A PASSION FOR EXTREME LIGHT

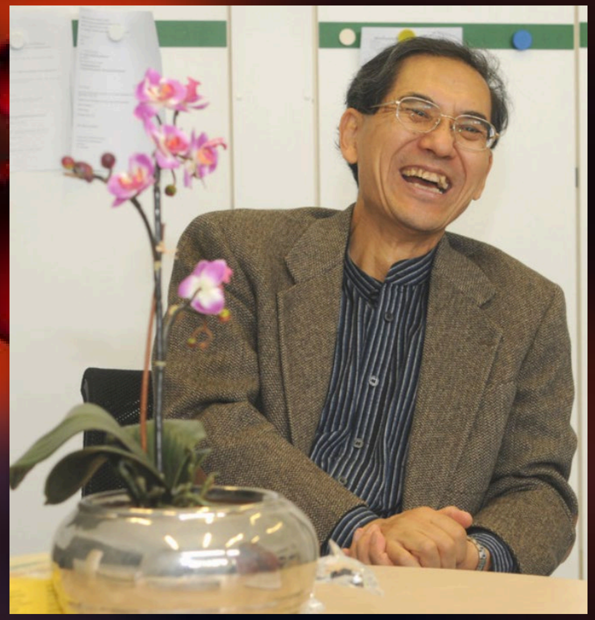
For the greatest benefit to human kind (Alfred Nobel)

