PASSION FOR EXTREME LIGHT: LASER INITIATED TRANSMUTATION

Presented by

Prof. Gérard Mourou

Nobel Prize for Physics, 2018

Tajima-Mourou transmutator concept

Transmutation of TRansUranic Minor Actinide (Np, Am, Cm) spent nuclear waste with a technique based on ultrashort (<10fs) laser pulses. The mechanism of coherent acceleration of ions by laser (CAIL) is capable to produce 14 MeV neutrons with high yield driven by 100 keV deuterium acceleration via DT (or DD) fusion reactions, when sub-10fs, high repetition rate laser is used (SYLOS).

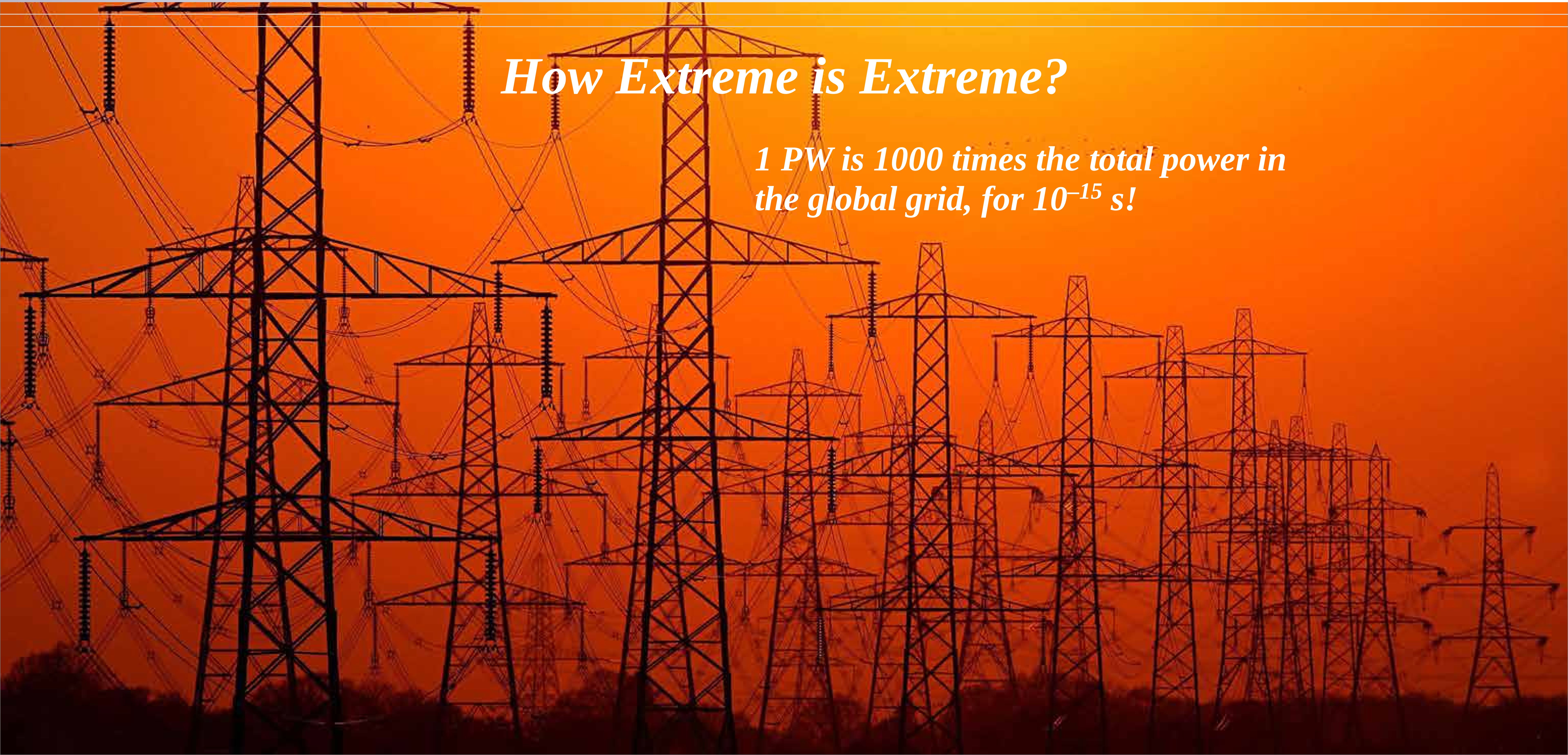
Novelty of the scheme: effcient generation of neutrons via ultrafast lasers (instead of nuclear reactors or accelerators).

The scheme is proposed by

T. Tajima and G. Mourou (Physics Nobel Laurate 2018)

How Extreme is Extreme?

1 PW is 1000 times the total power in the global grid, for 10^{-15} s!



How Much Pressure Does a PW Laser Exert?

1 PW/1µm spot size corresponds to 10^{23} w/cm^2

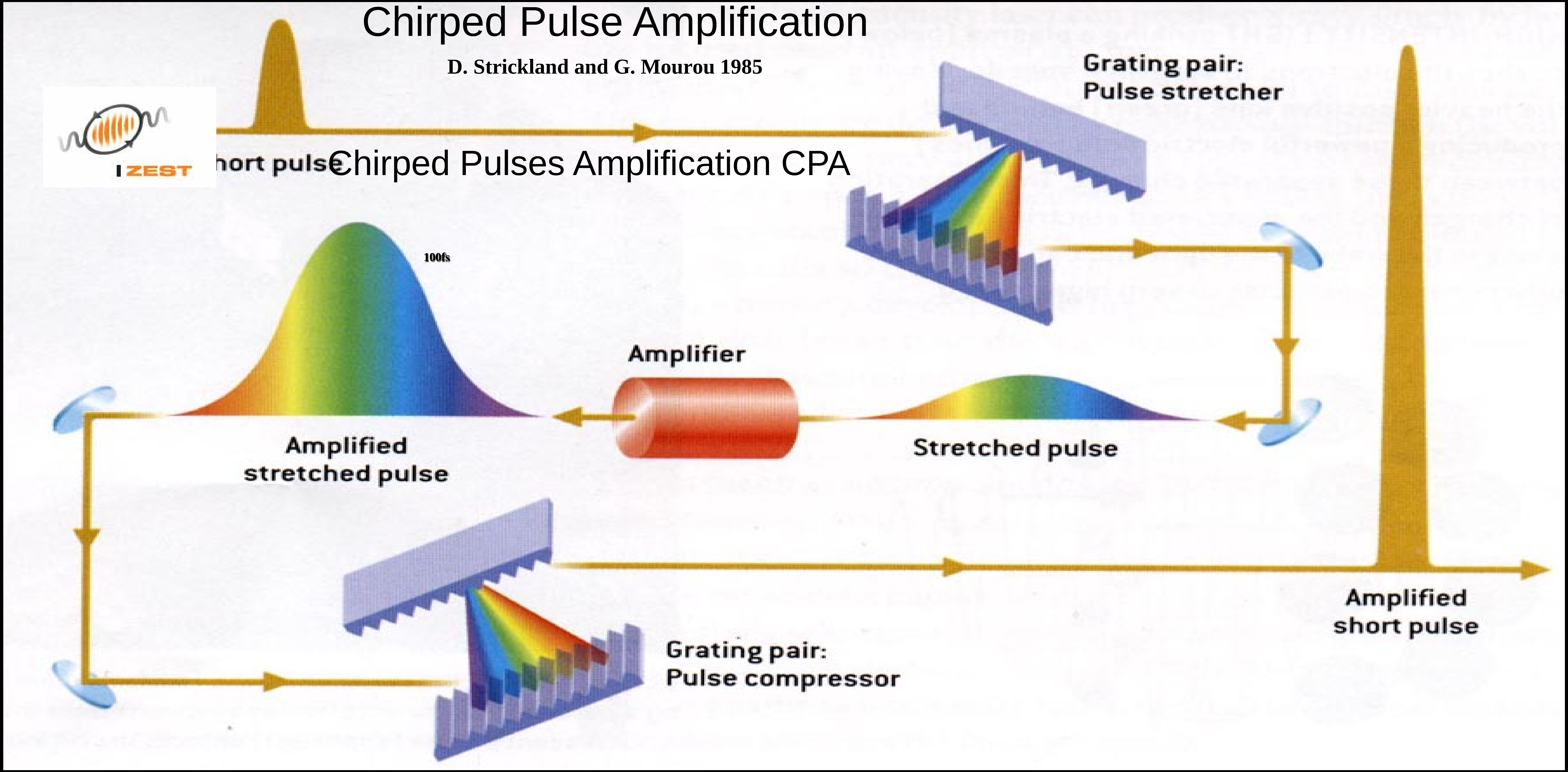
That is the equivalent of the pressure of 10 million Eiffel Towers on the tip of your finger!!

Seriously extreme!

