Laser Acceleration – Towards Highest Gradients

Luis Roso
Director
Centro de Láseres Pulsados,
CLPU, Salamanca
Spain

Grand Challenges in Accelerator Optimisation

CERN, Switzerland: 26th/27th June 2013

UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"

Junta de Castilla y León

MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

VNiVERSiDAD D SALAMANCA

Optimization of Particle Accelerators

Pulsed laser technology

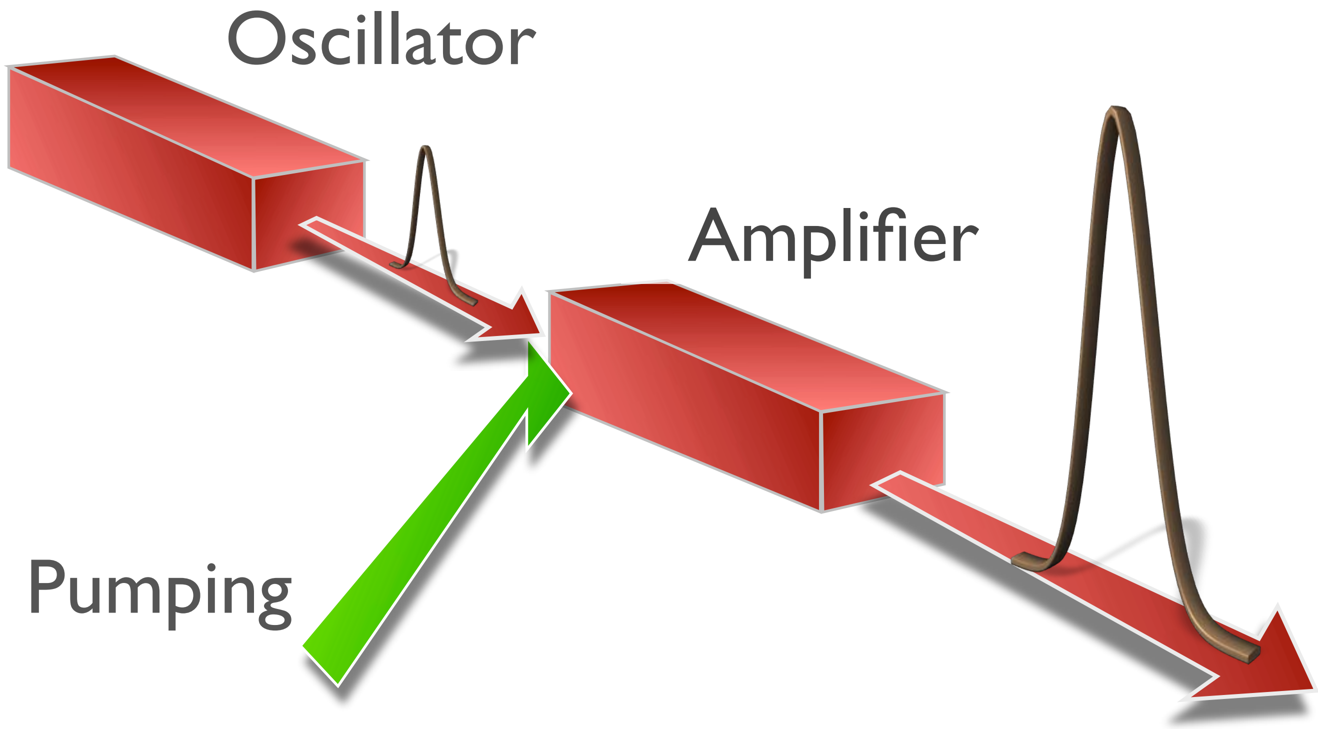
Extreme lasers

What do they offer to optimize particle acceleration
- Improve existing strategies
- New ideas

Pulsed lasers

Oscillator + Amplifier

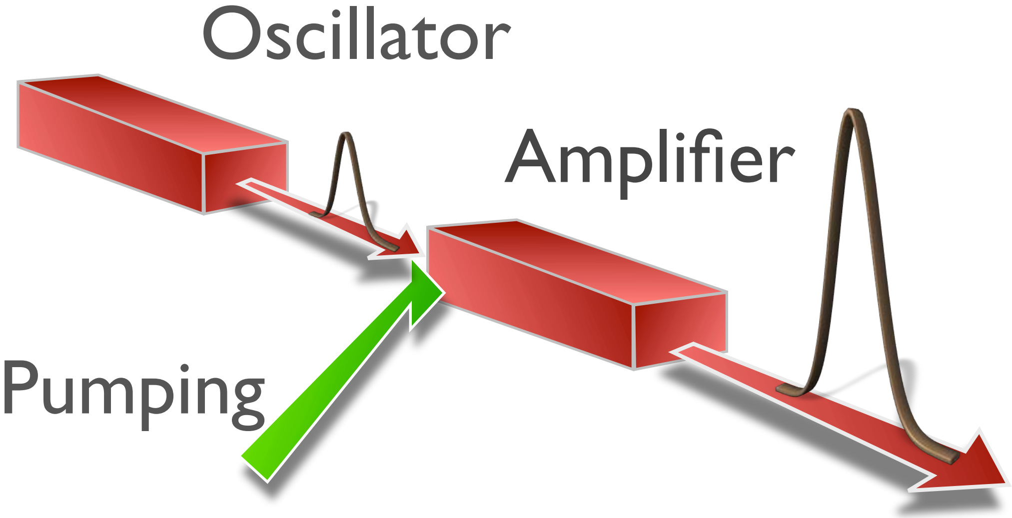
Main limitation for amplification is damage threshold of the amplifier



Oscillator + Amplifier

To avoid damage of the amplifier,
there are two options:

Expand the beam in tranversally
... big crystals
Expand the beam longitudinaly
i.e expand in time
...stretch the pulse



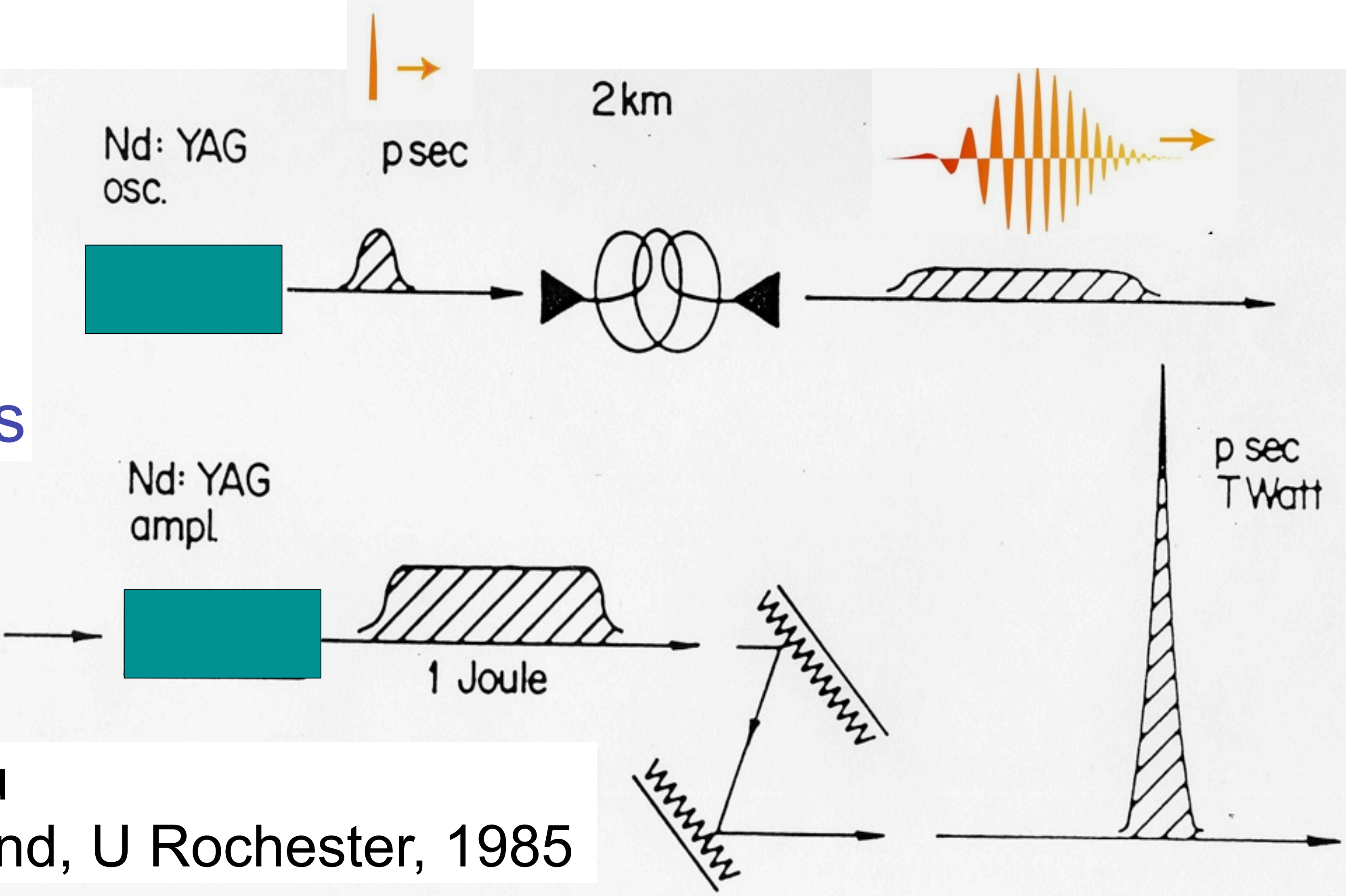
Chirped Pulse Amplification, CPA

Three steps

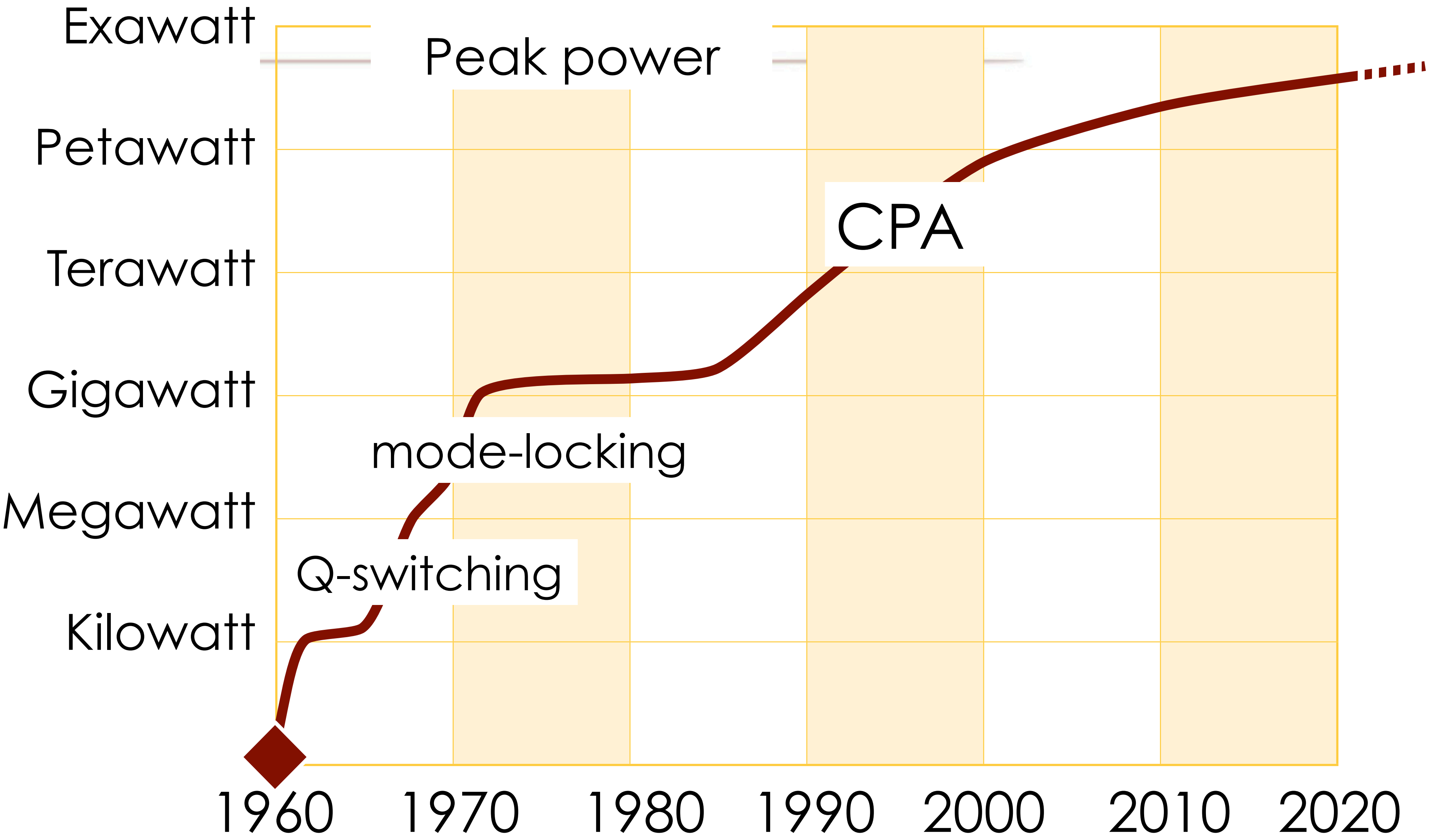
1.- strectch

2.- amplify

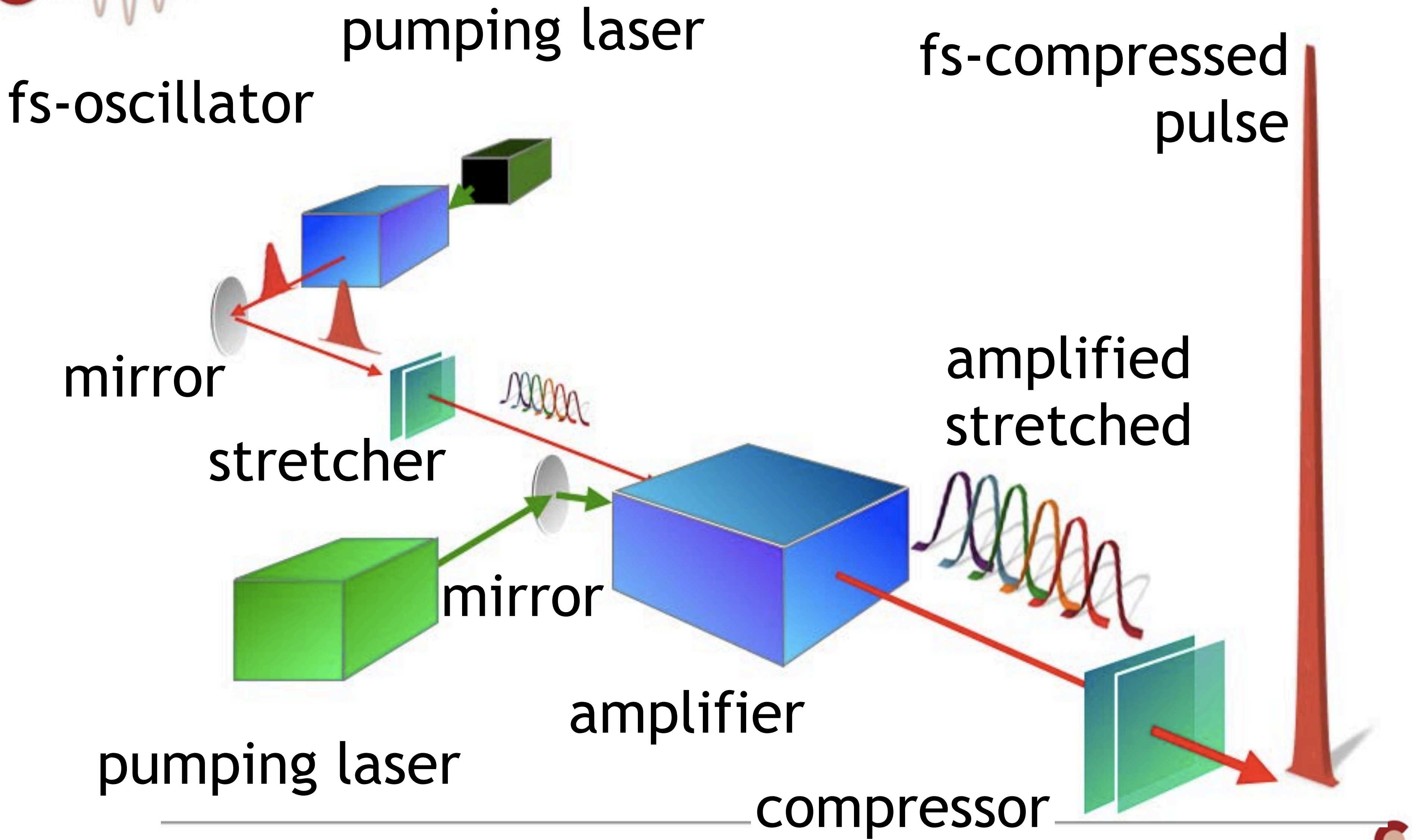
3.- compress



Gerard Mourou
Donna Strickland, U Rochester, 1985


Peak power
Exawatt
Petawatt
Terawatt
Gigawatt
Megawatt
Kilowatt
CPA
mode-locking
Q-switching
1960
1970
1980
1990
2000
2010
2020