Transmutation des Déchets Nucléaires

Presented by

Prof. Gérard Mourou

Nobel Prize for Physics, 2018

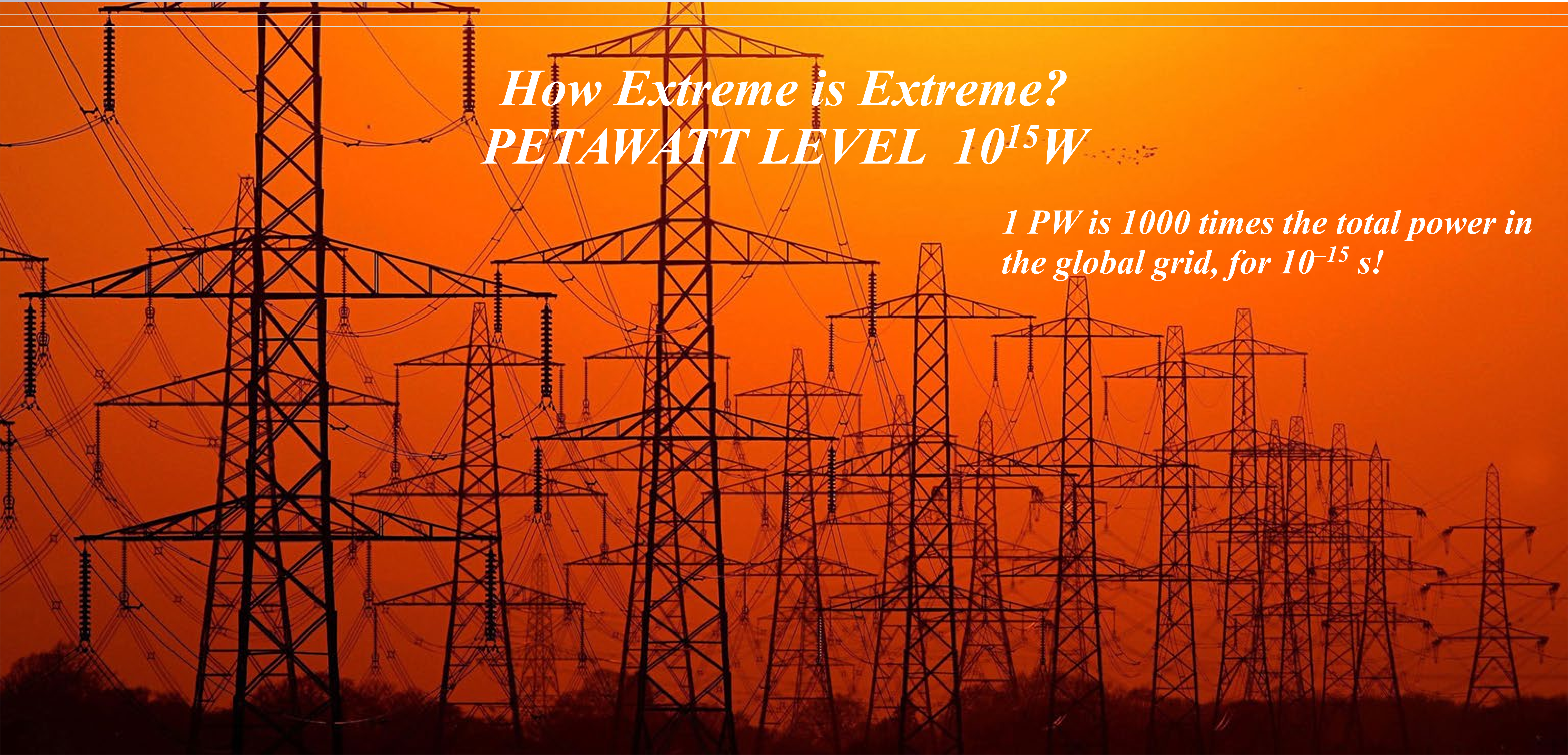


Toshiki Tajaima

Gérard Mourou

Donna Strickland

PRIX NOBEL de PHYSIQUE 2018



How Extreme is Extreme?
PETAWATT LEVEL 10^{15}W

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!

LA LUMIERE EXTREME:

Fournit les intensités les plus élevées,

Les champs électriques les plus grands,

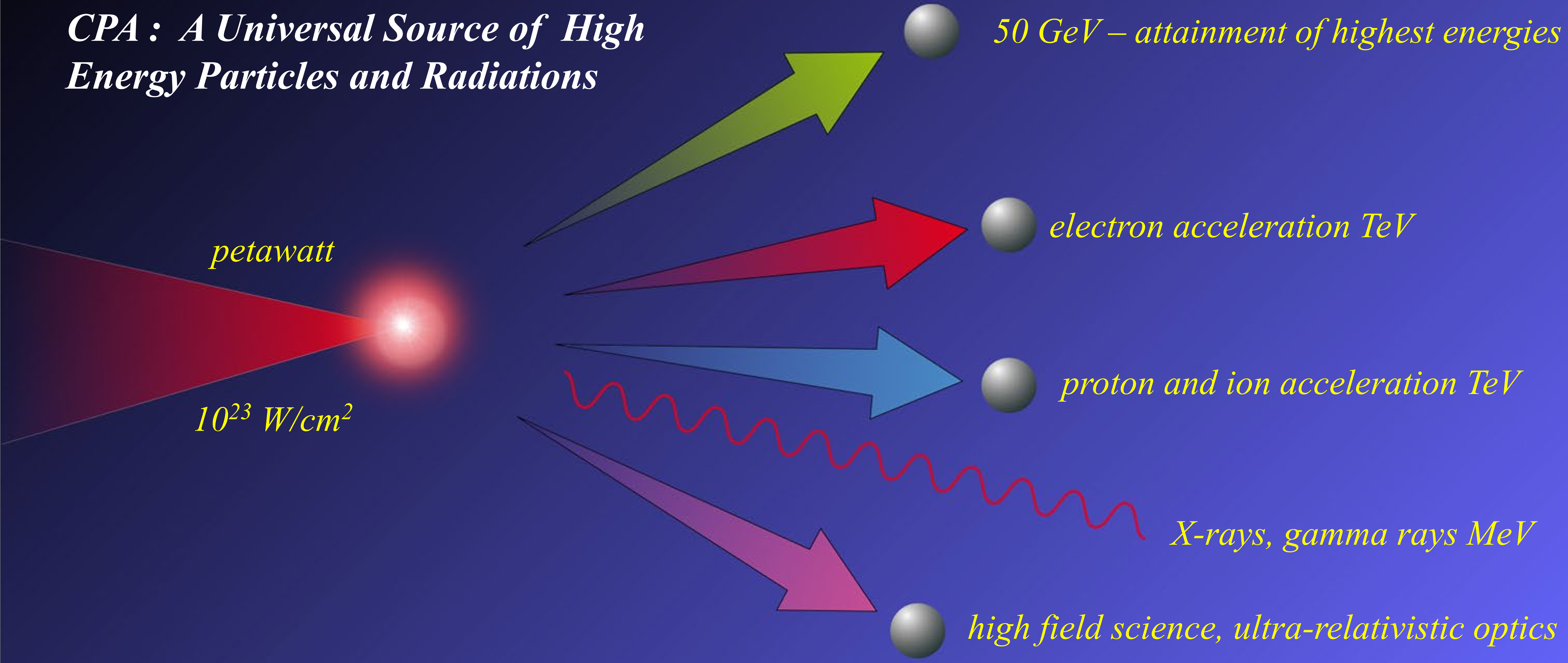
Les pressions les plus importantes,

Les accelérations les plus grandes

Les températures les plus élevées

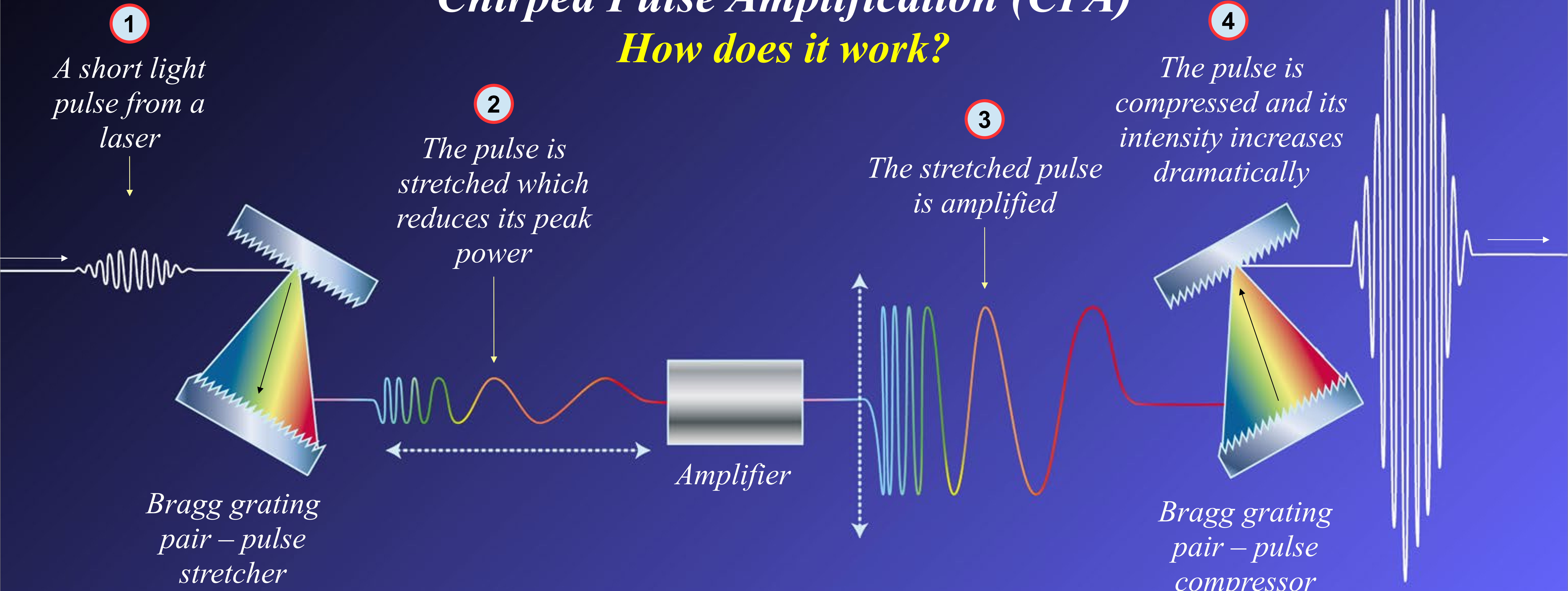
Elle est la source universelle de particules et de radiations de haute énergie.