Chirped Pulse Amplification

D. Strickland and G. Mourou 1985

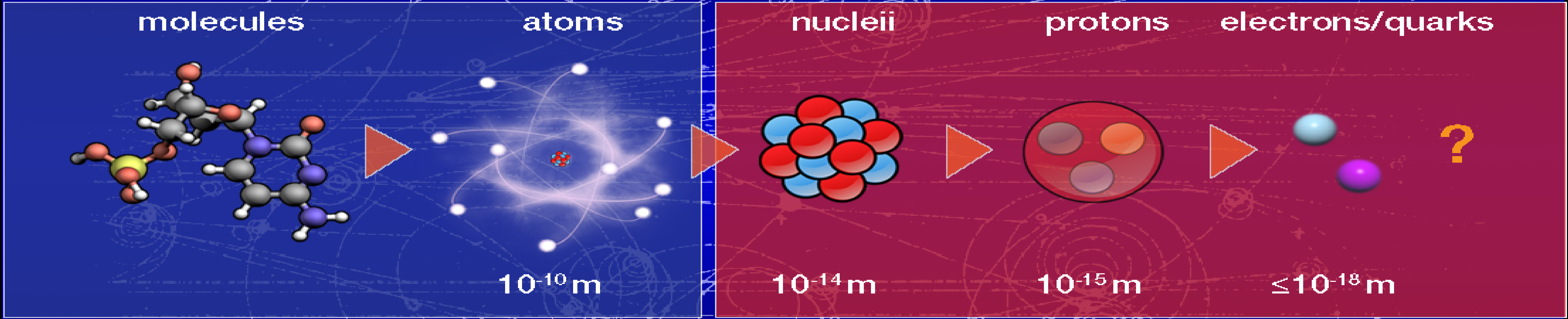
Chirped Pulses Amplification CPA



Laser Exploration : From Atomic to Sub-Atomic

eV → TeV

ATOMIC | SUB-ATOMIC

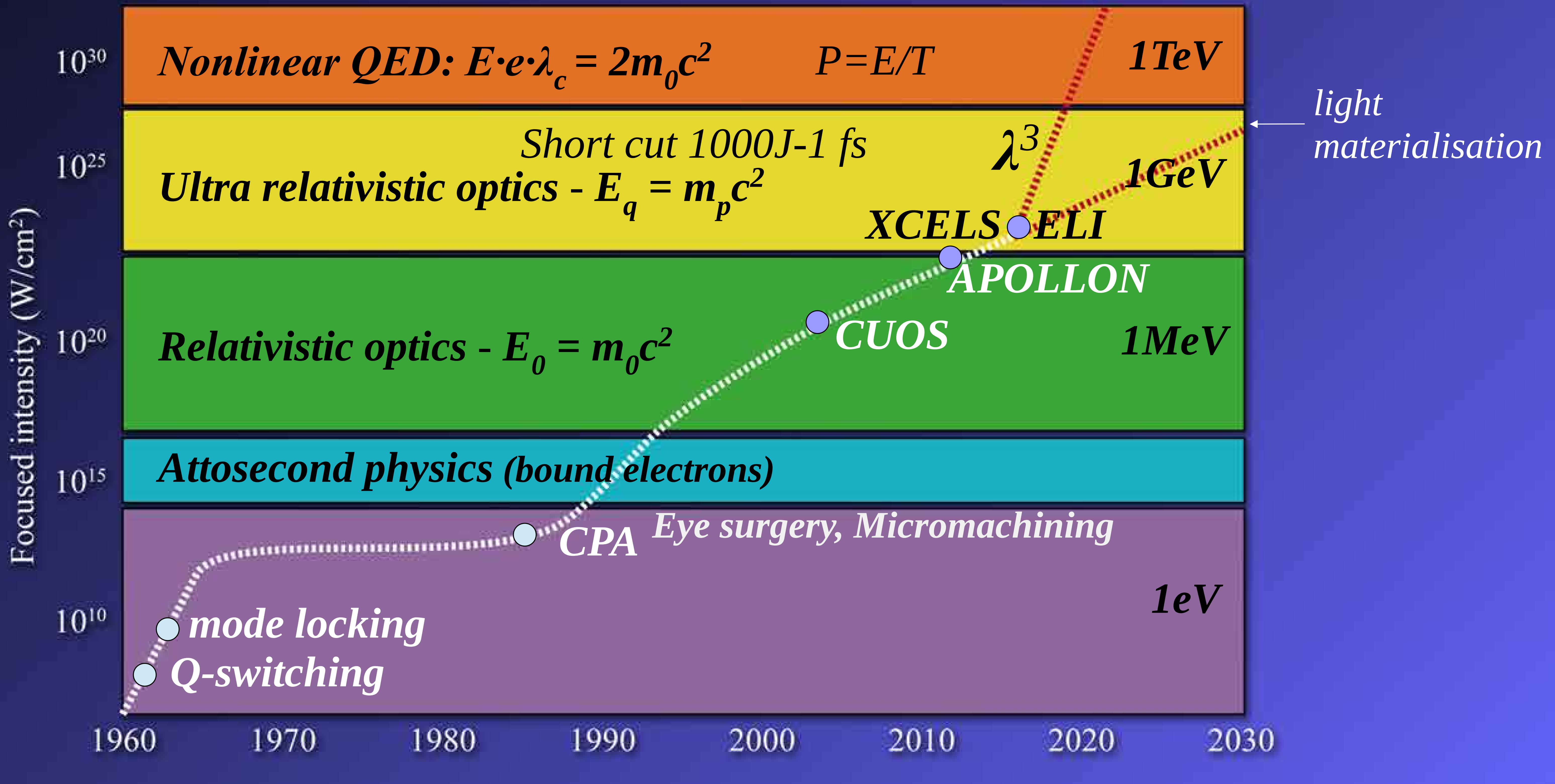


Extreme light Laser is capable to produce,

1. the largest peak power,
2. the largest temperature,
3. the largest pressure,
4. largest acceleration,
5. the largest field.

It is a universal source of High Energy Particles and Radiations

Extreme light roadmap and ultra high intensity shortcut



Extreme Light Infrastructure - ELI

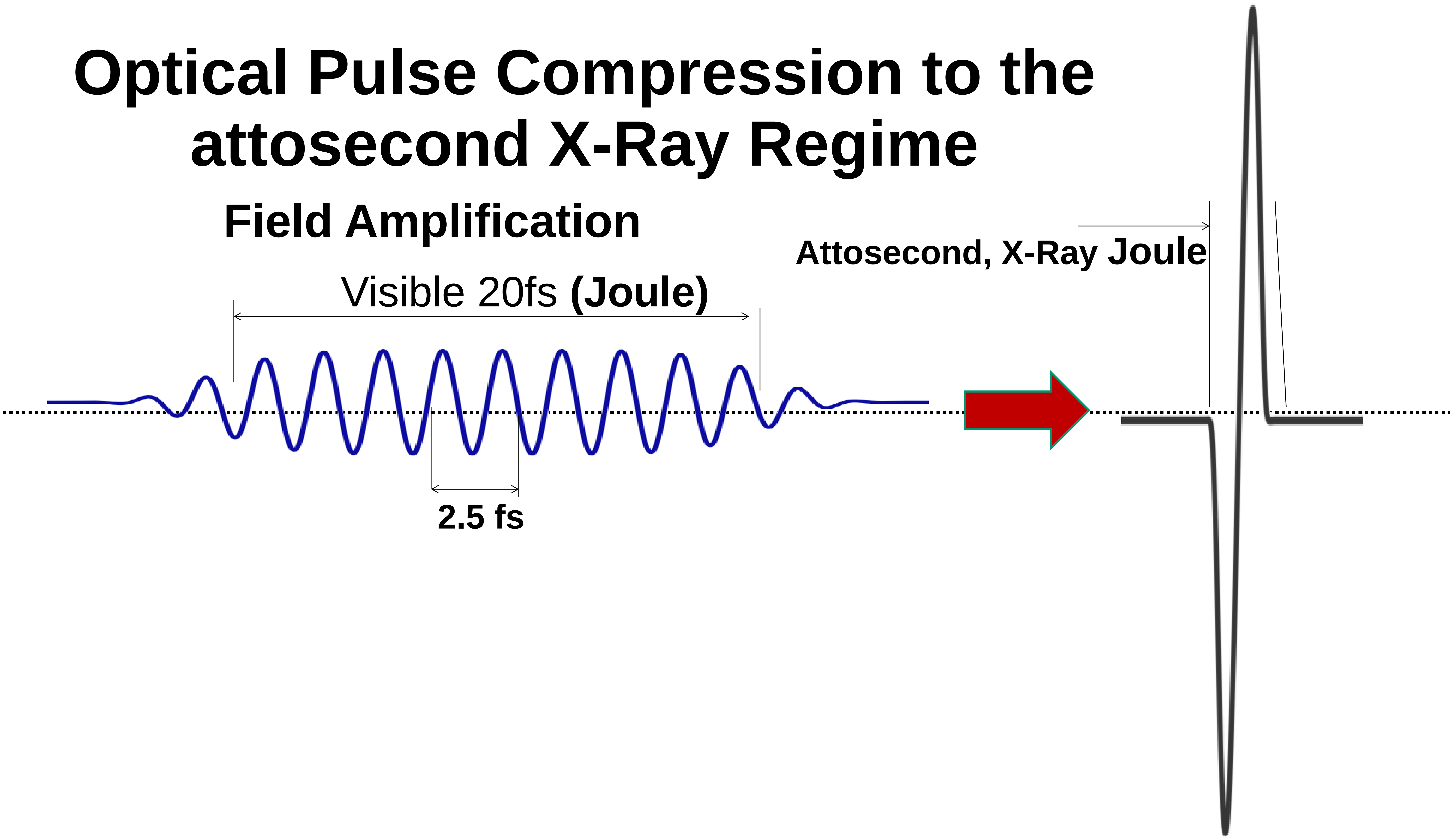
The Largest Civilian Laser Infrastructure

Initiated and Coordinated(PP) by, G. Mourou (EP)