CPA Chirped Pulse Amplification



pumping laser

fs-oscillator

fs-compressed pulse

mirror

stretcher

amplified stretched

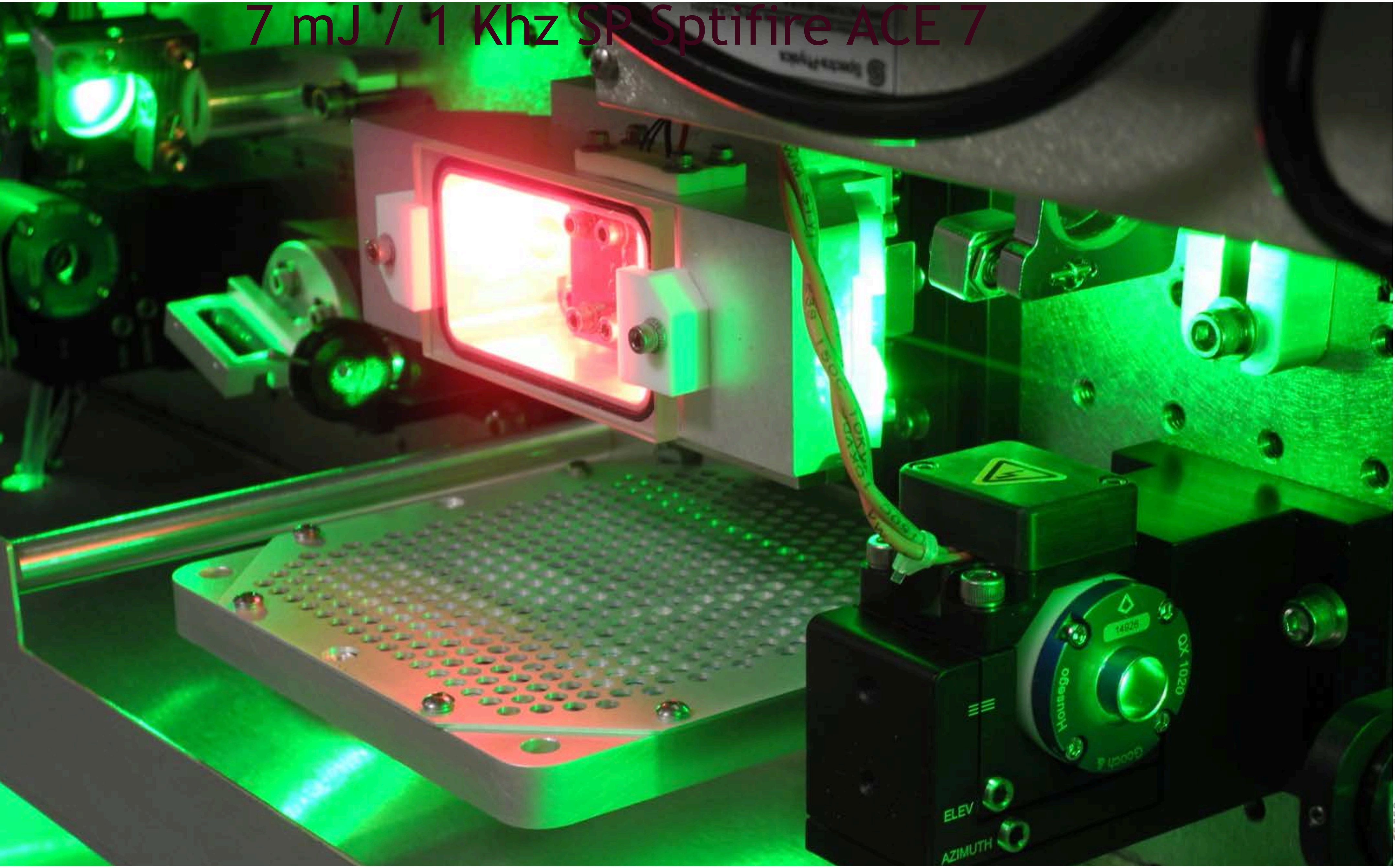
mirror

amplifier

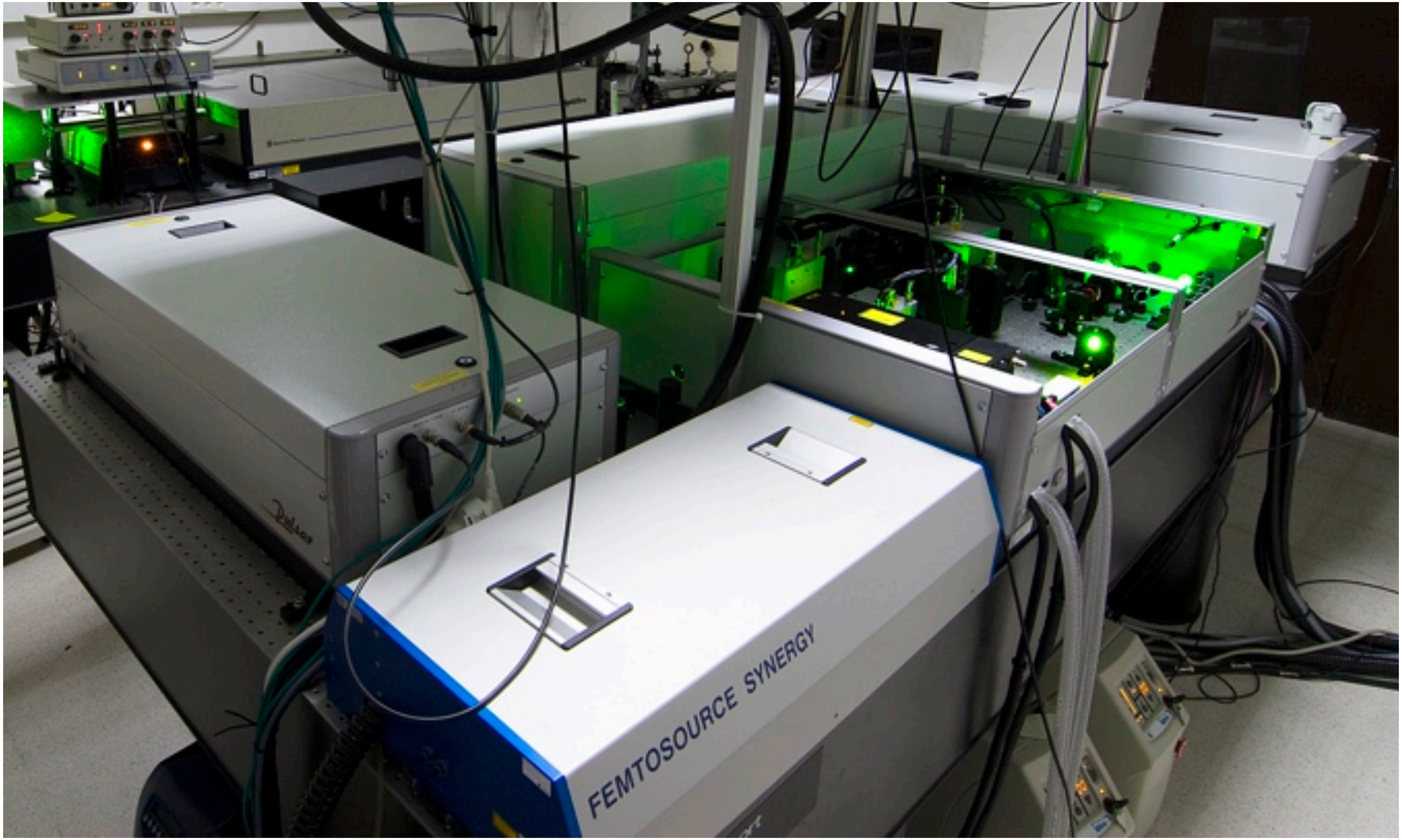
pumping laser

compressor

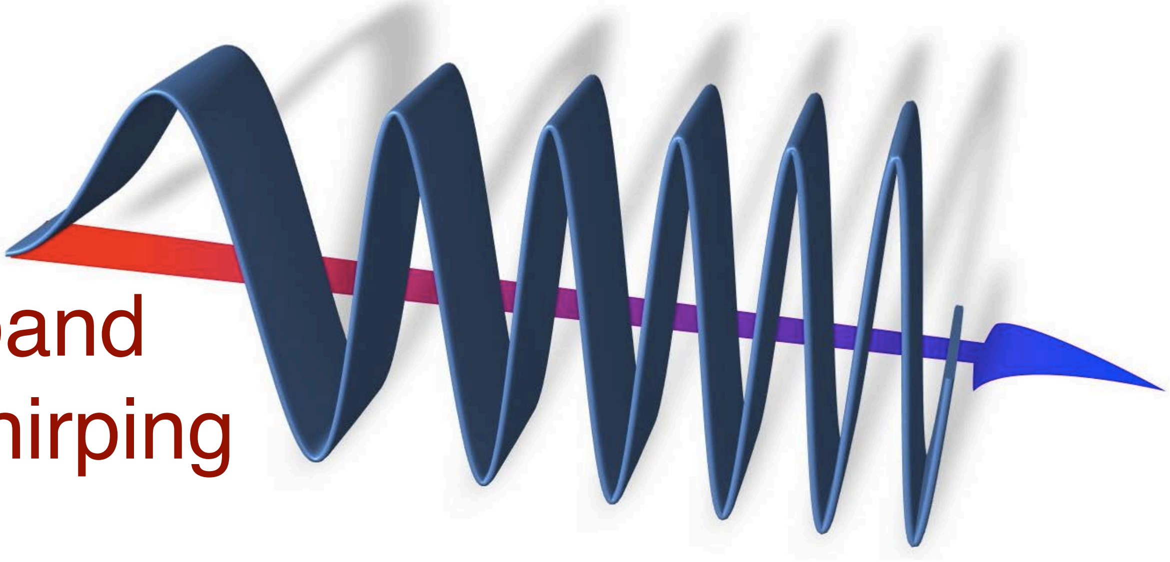
7 mJ / 1 Khz SP Sptifire ACE 7



CENTRO DE
LASERES
PULSADOS
ULTRACORTOS
ULTRAINTENSOS

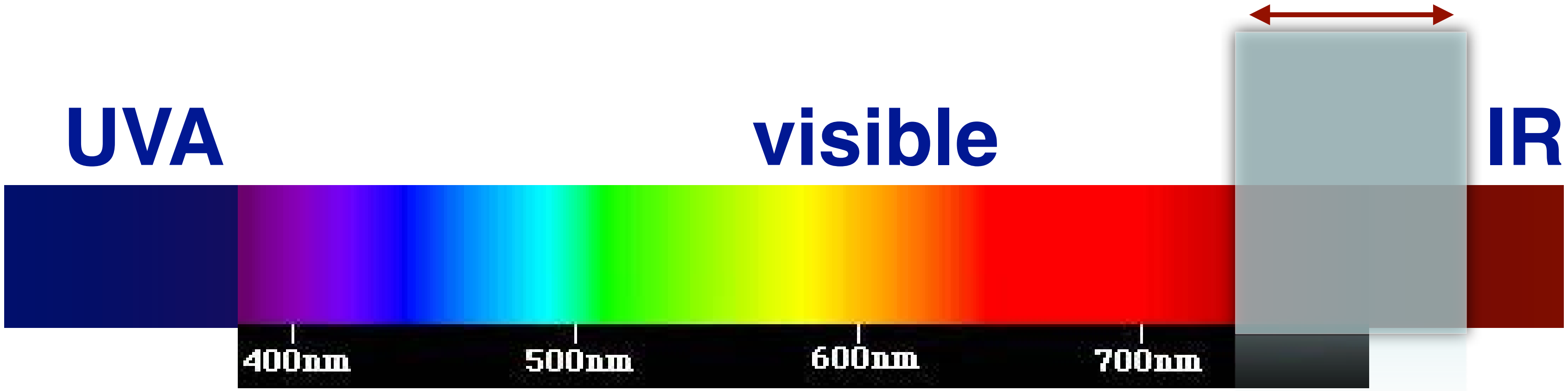

FEMTOSOURCE SYNERGY

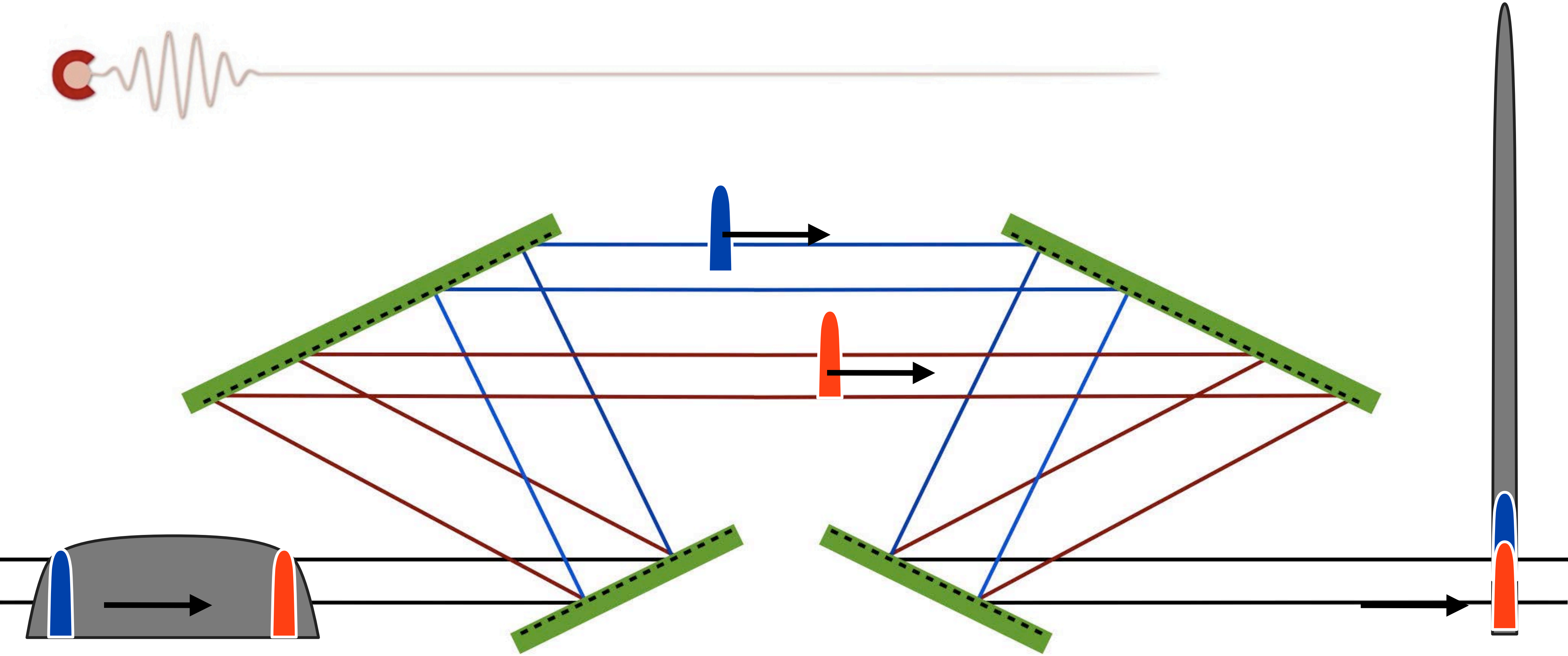
short pulse = broadband laser

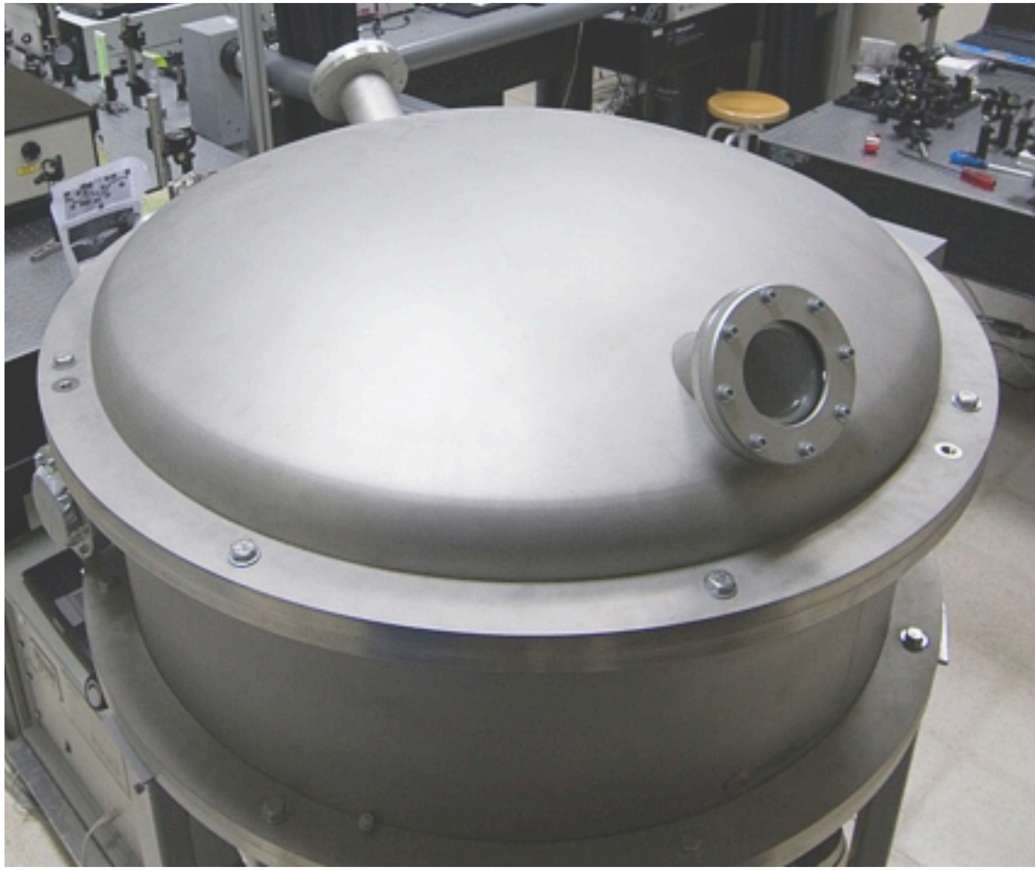


broadband
allows chirping

30 fs
30 nm



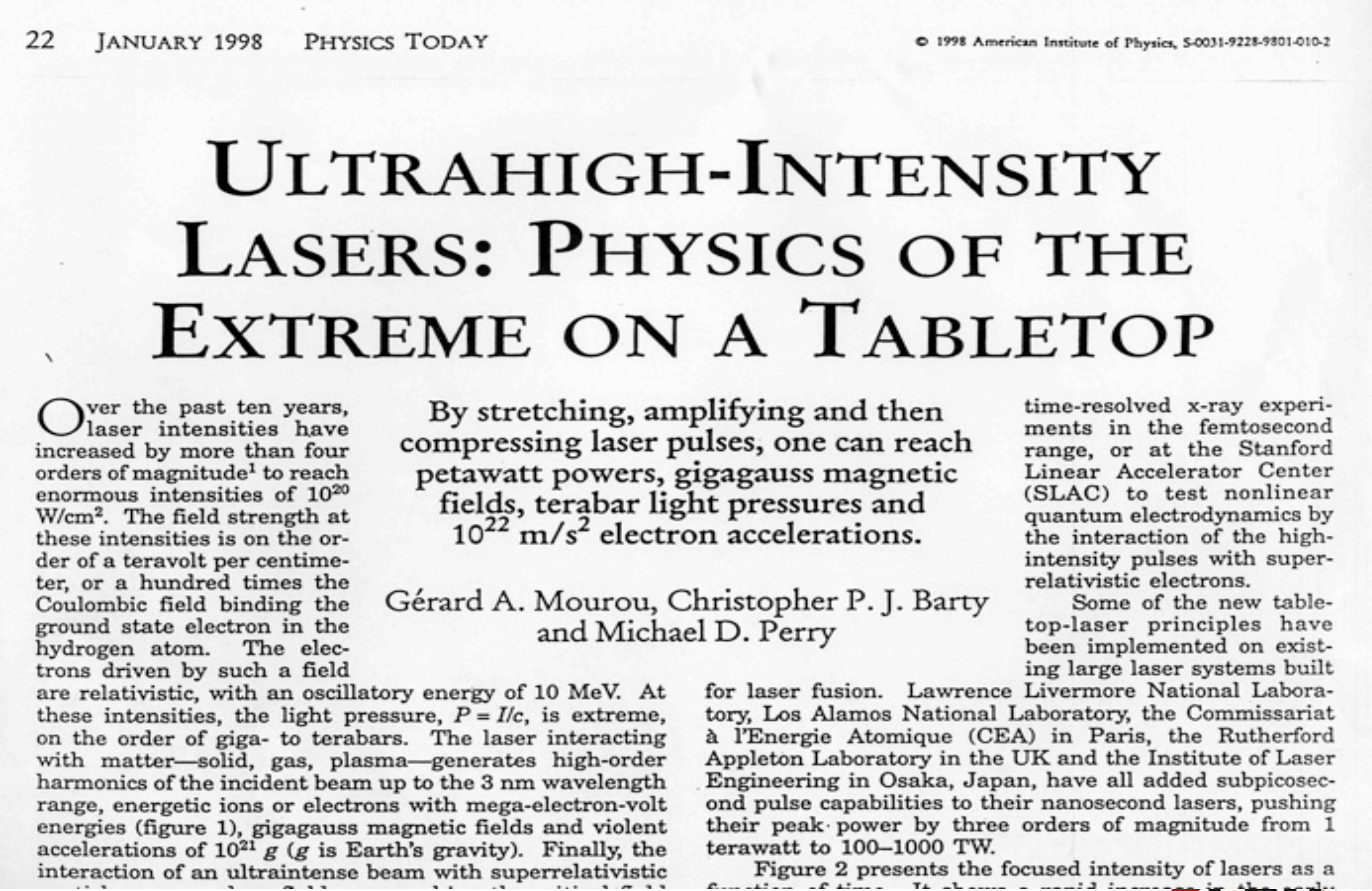




Technology limits

Table Top Terawatt T^3

CLPU
CENTRO DE
LÁSERES
PULSADOS
ULTRACORTOS
ULTRAINTENSOS



22 JANUARY 1998 PHYSICS TODAY

ULTRAHIGH-INTENSITY LASERS: PHYSICS OF THE EXTREME ON A TABLETOP

By stretching, amplifying and then compressing laser pulses, one can reach petawatt powers, gigagauss magnetic fields, terabar light pressures and 10^{22} m/s^2 electron accelerations.

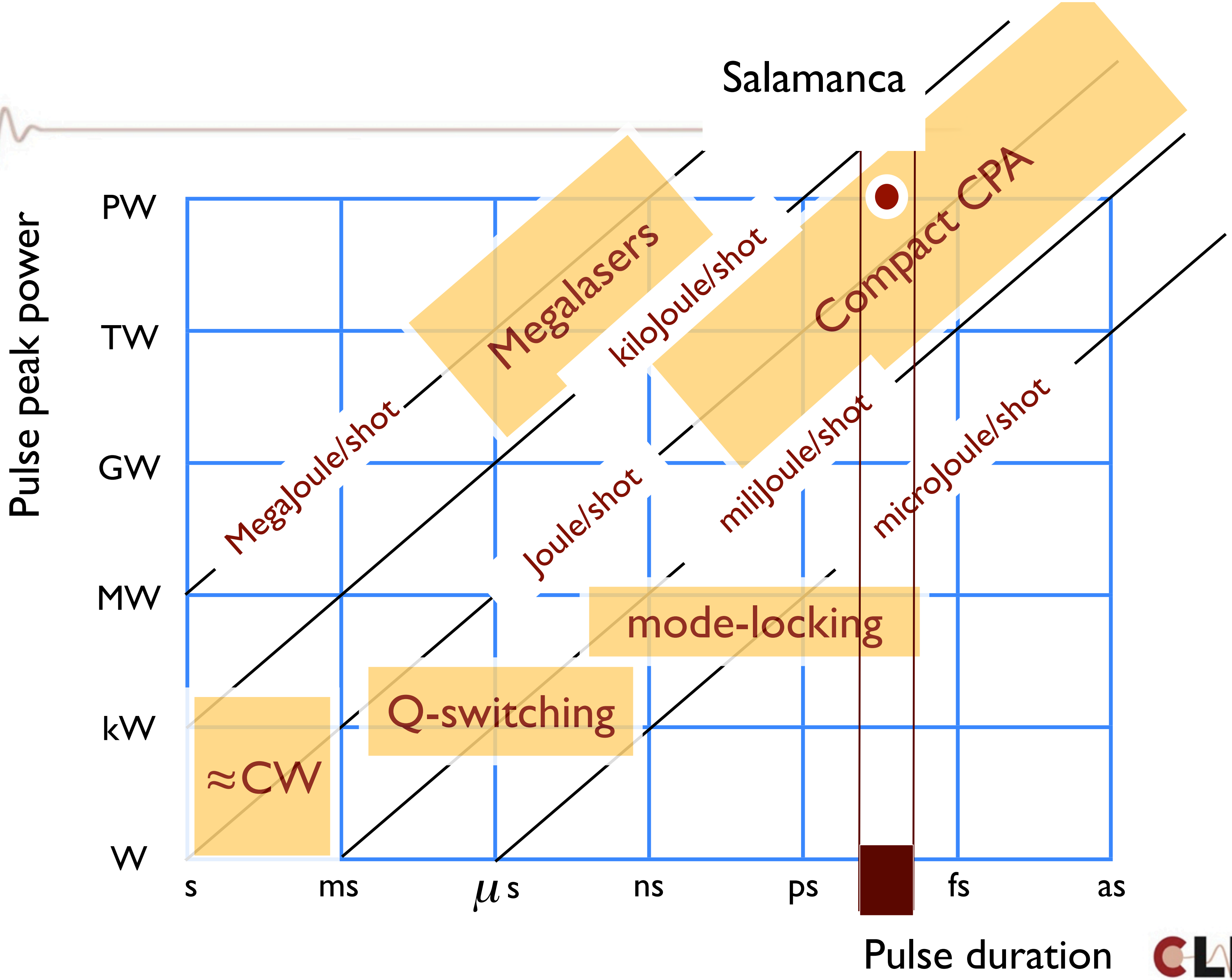
Gérard A. Mourou, Christopher P. J. Barty and Michael D. Perry

Over the past ten years, laser intensities have increased by more than four orders of magnitude[1] to reach enormous intensities of 10^{20} W/cm^2. The field strength at these intensities is on the order of a teravolt per centimeter, or a hundred times the Coulombic field binding the ground state electron in the hydrogen atom. The electrons driven by such a field are relativistic, with an oscillatory energy of 10 MeV. At these intensities, the light pressure, $P = I/c$, is extreme, on the order of giga- to terabars. The laser interacting with matter—solid, gas, plasma—generates high-order harmonics of the incident beam up to the 3 nm wavelength range, energetic ions or electrons with mega-electron-volt energies (figure 1), gigagauss magnetic fields and violent accelerations of 10^{21} g (g is Earth's gravity). Finally, the interaction of an ultraintense beam with superrelativistic

time-resolved x-ray experiments in the femtosecond range, or at the Stanford Linear Accelerator Center (SLAC) to test nonlinear quantum electrodynamics by the interaction of the high-intensity pulses with super-relativistic electrons.

Some of the new tabletop-laser principles have been implemented on existing large laser systems built for laser fusion. Lawrence Livermore National Laboratory, Los Alamos National Laboratory, the Commissariat à l'Energie Atomique (CEA) in Paris, the Rutherford Appleton Laboratory in the UK and the Institute of Laser Engineering in Osaka, Japan, have all added subpicosecond pulse capabilities to their nanosecond lasers, pushing their peak power by three orders of magnitude from 1 terawatt to 100–1000 TW.

Figure 2 presents the focused intensity of lasers as a


Salamanca
Pulse peak power
PW
TW
GW
MW
kW
W
s
ms
μs
ns
ps
fs
as
Pulse duration
Megalasers
Compact CPA
MegaJoule/shot
kiloJoule/shot
Joule/shot
miliJoule/shot
microJoule/shot
mode-locking
Q-switching
≈CW

Ultraintense lasers

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

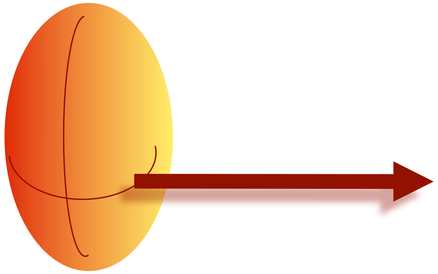
$$\text{watt} = \frac{\text{joule}}{\text{sec}}$$

Ultrashort pulses

femtosecond

1 fs = 0. 000 000 000 000 001 second

Temporal concentration of energy

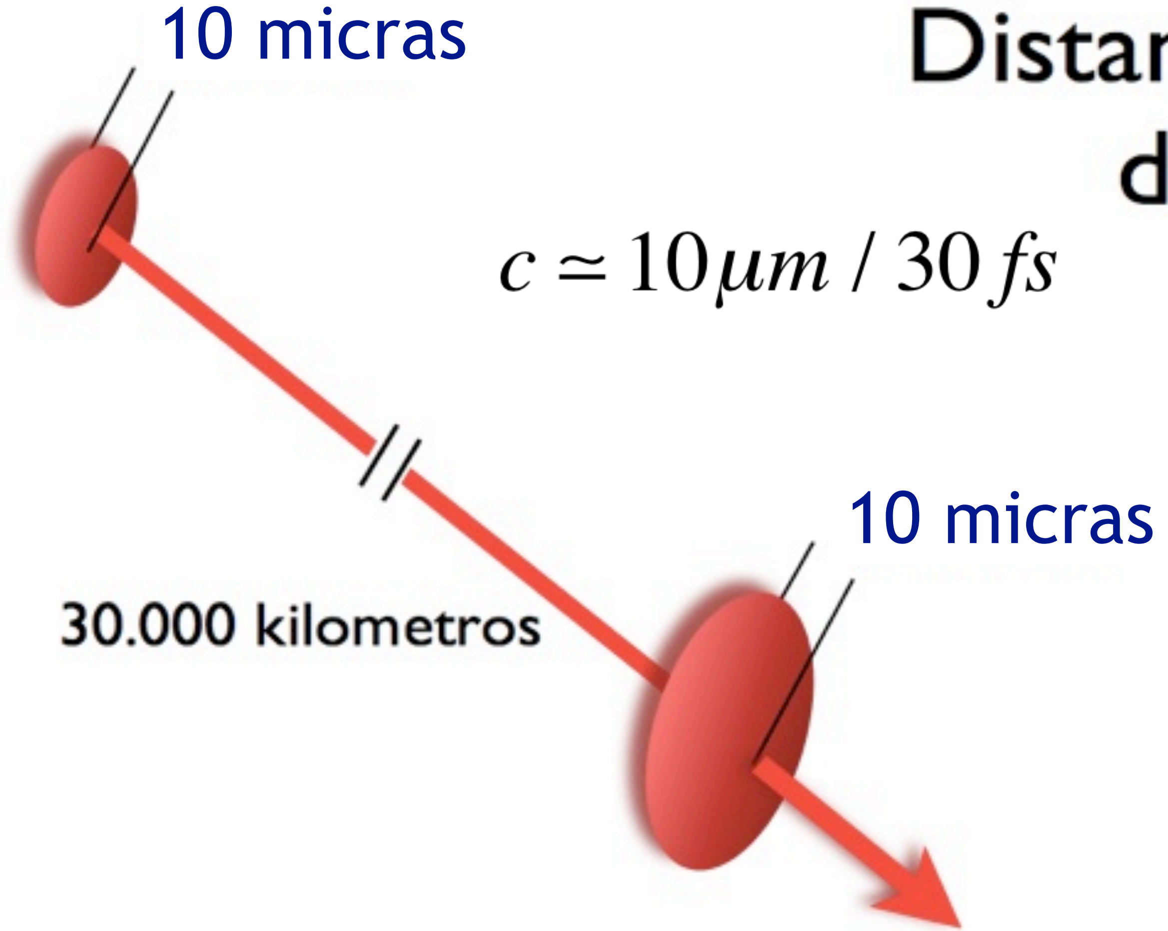


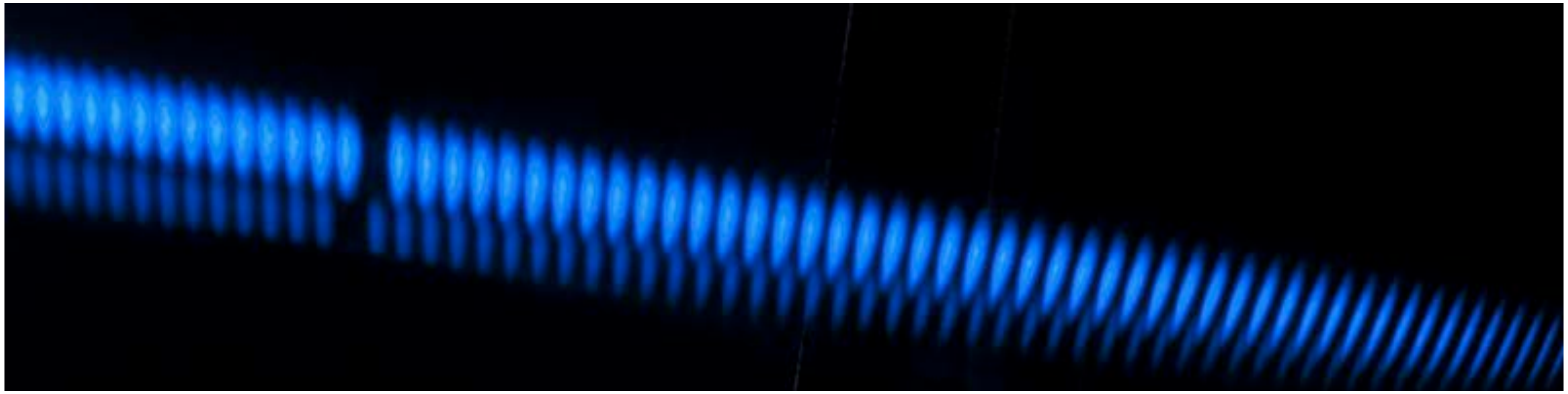
True light bullets

Not a beam

Distancia entre dos pulsos

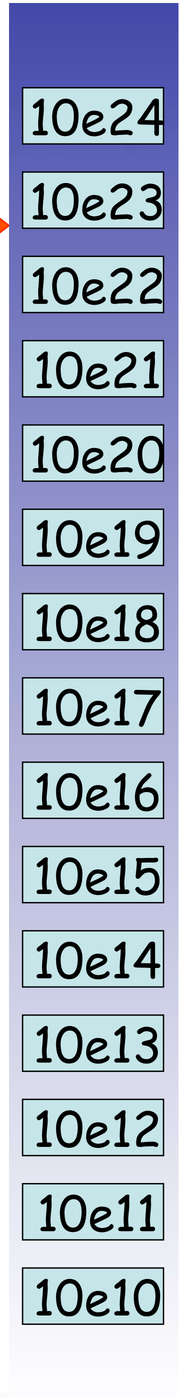
$$c \simeq 10 \mu m / 30 fs$$

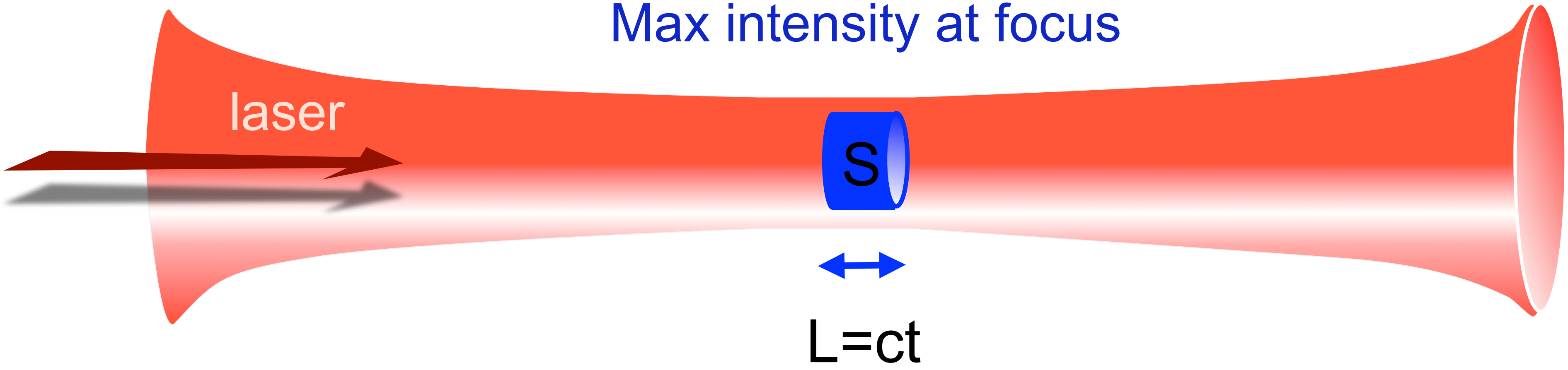


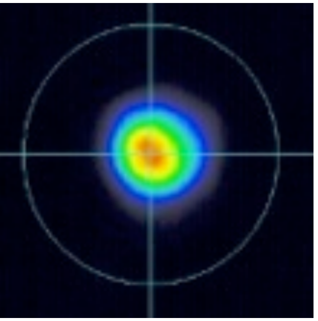


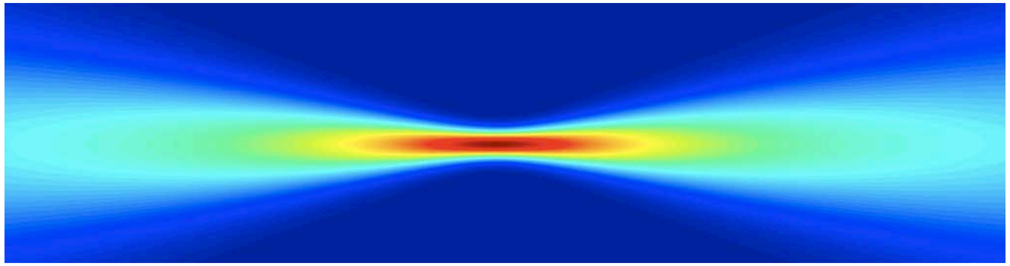
Intensity is the key parameter

$$Intensity = \frac{power}{surface}$$



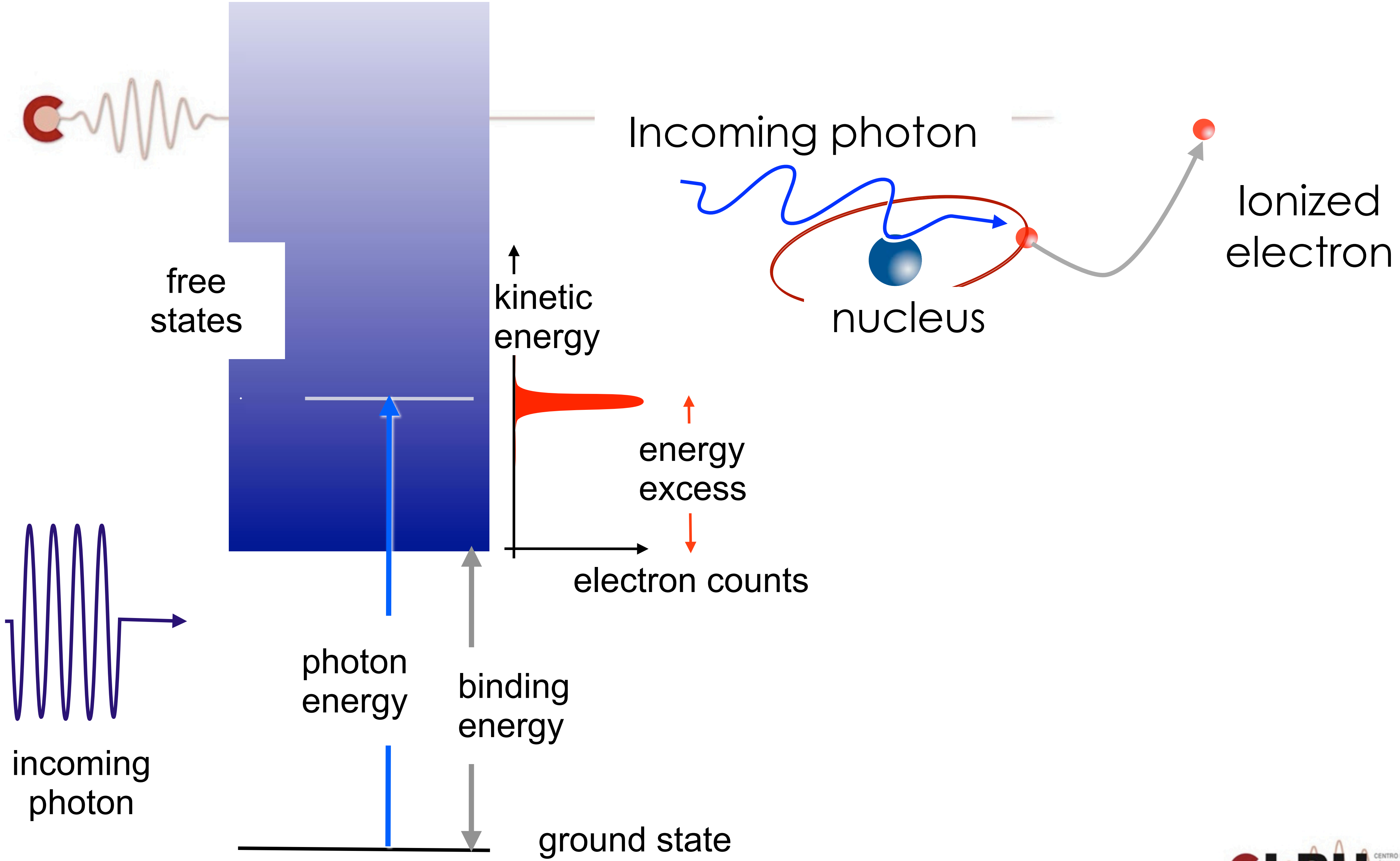






Non linear effects depend mostly on peak intensity

Photoionization



Incoming photon

nucleus

Ionized electron

free states

kinetic energy

energy excess

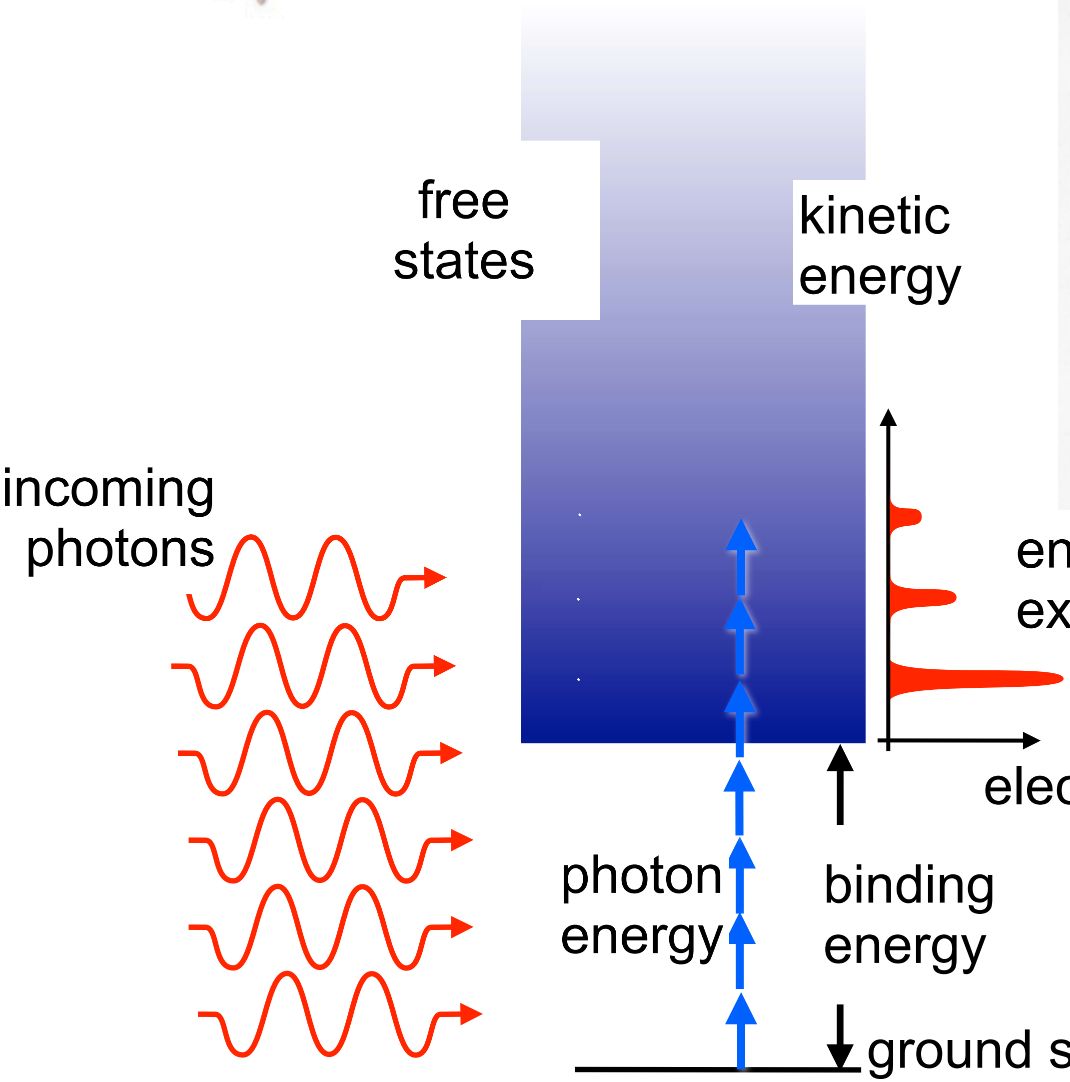
electron counts

photon energy

binding energy

incoming photon

ground state



free states

kinetic energy

incoming photons

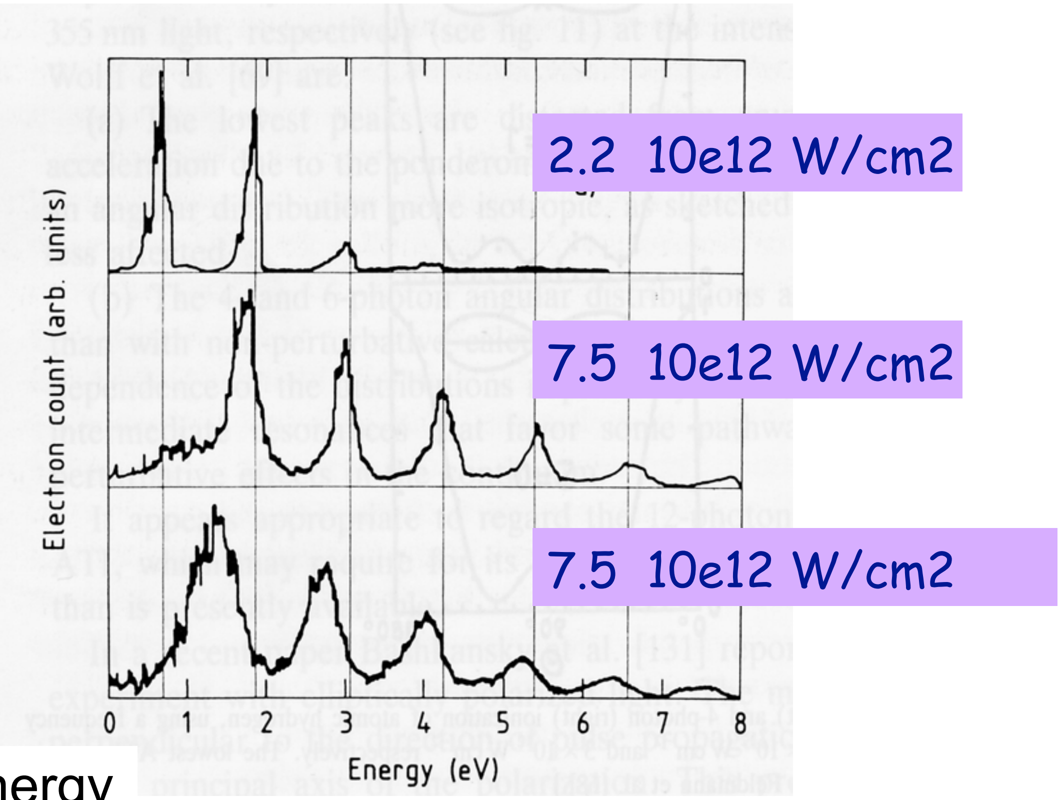
energy excess

electron counts

photon energy

binding energy

ground state



2.2 10e12 W/cm2

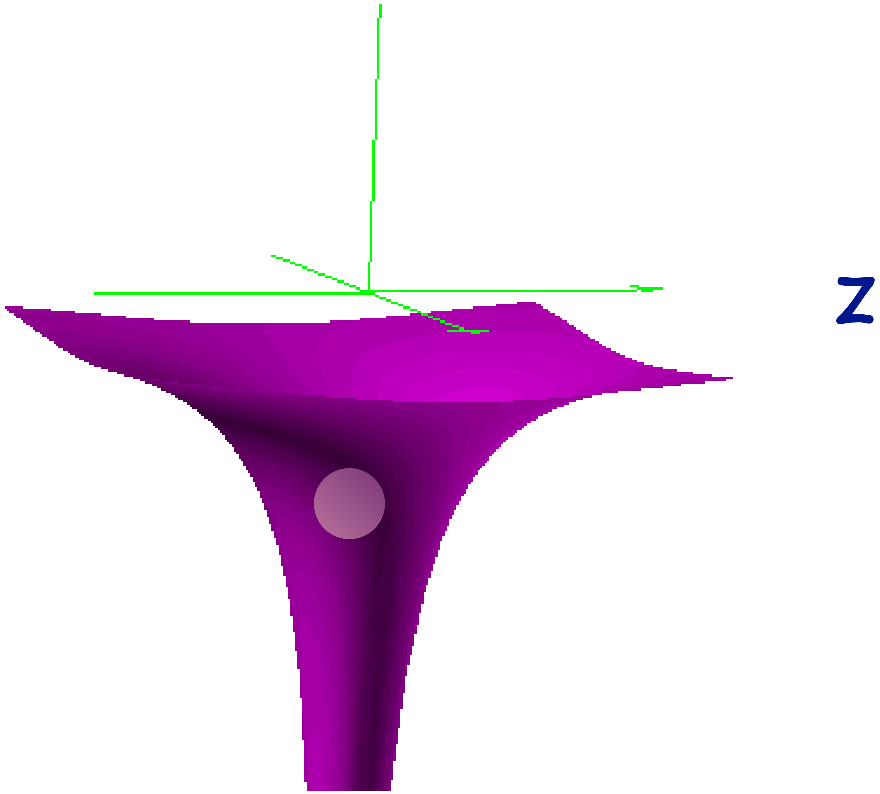
7.5 10e12 W/cm2

7.5 10e12 W/cm2

P Agostini et al, 1979

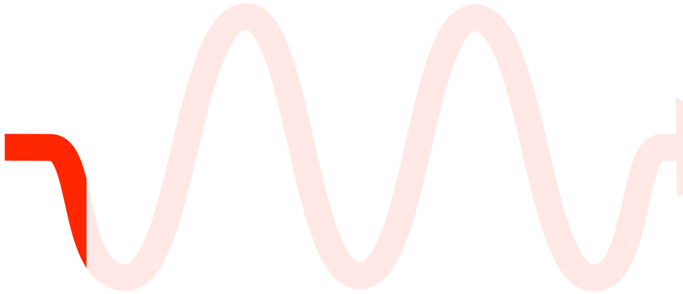
Atomic unit of intensity 3,4 x 10^{16} W/cm^2