CPA : A Universal Source of High Energy Particles and Radiations



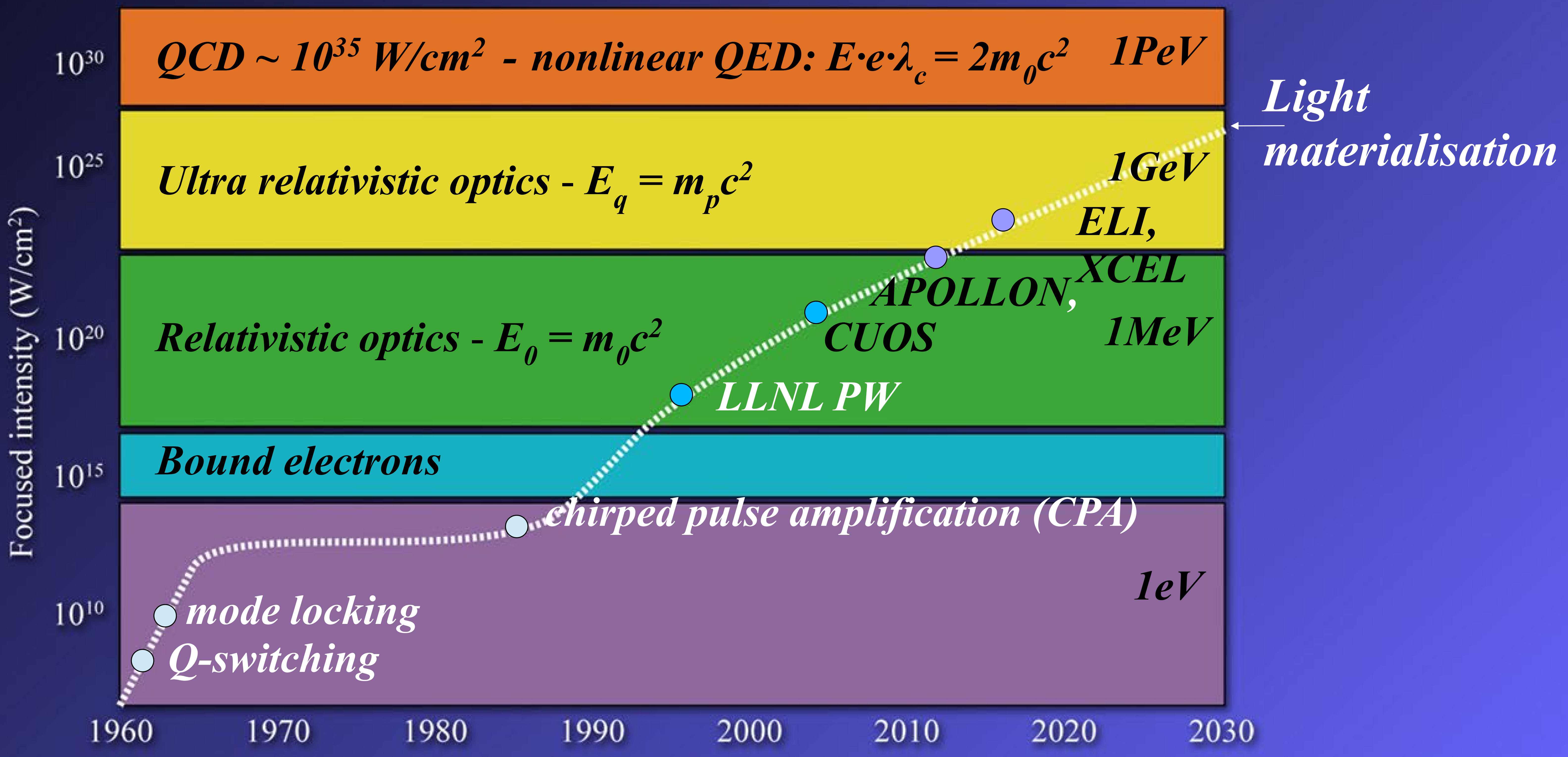
Chirped Pulse Amplification (CPA)

How does it work?