ELI (Delivery Consortium) W. Sandners

Optical Pulse Compression to the attosecond X-Ray Regime

Field Amplification



Thin Film Pulse Compression

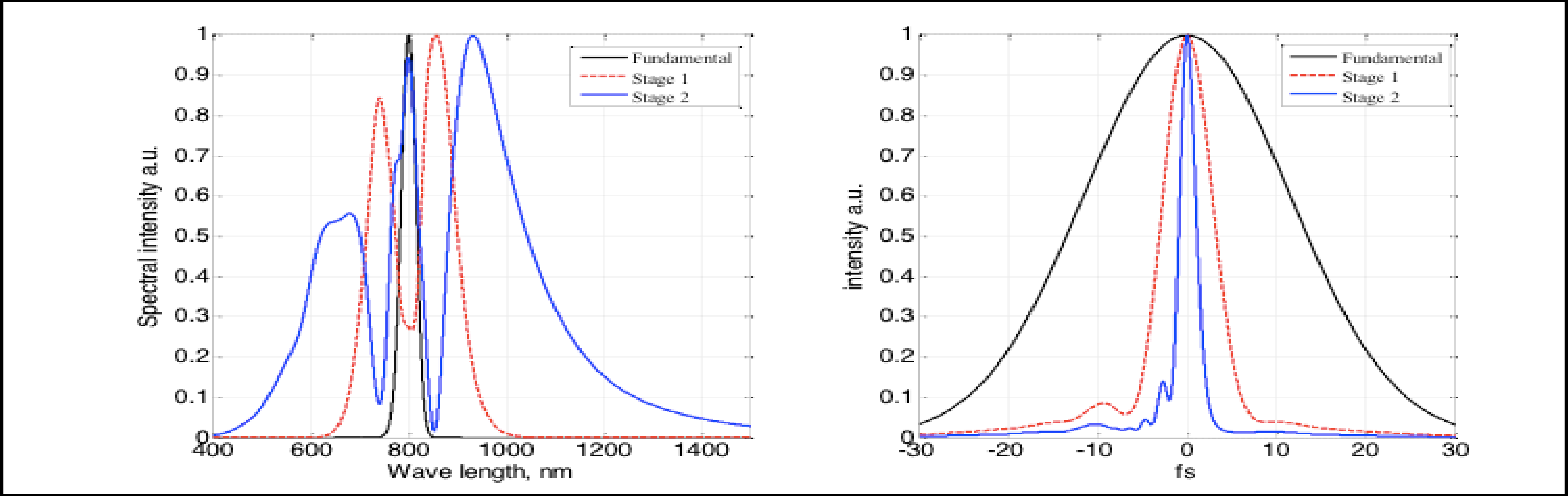
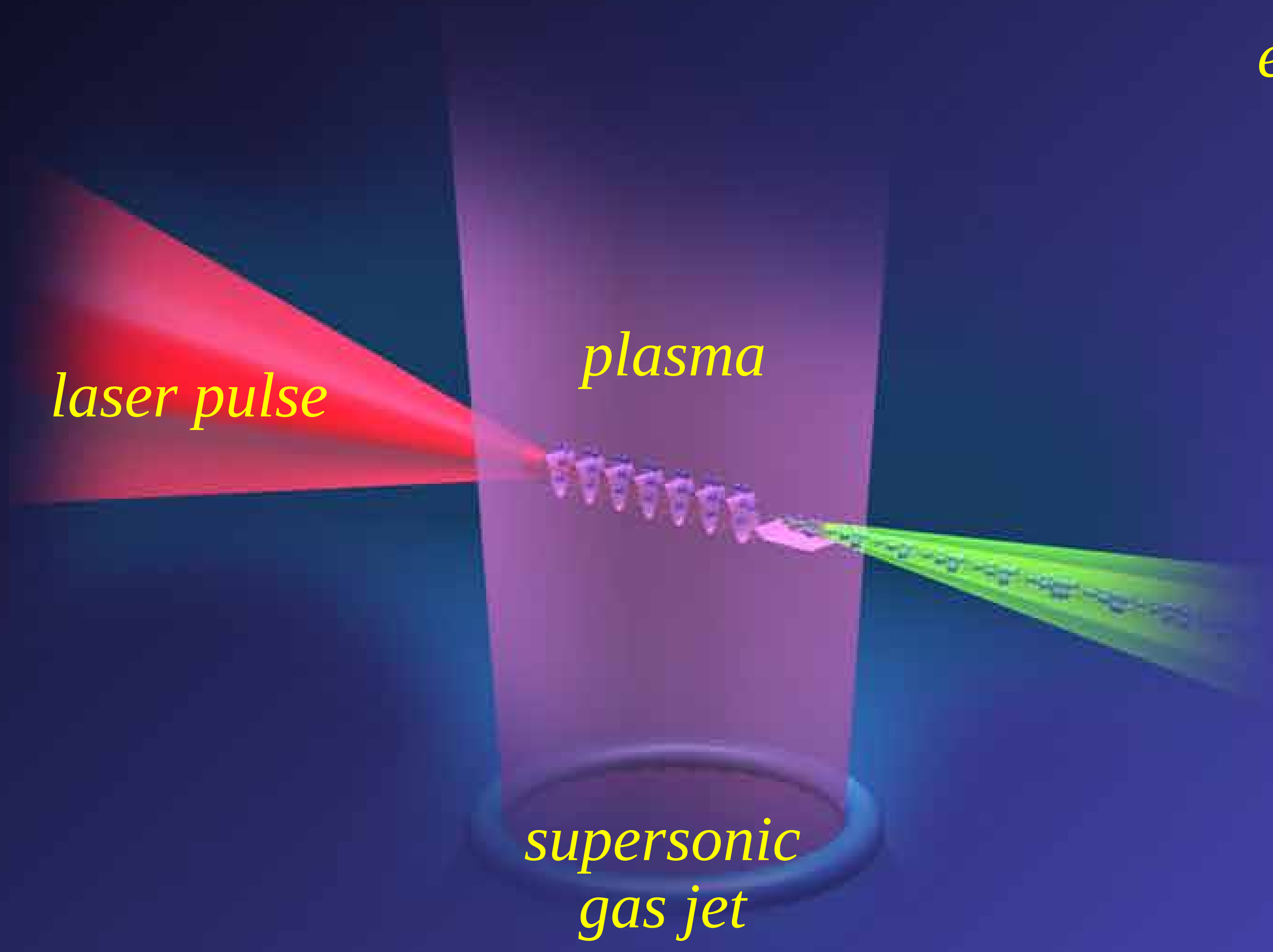
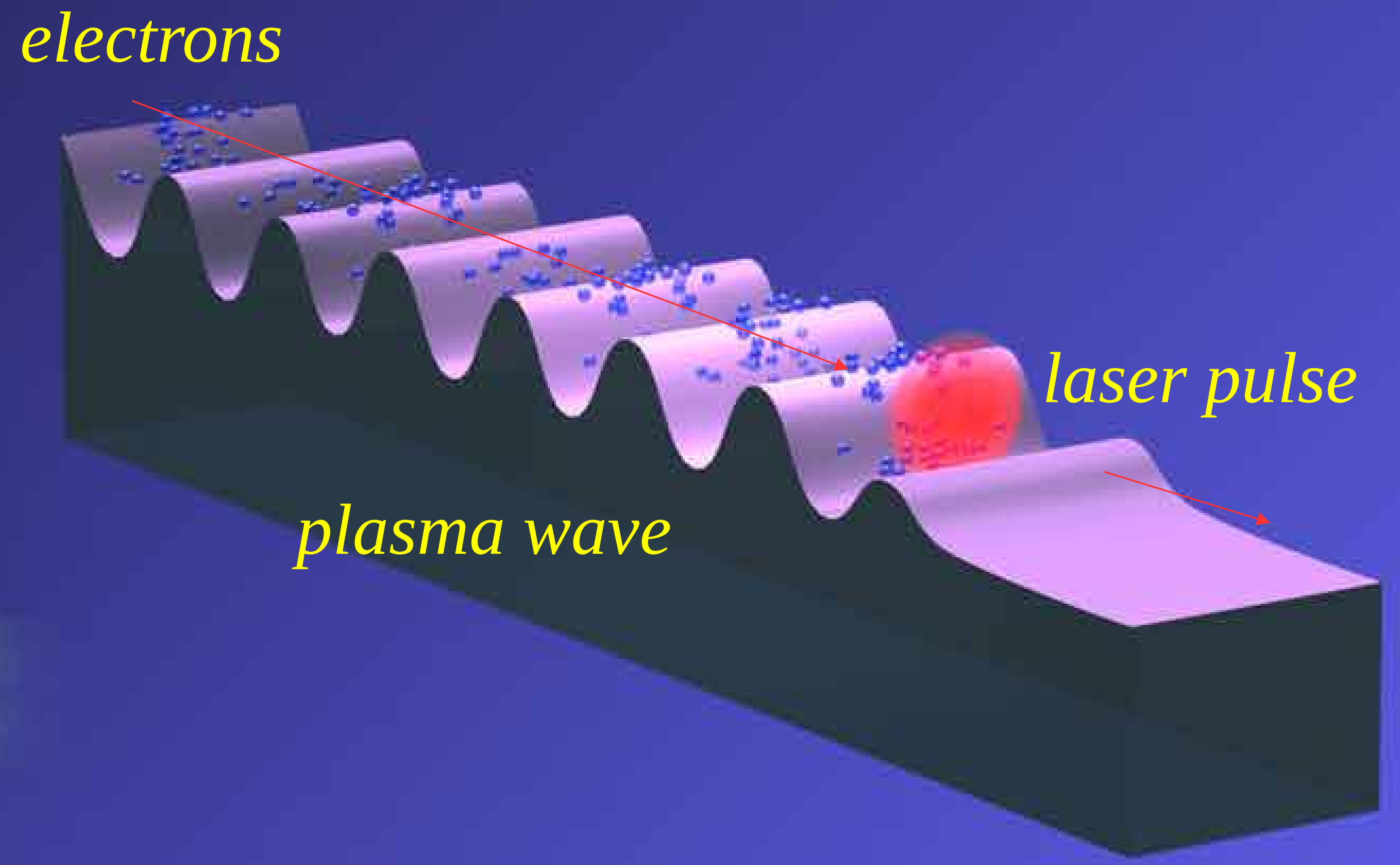


Fig. 4 shows the successive spectra and pulse durations corresponding to the laser out put, after the first stage and second stage. After the first stage the pulse 6.4fs, after the second stage the pulse is shrunk to 2.1fs