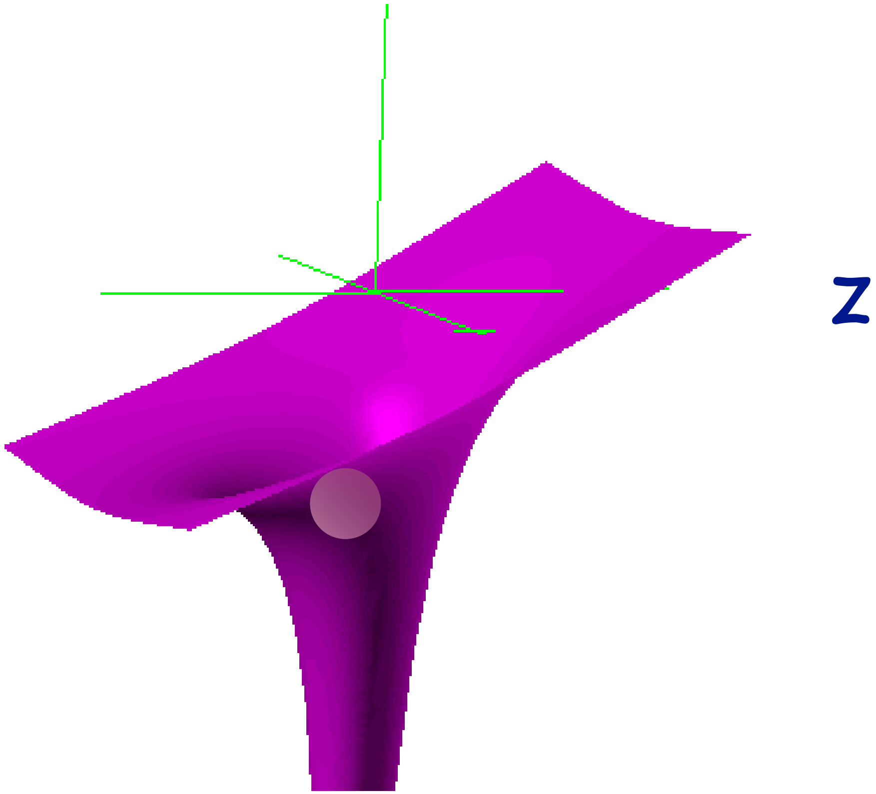
$$V(r) - e\,z\,E_0 \sin(\omega_L t)$$



Atomic unit of intensity 3,4 x 10^{16} W/cm^2

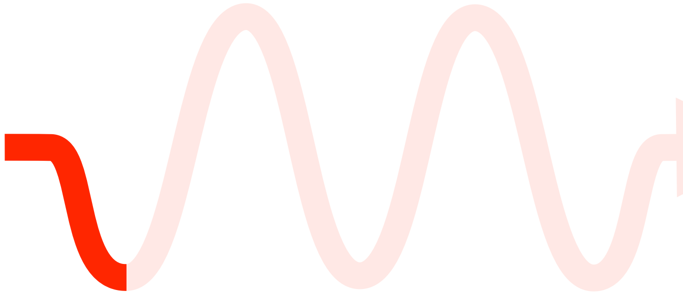
$$V(r) - e\, z\, E_0 \sin(\omega_L t)$$

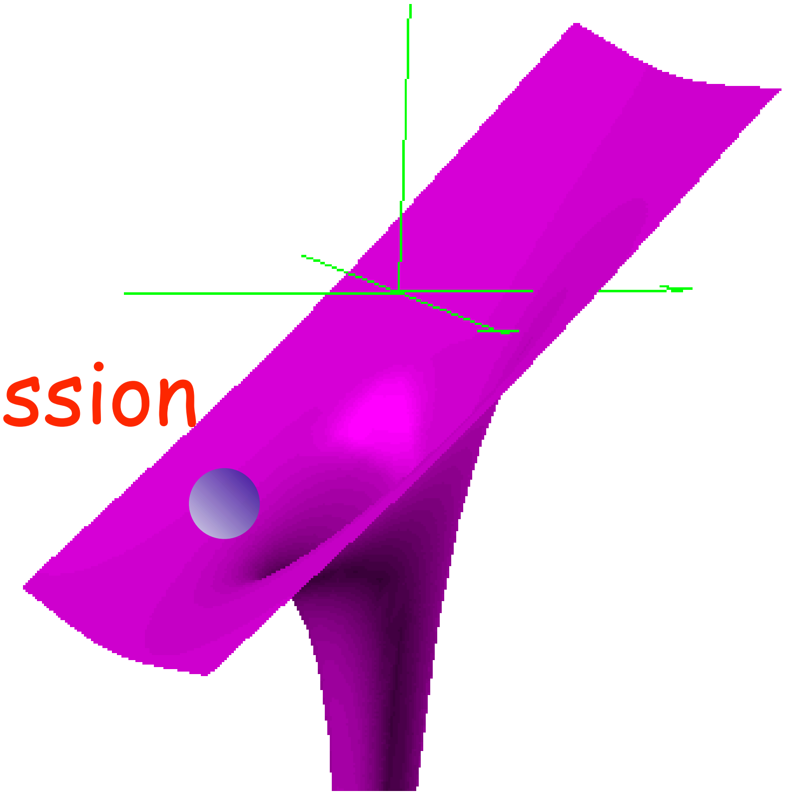




Atomic unit of intensity 3,4 x 10^{16} W/cm^2

$$V\left(r\right)-e\,z\,E_0\sin(\omega_L t)$$



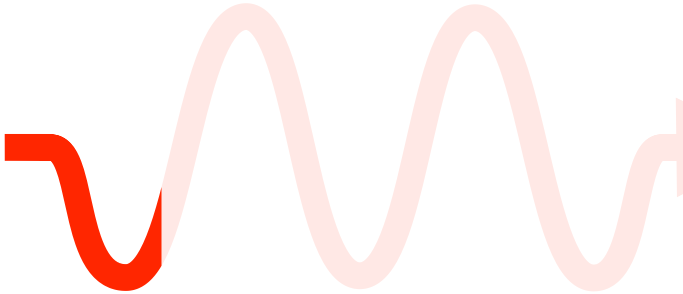


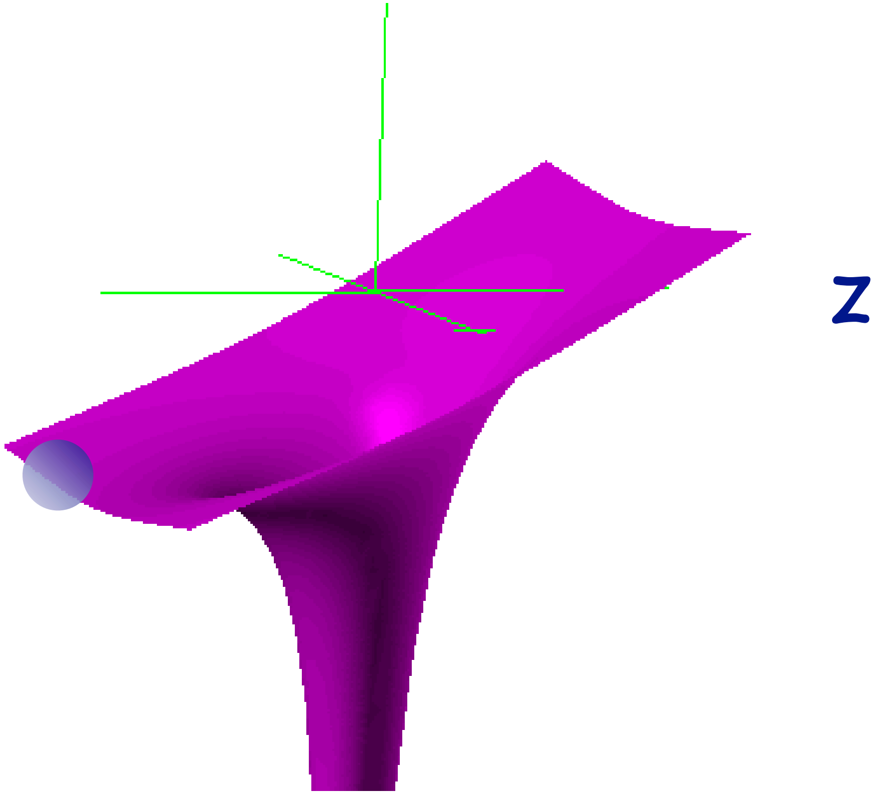
barrier supression

z

Atomic unit of intensity 3,4 x 10^{16} W/cm^2

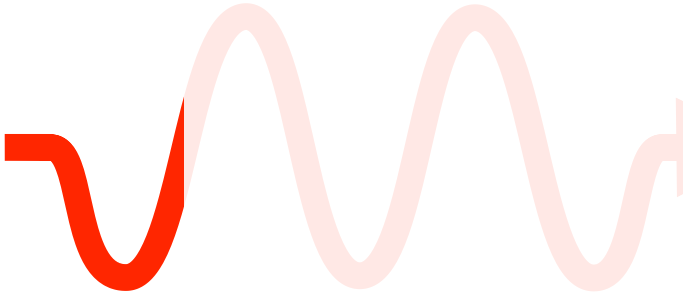
$$V(r) - e\,z\,E_0 \sin(\omega_L t)$$

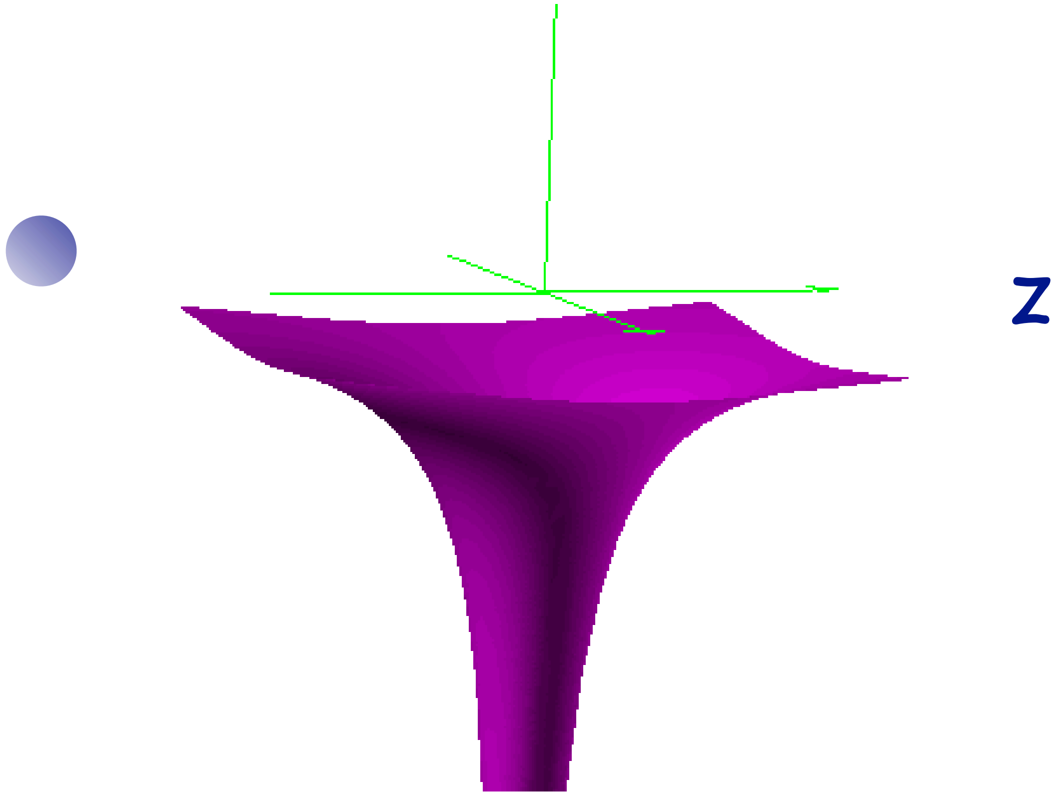




Atomic unit of intensity 3,4 x 10^{16} W/cm^2

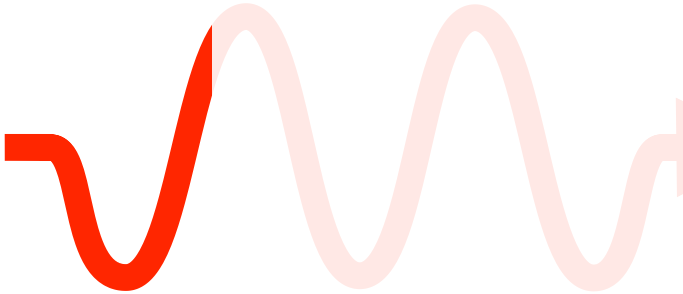
$$V(r) - e\, z\, E_0 \sin(\omega_L t)$$

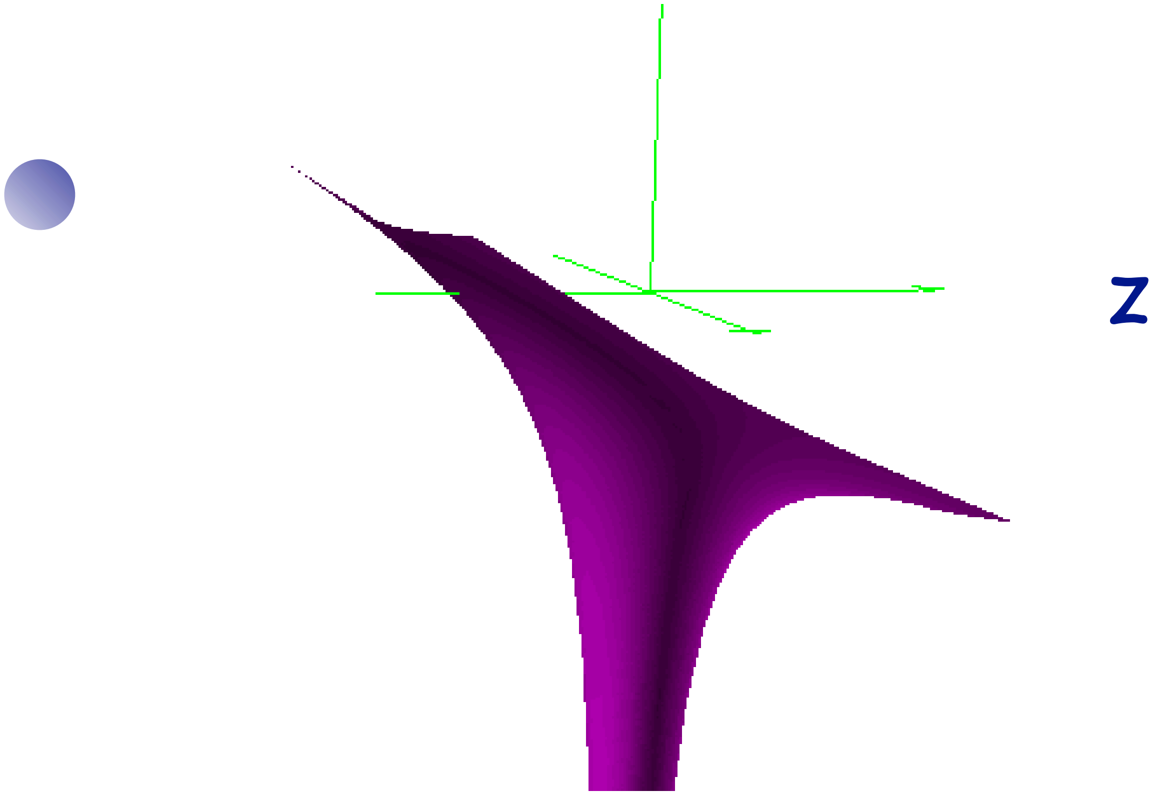




Atomic unit of intensity 3,4 x 10^{16} W/cm^2

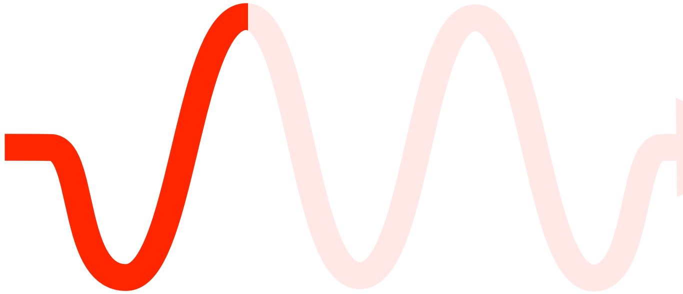
$$V(r) - e\, z\, E_0 \sin(\omega_L t)$$

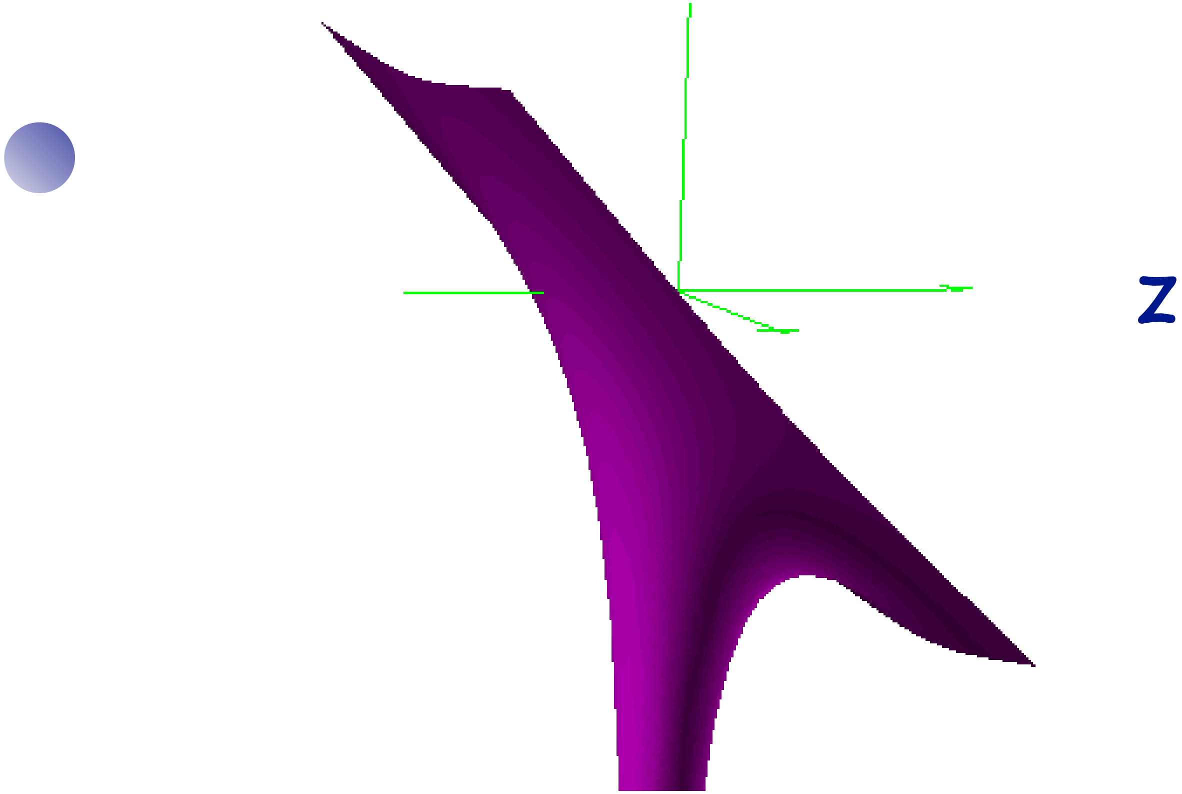




Atomic unit of intensity 3,4 x 10^{16} W/cm^2

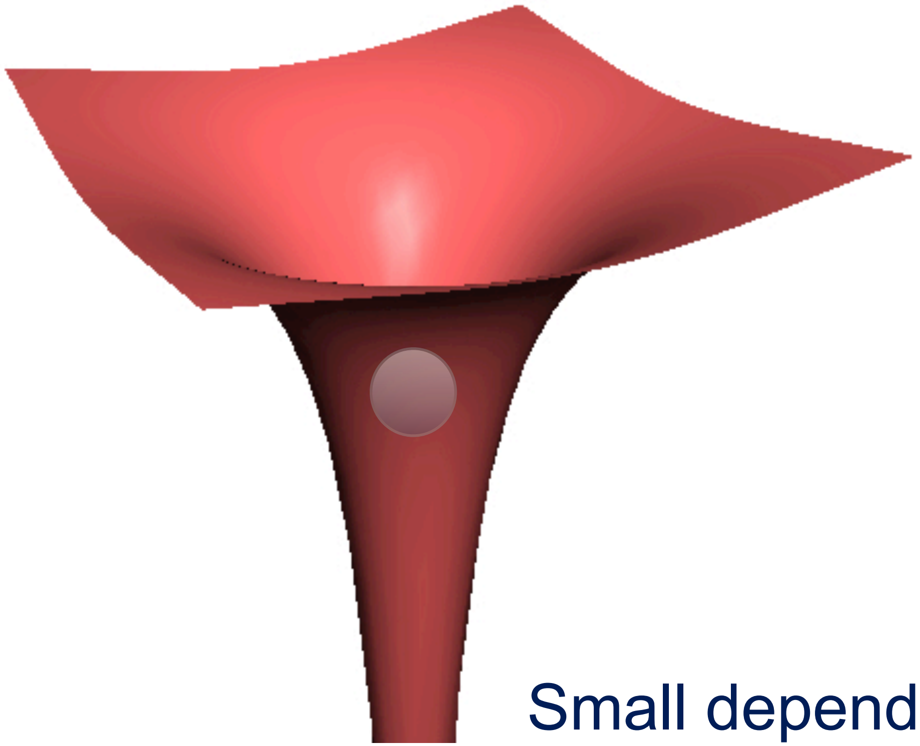
$$V(r) - e\, z\, E_0 \sin(\omega_L t)$$

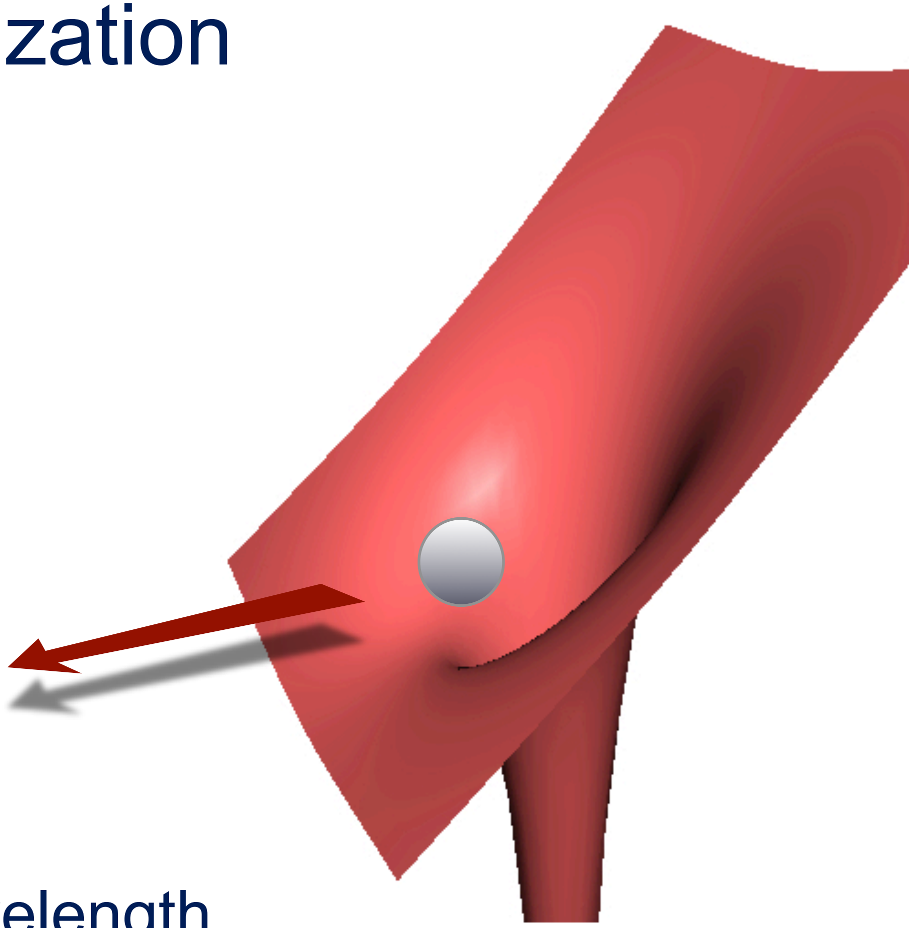




Ionization at 10^{16} W/cm^2

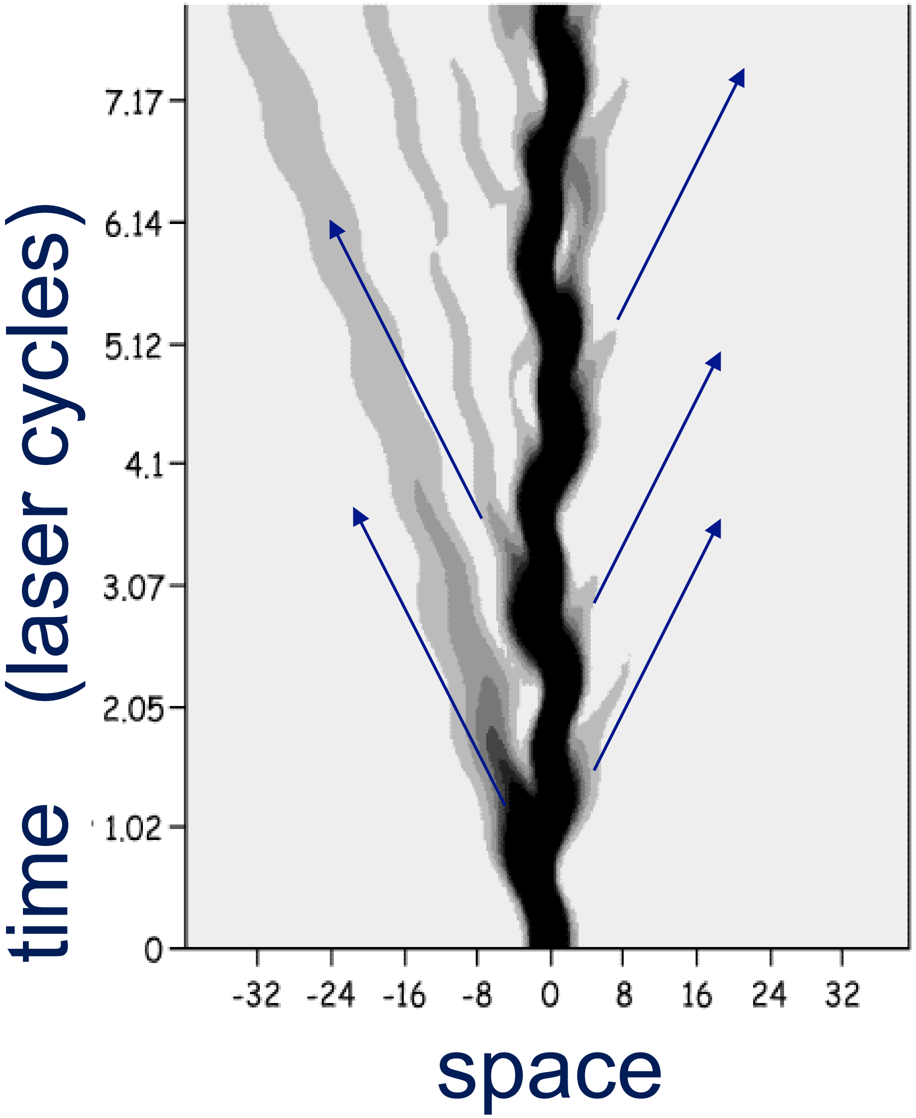
Over the barrier ionization

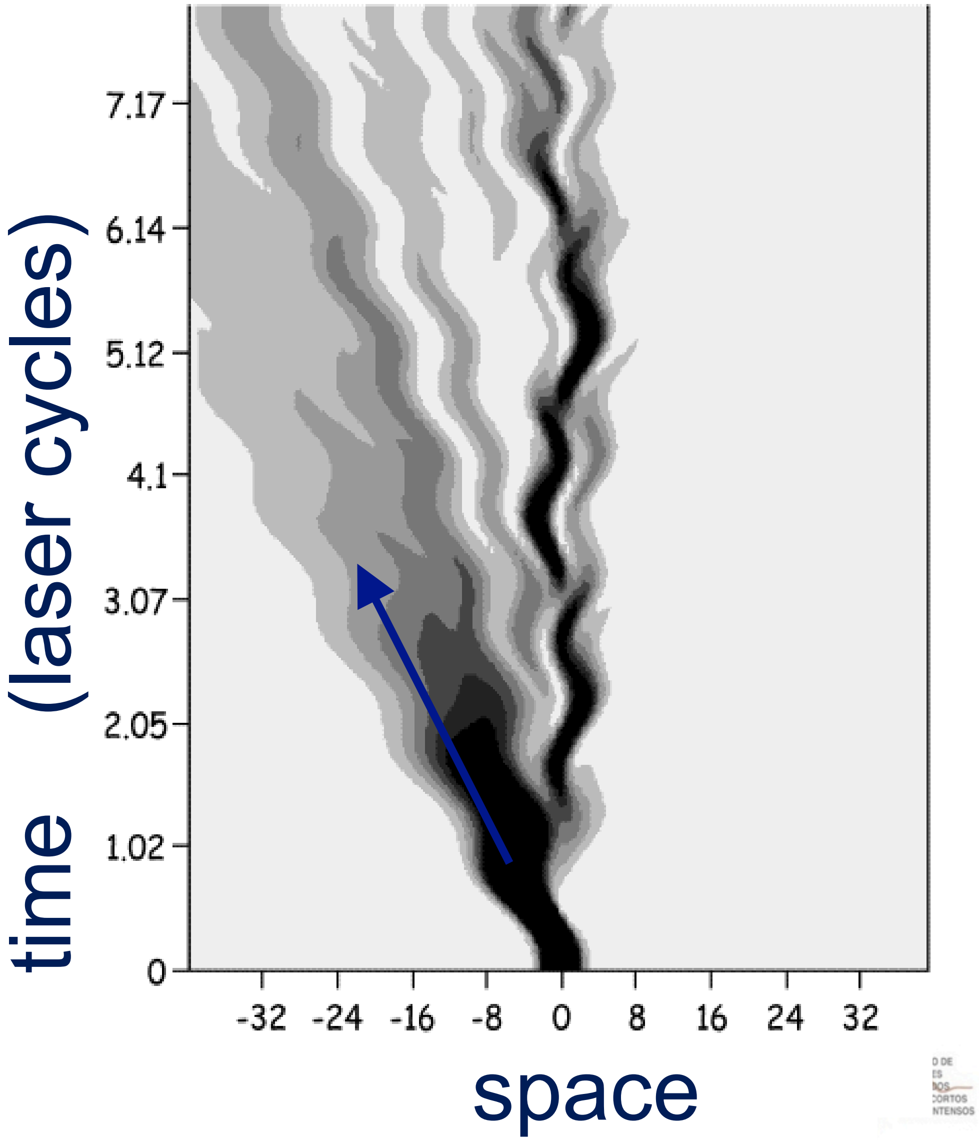




Small dependence on wavelength
Laser period accounts only for
the time that “the cage door” is opened.

Over the barrier ionization 10^{16} W/cm^2



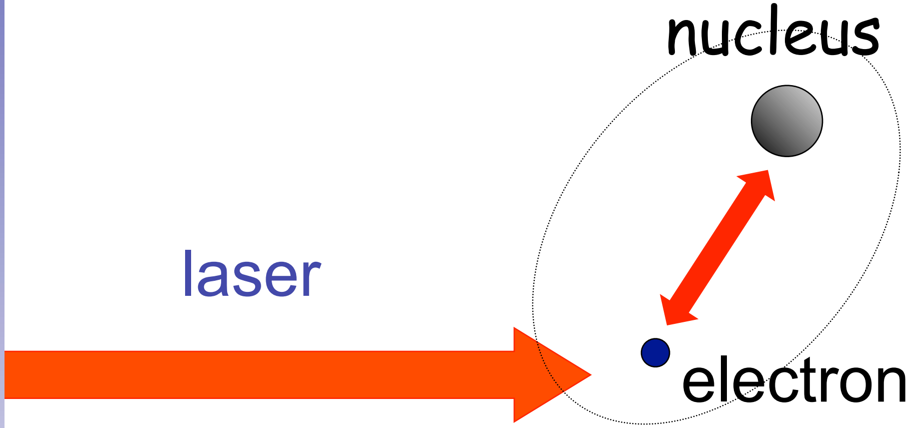


Atomic unit of intensity 3,4 x 10^{16} W/cm^2

10e24
10e23
10e22
10e21
10e20
10e19
10e18
10e17
10e16
10e15
10e14
10e13
10e12
10e11
10e10

W/cm^2

W/cm^2



Intensity
3,4 x 10^{16} W/cm^2
Electric field
5,1 x 10^9 V/cm

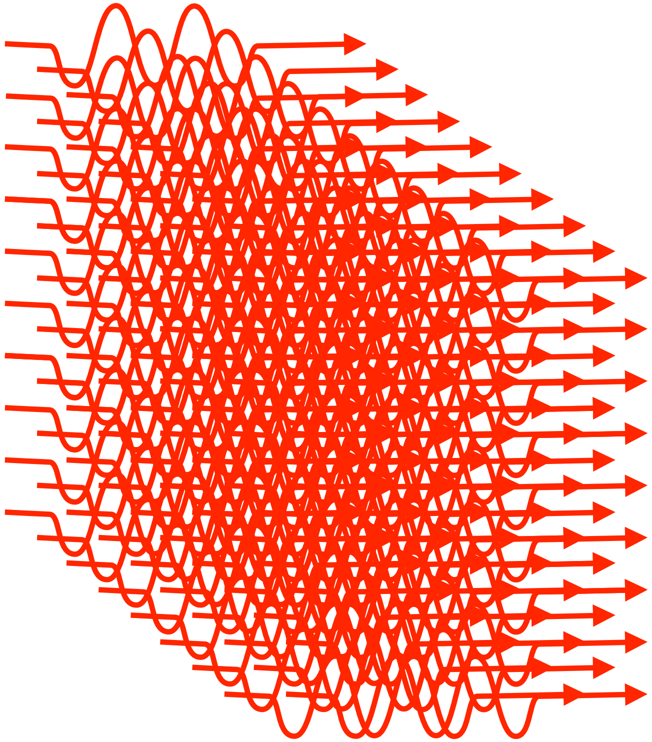
Interaction:
electron-nucleus
electron-laser
of same strength

Atom loses its meaning
beyond atomic unit of intensity ... plasma

One basic question

Photons are bosons,
a laser is a collection on bosons in the same quantum state.