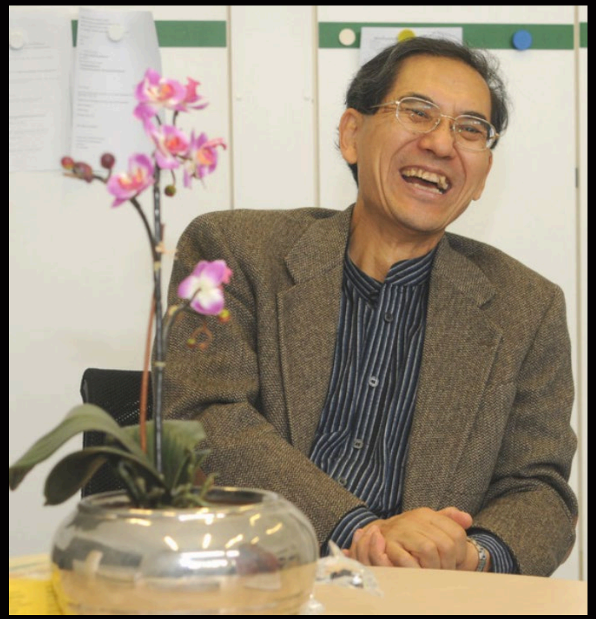


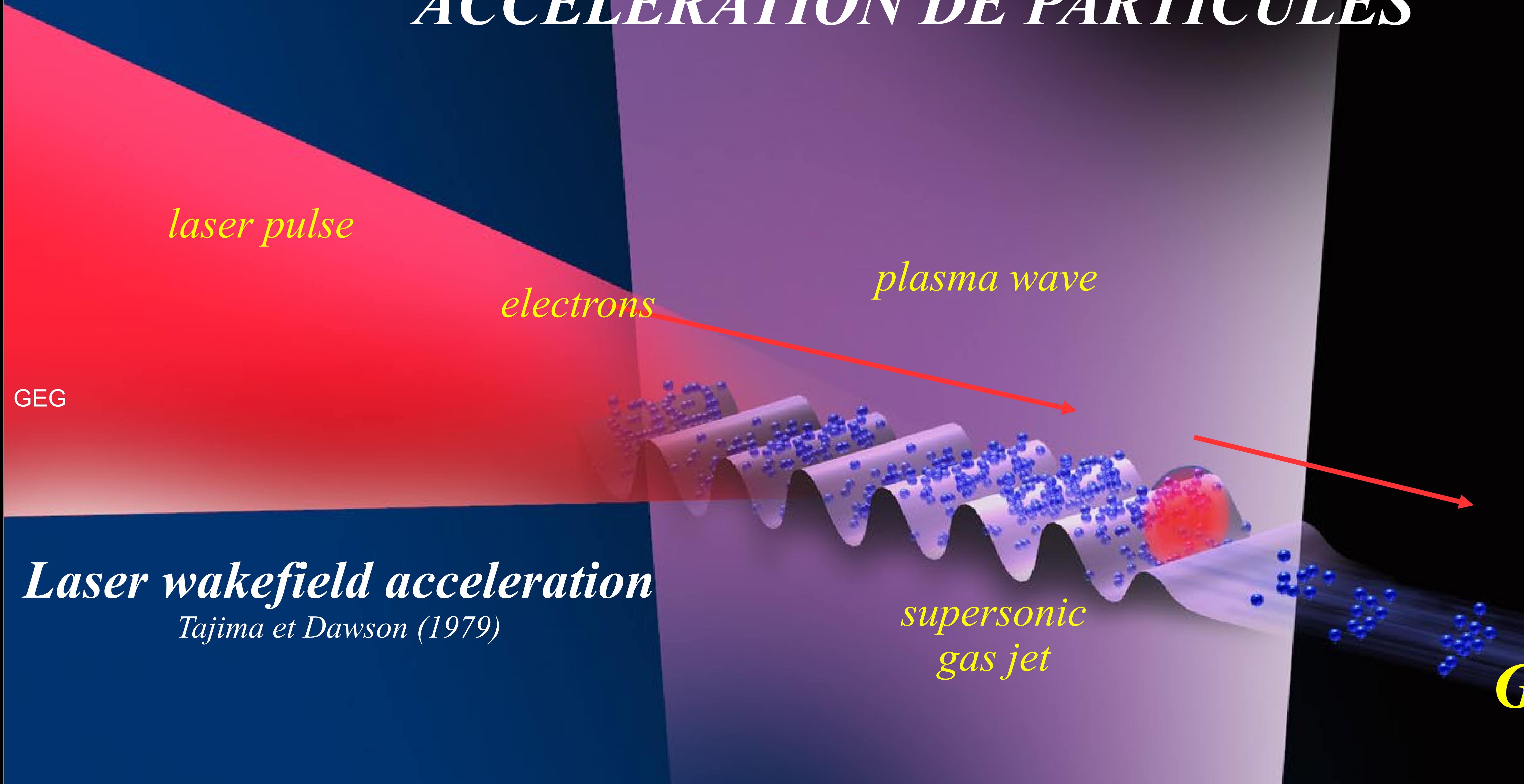
Extreme light ultra high intensity roadmap