Giant wakefield acceleration

Tajima et Dawson (1979)



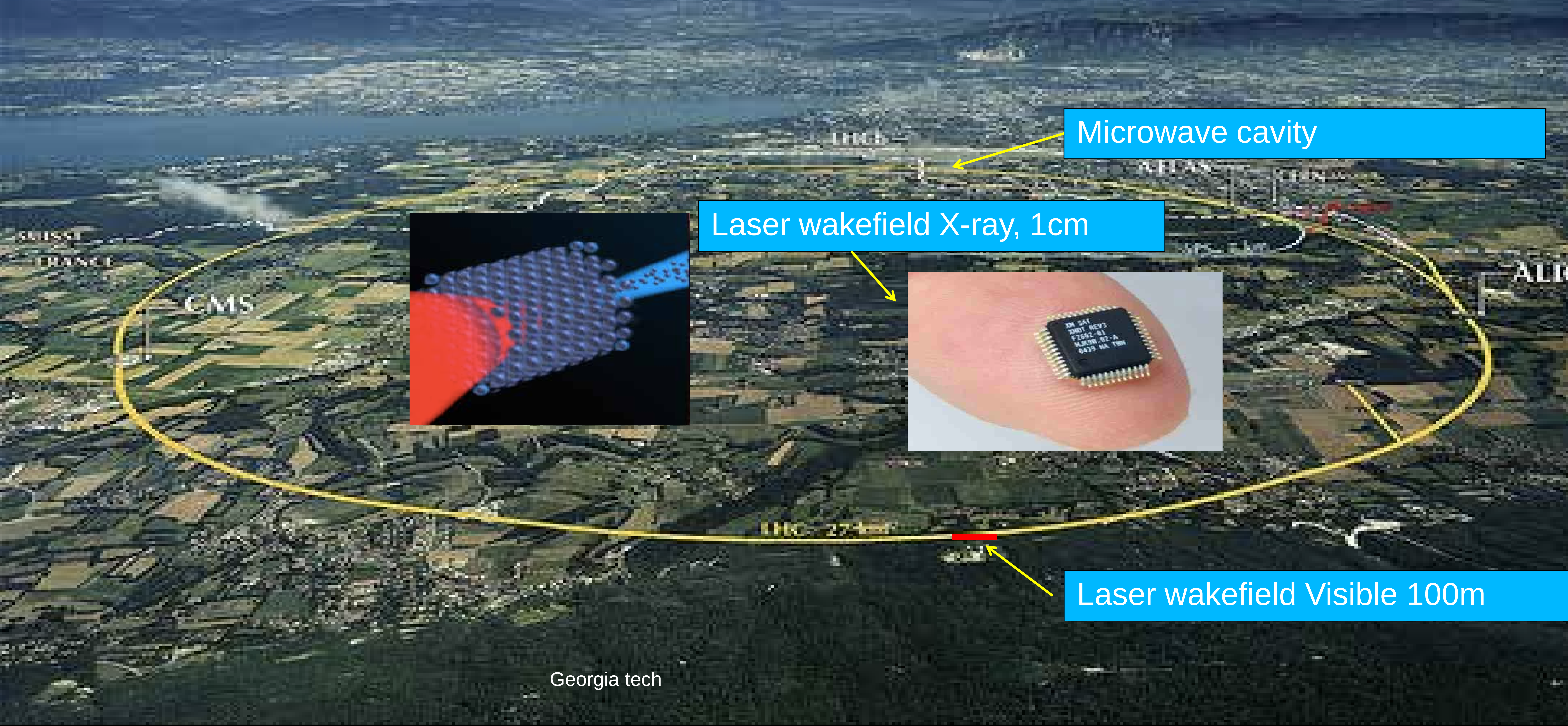


High Energy beam
GeV/cm

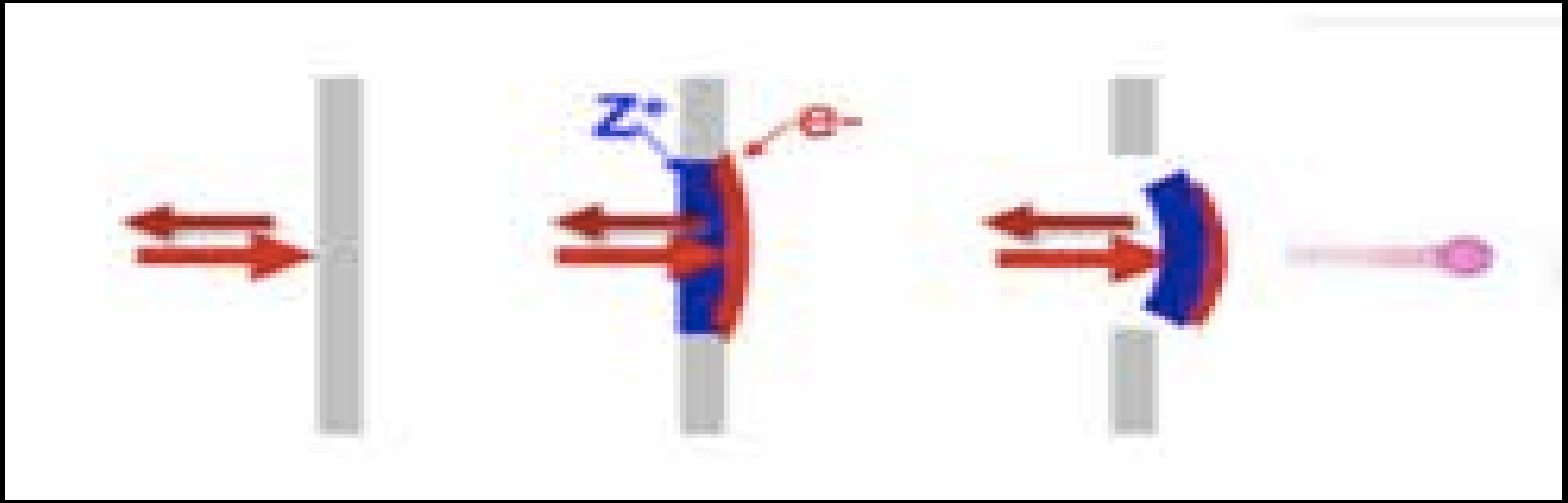
Synchrotron SOLEIL 3GeV

S

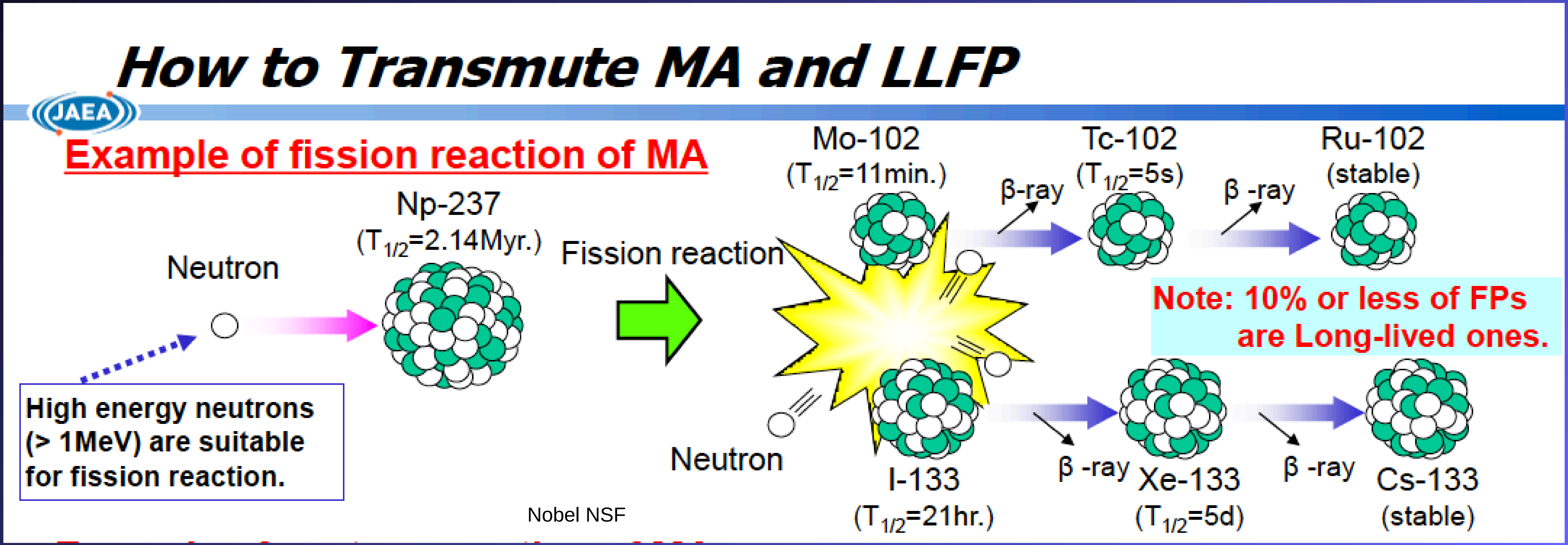
Outlook for
Laser-Particle acceleration TeV