How many can we pack?
Is there any fundamental limit?

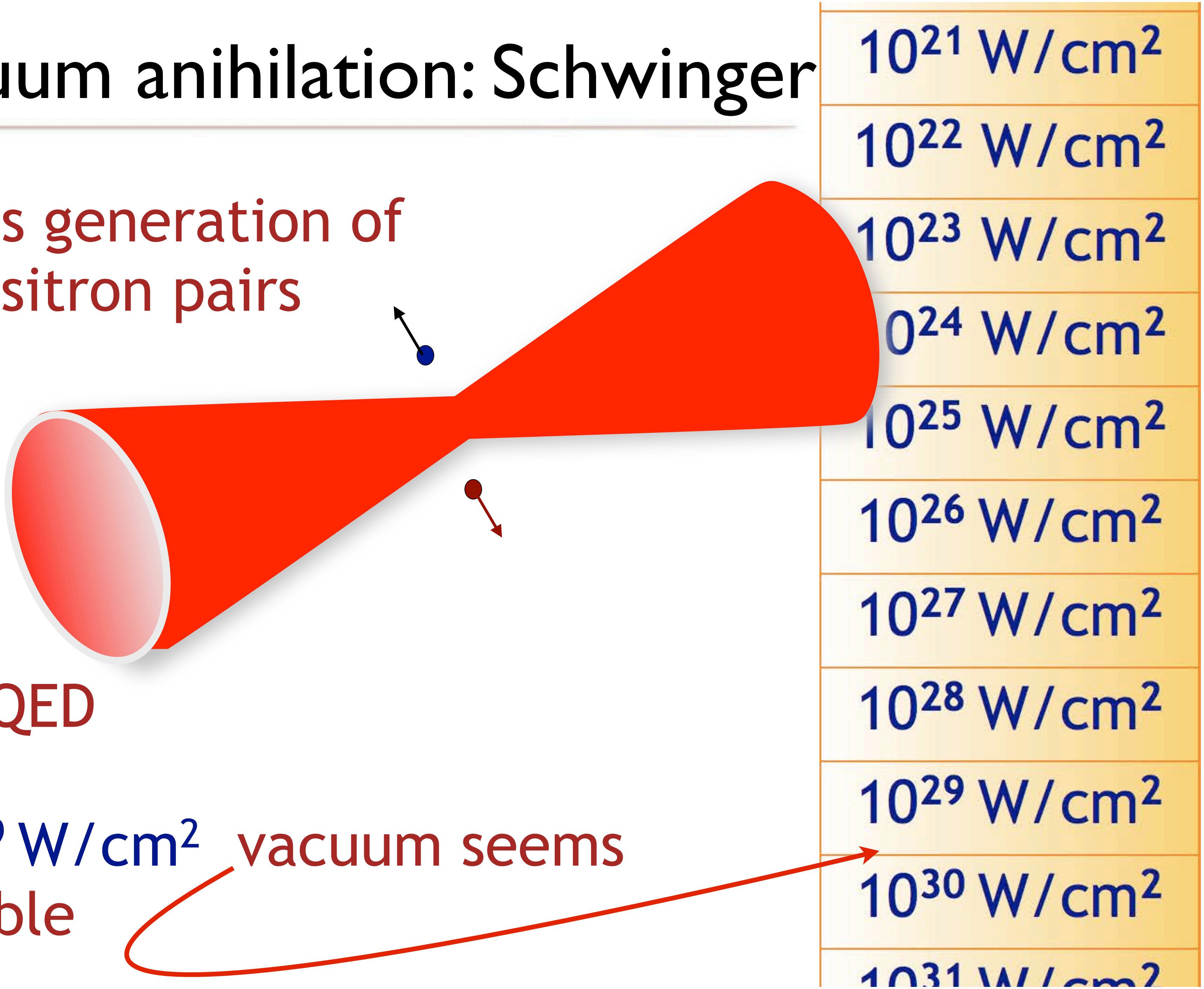


10^{29} W/cm^2

Schwinger limit

Vacuum anihilation: Schwinger

Spontaneous generation of electron-positron pairs

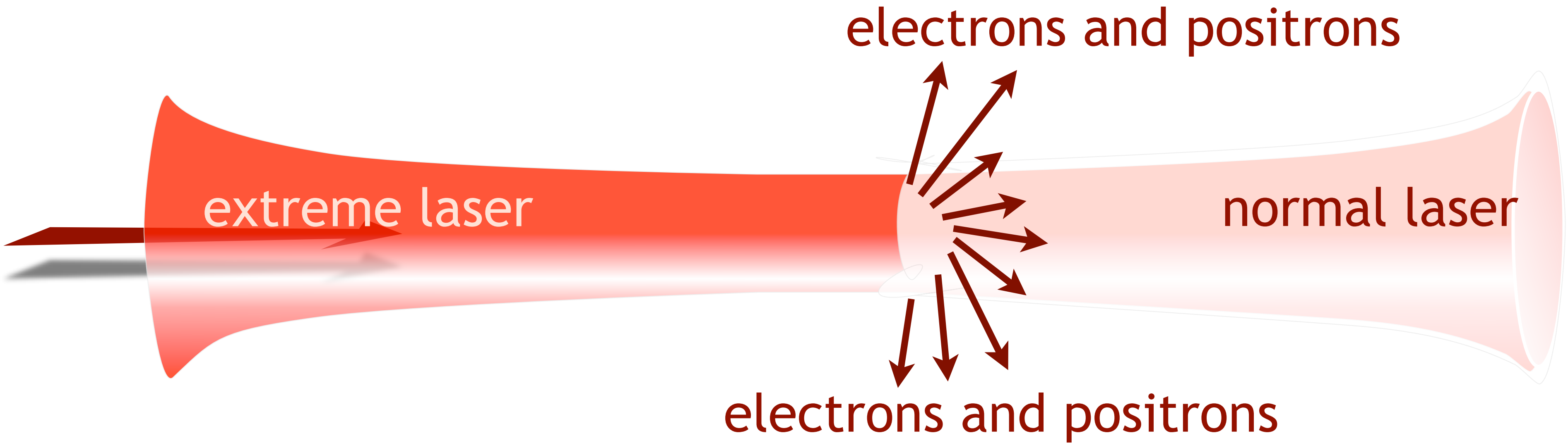


Non-linear QED

Beyond 10^{29} W/cm^2 vacuum seems to be unstable

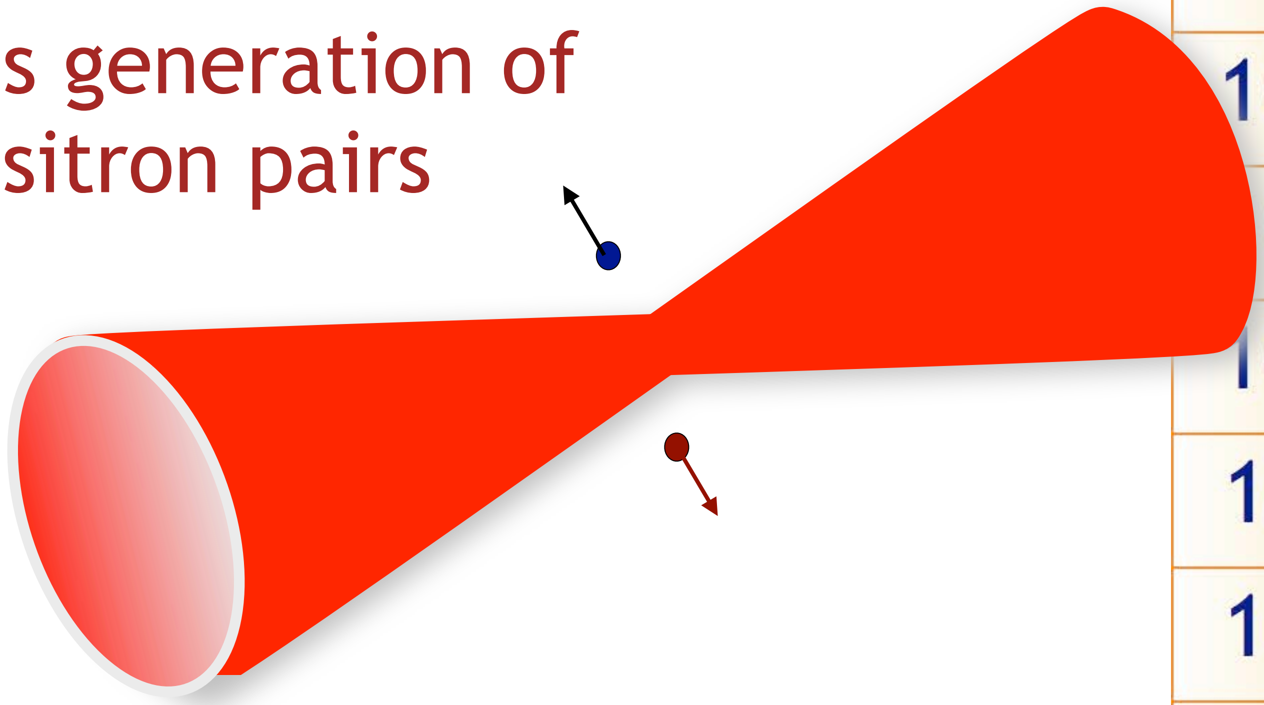
Is this an absolute barrier???

energy density	laser intensity
3 mJ/nm^3	10^{29} W/cm^2
3 $MJ/microm^3$	



Vacuum anihilation: Schwinger

Spontaneous generation of electron-positron pairs



Non-linear QED

Beyond 10^{29} W/cm^2 vacuum seems to be unstable

10^{21} W/cm^2

10^{22} W/cm^2

10^{23} W/cm^2

0^{24} W/cm^2

10^{25} W/cm^2

10^{26} W/cm^2

10^{27} W/cm^2

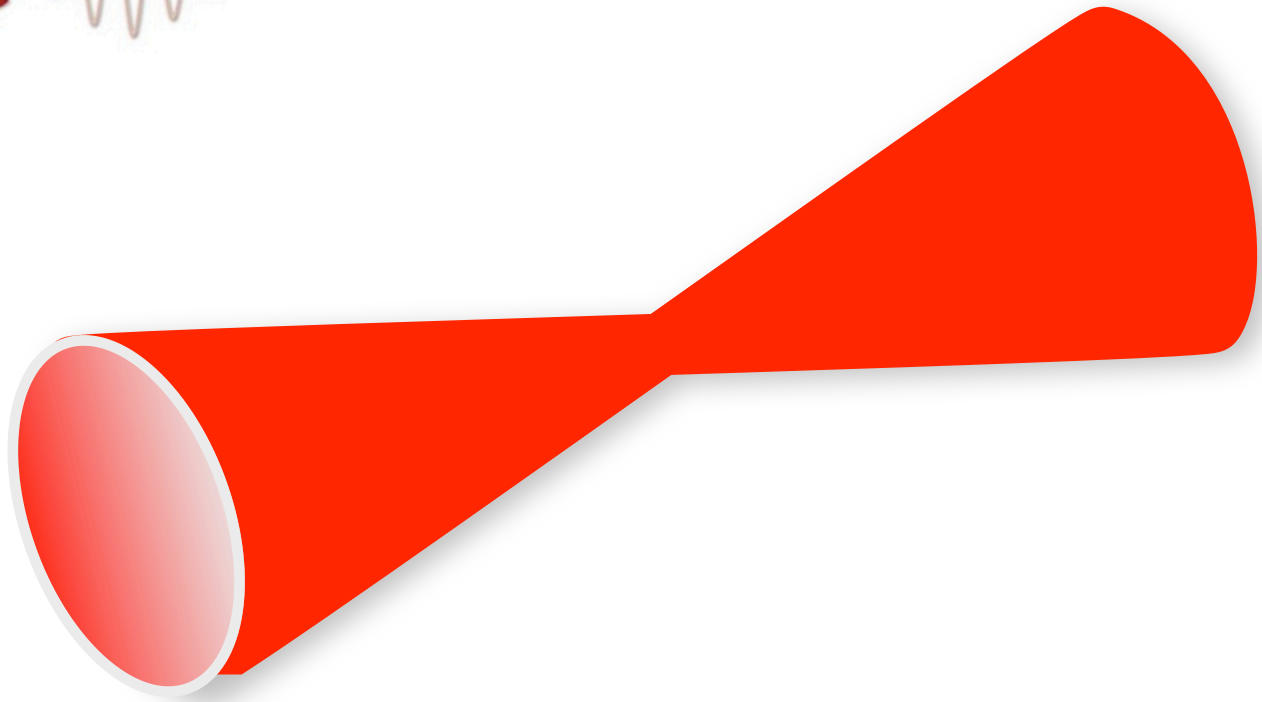
10^{28} W/cm^2

10^{29} W/cm^2

10^{30} W/cm^2

10^{31} W/cm^2

The present



10^{16} W/cm^2

10^{17} W/cm^2

10^{18} W/cm^2

10^{19} W/cm^2

10^{20} W/cm^2

10^{21} W/cm^2

10^{22} W/cm^2

10^{23} W/cm^2

10^{24} W/cm^2

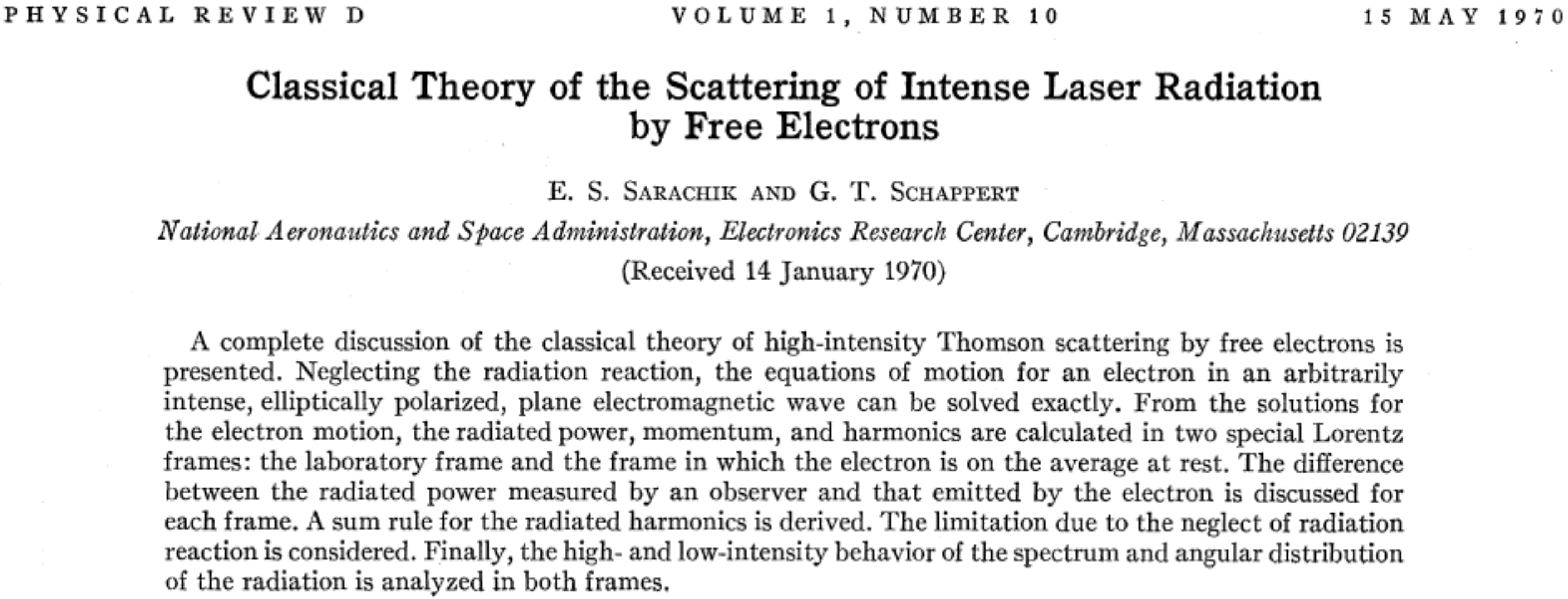
10^{25} W/cm^2

World record

Charge acceleration

	Intensity	Electric field	Year
	10^{16} W/cm^2	2.8 10^9 V/cm	1990
atomic unit	3.5 10^{16}	5.14 10^9 V/cm	1990
	10^{18} W/cm^2	2.8 10^{10} V/cm	1990
	10^{20} W/cm^2	2.8 10^{11} V/cm	2000
	10^{22} W/cm^2	2.8 10^{12} V/cm	2007
	10^{23} W/cm^2	~10^{13} V/cm	2013
Schwinger limit	10^{29} W/cm^2	~10^{16} V/cm	???

Origins ...



PHYSICAL REVIEW D VOLUME 1, NUMBER 10 15 MAY 1970

Classical Theory of the Scattering of Intense Laser Radiation by Free Electrons

E. S. Saracнik and G. T. Schappert

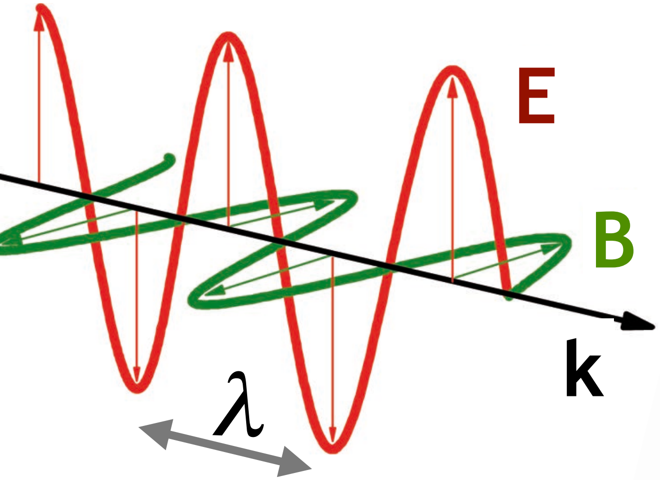
National Aeronautics and Space Administration, Electronics Research Center, Cambridge, Massachusetts 02139

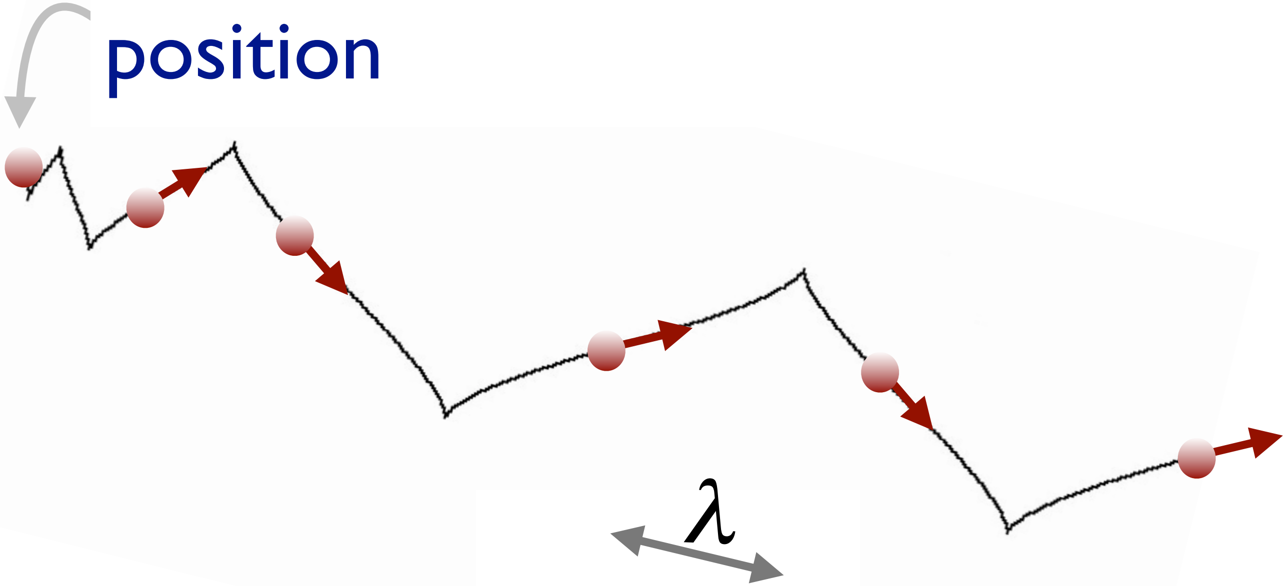
(Received 14 January 1970)

A complete discussion of the classical theory of high-intensity Thomson scattering by free electrons is presented. Neglecting the radiation reaction, the equations of motion for an electron in an arbitrarily intense, elliptically polarized, plane electromagnetic wave can be solved exactly. From the solutions for the electron motion, the radiated power, momentum, and harmonics are calculated in two special Lorentz frames: the laboratory frame and the frame in which the electron is on the average at rest. The difference between the radiated power measured by an observer and that emitted by the electron is discussed for each frame. A sum rule for the radiated harmonics is derived. The limitation due to the neglect of radiation reaction is considered. Finally, the high- and low-intensity behavior of the spectrum and angular distribution of the radiation is analyzed in both frames.

Electron driven by a laser field

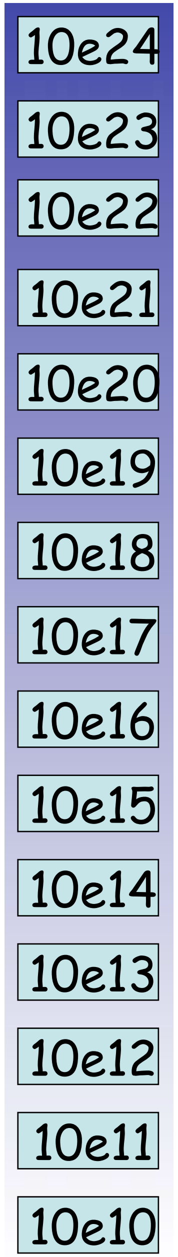
Plane wave laser pulse





electron's initial position

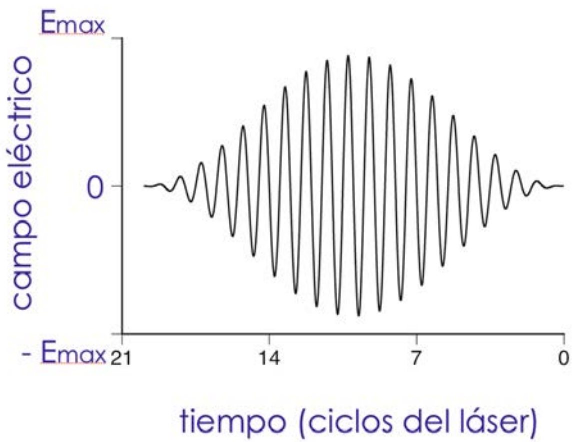
W/cm^2

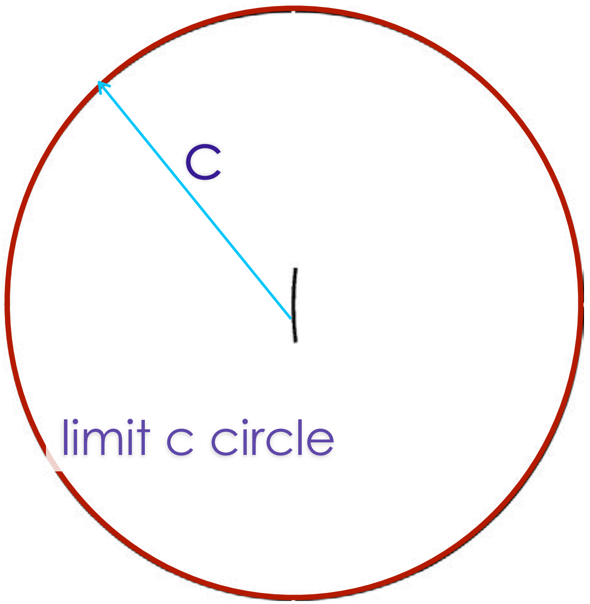


$$-e\left(\vec{E}+\frac{\vec{v}}{c}\times\vec{B}\right)=\vec{F}=\frac{d\vec{p}}{dt}$$

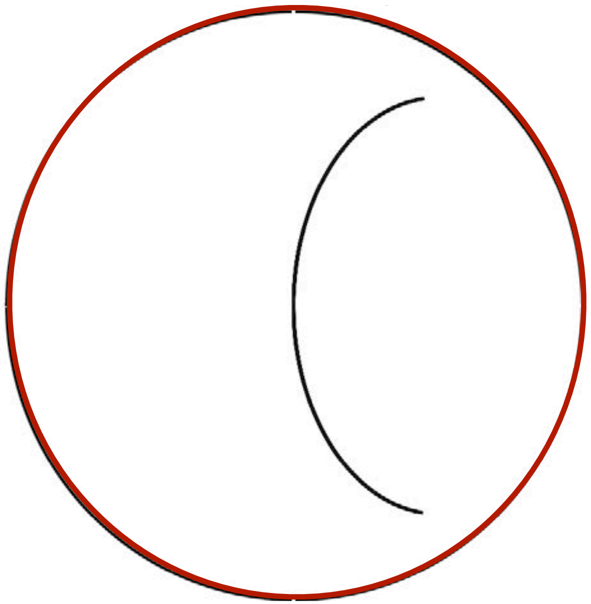
800 nm
2 10^19 W/cm2

Plane wave laser pulse

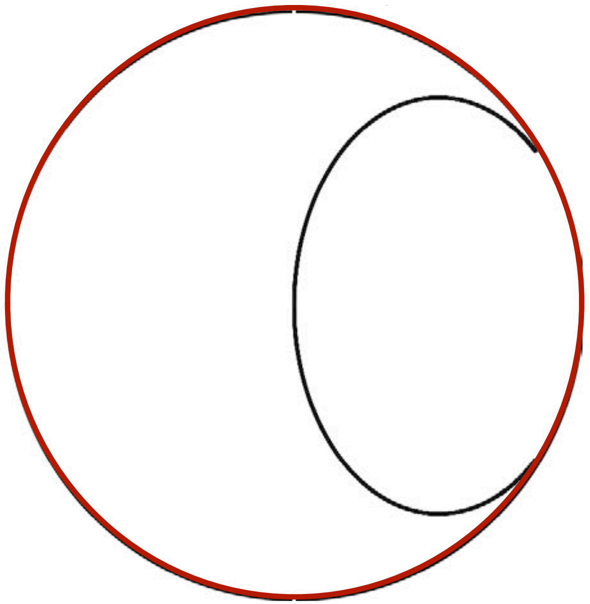




3.4×10^{16} W/cm^2

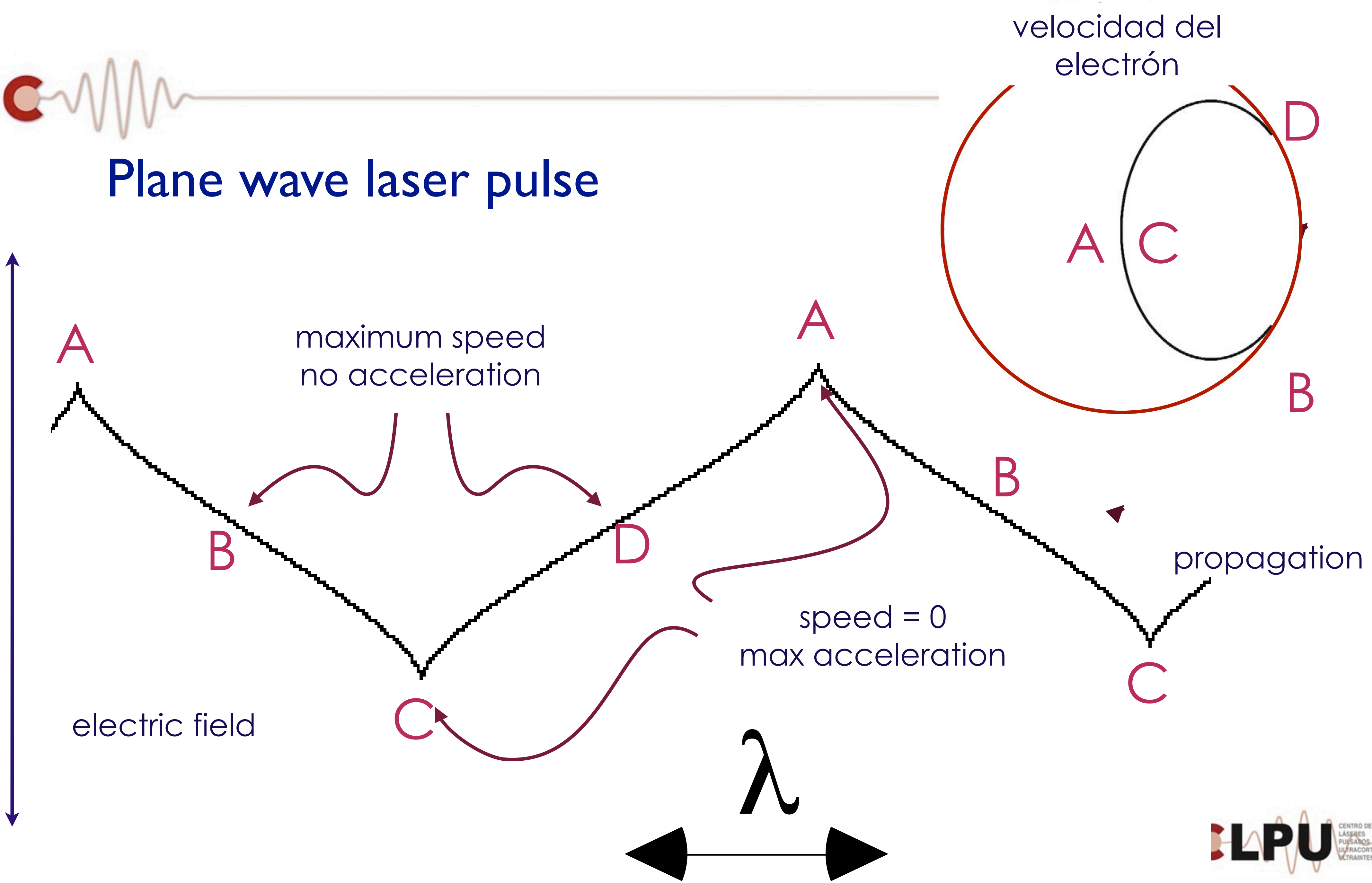


3.4×10^{18} W/cm^2



2.1×10^{19} W/cm^2

Plane wave laser pulse



velocidad del electrón

maximum speed
no acceleration

speed = 0
max acceleration

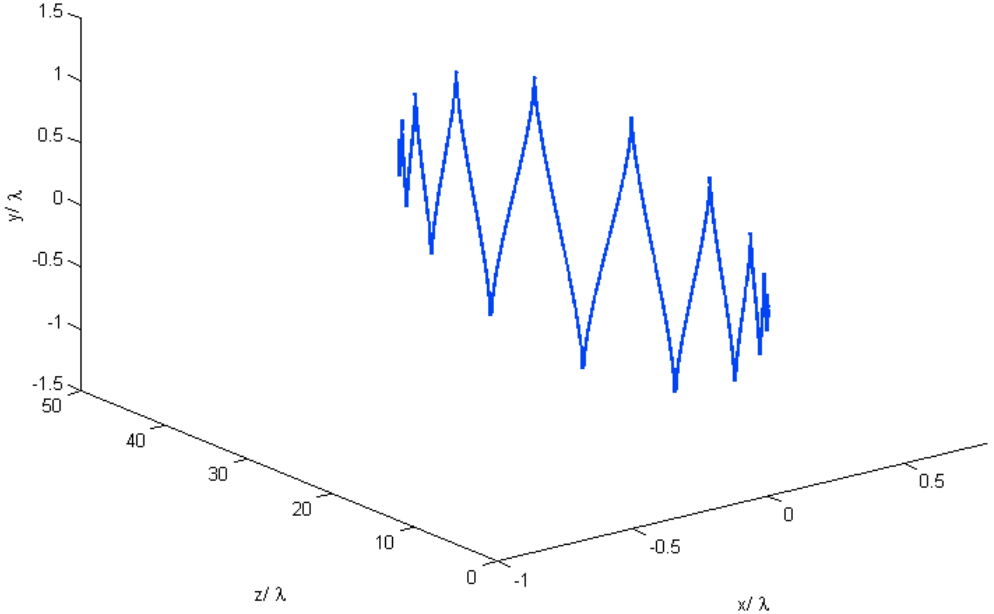
electric field

propagation

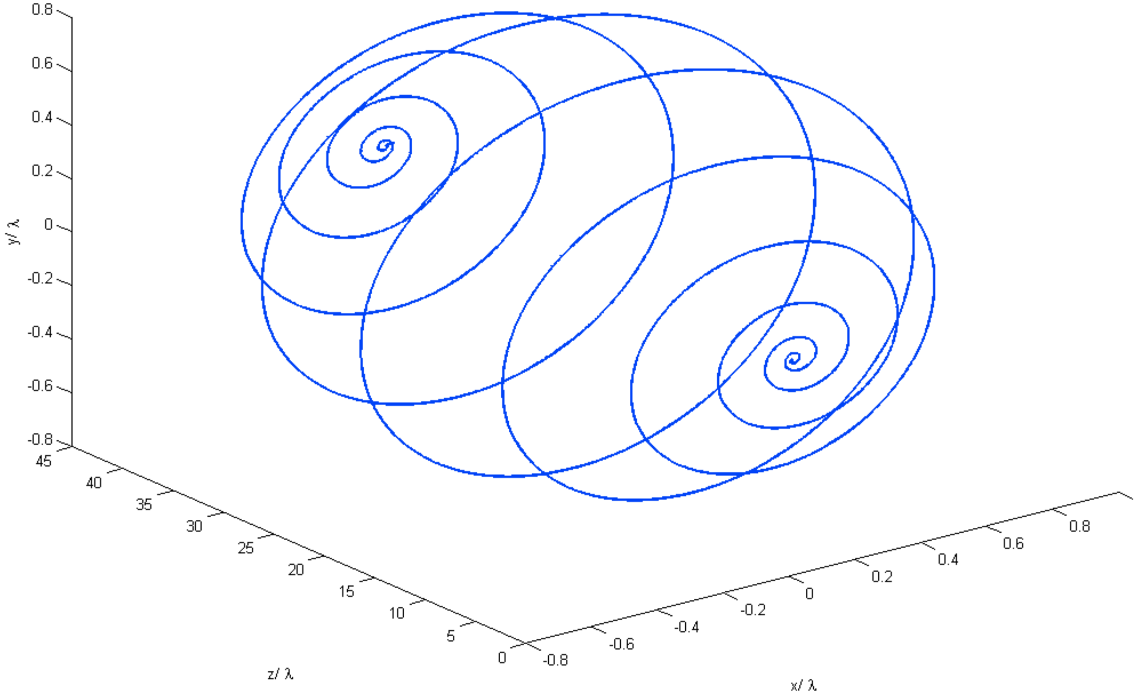
Polarization

Plane wave laser pulse

Linear



Circular



Coupling laser-charge

The max energy of a charged particle inside a laser field is:

charge

$$E_{\max} = mc^2 + \frac{1}{4}\frac{q^2}{m\omega^2} I$$

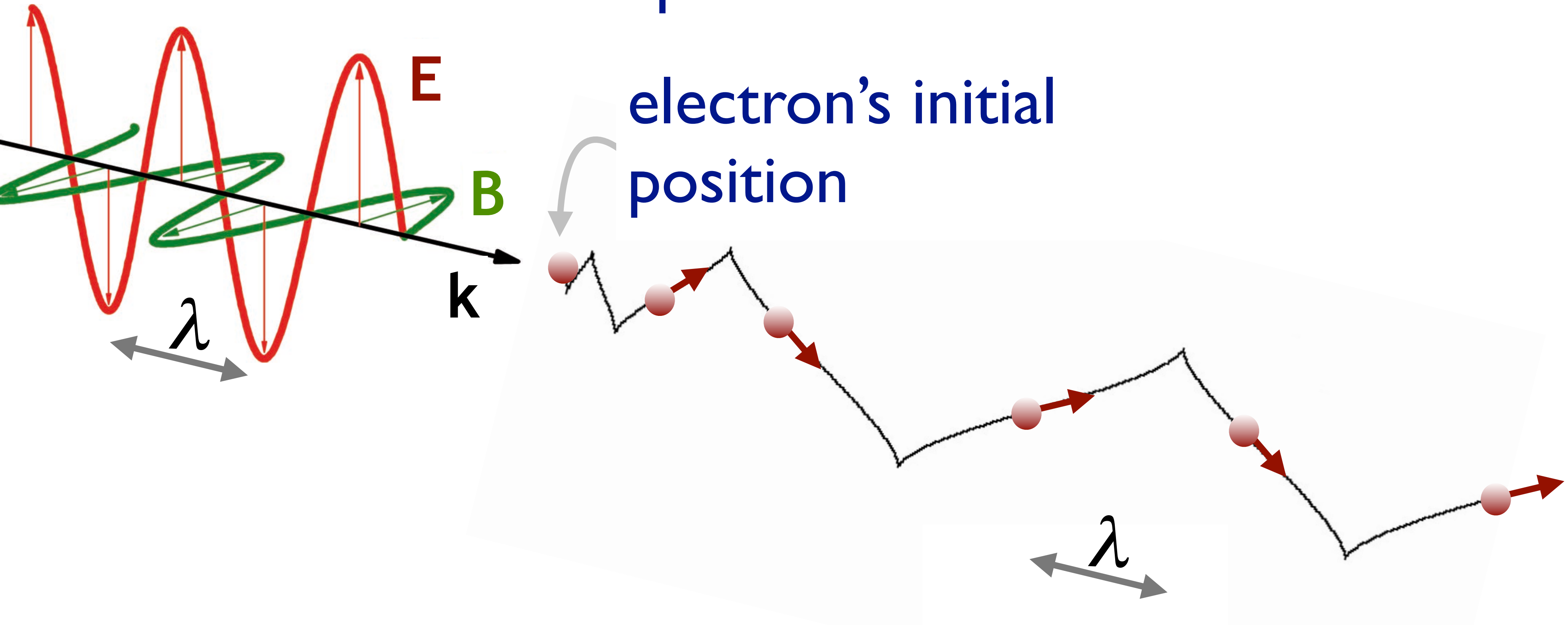
intensity

mass

Plane wave laser pulse

This is the typical figure-of-eight motion

Plane wave laser pulse

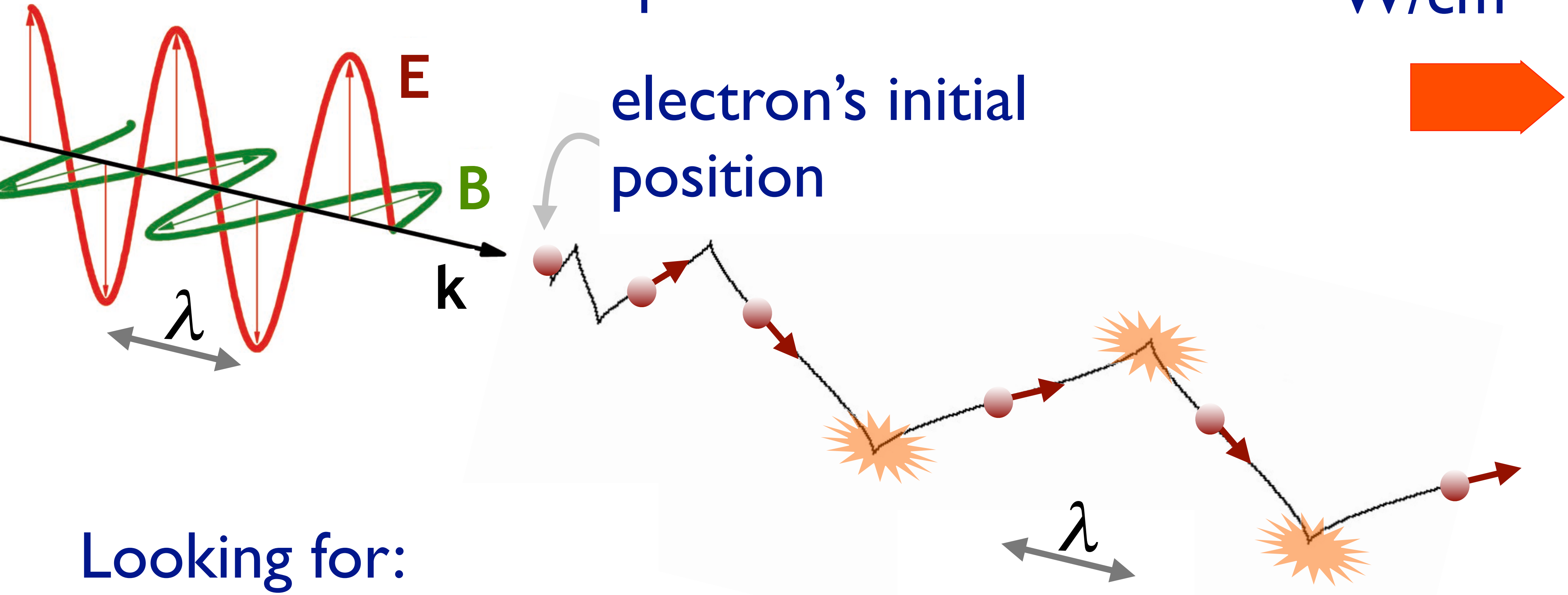


electron's initial position

$$-e\left(\vec{E}+\frac{\vec{v}}{c}\times\vec{B}\right)=\vec{F}=\frac{d\vec{p}}{dt}$$

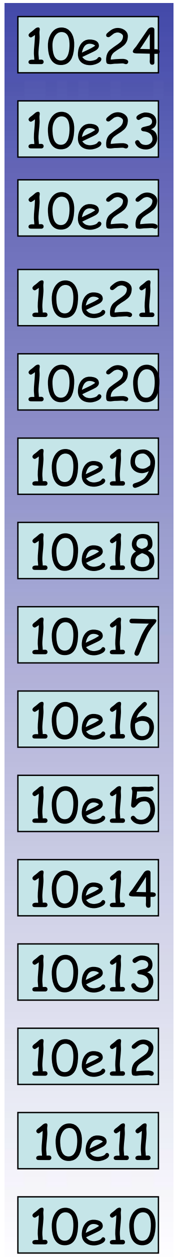
Electron driven by a laser field

Plane wave laser pulse



electron’s initial position

W/cm^2



Looking for:
acceleration or
celerity ?

Radiation reaction

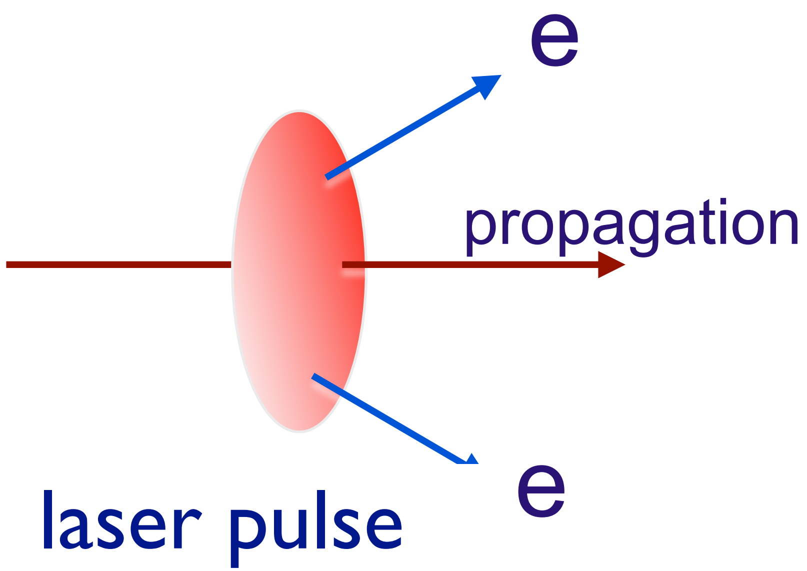
beyond 10^{23} W/cm^2

Coupling laser - electron

Very efficient

$$E_{\max} = m c^2 + \frac{1}{4}\frac{q^2}{m\,\omega^2} I$$

Intensity	Max energy of an electron inside this field
10^{16} W/cm^2	1 KeV
10^{19} W/cm^2	1 MeV
10^{20} W/cm^2	10 MeV
10^{21} W/cm^2	100 MeV
10^{22} W/cm^2	1 GeV
10^{23} W/cm^2	10 GeV

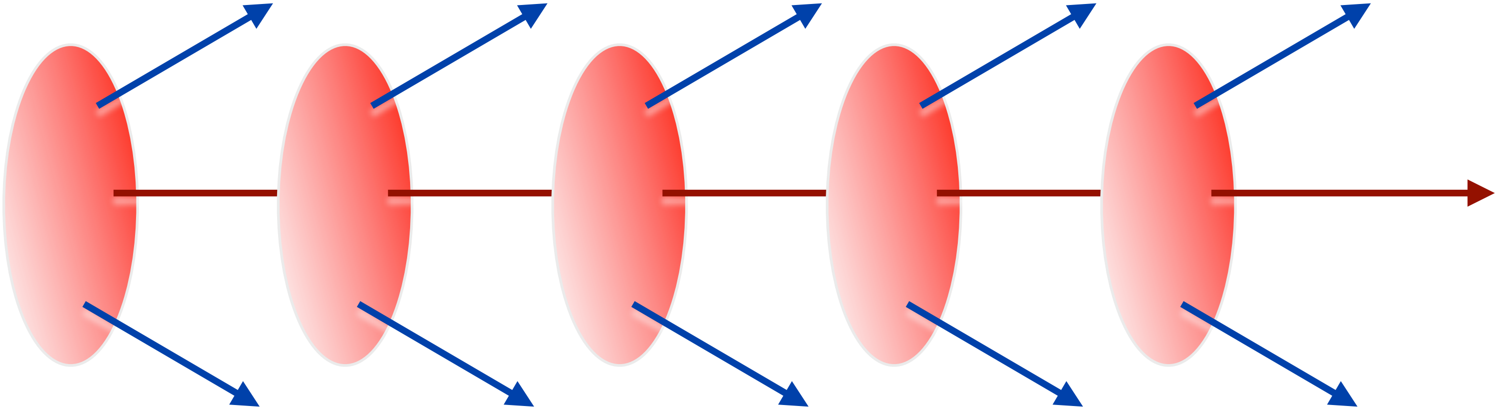


Coupling laser - electron

Coupling is very efficient

$$E_{\max} = m c^2 + \frac{1}{4}\frac{q^2}{m\,\omega^2} I$$

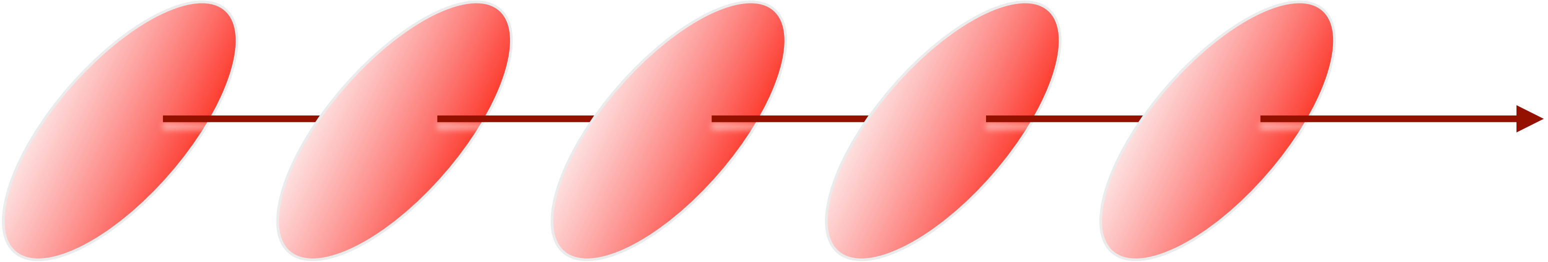
One big problem:
magnetic field push the trajectory at an angle



Acceleration in the forward direction

Two possibilities:

- Tailor the laser pulses (phase and intensity in different directions)
- Use plasma effects to compensate (collective motion in the forward direction)

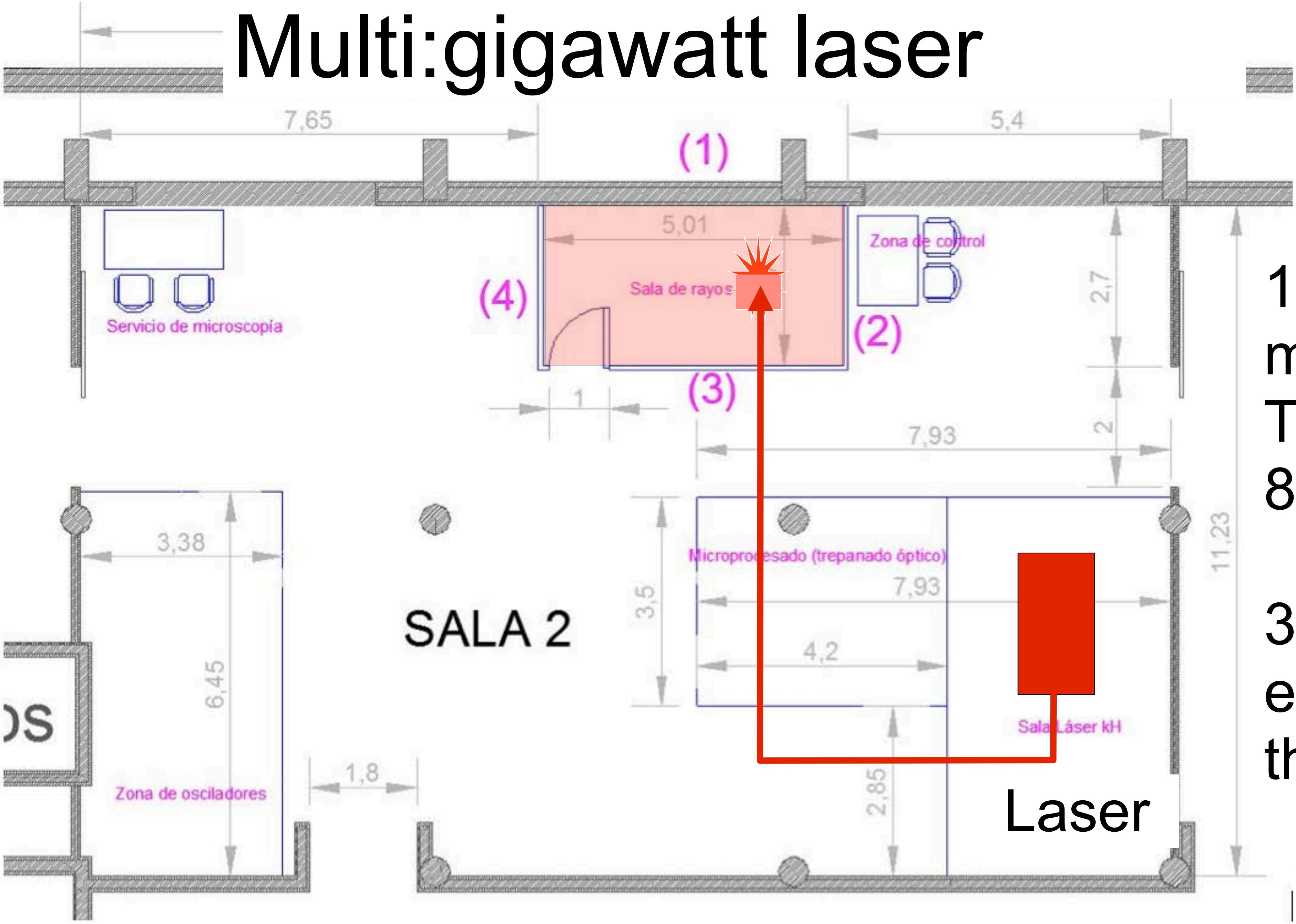


Realistic limits

Peak power	Focal spot waist microns	Intensity	Electron energy max
10 GW	$w_0 = 1$	$3\ 10^{17}$ W/cm^2	30 kev
1 TW	$w_0 = 1$	$3\ 10^{19}$ W/cm^2	3 MeV
100 TW	$w_0 = 1$	$3\ 10^{21}$ W/cm^2	300 MeV
	$w_0 = 10$	$3\ 10^{19}$ W/cm^2	3 MeV
1 PW	$w_0 = 1$	$3\ 10^{22}$ W/cm^2	3 GeV
	$w_0 = 10$	$3\ 10^{20}$ W/cm^2	30 MeV
10 PW	$w_0 = 1$	$3\ 10^{23}$ W/cm^2	30 GeV
	$w_0 = 10$	$3\ 10^{21}$ W/cm^2	300 MeV
10 ZW	$w_0 = 1$	$3\ 10^{29}$ W/cm^2	30 PeV

Not soon !!!

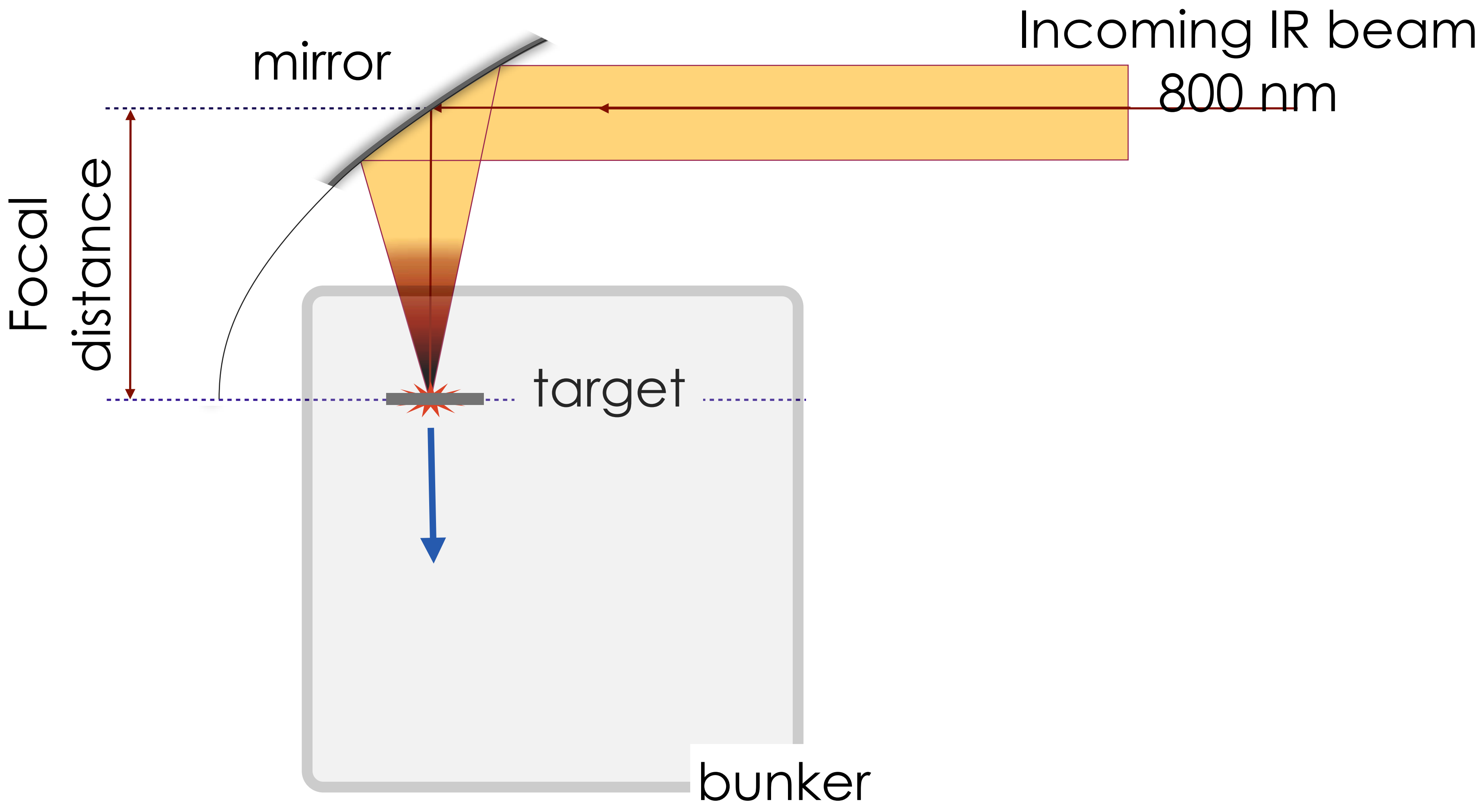
Multi:gigawatt laser



10 GW
mJ/shot
Ti:Sapp
800 nm

30 keV
electrons
thermal

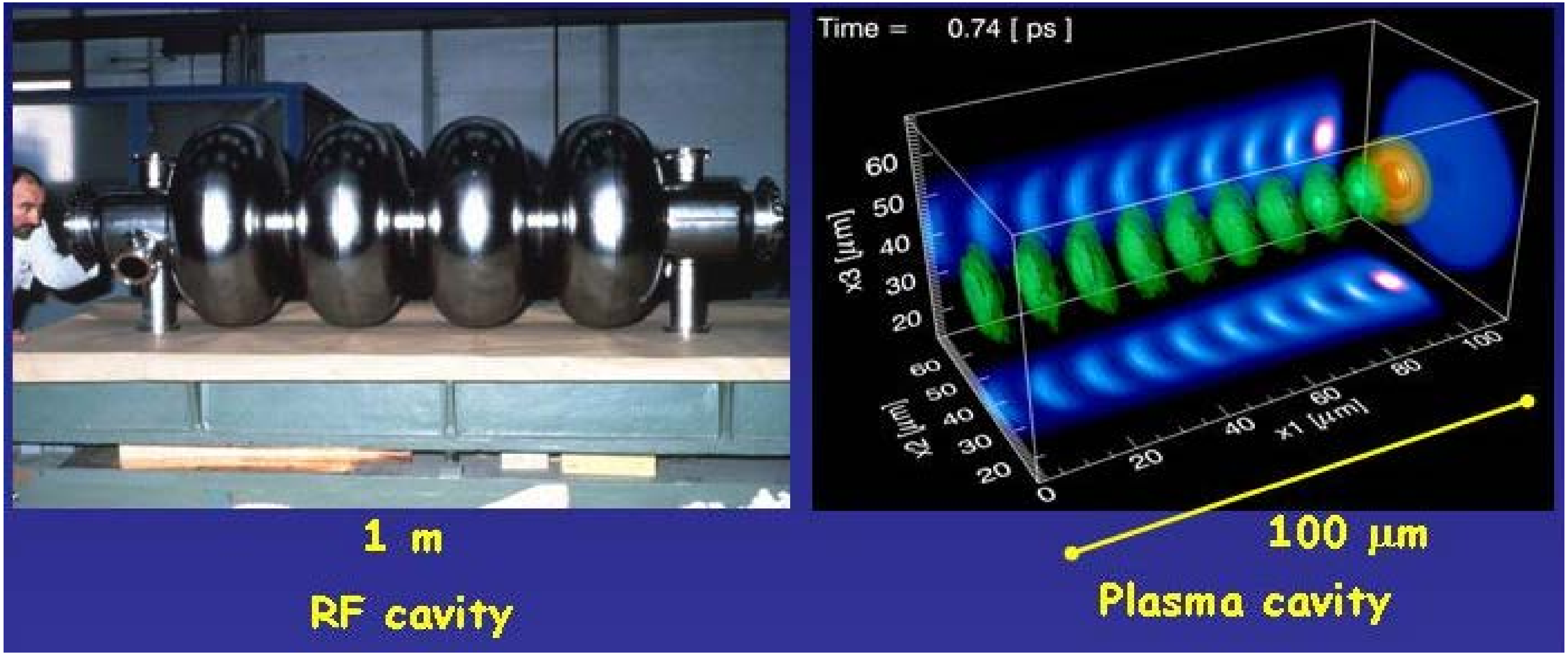
Radioprotection



Plasma effects

Aceleradores

Conventional Laser



From Victor Malka

Plasma accelerators

Idea from:

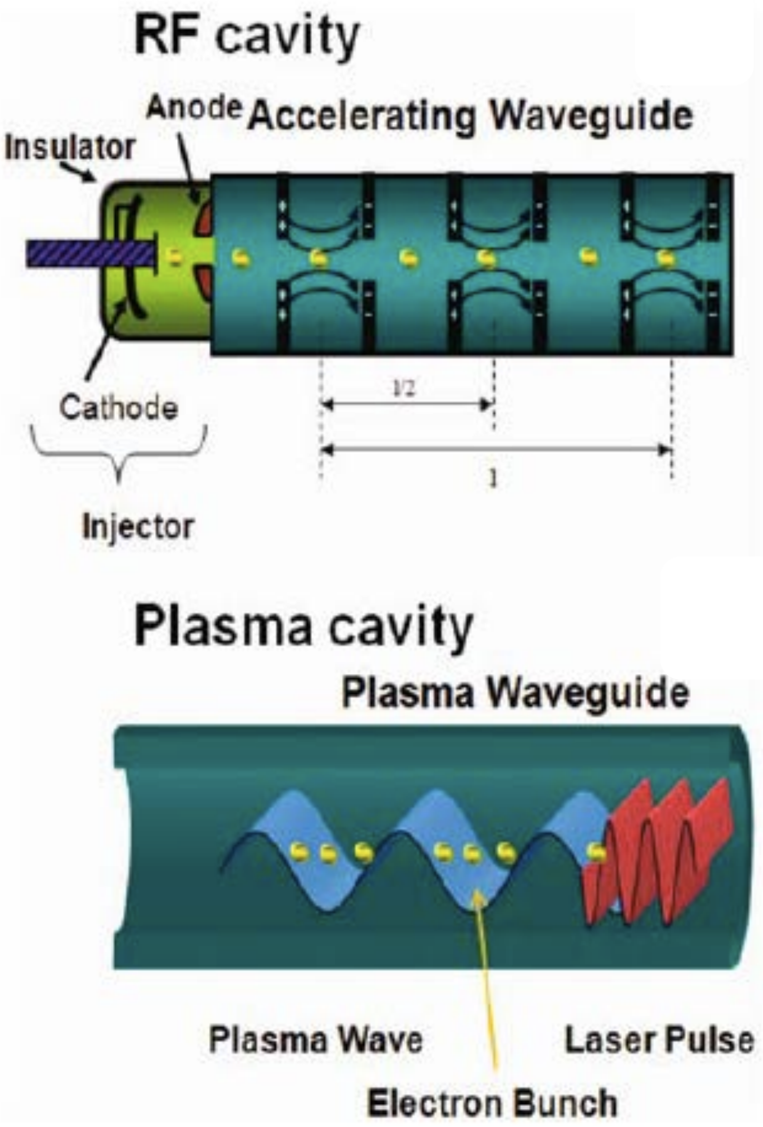
T Tajima and J N Dawson

Phys Rev Lett 1979

An intense electromagnetic pulse can create a weak of plasma oscillations.

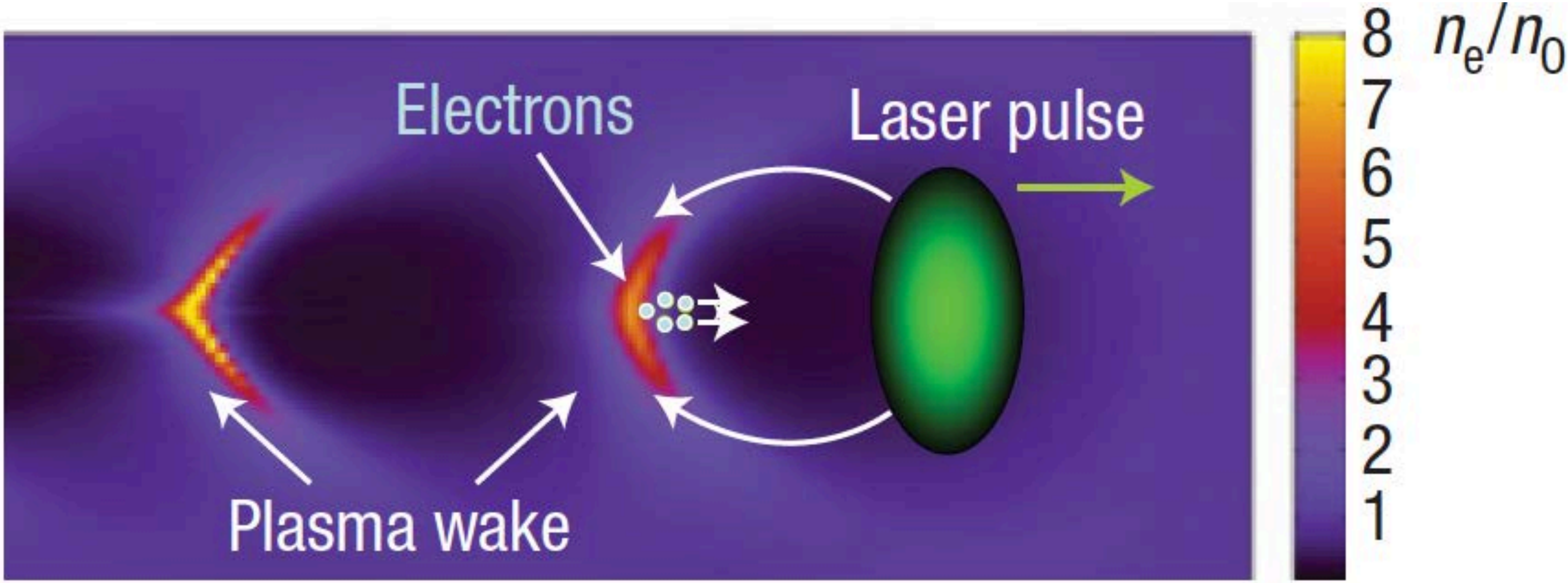
Electrons trapped in the wake can be accelerated to high energy.

GeV/cm



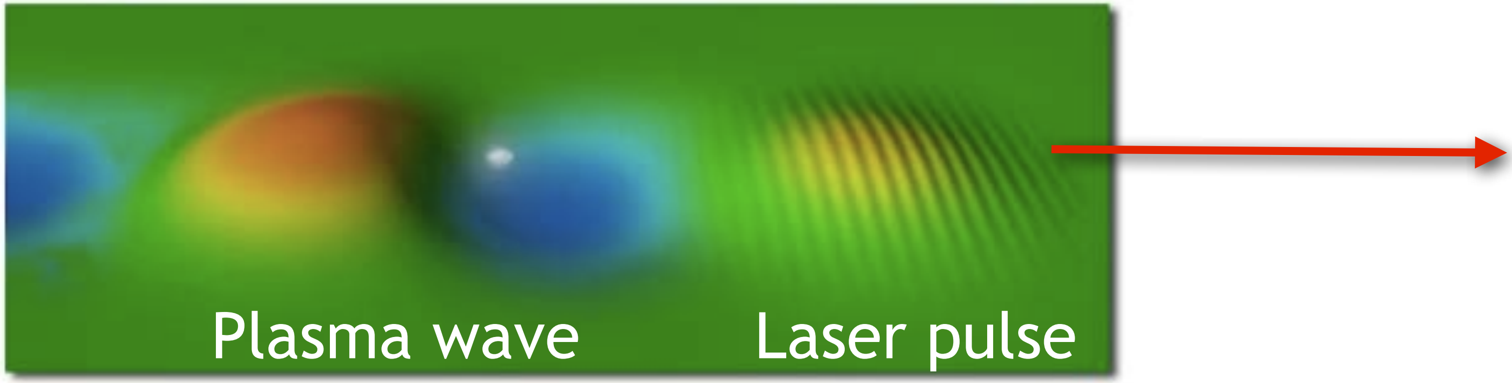
Bulanov et al.
Eur Phys Jour D 2009

Laser induced acceleration



From Victor Malka

Laser wakefield acceleration



from W Leemans Berkeley

Laser Electron Accelerator

Nature 431, 541-544 2004

A laser–plasma accelerator producing monoenergetic electron beams

J. Faure et al

V Malka Group

Laser accelerators
100 GeV/m

The resulting electron beam is extremely collimated and quasi-monoenergetic, with a high charge of 0.5 nC at 170 MeV.

30 September 2004

International weekly journal of science

nature

www.nature.com/nature

Dream beam

The dawn of compact particle accelerators

Offshore tuna ranches
A threat to US waters?

