attosecond to zeptosecond (e.g. 1,000 time less laser-matter interaction.

ELI : an outstanding tool !

Unraveling the ultrafast processes from molecules to quarks at the attosecond timescale

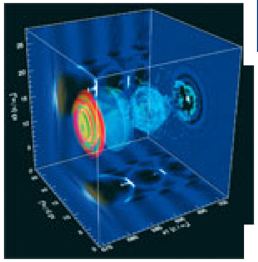


A recent revolution in laser technology has opened the door to a generation of flashes of light that can freeze the ultrafast motion of electrons inside atoms and molecules. Our emerging capability of generating reproducible attosecond-duration bursts of light marks the beginning of a new era in exploring motion in the microcosm : the era of attoscience. Attoseconds (10^{-18}s) constitute the natural scale for the motion of electrons at the atomic scale. This motion now comes under scrutiny in real-time studies.

Providing femtosecond sources of particles

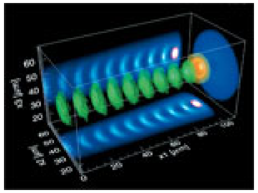
ELI laser interaction with matter will lead to the generation of particle and radiation beams with original properties. Attosecond time durations of energetic electrons and intense x-rays are foreseen.

ELI will be the only European and International Centre for Femtosecond x-rays Innovative schemes of compact particle accelerators would lead to attosecond energetic (up to the TeV) electron bunches as well as bright flashes of x and g rays. These intrinsically synchronised particle and radiation ultra-short beams will offer unique tools for studying matter through pump-probe experiments.



Femtosecond x-ray

For decades x-rays emitted by synchrotrons have been widely used in Biology, Chemistry and Physics to probe or excite a very large diversity of samples. Although these machines remain of great importance for users, new sources based on ultra-intense lasers are offering a fresh approach by shortening the pulse duration by a factor of 100,000 or by increasing the number of photons per pulse by 9 orders of magnitude. Thanks to the versatility of its laser, ELI will offer the unique possibility to achieve pump-probe experiments by coupling attosecond x-ray pulses with femtosecond particle beams.



Your contribution here!