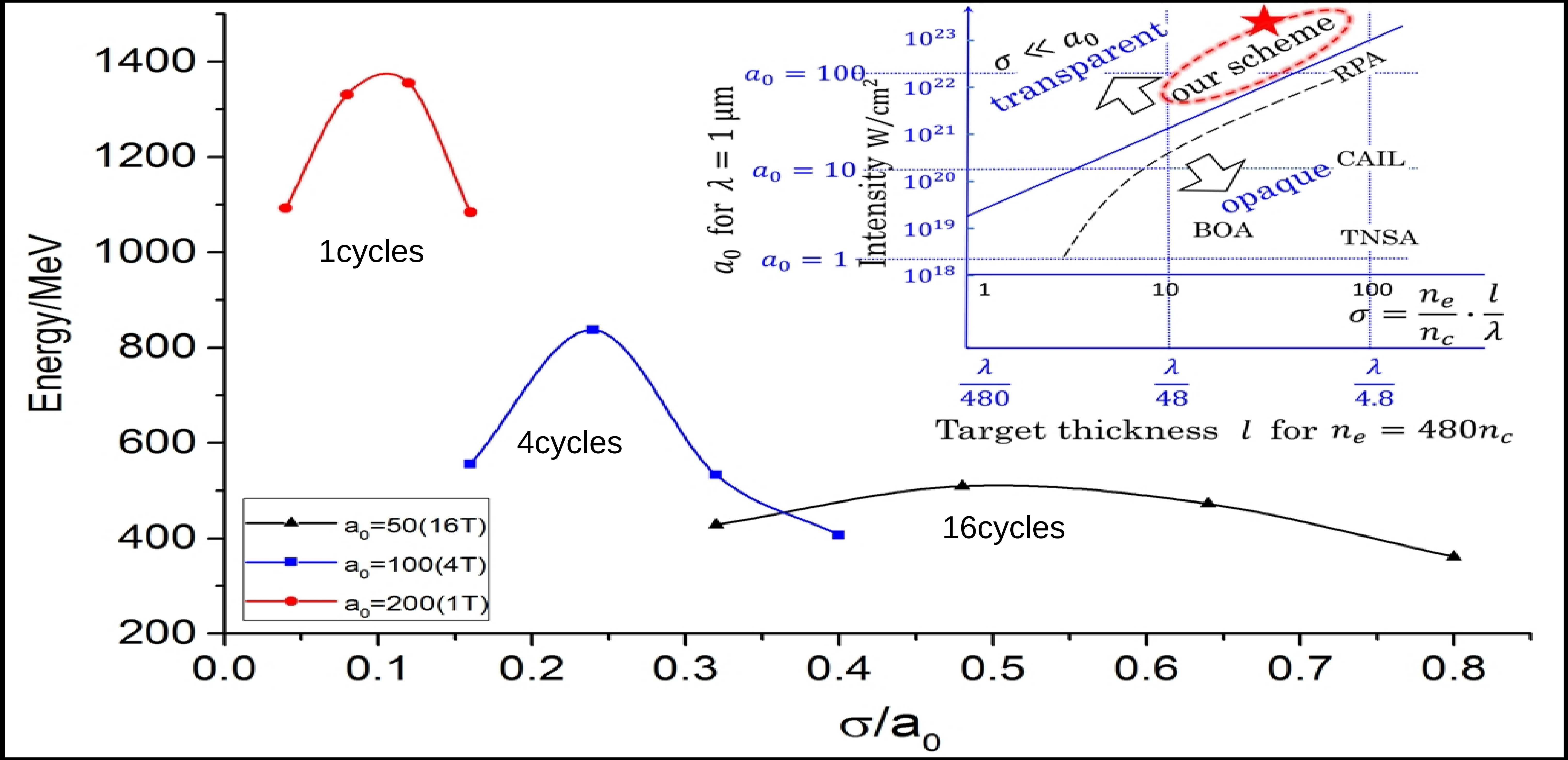
Low Hanging Fruit: High Energy Proton GeV Generation



NUCLEAR TRANSMUTATION CONCEPT



Applications of Single Cycle to Proton Generation vs a_0



A PASSION FOR EXTREME LIGHT

For the greatest benefit to human kind (Alfred Nobel)