The Earth's hum
Sounds of air and sea

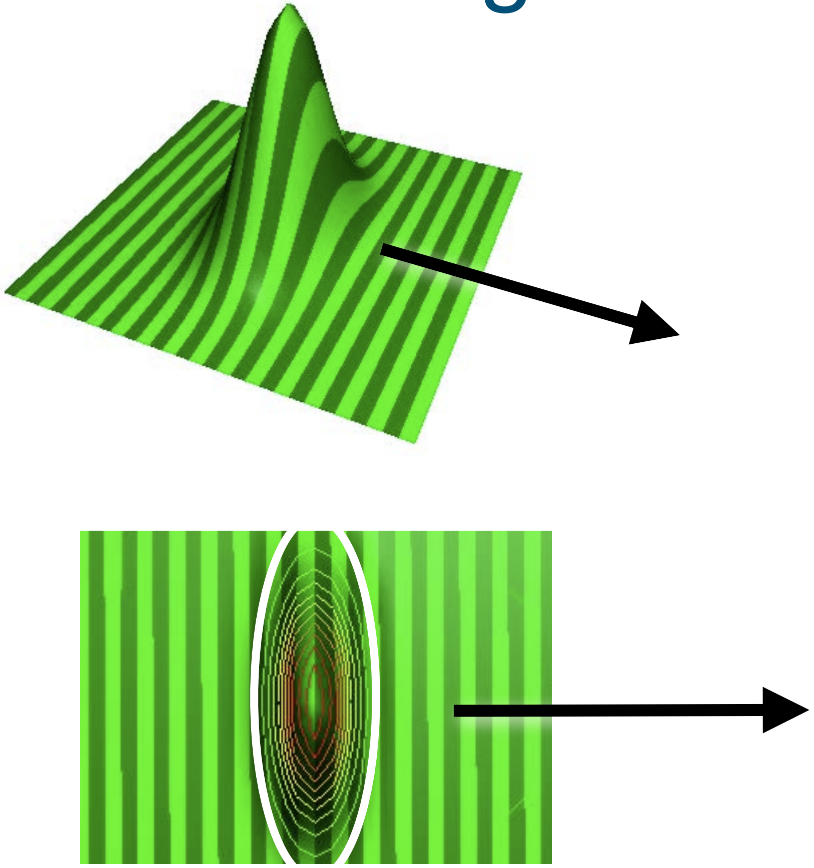
Protein folding
Escape from the ribosome

Human ancestry
One from all and all from one

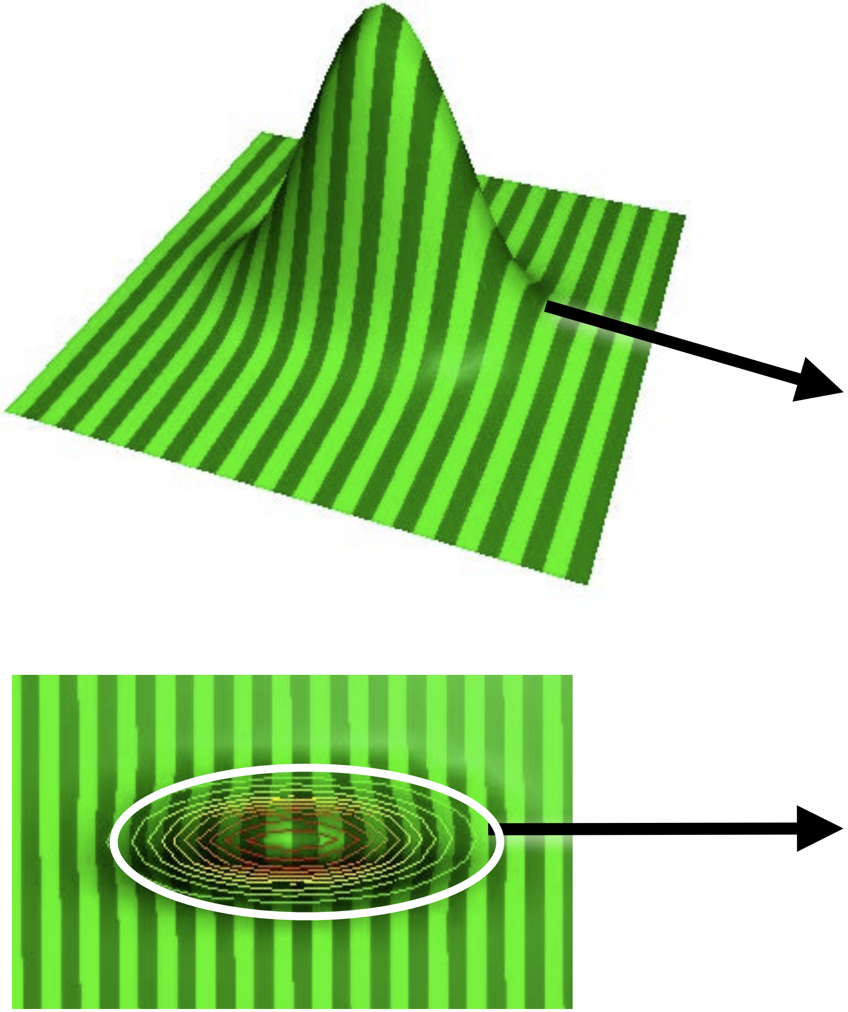
technology feature RNA interference

Bubble Electron Acceleration

waist > length

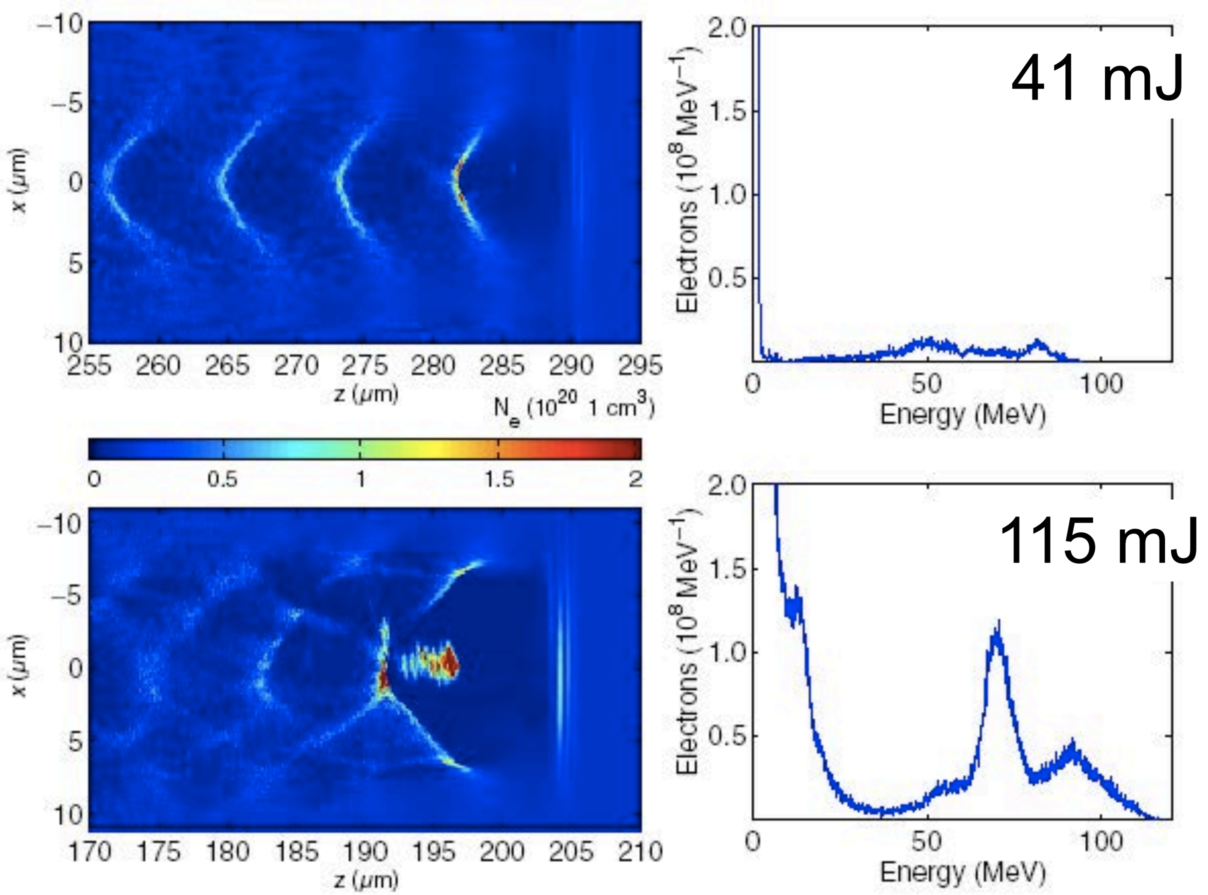


Bubble



Wakefield

Bubble Electron Acceleration



Simulation for
5 fs pulse

M Geissler, J Schreiber, and J Meyer-ter-Vehn New J. Phys. 8 (2006) 186
Bubble acceleration of electrons with few-cycle laser pulses

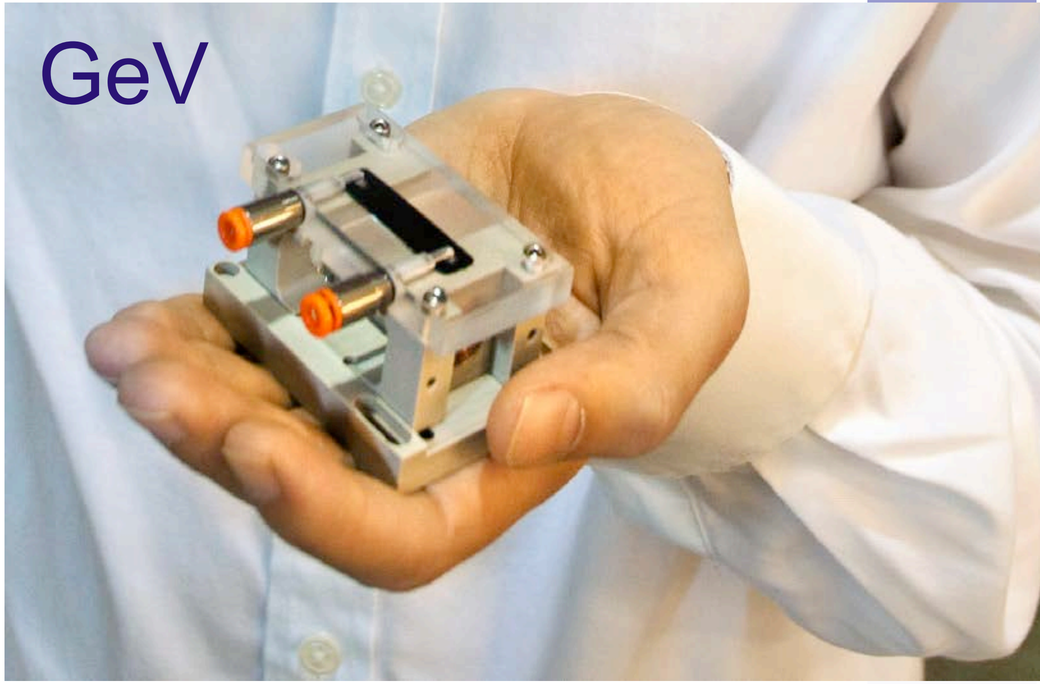
Laser induced acceleration

W/cm²

10e24
10e23
10e22
10e21
10e20

Max energy over a very short distance

Compact accelerator



GeV

Wim Leemans, Berkeley

New concepts
New safety regulations

Average current (hours)
Instant current (seconds)
Peak current (femtoseconds)

Proton / ion acceleration

Direct laser acceleration

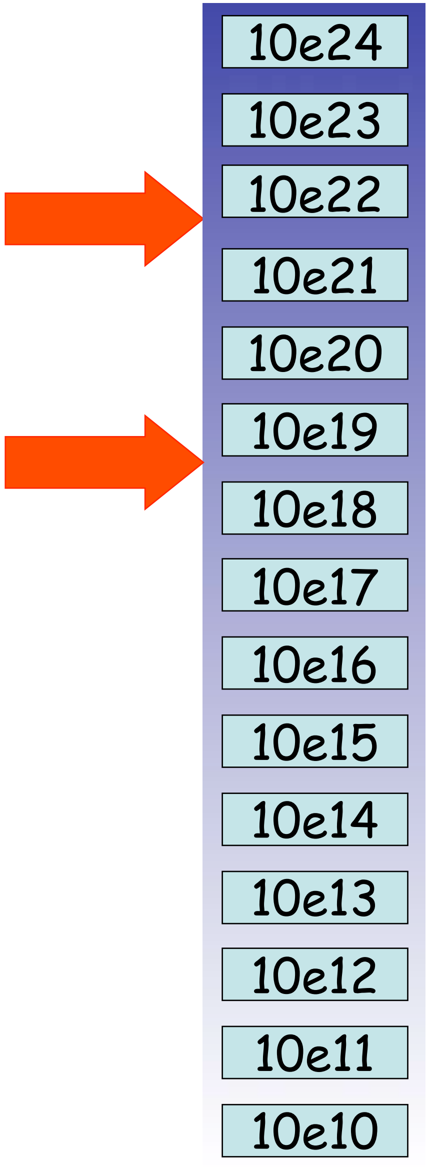
$$E_{max} = \boldsymbol{M} c^2 + \frac{1}{4}\frac{q^2}{\boldsymbol{M}\,\omega^2} I$$

Due to the small mass,

electrons couple much more efficiently to laser !!!

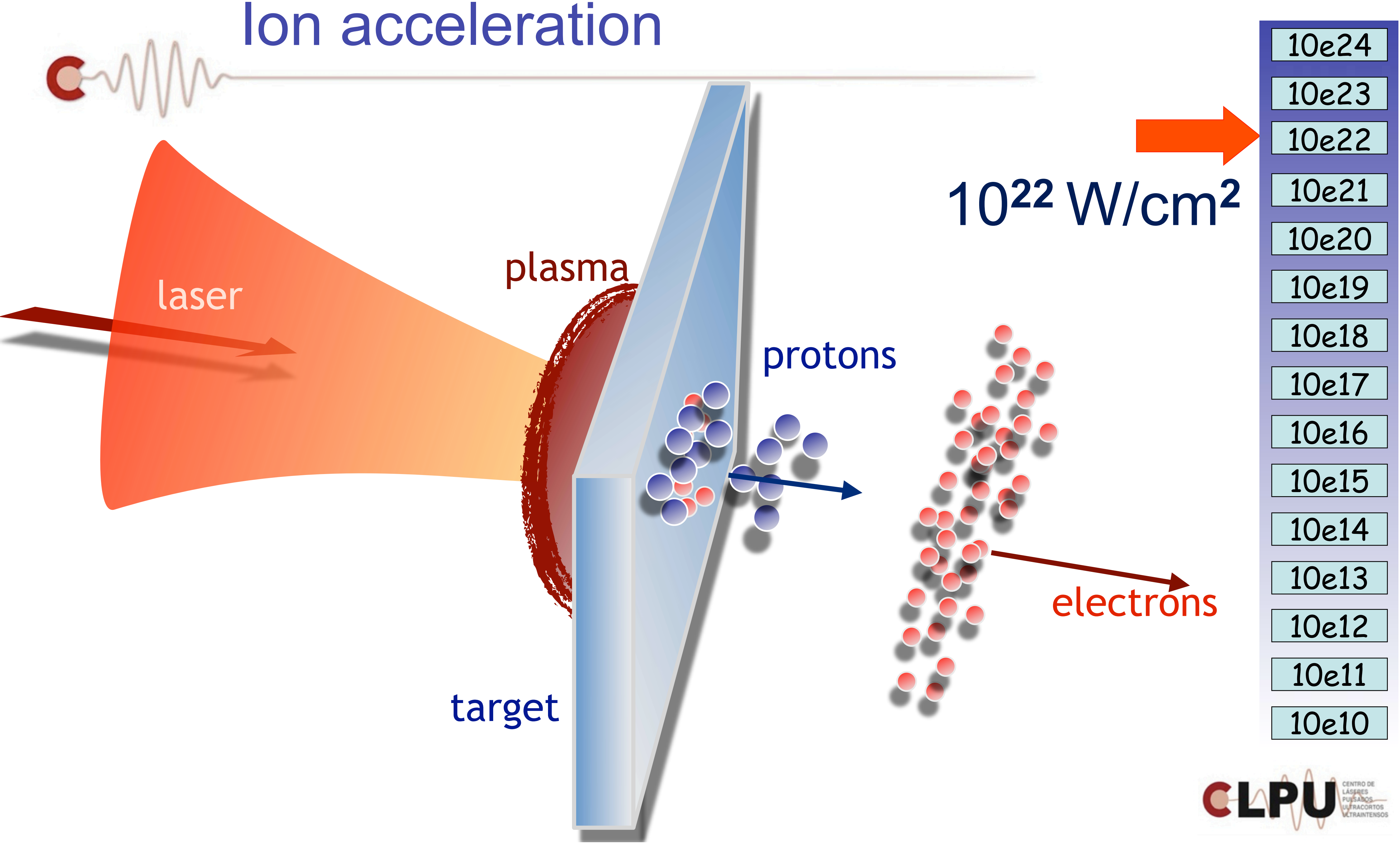
Direct electron acceleration is the goal ...

Direct proton acceleration is less efficient ...



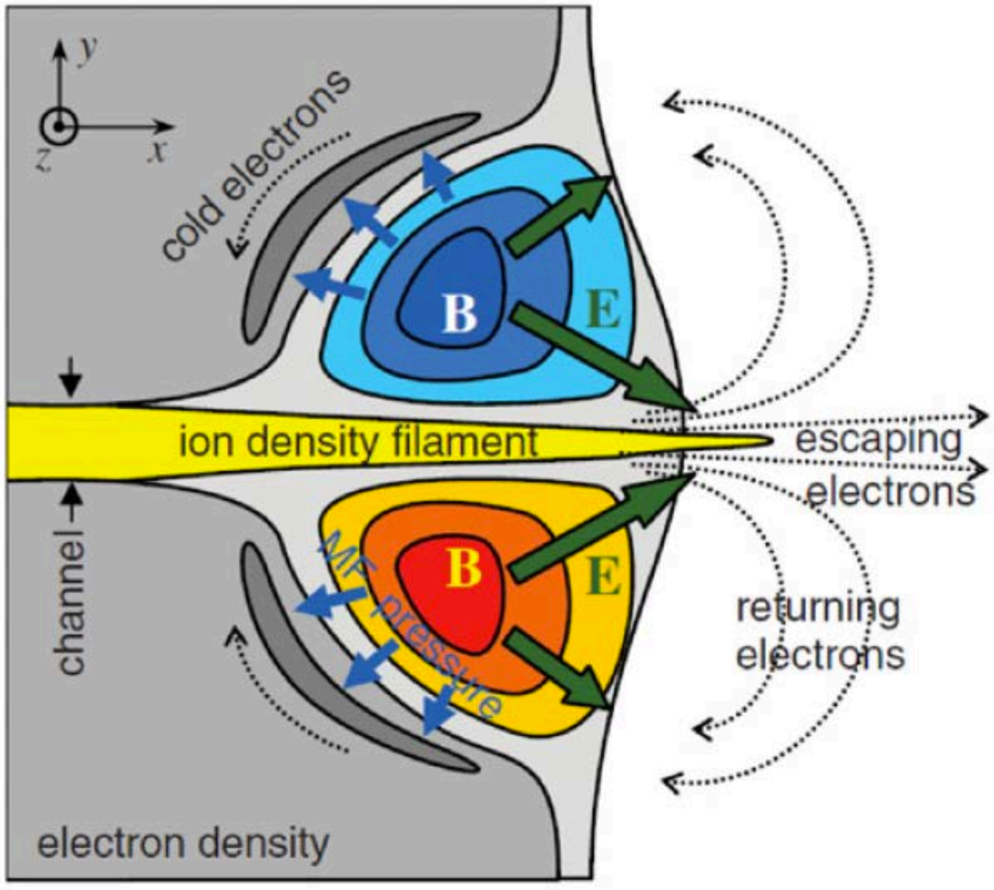
10e24
10e23
10e22
10e21
10e20
10e19
10e18
10e17
10e16
10e15
10e14
10e13
10e12
10e11
10e10

Ion acceleration



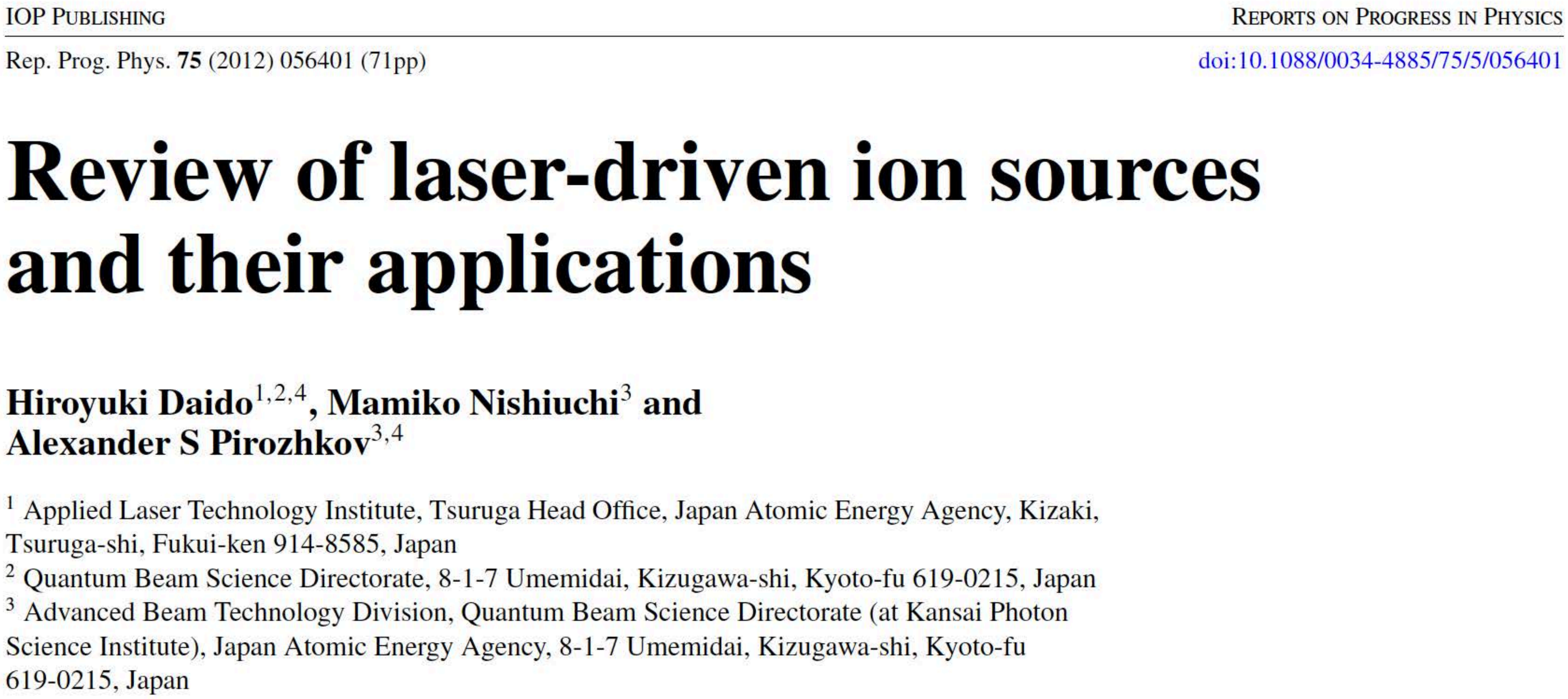
10^{22} W/cm^2

Laser induced acceleration



Daido et al, Rep Prog Phys, 75 (2012) 056401

Laser induced acceleration



IOP PUBLISHING REPORTS ON PROGRESS IN PHYSICS

Rep. Prog. Phys. **75** (2012) 056401 (71pp) doi:10.1088/0034-4885/75/5/056401

Review of laser-driven ion sources and their applications

Hiroyuki Daido[1,2,4], **Mamiko Nishiuchi**[3] **and**
Alexander S Pirozhkov[3,4]

[1] Applied Laser Technology Institute, Tsuruga Head Office, Japan Atomic Energy Agency, Kizaki, Tsuruga-shi, Fukui-ken 914-8585, Japan
[2] Quantum Beam Science Directorate, 8-1-7 Umemidai, Kizugawa-shi, Kyoto-fu 619-0215, Japan
[3] Advanced Beam Technology Division, Quantum Beam Science Directorate (at Kansai Photon Science Institute), Japan Atomic Energy Agency, 8-1-7 Umemidai, Kizugawa-shi, Kyoto-fu 619-0215, Japan

Particle accelerators

Short distances and high g levels

Radiofrequency fields < 100 MVolt /m

Laser fields > 100 GVolt /m

possibility to get TeV in a few meters !!!

ideal for short lived particles such as:

- charged pions (lifetime of 26 ns)
- taus (lifetime of 290 fs)

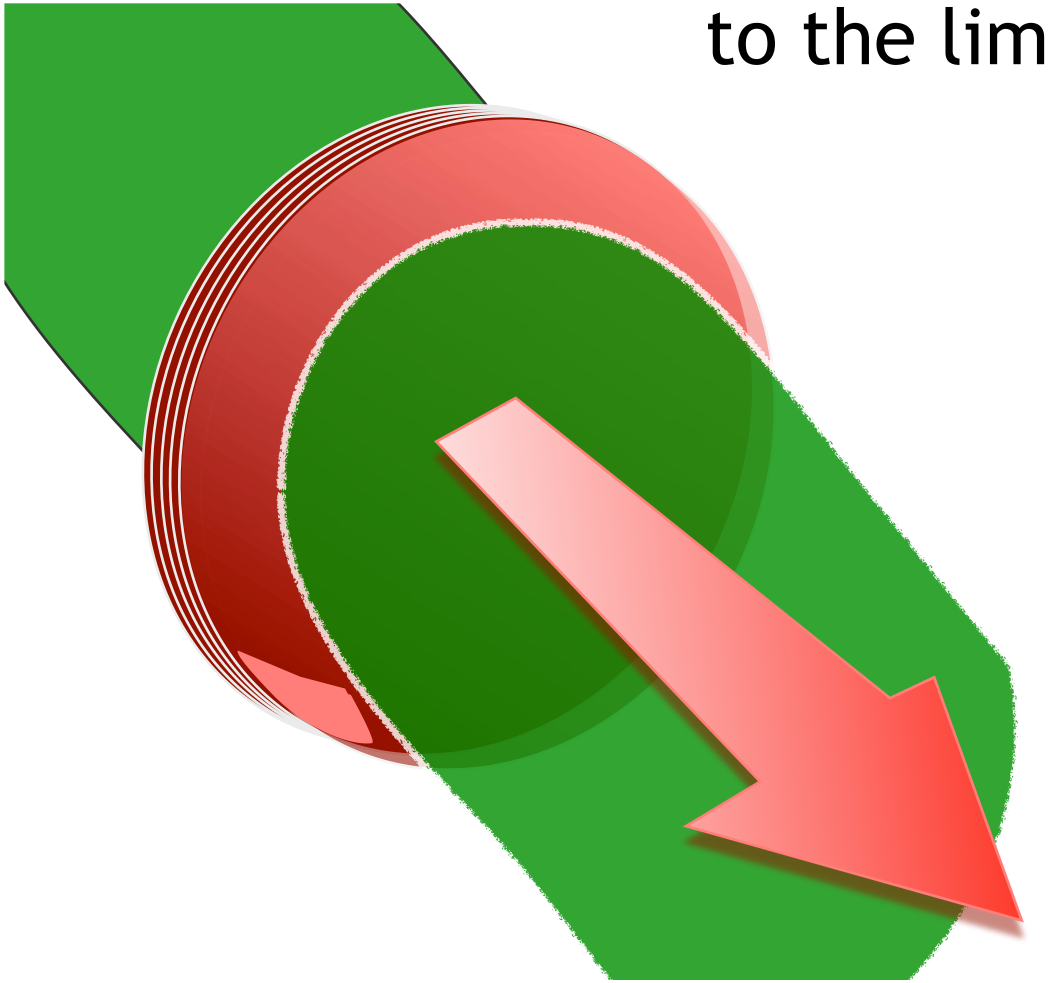
That can live much longer in lab time.

Conventional accelerators have not time to accelerate them!

A bit more of lasers

Petawatt

Technology
to the limit



$$\mathrm{PW} = \frac{\mathrm{MJ}}{\mathrm{ns}} = \frac{\mathrm{kJ}}{\mathrm{ps}} = \frac{30\ \mathrm{J}}{30\ \mathrm{fs}} = \frac{\mathrm{joule}}{\mathrm{fs}}$$

