Intense laser infrastructures

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Intense laser infrastructures

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A very high power focused into tiny spots
to produce hot and dense matter and intense fields

Hot and dense matter relevant to ...

Energy production in the sun

15 000 000°

Structure of planetary cores

Millions of atmospheres

Access to the domain of high-energy density

Intense fields to accelerate particles ...

Acceleration of GeV electrons over few mm

Laser beam

Gas jet

GeV electrons

W.P. Leemans et al., Nature Physics 2, 696 (2006)

Three families of laser systems for complementary applications

Illustration with the French panorama

Nanosecond family - Nd:glass amplifiers up to 400 mm

from 1 kJ - tennis court size

LULI2000

LULI2000

to MJ - Eiffel tower size

NIF

LMJ

Picosecond family – chirped-pulse amplification

Nd:glass amplifiers up to 400 mm

Picosecond family - Nd:glass amplifiers up to 400 mm

from 10 J

LULI-ELFIE

LFEX-OSAKA

PETAL-Aquitaine

to kJ

Ω -EP

VULCAN

Main ns-ps laser facilities

Femtosecond family – Ti:Sa amplifiers up to 150 mm

from 100 TW – 10 J

LASERIX

HERCULES

TREX - LBNL

to PW

APOLLON

Hungary

Czech Republic

ELI s

Romania

Centre interdisciplinaire lumière extrême

CILEX- APOLLON

General objective

Develop **CILEX**

a Research Centre on Intense Lasers, Plasmas and Applications

hosting the most powerful lasers

APOLLON 10P

and smaller scale facilities

CILEX-PHAC

for pluridisciplinary programs

and training of scientists
and engineers

Operated as a user-facility

Three scientific domains in the high-intensity regime

Science at ultra-high intensity

ultra-relativistic regime

particle physics

field theory ...

Attosecond science

attosecond scale imaging

electron dynamics in atoms, molecules,
plasmas or solids

High-energy beams

ultra short beams

of energetic particles ($>10 \text{ GeV}$)
and radiation $\rightarrow \gamma$

and applications

At high intensity, laser-matter interaction produces high-energy e^-

At high intensity $v \times B$ term accelerates electrons forward with $v \approx c$

On solid targets E or $v \times B$ injects electrons at ω or 2ω

sub-fs electron bunches at 2ω

H. Popescu et al., *Physics of Plasmas* **12**, 063106 (2005)

Laser-matter interaction as a photon – electron transformer ...

A large fraction of laser energy converted to high-energy electrons

The parameters of the electron beams are extreme and physics is complex

Order of magnitude for 1 J and 1 MeV

$$Q \approx \mu\text{C}, \tau < \text{ps}, \Phi \approx 10 \mu\text{m}, I > 10^6 \text{A}, j \approx 10^{11} \text{A/cm}^2$$

Space charge effects

Induced fields: **return current**, focusing, guiding

Instabilities : **Weibel**, filamentation, coalescence, ...

Collisions: **slowing down**, scattering

Accelerated electrons induce high E-field accelerating ions

today : small fraction of electrons ejected

present record: protons ≈ 100 MeV

tomorrow : expulsion of all electrons inside focal spot

multi-GeV protons

T. Esirkepov et al., *Physical Review Letters* **92**, 175003 (2004)

Laser electron acceleration: toward high energies

Acceleration to high energies $\rightarrow$ TeV ?

multistage acceleration

quality, stability of beams

example of 2 possible injector+accelerator setup schemes

Laser beams - a variety of generation mechanisms of intense and collimated X and γ -ray beams

Betatron emission: electrons inside the plasma

Free-electron laser: electrons + undulator

Compton scattering: electrons + laser

The interesting case of electron beam - laser beam interaction

In its rest frame, the electron sees a frequency $\approx 2\gamma\nu$

... it emits a dipole radiation at frequency $2\gamma\nu$

... back to the lab frame it emits at frequency $4\gamma^2\nu$

High-order harmonics, attosecond pulses

Simulations predict wide enough spectra
for attosecond to zeptosecond pulses

80 as already demonstrated

F. Krausz et al., (2008)

An example of physics at ultra-high intensities (??)

e^-e^+ pair production: Schwinger limit

Laser fields separates virtual electron and positron

Condition:

separate the 2 particles by Compton length during lifetime

or

transfer energy $2mc^2$ with E_{laser}

$$eE\lambda_c/(2\pi)^2 > 2mc^2$$

$$I > 10^{29} \text{ W/cm}^2 \cdot \mu\text{m}^2$$

We are very very very far from it ...

... but nice physics can be studied below this limit

(cf. M. Marklund)

My own experience on strange physics (for a plasma physicist !!)

Light shining through the wall (C. Robilliard et al.)

C. Robilliard et al., PRL **99**, 190403 (2007)

Search for axions by light shining through the wall

Or: How to be sure your result is correct ?

My own experience ... (2)

Stimulated photon scattering at a cms energy of 0.8 eV

(D. Bernard, F. Moulin, F. Amiranoff)

D. Bernard et al., EPJ D 10, 141 (2000)

40 fs, 4-6 μm focal spots

Collision between 3 fs beams in vacuum

Detection of scattered photons ?

$\sigma < 10^{-48} \text{ cm}^2$ - still 18 orders of magnitude from QED

Or: How to be sure your result is correct ?

A few characteristic parameters

All values for 1 J - 3 fs - 1 μm^2 at 1 μm wavelength

$$I \approx 3 \cdot 10^{22} \text{ W/cm}^2$$

$$n_{\text{ph}} \approx 10^{31} \text{ photons/cm}^3$$

in beam-beam collisions ≈ 1 event for $\sigma > 10^{-46} \text{ cm}^2$

$$\text{energy density} \approx 10^{12} \text{ J/cm}^3$$

$$E \approx 5 \cdot 10^{14} \text{ V/m}$$

$$50 \text{ kV/\AA}$$

$$0.5 \text{ V/fm}$$

better for you to check ...

and find other parameters of interest

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