RELATIVISTIC PROTON ACCELERATOR
for
TRANSMUTATION

Projet MYRRHA

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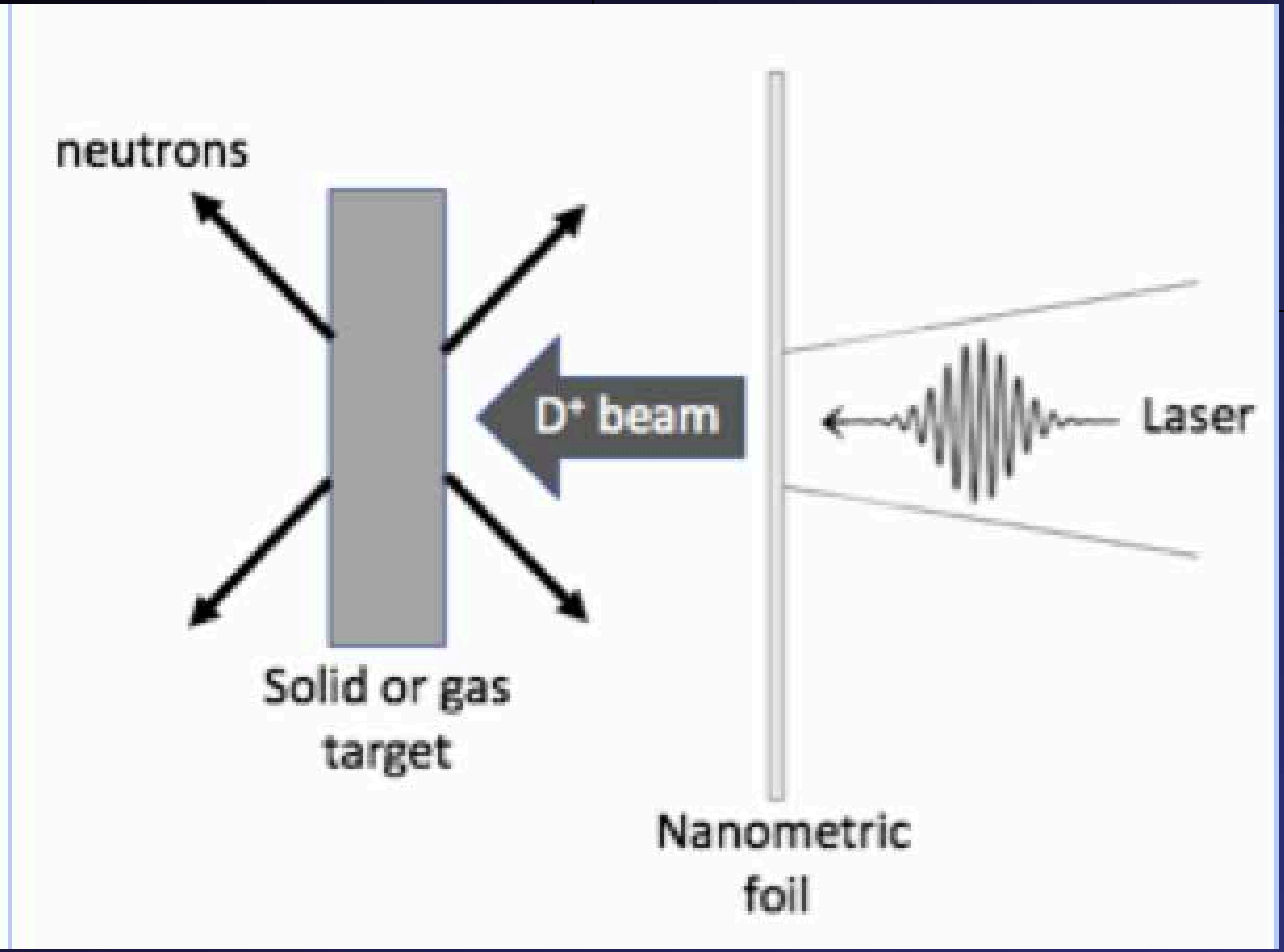
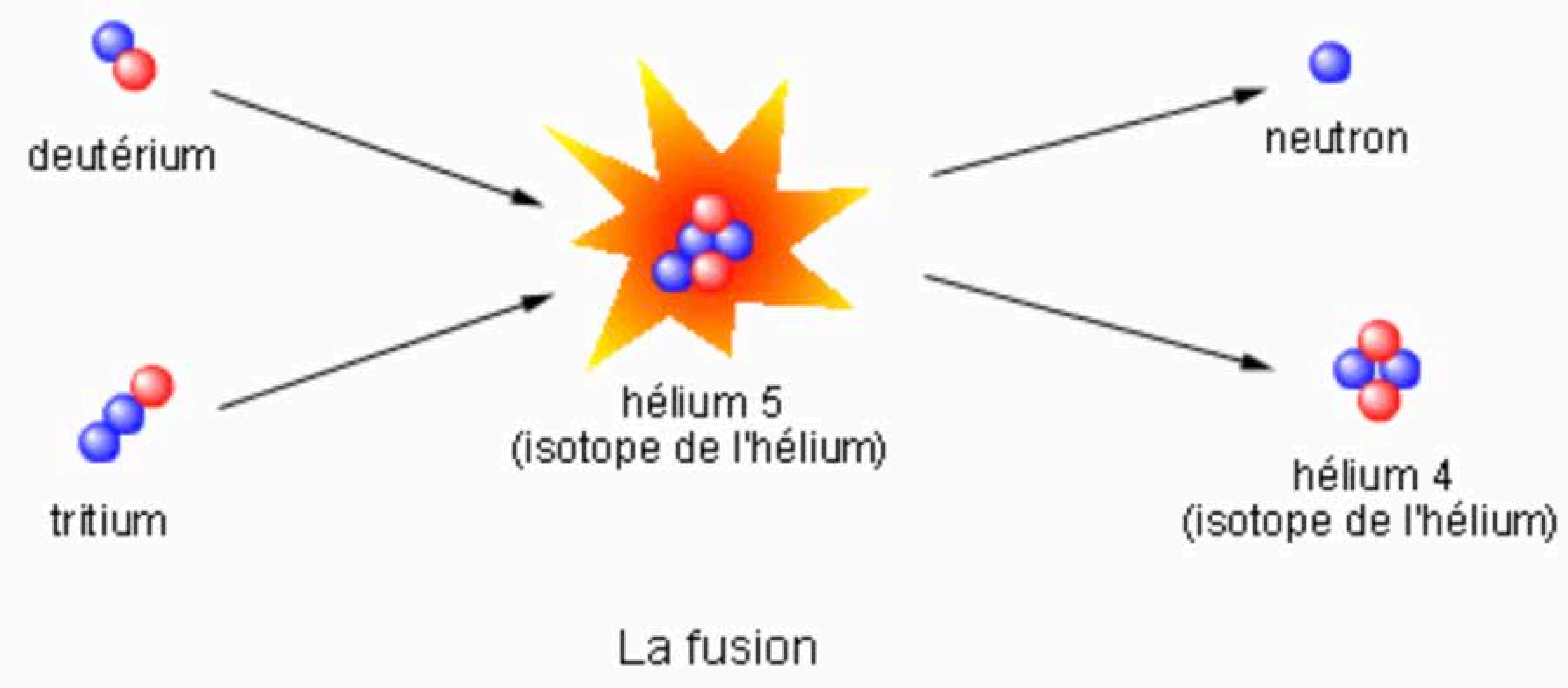
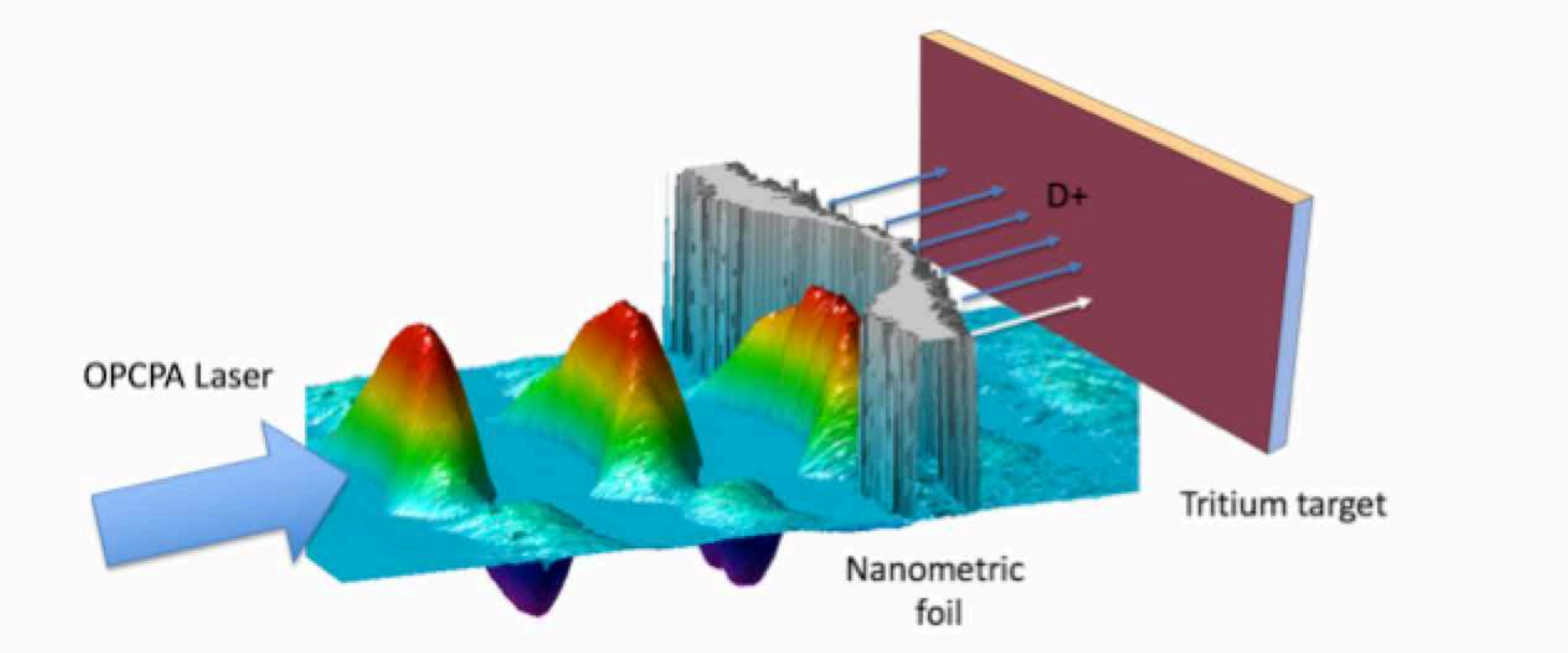
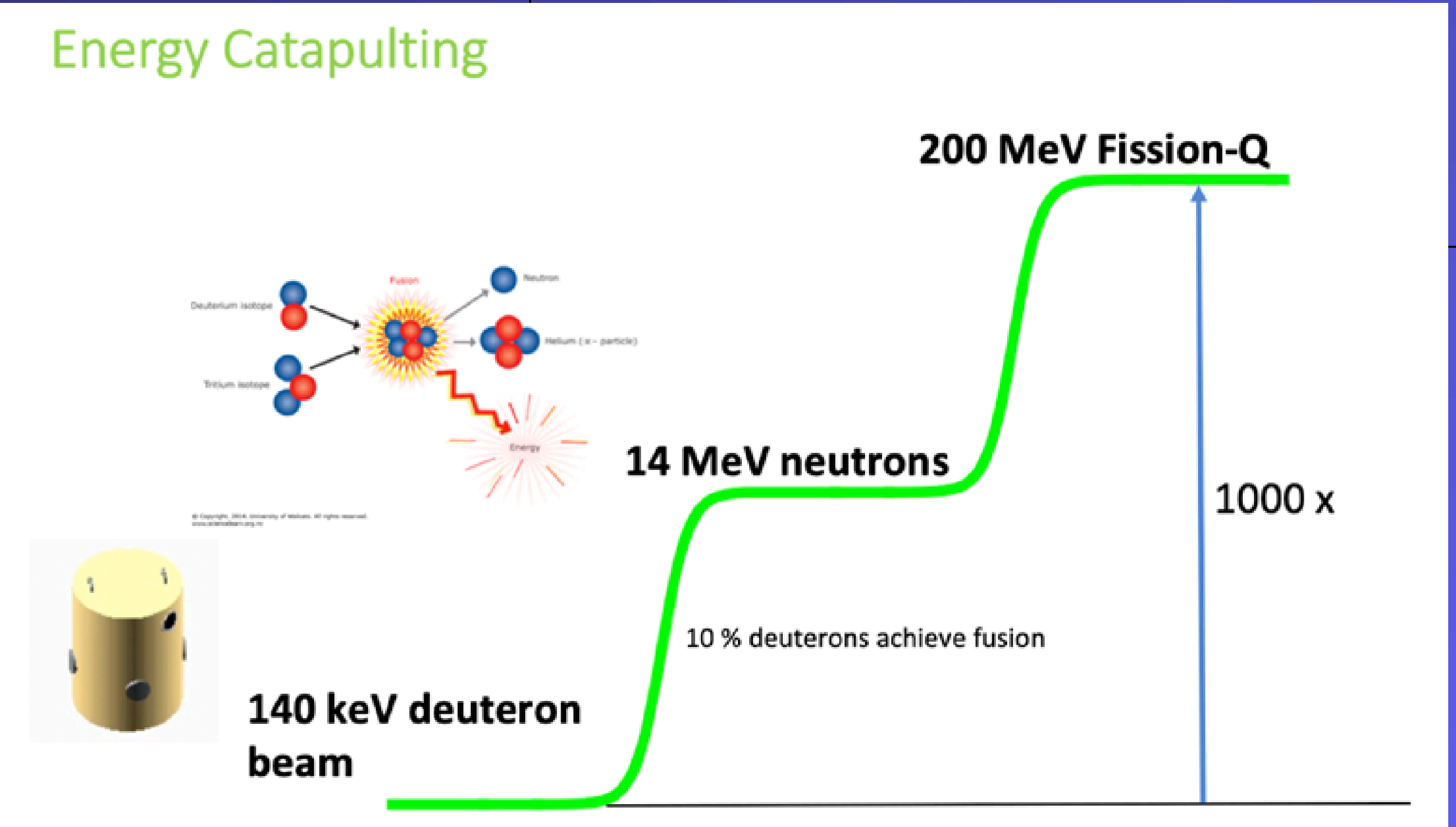








LASER INITIATED TRANSMUTATION

Here we assume variety of efficiencies. The final result is the **electrical power out is 132 MW** and **electrical power to laser is 392 MW** and we can transmute 173 kg of transuraniums

Comparison with MYRRHA. Here we are assuming **perfectly** efficient process for MYRRHA and LIT. On this scale we are 60 times more efficient.

The most idealized case of LIT: In this case we require only 0.03 MW power into the laser to obtain 120 MW out to transmute 155 kg of transuraniums.