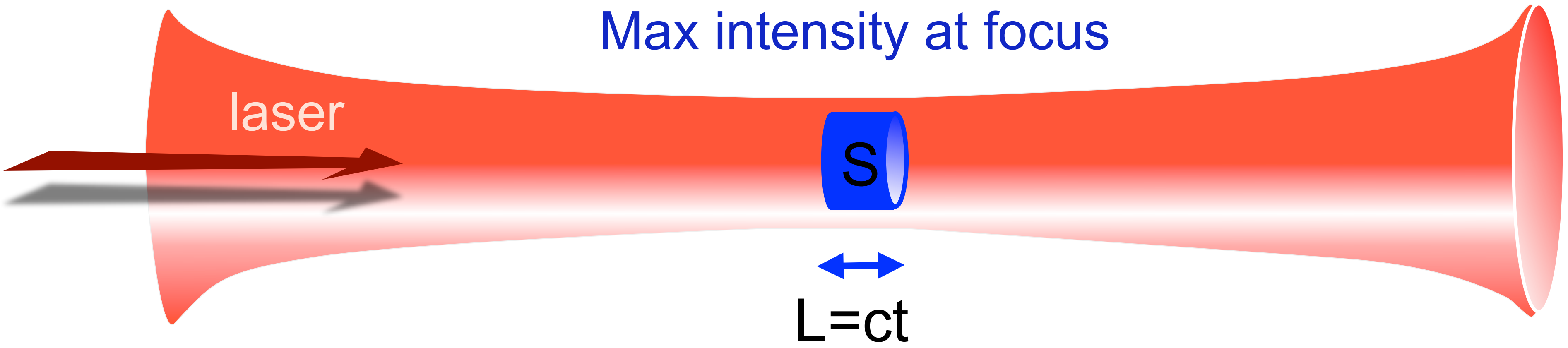
Intensity

$$PW = \frac{MJ}{ns} = \frac{kJ}{ps} = \frac{30\ J}{30\ fs} = \frac{joule}{fs}$$

For acceleration the key is to concentrate energy in space and time

Good optical quality

$$Intensity = \frac{power}{surface}$$



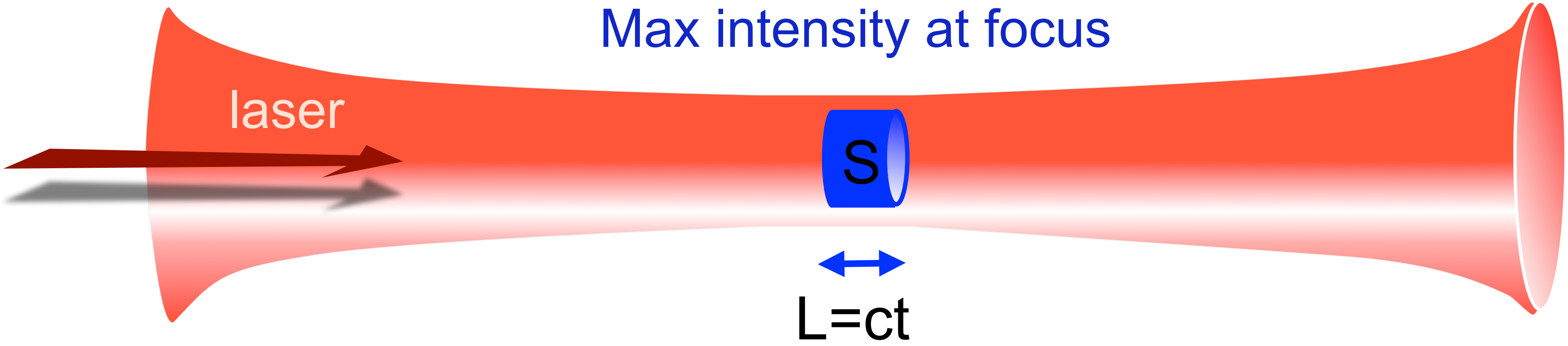
Intensity

$$PW = \frac{MJ}{ns} = \frac{kJ}{ps} = \frac{30\ J}{30\ fs} = \frac{joule}{fs}$$

For acceleration the key is to concentrate energy in space and time

Good optical quality

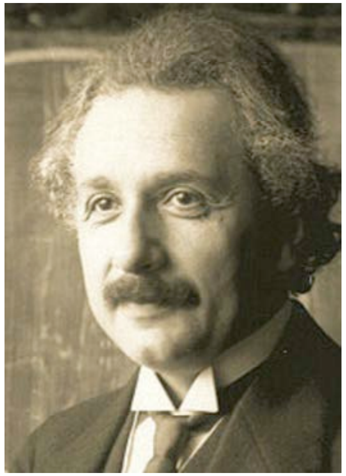
$$Intensity = \frac{power}{surface}$$



Pulse energy confined in a volume SL

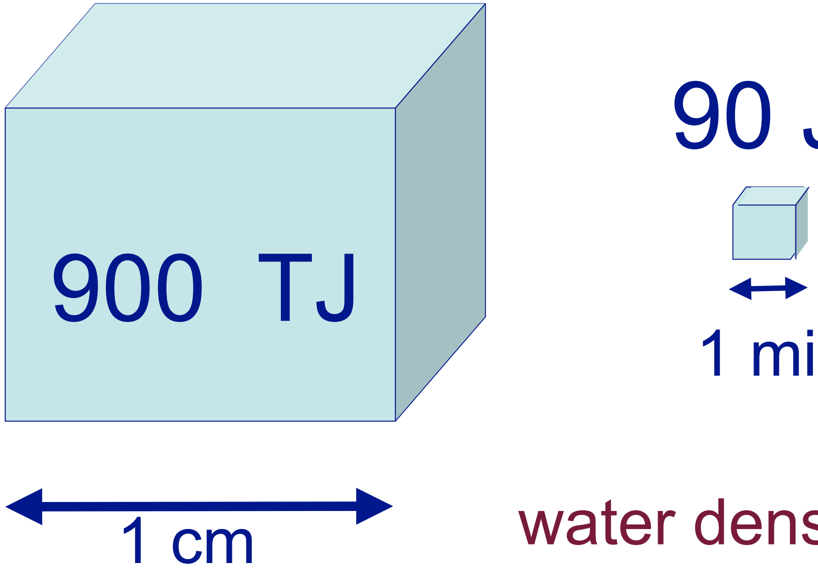
Energy concentration

Energy and mass



$$E=mc^2$$

$$E=8.9876\ 10^{16}\ \mathrm{J/kg}$$



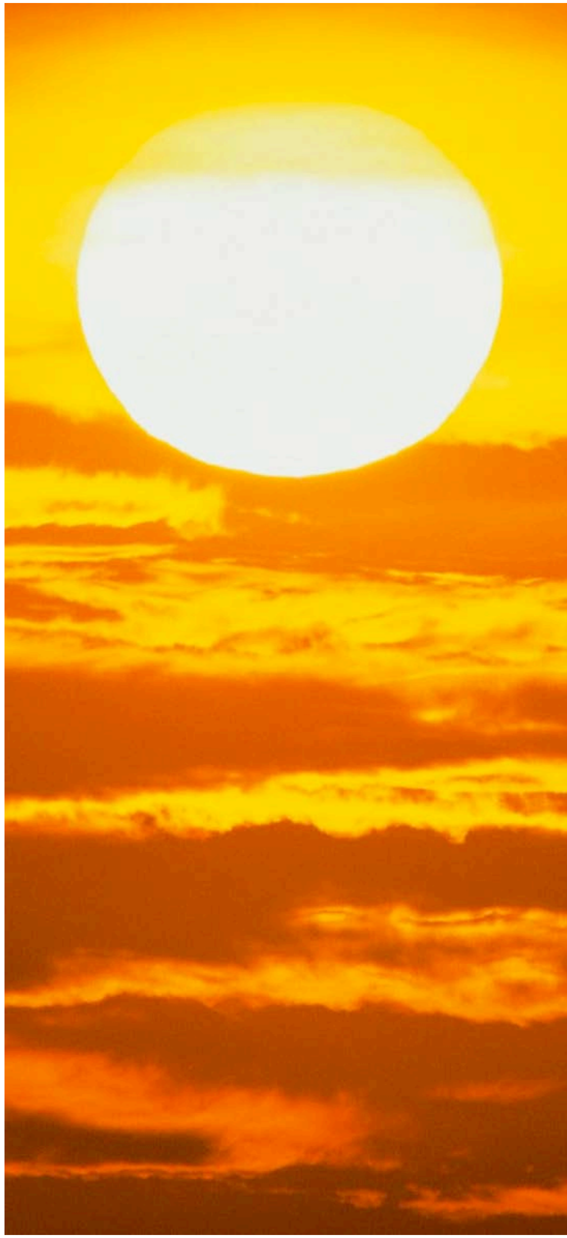
900 TJ

1 cm

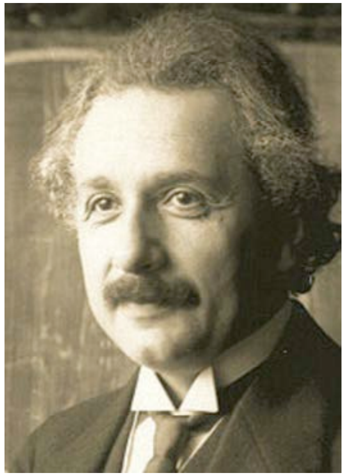
90 Joule

1 micron

water density 1 gram/cm3



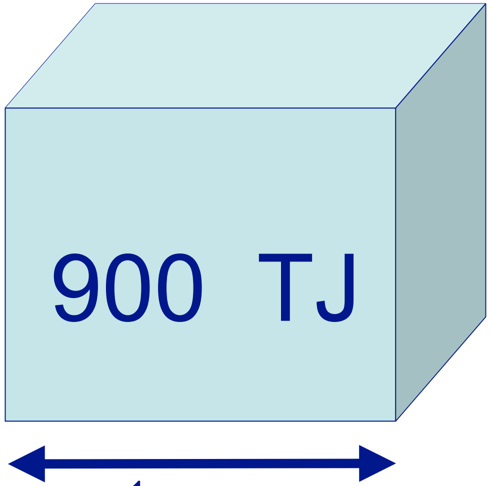
Energy and mass



$$E\xcancel{=m}c^2$$

$$I = \rho c^3$$

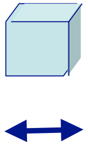
water density 1 gram/cm3



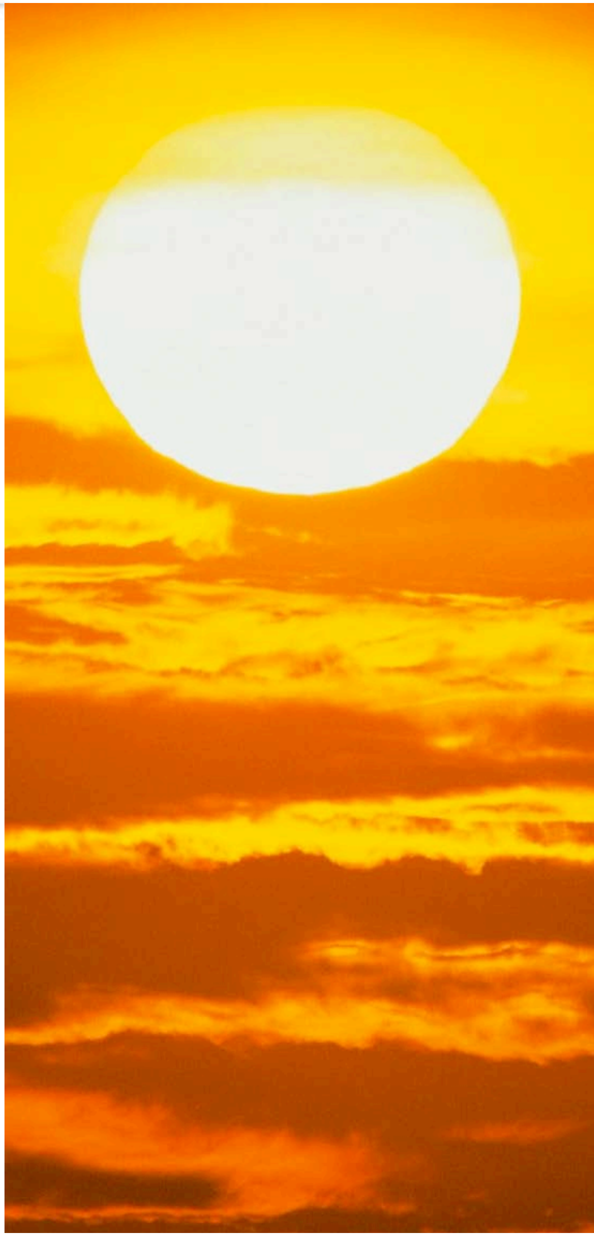
900 TJ

1 cm

90 Joule



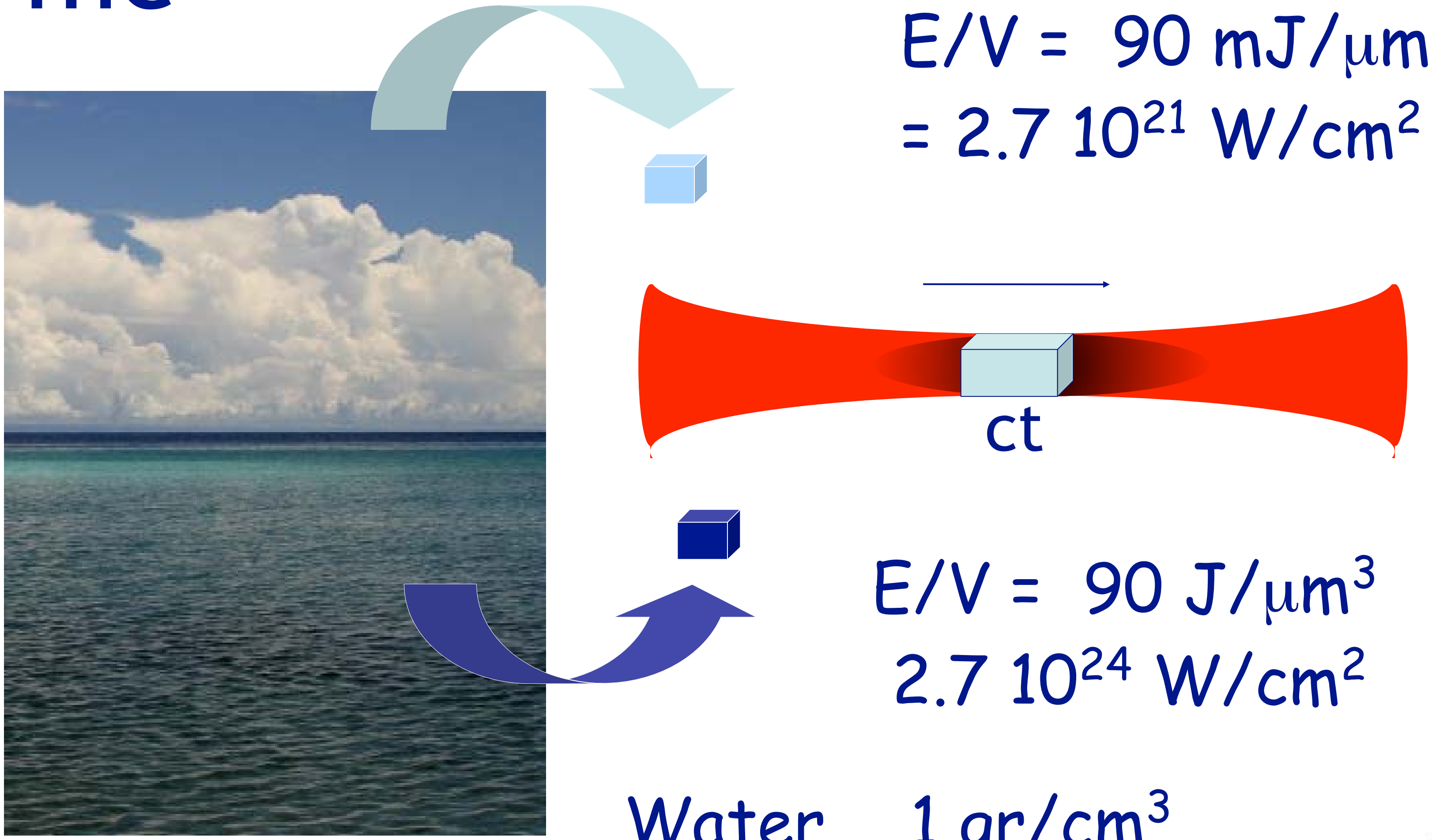
1 micron



Intensity

$E=mc^2$

Air … 1 mgr/cm^3



$E/V = 90\ mJ/\mu m^3$
$= 2.7\ 10^{21}\ W/cm^2$

$E/V = 90\ J/\mu m^3$
$2.7\ 10^{24}\ W/cm^2$

Water … 1 gr/cm^3

The ideal laser ?

Wavelength

800 nm Titanium:Sapphire ... my favourite now

1040 - 1080 nm Ytterbium in some crystals

1050 nm Nd glass for longer pulses (ps)

and

1 micron CO2 lasers
Terawatt CO2 lasers

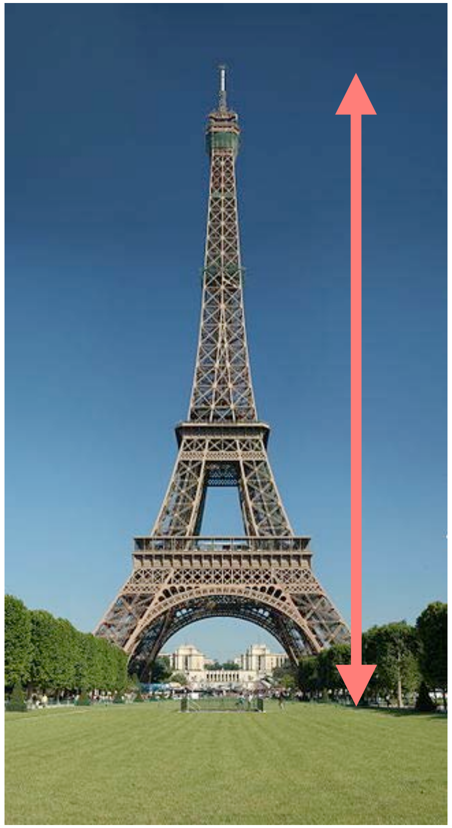
$$E_{\max} = m c^2 + \frac{1}{4} \frac{q^2}{m \omega^2} I$$

Parameters for laser induced acceleration

Peak intensity	10^{22} W/cm^2
Duration	50 fs (sub ps)
Wavelength	800 nm - 10 microns
Repetition rate	1 shot/sec ... 10 shot/sec
Contrast	$10^8:1$ $10^{10}:1$

Contrast

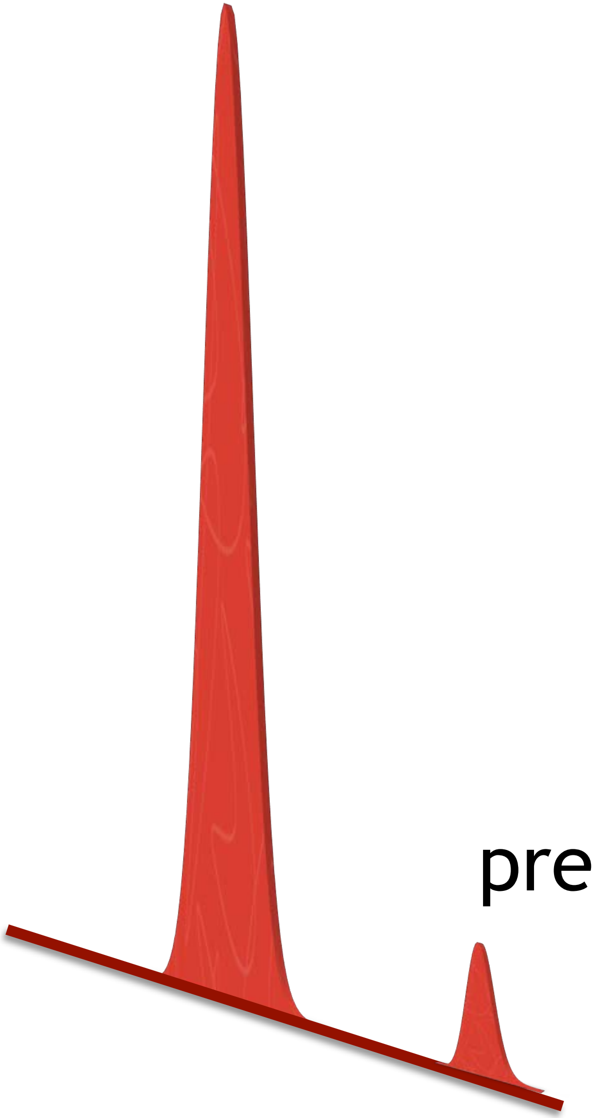
contrast better than 10^8



324 m

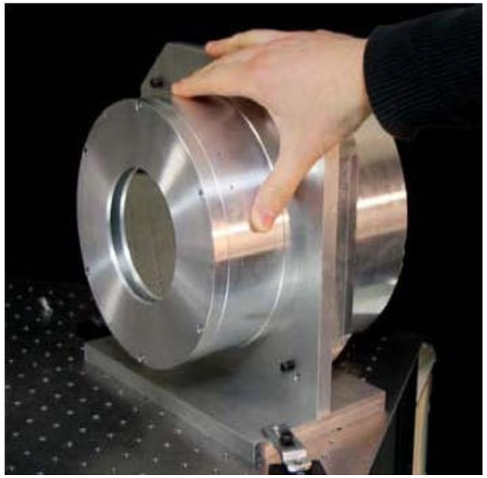
10^8

3,24 microns



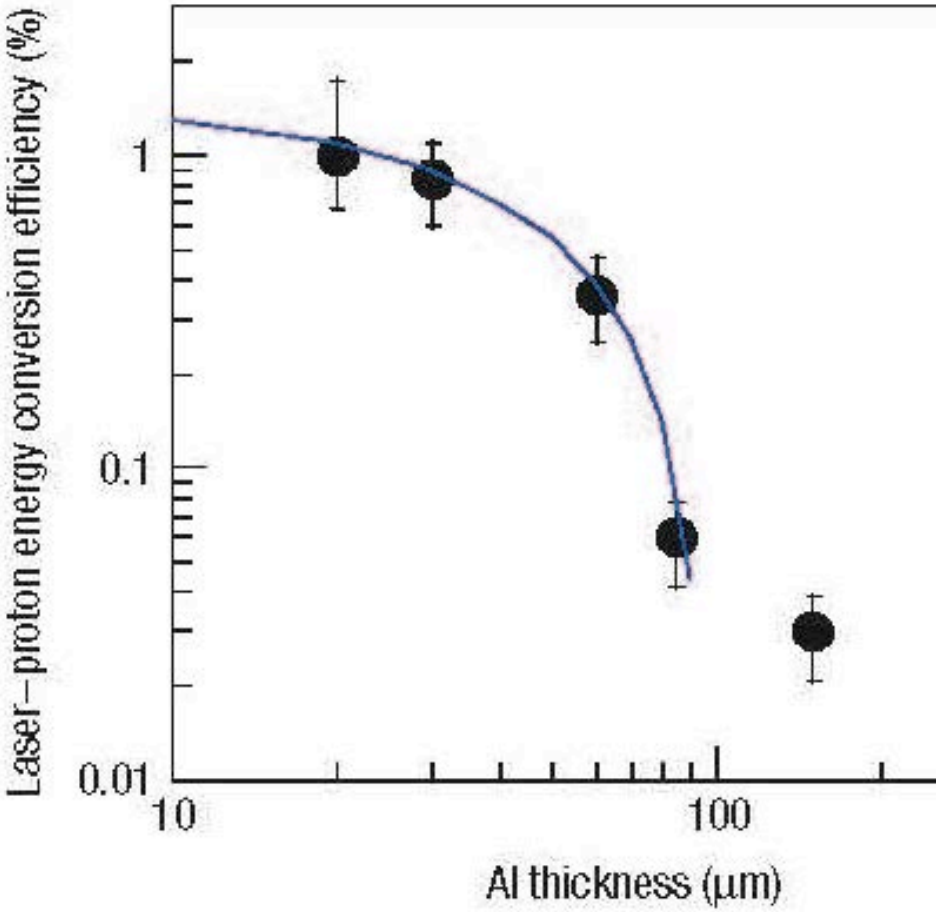
peak intensity

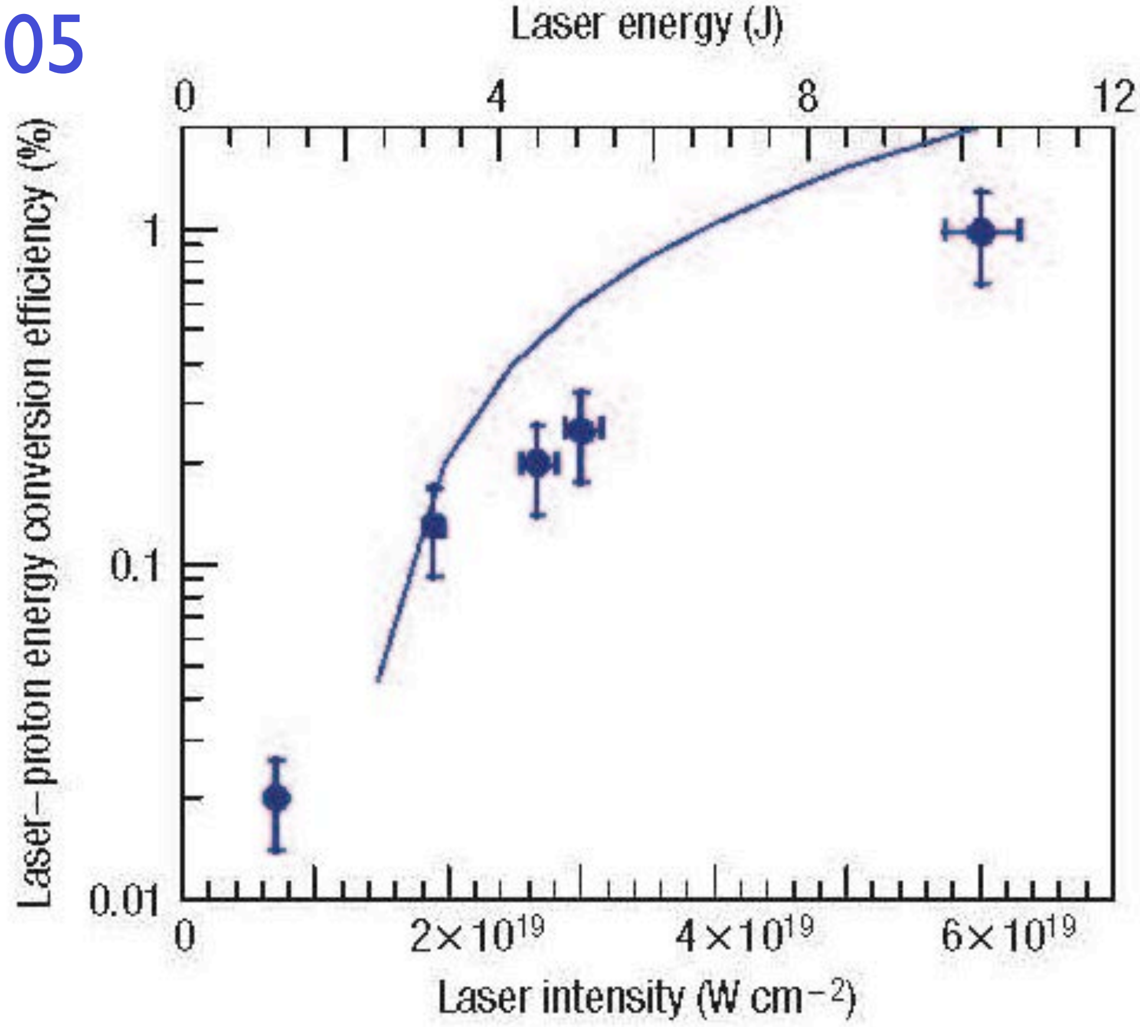
pre-pulse



Conversion efficiency

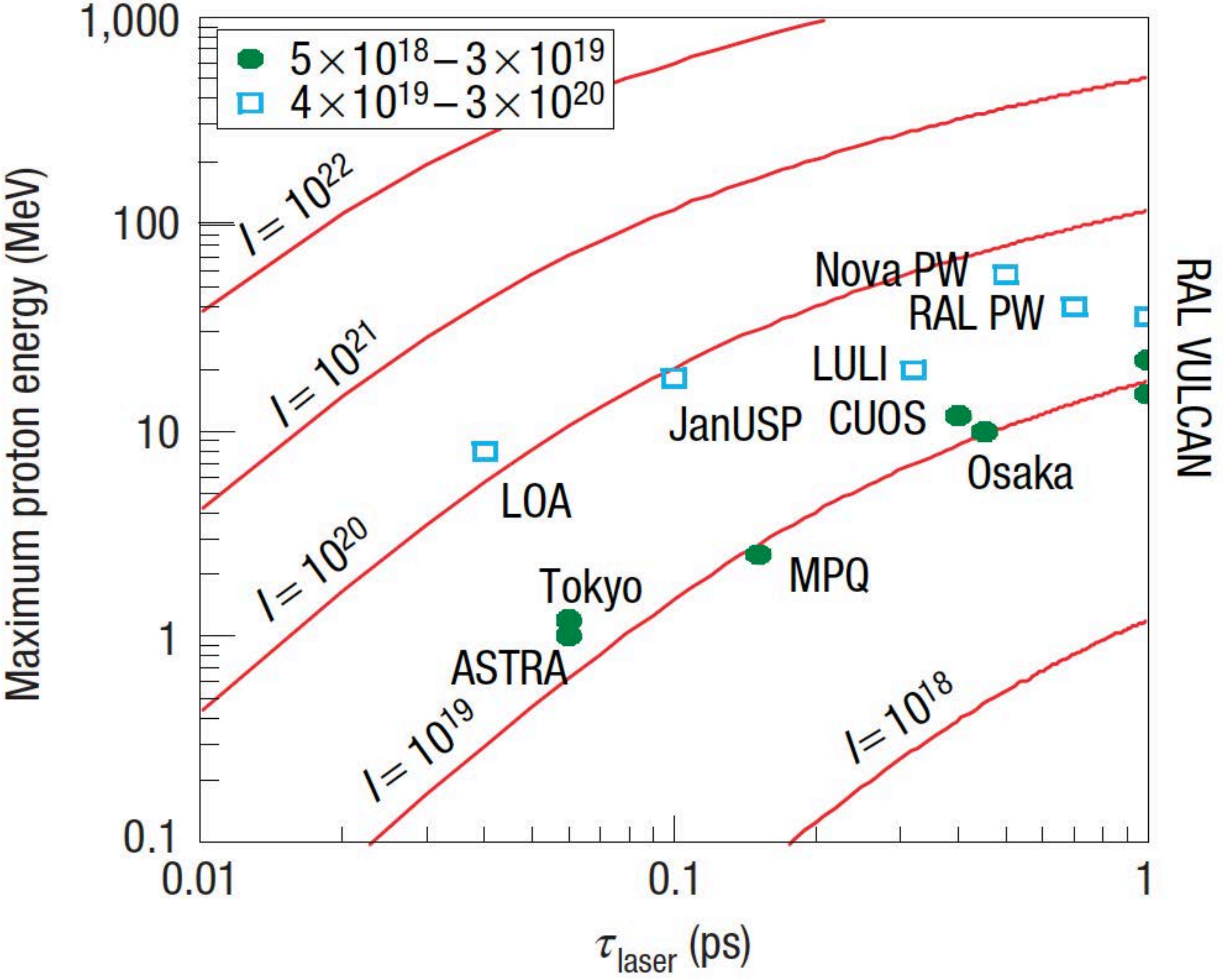
J Fuchs et al, Nature 2005





Laser induced acceleration

J Fuchs,
NaturePhysics
2005...



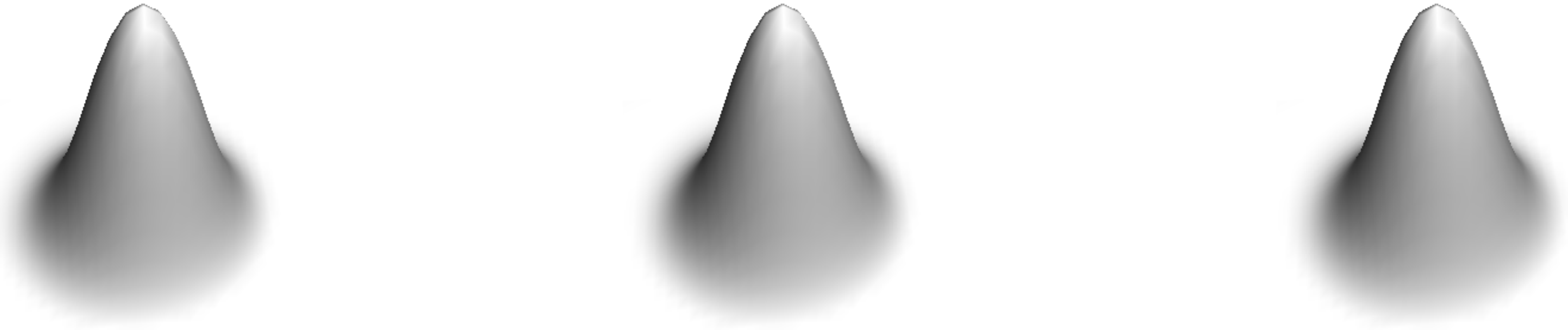
Proton flux for 30J/30fs

200 MeV 3 10^{-11} J

30 J at 1 percent efficiency = 0,3 J of protons

10^{-10} protons/shot at 200 MeV

In 30 fs --- kiloAmp!!! peak currents possible



Laser acceleration

Pros

- Compact
- Radioprotection just before focal point
- Suitable for carbon ions
- Rapid advance, tech far from limit
- Monoenergeticity possible

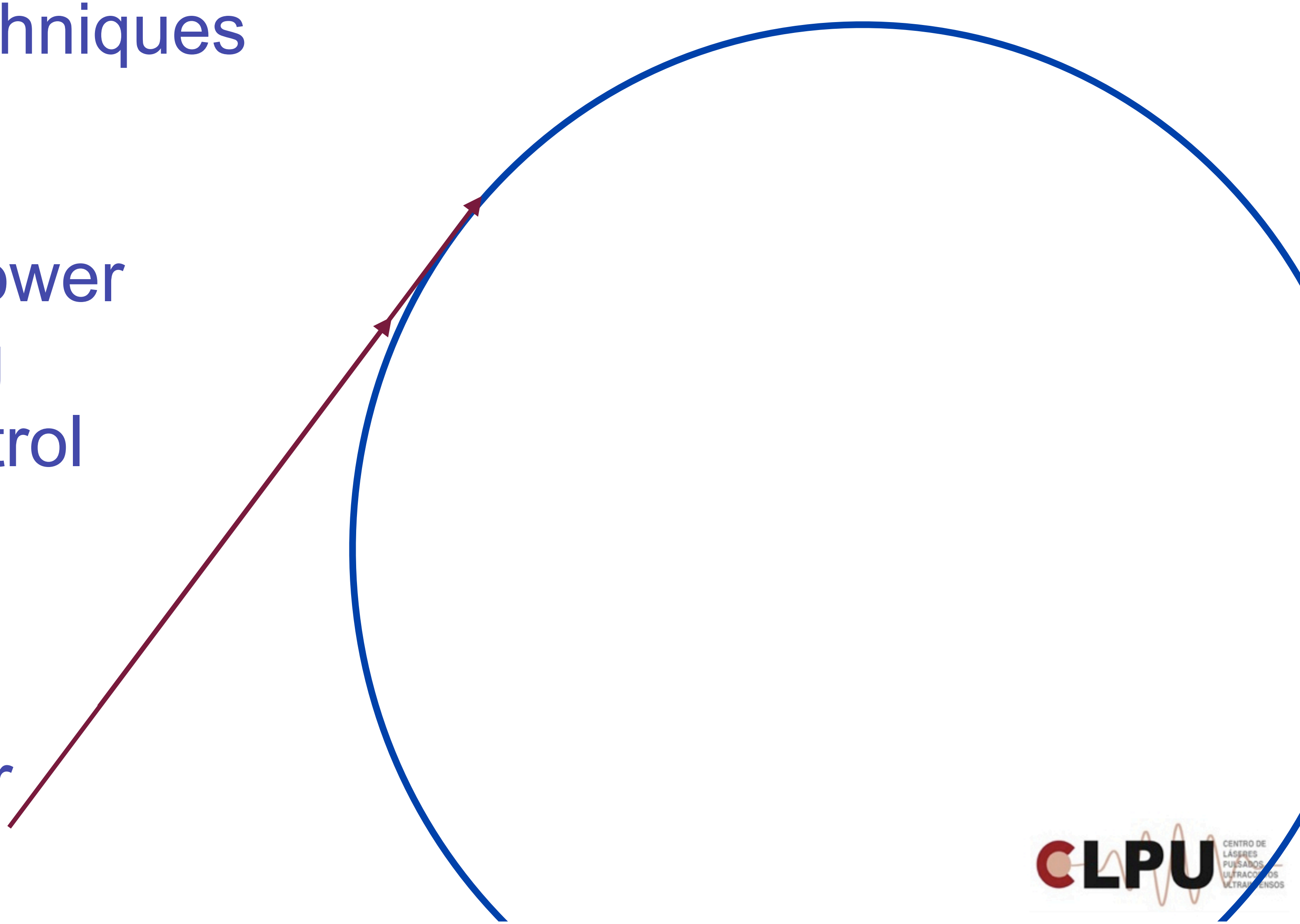
Cons

- Flux, average. Need of higher rep rates
- Conversion efficiency
- Need to fine control of laser parameters
- Need of target developments (clusters)
- Tech in progress

RF vs laser

Combined techniques

Laser peak power
Pulse tailoring
Coherent control



laser


CLPU
CENTRO DE
LÁSERES
PULSADOS

Pulsed Lasers Center
Salamanca, Spain

Consortium signed December 2007,

Partners	Percent
Ministerio de Economia y Competitividad	50
Junta de Castilla y León	45
Universidad de Salamanca	5

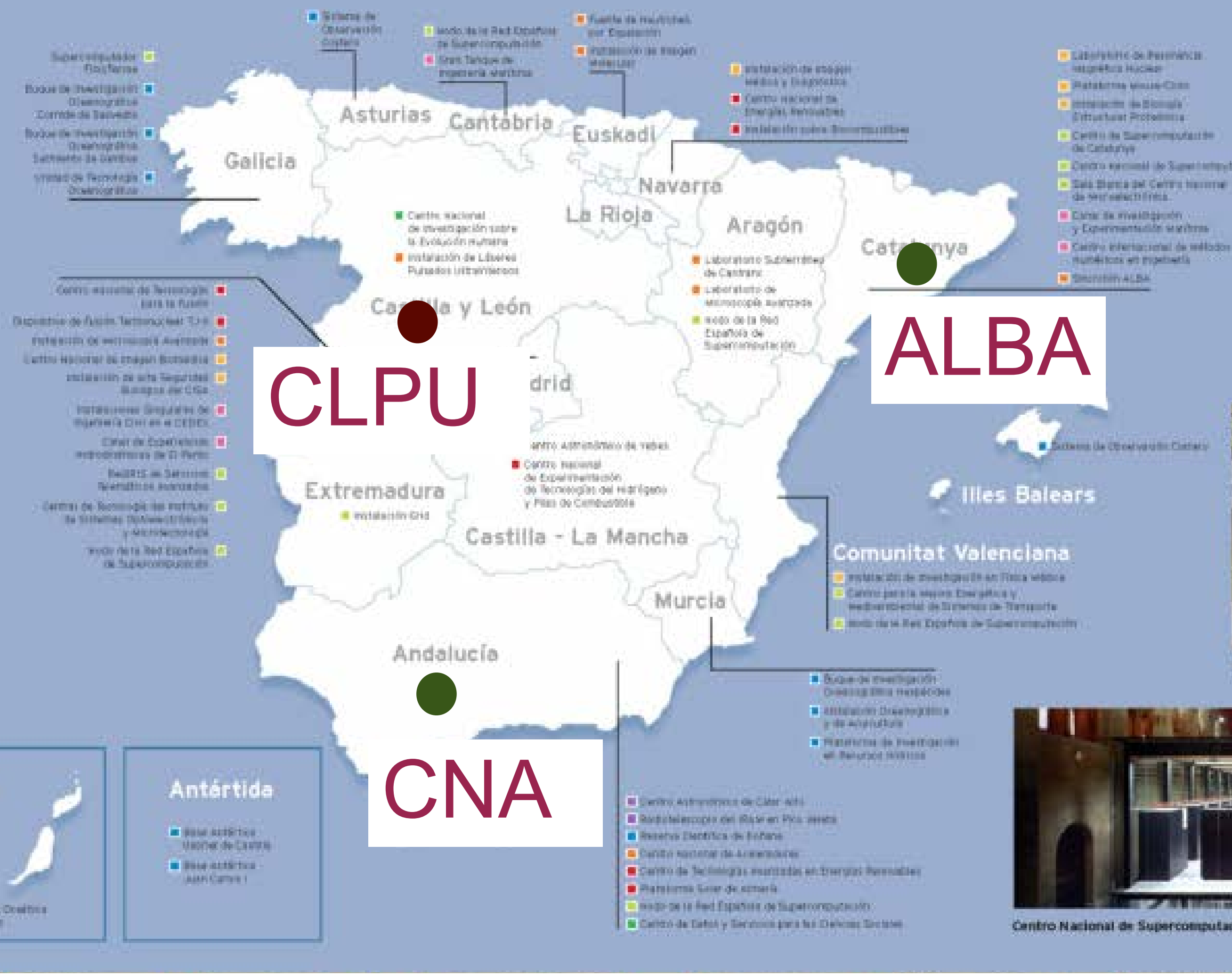
MAPA DE INSTALACIONES CIENTÍFICAS Y TÉCNICAS SINGULARES

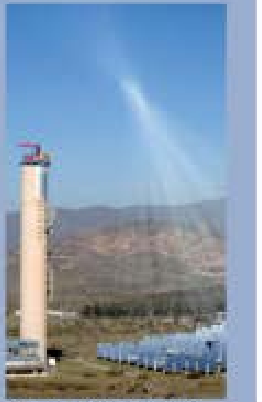

Buque de Investigación Oceanográfica Hespérides

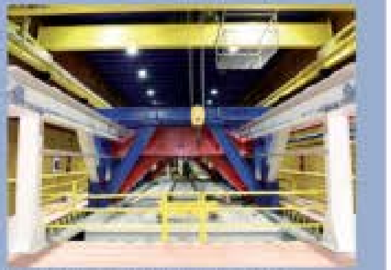

Canal de Experiencias Hidrodinámicas de El Pardo


Centro Astronómico de Yebes


Sala Blanca del Centro Nacional de Microelectrónica




Plataforma Solar de Almería


Instalación de Ingeniería Civil del CEDEX

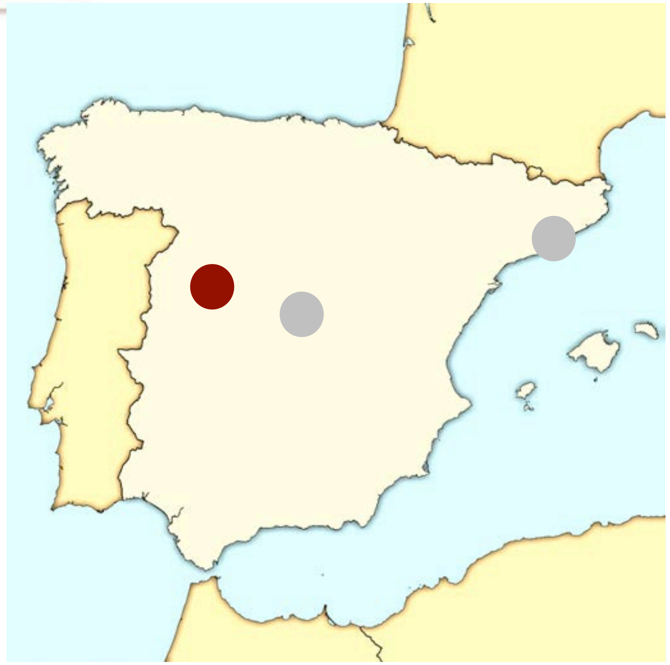

Reserva Científica de Doñana


Gran Telescopio CANARIAS


Centro Nacional de Supercomputación

Áreas de Investigación

Pulsed Lasers Center, CLPU, Salamanca



Facility open to the domestic and international scientific community.