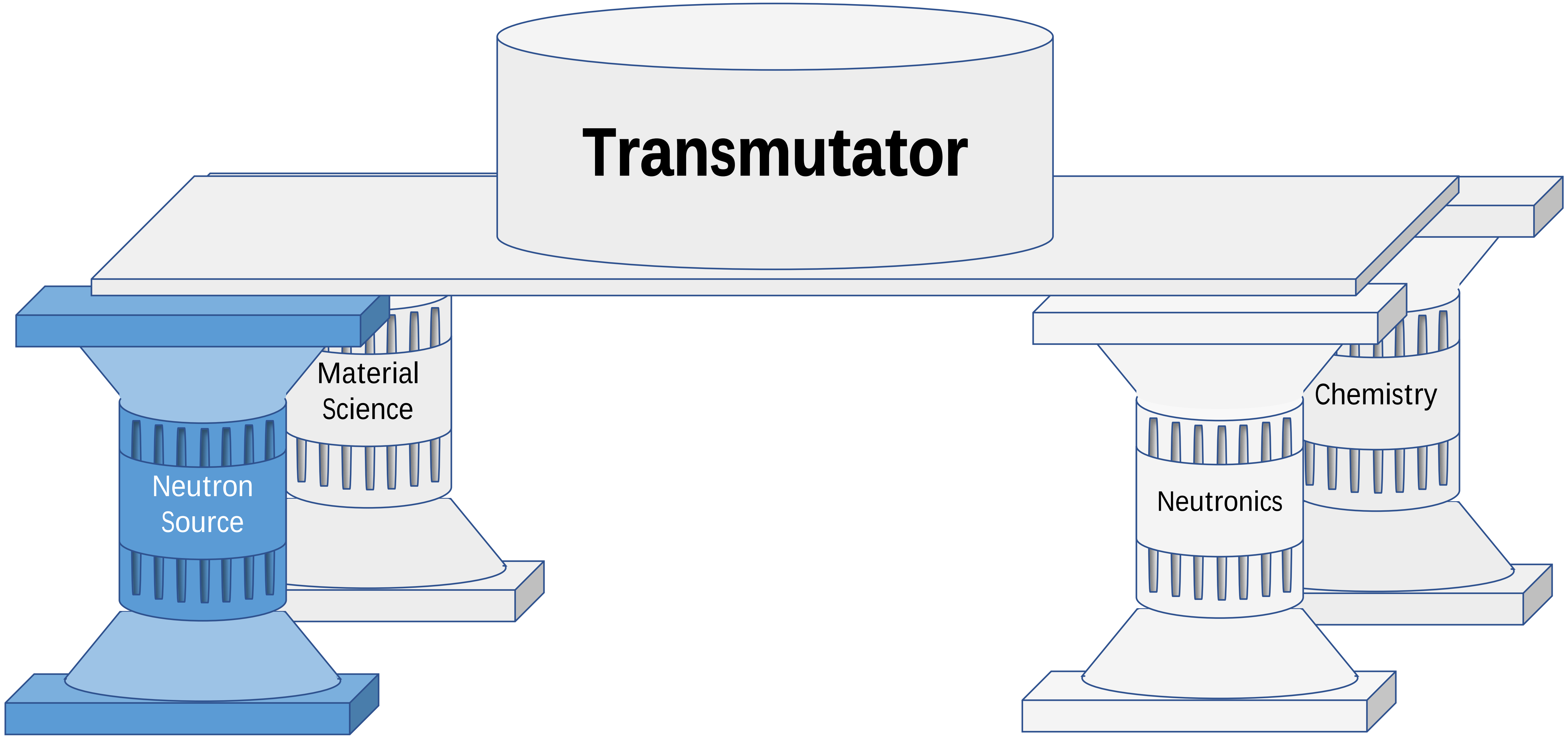
Name	Value	Unit	Description
Laser intensity	$8. \times 10^{17}$	W/cm^2	Peak intensity
Laser wavelength	800	nm	
Laser spot size	5	μm	Focal spot at $1/e^2$
Laser pulse length	50.	fs	Laser pulse
Laser energy	0.015708	J	Energy delivered in one pulse
Num. neutrons	2.07345×10^7	⌗	⌗ of neutrons produced in one pulse
Laser rep. rate	100 000	rep/s	Laser repetition rate
Num. of fibers	100 000	⌗	Number of fibers
Source neutron power	0.464453	MW	Source neutron power
Source neutron rate	2.07345×10^{17}	n/s	Source neutron rate
Total neutron rate	1.3823×10^{19}	n/s	Total neutron rate incl. $1/(1-k_{keff})$
Total neutron power	30.9635	MW	Total neutron power incl. $1/(1-k_{keff})$
⌗ neutrons per fission	2.1	n/fission	⌗ of neutrons released in fission event
keff	0.985	⌗	Multiplicative factor
Energy per fission	210	MeV	Released energy per fission
Laser to deuteron efficiency	0.2	⌗	Conversion efficiency from laser to deuteron
Deuteron to neutron efficiency	0.0004	⌗	Conversion efficiency from deuteron to neutron
Foil density	3.3×10^{23}	$1/cm^3$	
Foil thickness	10.	nm	
a0	0.60821		
sigma	2.36515		$=n_e * D/(n_c * \lambda_L)$
Thermal efficiency	0.6	⌗	Conversion efficiency from molten salt to electricity
Laser efficiency	0.4	⌗	Conversion efficiency from electricity to laser
Core thermal power	221.168	MWth	Core power generated by fission
Core electrical power OUT	132.701	MWe	Electrical power generated by fission
Laser power needed	157.08	MW	Laser power needed to generate neutrons
Electricity IN to generate laser	392.699	MWe	Electrical power needed to generate laser
We can transmute	173.07	kg of TRU in year	kg of TRU in year
This operation requires	32.6238	grams/year	grams of tritium per year

Number of neutrons	1.875×10^{17}	n/s
Required power	0.6	MW
We can transmute	156.506	kg of TRU in year

Number of neutrons	1.86611×10^{17}	n/s
Required power	0.0113097	MW
We can transmute	155.763	kg of TRU in year

Laser based transmutator – The initial approach

Initial aim: go for a prototype of a laser based transmutator



Initial approach
Pillars and tasks

PI: T Tajima

Laser: neutron/monitor

(Mourou)

Laser-driven neutron, monitor

Demonstration of CAIL

Team: EP, ELI, Thales, TAE

Neutronics

(Gales)

MA transmutation
Pu + MA

Various composition of wastes, design of the system

Team: TAE (Google), CEA, Orano, EDF, CNRS

Wall materials

(Massard)

Carbon-based: invented

Immerse into molten salt and reactor to test

Team : TAE, UWM, UCI, CEA, Orano, EDF

Chemistry

(Serp, Delpech)

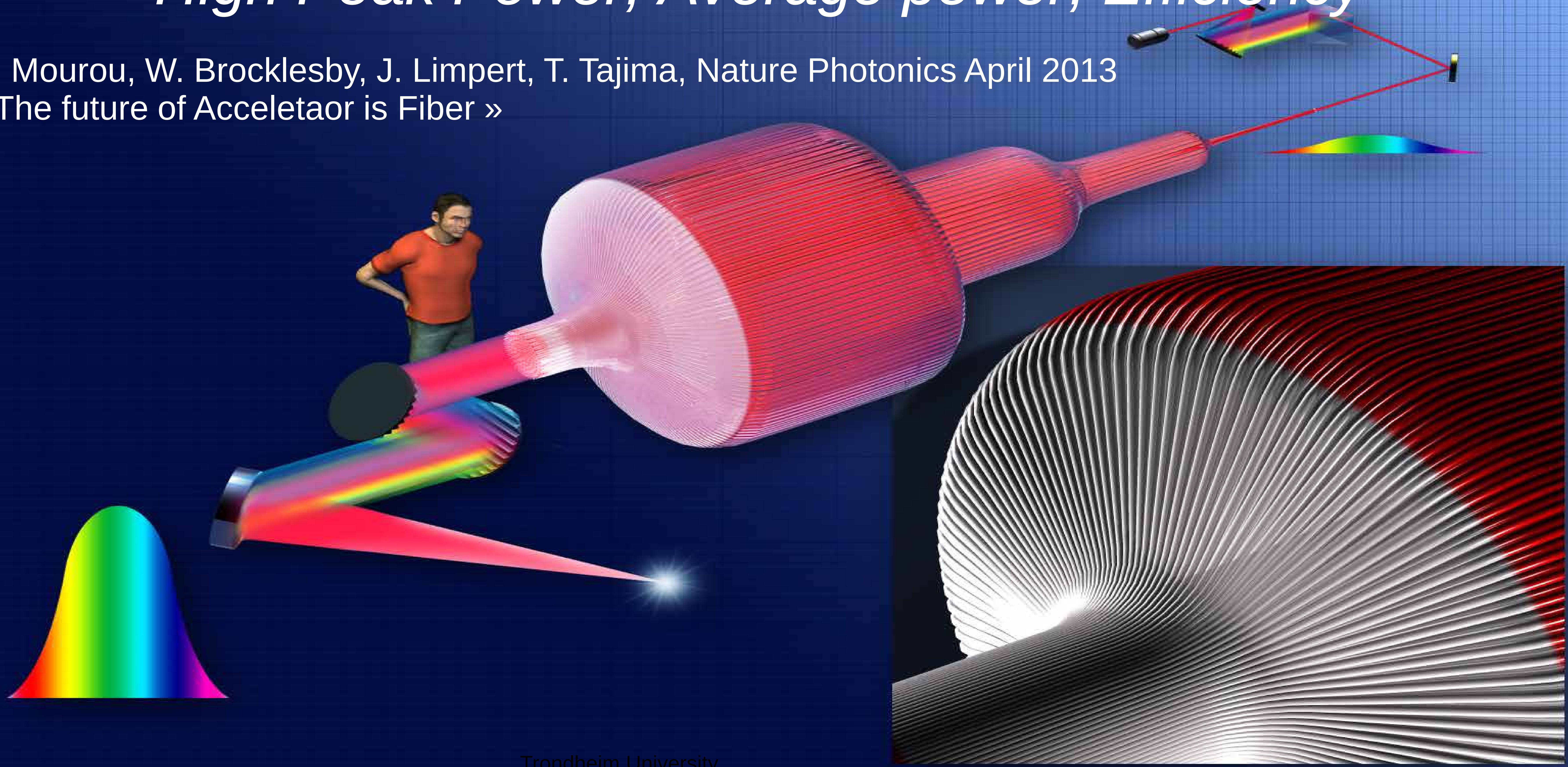
Separation in liquid

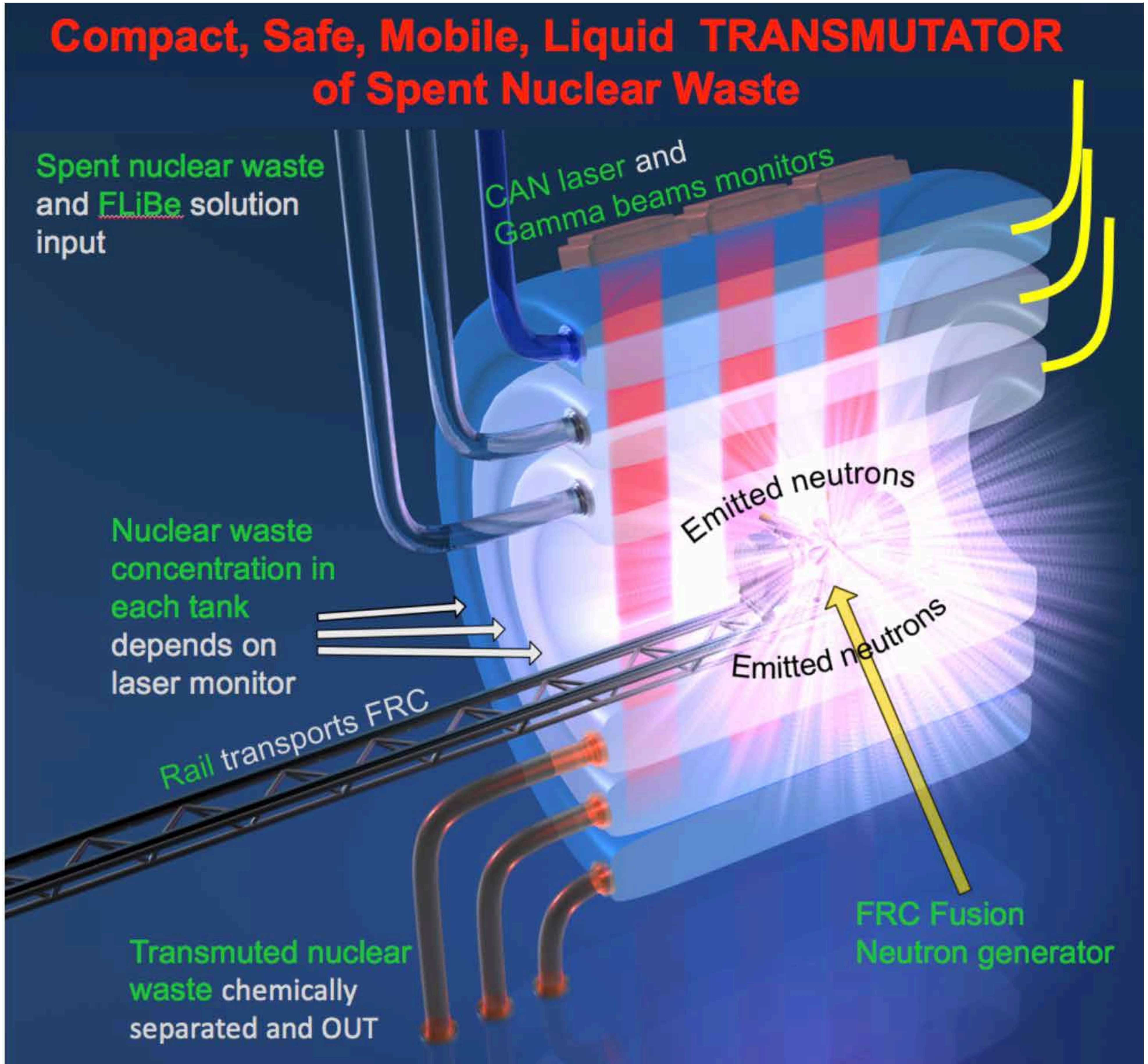
Solvent choice

Team: CEA, CNRS, Orano

CAN Coherent Amplification Network
High Peak Power, Average power, Efficiency

G. Mourou, W. Brocklesby, J. Limpert, T. Tajima, Nature Photonics April 2013
« The future of Acceletaor is Fiber »





Compact, Safe, Mobile, Liquid TRANSMUTATOR
of Spent Nuclear Waste
Spent nuclear waste
and FLiBe solution
input
CAN laser and
Gamma beams monitors
Emitted neutrons
Nuclear waste
concentration in
each tank
depends on
laser monitor
Emitted neutrons
Rail transports FRC
FRC Fusion
Neutron generator
Transmuted nuclear
waste chemically
separated and OUT

EXTREME LIGHT: NUCLEAR TRANSMUTATION

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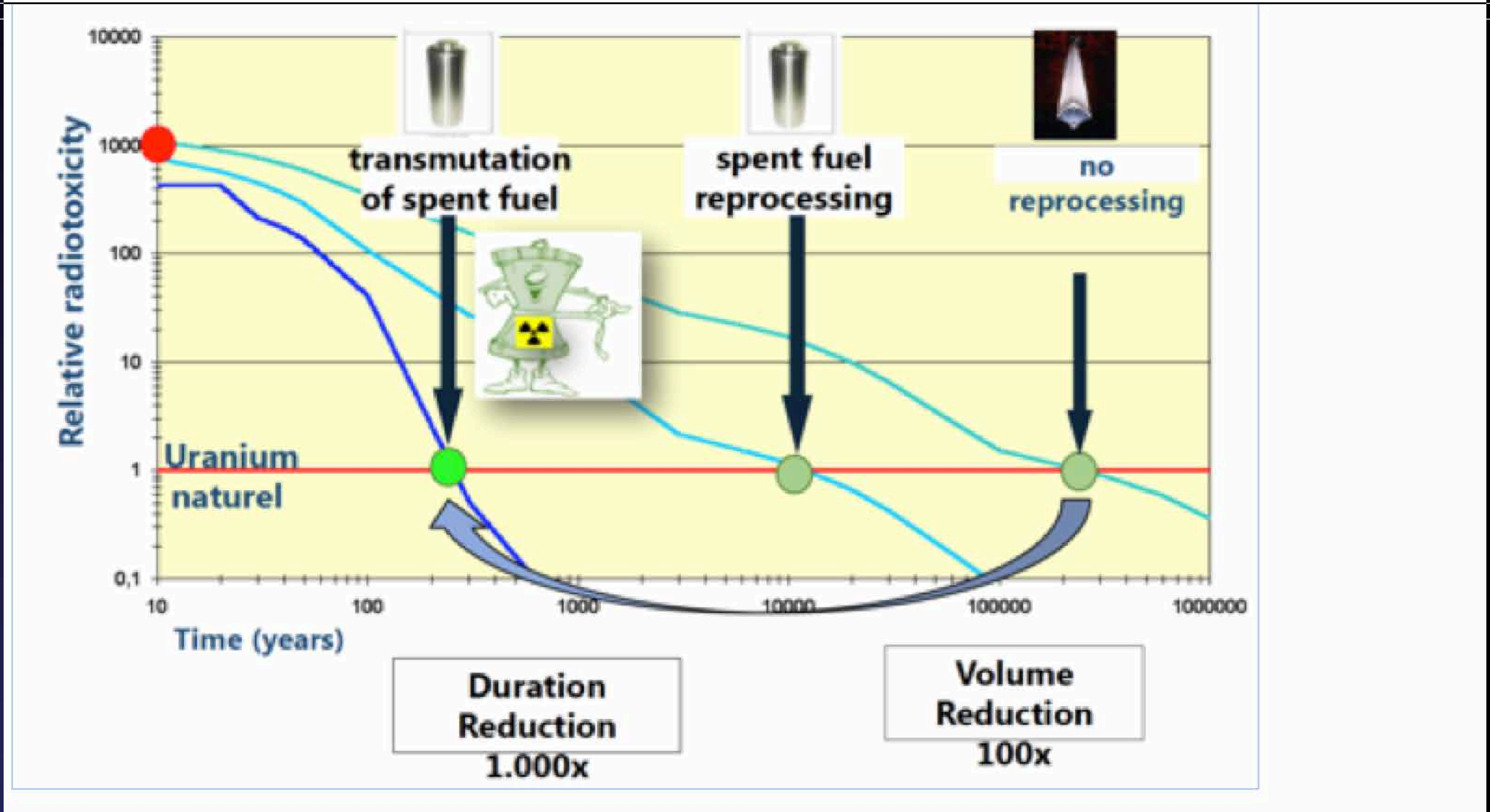

The radiotoxicity of the spent nuclear fuel may be reduced from the level of no reprocessed case to a level reduced by about 1000 times if we transmute the spent fuel. This is why the substantial benefit may be gained by the transmutation.

Aim:
Experimental demonstration of transmutation of TransUranic Minor Actinide (Np, Am, Cm) spent nuclear waste with a technique based on ultrashort laser pulses.

The mechanism of coherent acceleration of ions by laser (CAIL) is capable of producing 14 MeV neutrons with high yield driven by 100 keV accelerated deuterons via DT or DD fusion reactions, when a sub-8fs, high repetition rate laser is used (SYLOS).

Tasks:

T1 Deuteron acceleration by few cycle laser pulses
M11 Demonstration of the CAIL scheme with the SYLOS Experimental Alignment laser (10 Hz)
M12 Development a deuteron accelerator with the SYLOS laser (1 kHz)

T2 Generation of fusion neutrons with accelerated deuterium

T3 Transmutation of TRU spent nuclear waste to safe radiotoxicity levels and volumes via neutrons genertated with the SYLOS laser (1 kHz)

Nuclear fission reactors generate a stream of radioactive nuclides of the spent fuel waste: in United States alone 90,000 metric tons requires disposal,and by 2020 the worldwide spent nuclear waste inventory will reach 200,000 metric tons,with 10,000 tons added each year. For example, nuclear power accounts for 77% of electricity in France, making the need for transmutation increasingly important.