Objectives:

- to operate a **Petawatt Laser**
- to develop ultra-short-pulse technology in Spain
- to **promote the use of such technology** in new fields

Junta de Castilla y León

MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD

VNiVERSiDAD
D SALAMANCA

CLPU CENTRO DE LASERES PULSADOS ULTRACORTOS ULTRAINTENSOS

CLPU
CENTRO DE LÁSERES PULSADOS ULTRACORTOS ULTRAINTENSOS

30 J
30 fs
800 nm
1 shot/second

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Junta de Castilla y León

VNiVERSiDAD D SALAMANCA

UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"

The VEGA laser

Titanium:sapphire technology
800 nm central wavelength

VEGA	power	energy	duration	rep rate	status
VEGA 1	20 TW	600 mJ	30 fs	10 / sec	2007
VEGA 2	200 TW	6 J	30 fs	10 / sec	2013
VEGA 3	1 PW	30 J	30 fs	1 /sec	2014

Junta de Castilla y León

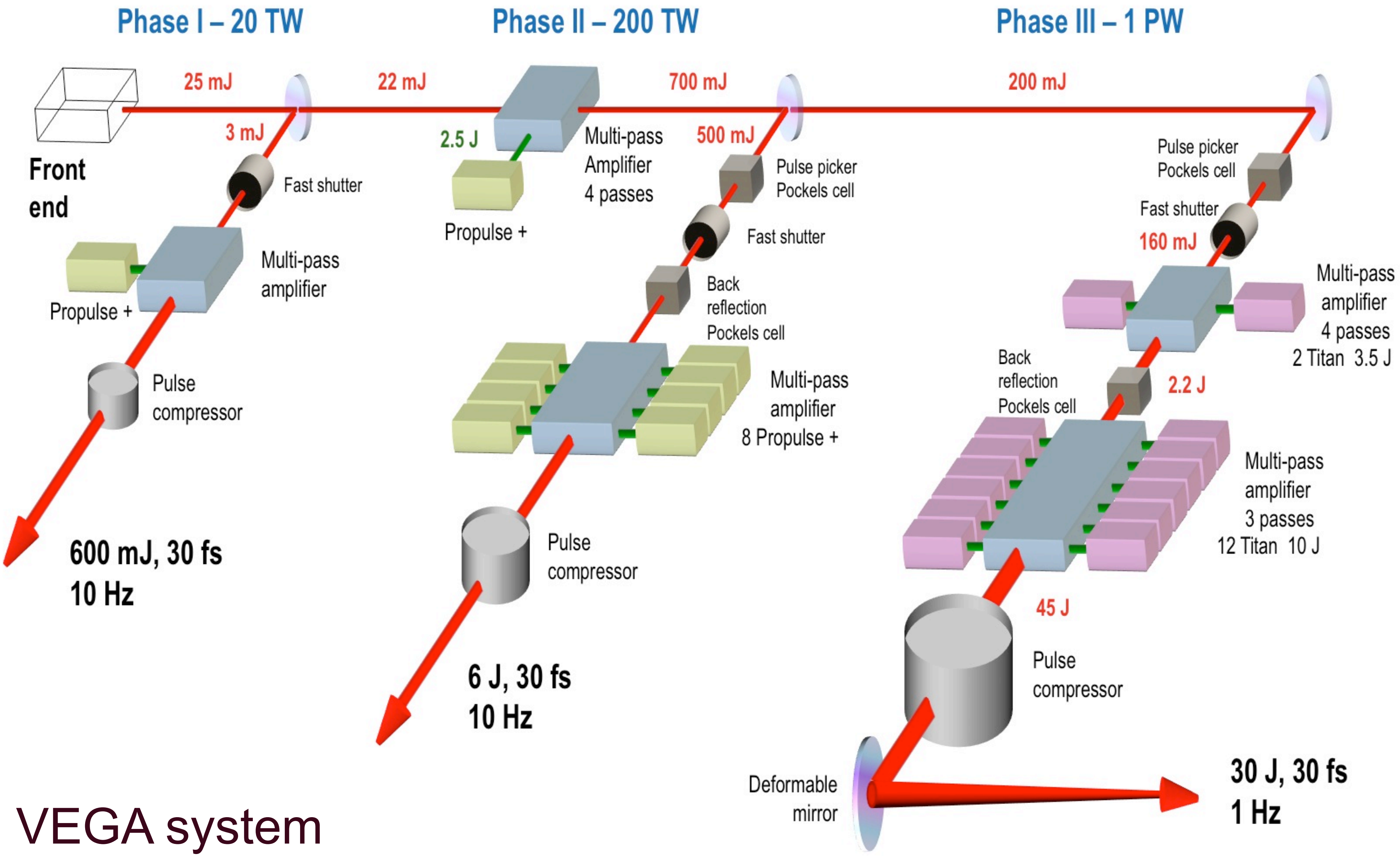
MINISTERIO
DE ECONOMÍA
Y COMPETITIVIDAD

VNiVERSiDAD
D SALAMANCA

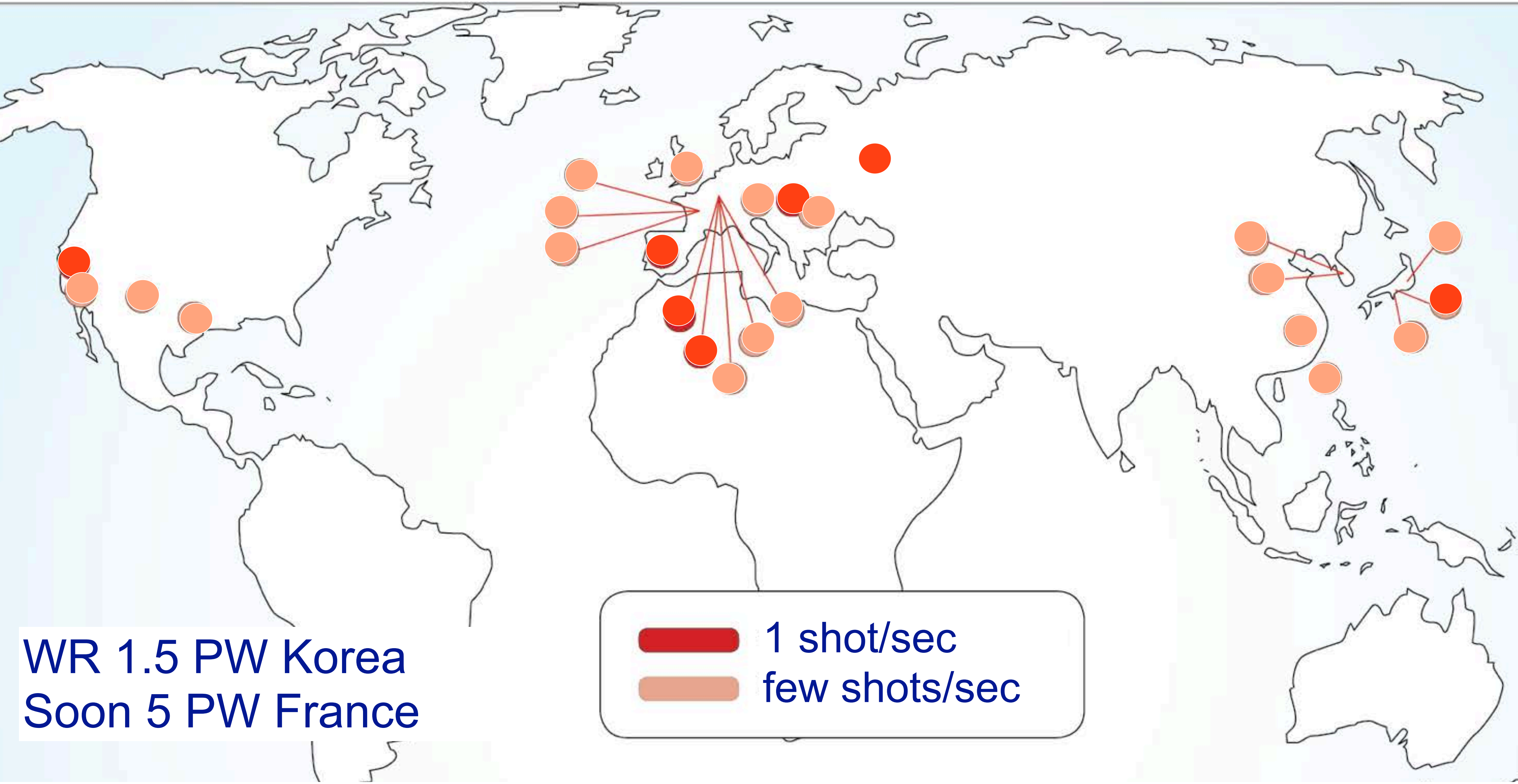
UNIÓN EUROPEA
FONDO
EUROPEO DE
DESARROLLO
REGIONAL
"Una manera de hacer Europa"

CLPU
CENTRO DE
LÁSERES
PULSADOS
ULTRACORTOS
ULTRAINTENSOS

VEGA system


Phase I – 20 TW
Phase II – 200 TW
Phase III – 1 PW
25 mJ
22 mJ
700 mJ
200 mJ
Front end
3 mJ
Fast shutter
Propulse +
Multi-pass amplifier
Pulse compressor
600 mJ, 30 fs
10 Hz
2.5 J
Propulse +
Multi-pass Amplifier 4 passes
500 mJ
Pulse picker Pockels cell
Fast shutter
Back reflection Pockels cell
Multi-pass amplifier
8 Propulse +
Pulse compressor
6 J, 30 fs
10 Hz
Pulse picker Pockels cell
Fast shutter
160 mJ
Multi-pass amplifier
4 passes
2 Titan 3.5 J
Back reflection Pockels cell
2.2 J
Multi-pass amplifier
3 passes
12 Titan 10 J
45 J
Pulse compressor
Deformable mirror
30 J, 30 fs
1 Hz

Petawatt lasers around the world



WR 1.5 PW Korea
Soon 5 PW France

🟥 1 shot/sec
🟧 few shots/sec

Trends

Good optical quality
1 - 0.1 PW   max intensity now with sub PW lasers

Repetition rate
Few shots/day VULCAN at RAL, Texas PW
Few shots/min
One shot/sec BELLA, Berkeley

Extremely short pulses
5 fs PW (Petawatt Field Sinthetizer at MPQ Garching)
Attosecond PW ... ???

Energy pulses of much longer duration ... ps, ns, ...
National Ignition Facility
Laser Megajoule   high density plasmas

HiPER

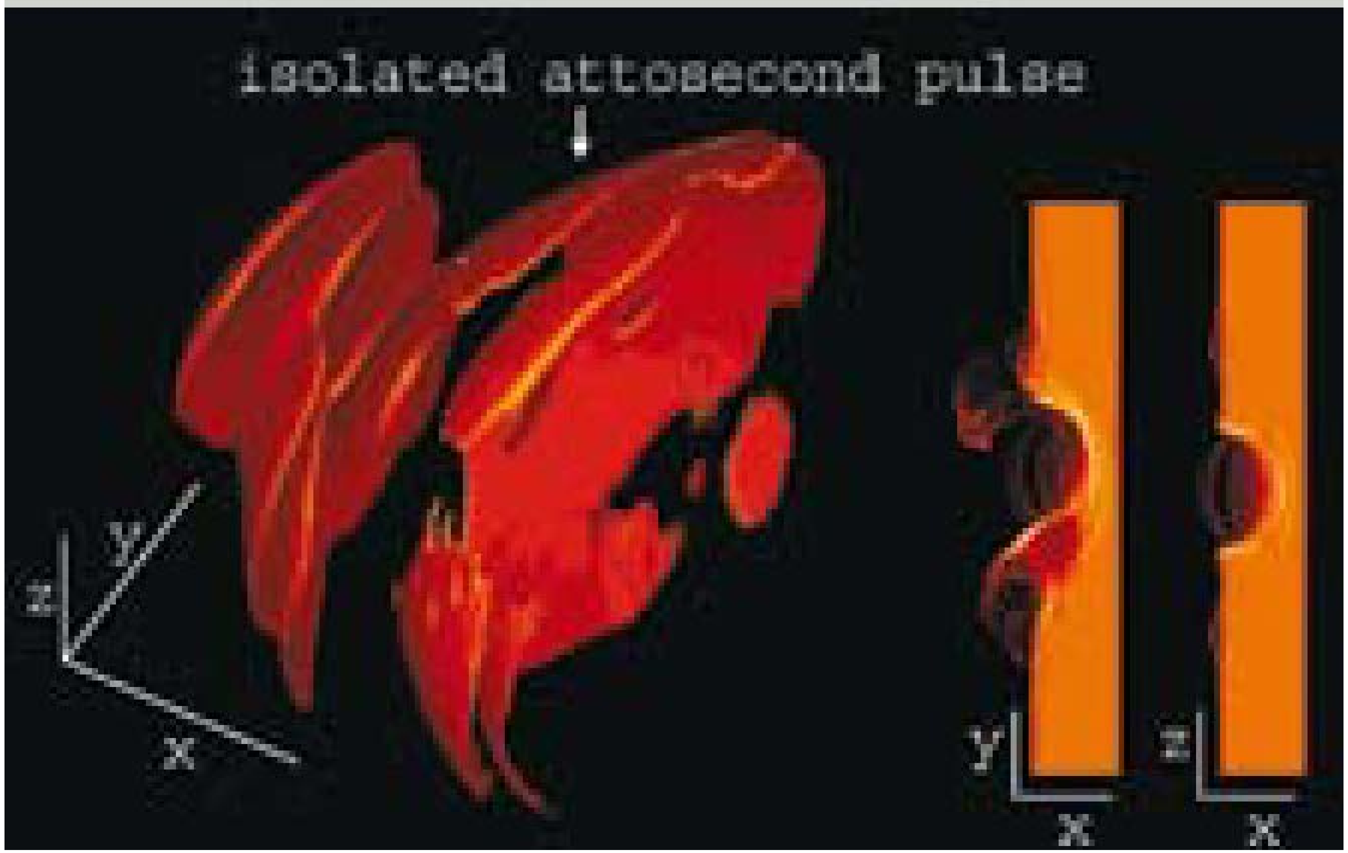
The facility

HiPER will be a large scale laser system designed to demonstrate significant energy production from inertial fusion, whilst supporting a broad base of high power laser interaction science. This is made feasible by the advent of a revolutionary approach to laser-driven fusion known as "Fast Ignition". HiPER will make use of existing laser technology in a unique configuration, with a 200 kJ long pulse laser combined with a 70 kJ short pulse laser.

ELI

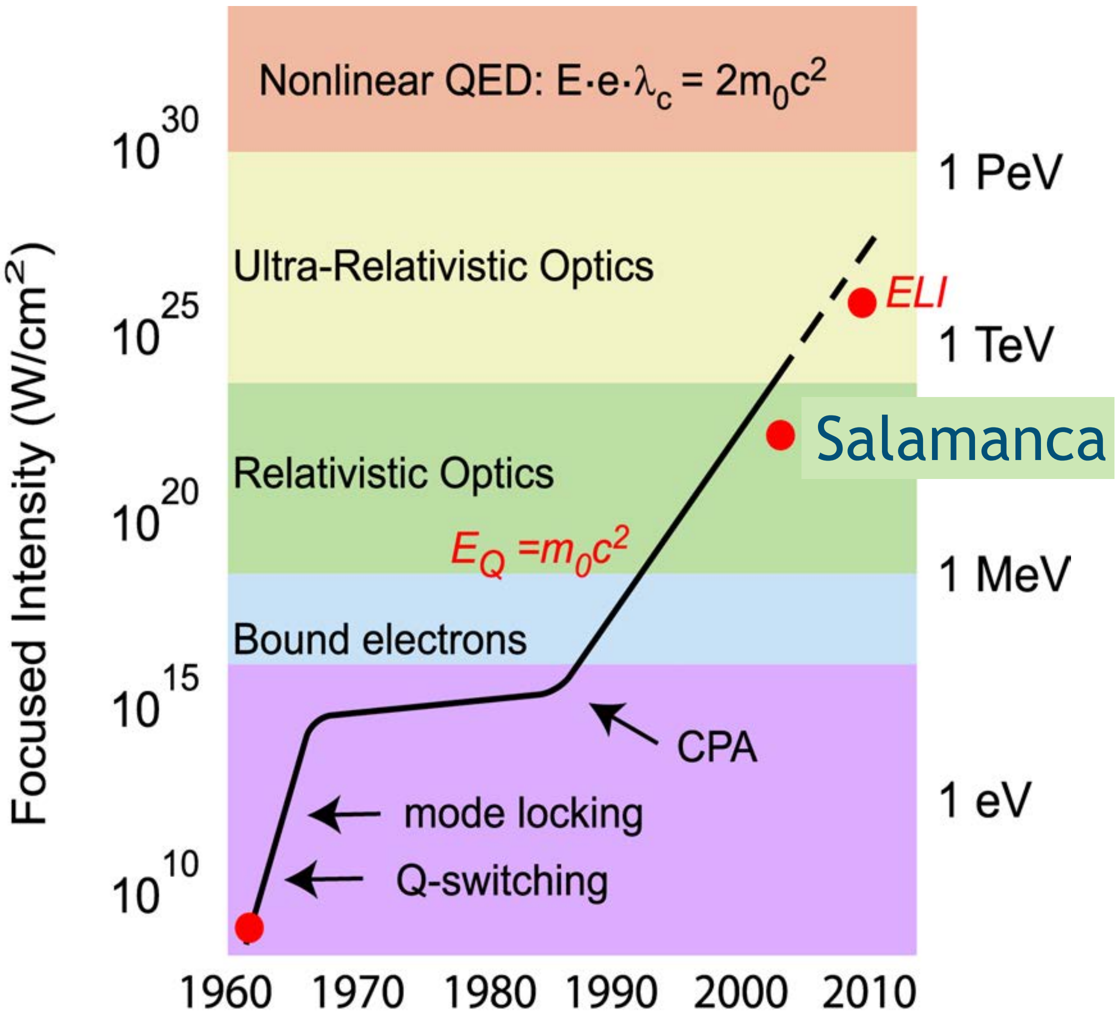
The facility

ELI will be a research infrastructure open to European scientists dedicated to the investigation and applications of laser matter interaction at the highest intensity level, i.e. more than 36 orders of magnitude higher than today's state of the art. ELI will comprise three branches: Ultra High Field Science that will explore laser matter interaction up to the nonlinear QED limit, Attosecond Laser Science will make possible temporal investigation at the attosecond scale of the electron dynamics in atoms, molecules, plasmas and solids and the High Energy Beam Facility devoted to the development of dedicated beam lines of ultra short pulses of high energy particles up to 100 GeV and radiation for European users. ELI will have a large societal benefit in medicine, material sciences and environment.



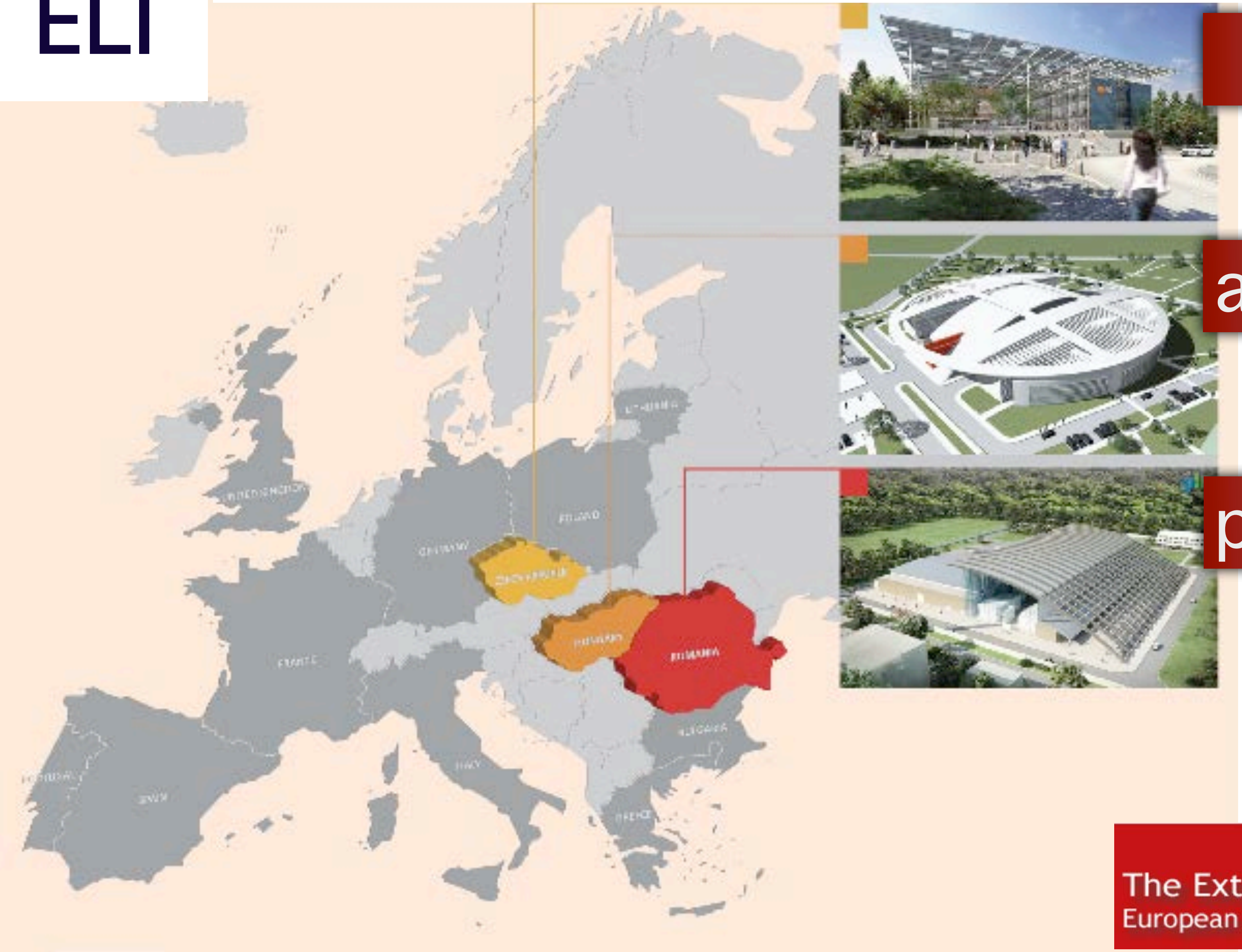
Extreme Light Infrastructure

10 PW 100 PW



Extreme Light Infraestructure

ELI



high fields

10 PW

attoseconds

10 PW

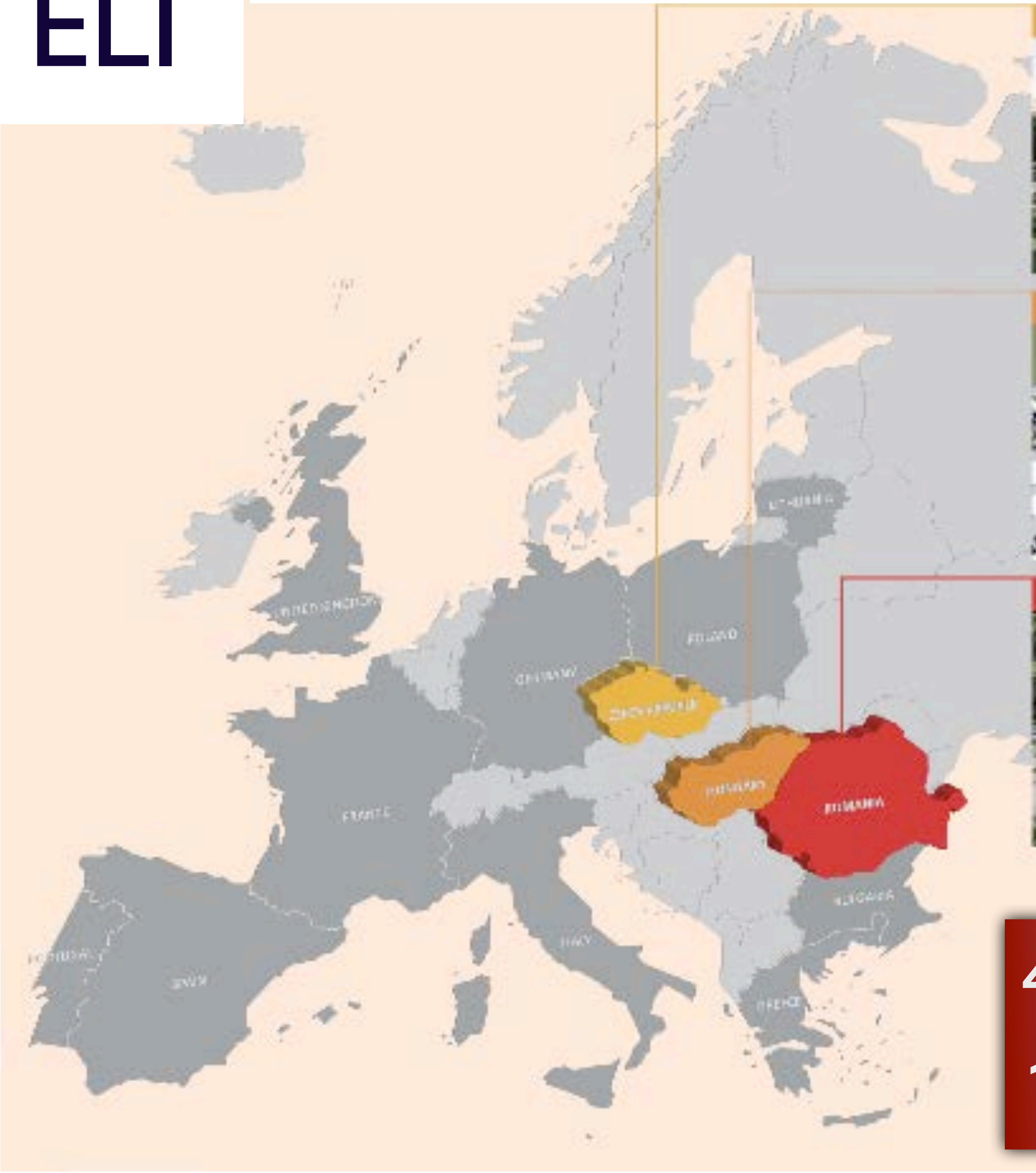
photonuclear

10 PW

The Extreme Light Infrastructure
European Project

Extreme Light Infraestructure

ELI



high fields

10 PW

attoseconds

10 PW

photonuclear

10 PW

4th pillar

100 PW

The Extreme Light Infrastructure

European Project

Technology Limits

10 PW feasible.-

Bottlenecks well stablished

- Big crystals
- Large diffraction grattings
- Expenside pumping lasers
- ...

100 PW Extreme Light Infraestructure

New schemes for Exawatt and Zetawatt systems

IZEST Associate Laboratories

Ecole Polytechnique - Palaiseau, France ①
CEA - Commissariat à l'Energie Atomique, Bordeaux, France ②
PPPL - Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA ③
FERMILAB - Fermi National Accelerator Laboratory, Chicago, Illinois, USA ④
LLNL - Lawrence Livermore National Laboratory, Livermore, California, USA ⑤
CUOS - Center for Ultrafast Optical Science, Ann Arbor, Michigan, USA ⑥
ALLS - Advanced Laser Light Source, Montreal, Canada ⑦
JAI - John Adams Institute for Accelerator Science, Oxford, UK ⑧
TOPS - TeraHertz to Optical Pulse Source, Strathclyde, UK ⑨
HHU - Heinrich Heine Universität, Düsseldorf, Germany ⑩
MEPhI - Moscow Engineering Physics Institute, Moscow, Russia ⑪

⑫ IAP - Institute of Applied Physics of RAS, Nizhny Novgorod, Russia
⑬ GIST - Gwangju Institute of Science and Technology, Gwangju, Republic of Korea
⑭ KEK - High Energy Accelerator Research Organization, Tsukuba, Japan
⑮ KPSI - Kansai Photon Science Institute, Kansai, Japan
⑯ LeCosPa - Leung Center for Cosmology and Particle Astrophyics, Taipei, Taiwan
⑰ CLPU - Centro de Láseres Pulsados Ultracortos Ultraintensos, Salamanca, Spain
⑱ CERN - Organisation Européenne pour la Recherche Nucléaire, Genève, Switzerland
⑲ SIOM - Shanghai Institute of Optics and Fine Mechanics, Shanghai, China
⑳ Kyoto University - Kyoto, Japan
㉑ ELI-NP - Extreme Light Infrastructure - Nuclear Physics, Magurele, Romania
㉒ Beijing University - Beijing, China
㉓ TCHILS - Texas Center for High Intensity Laser Science, Austin, USA

CENTRO DE LÁSERES PULSADOS ULTRACORTOS ULTRAINTENSOS

Conclusions

Conclusions

Present are linacs, cyclotrons, ...

Accelerators are at CERN

And also in our everyday life

- Security
- Medicine
- Food processing

Conclusions

ACCELERATORS FOR AMERICA'S FUTURE

Present are linacs, cyclotrons, ...

Future are laser accelerators.

OPAC

Electrons	GeV
Protons / Ions	100 MeV/n
X-ray incoherent	MeV
X-ray laser	KeV

LA³NET

CLPU CENTRO DE LÁSERES PULSADOS ULTRACORTOS ULTRAINTENSOS

CLPU CENTRO DE LÁSERES PULSADOS ULTRACORTOS ULTRAINTENSOS

UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"

Salamanca - Spain

Thank you!

www.clpu.es
roso@clpu.es

GOBIERNO DE ESPAÑA MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD

Junta de Castilla y León

VNiVERSiDAD D SALAMANCA

Salamanca - Spain

Thank you!

www.clpu.es
roso@clpu.es

CLPU
CENTRO DE LÁSERES PULSADOS ULTRACORTOS ULTRAINTENSOS

UNIÓN EUROPEA
FONDO EUROPEO DE DESARROLLO REGIONAL
"Una manera de hacer Europa"

Salamanca - Spain

Thank you!

www.clpu.es
roso@clpu.es

GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
Junta de Castilla y León
VNiVERSiDAD D SALAMANCA