EXCEL



ACCELERATION DE PARTICULES





Laser wakefield acceleration

Tajima et Dawson (1979)

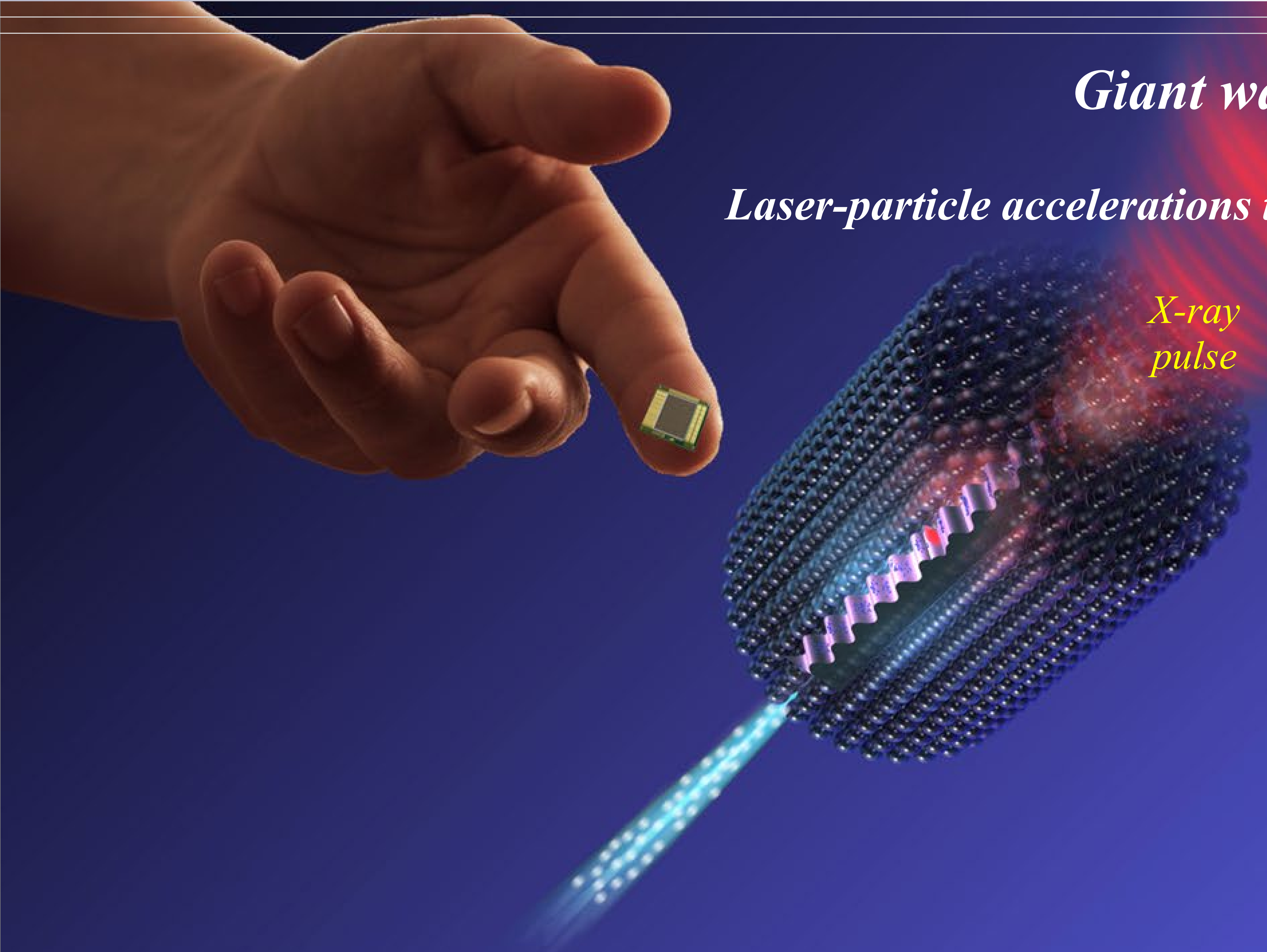
Synchrotron SOLEIL 3GeV

S

Giant wakefield acceleration in solid

Tajima et Dawson (1979)

Laser-particle accelerations to the TeV/cm level become possible



Tomorrow

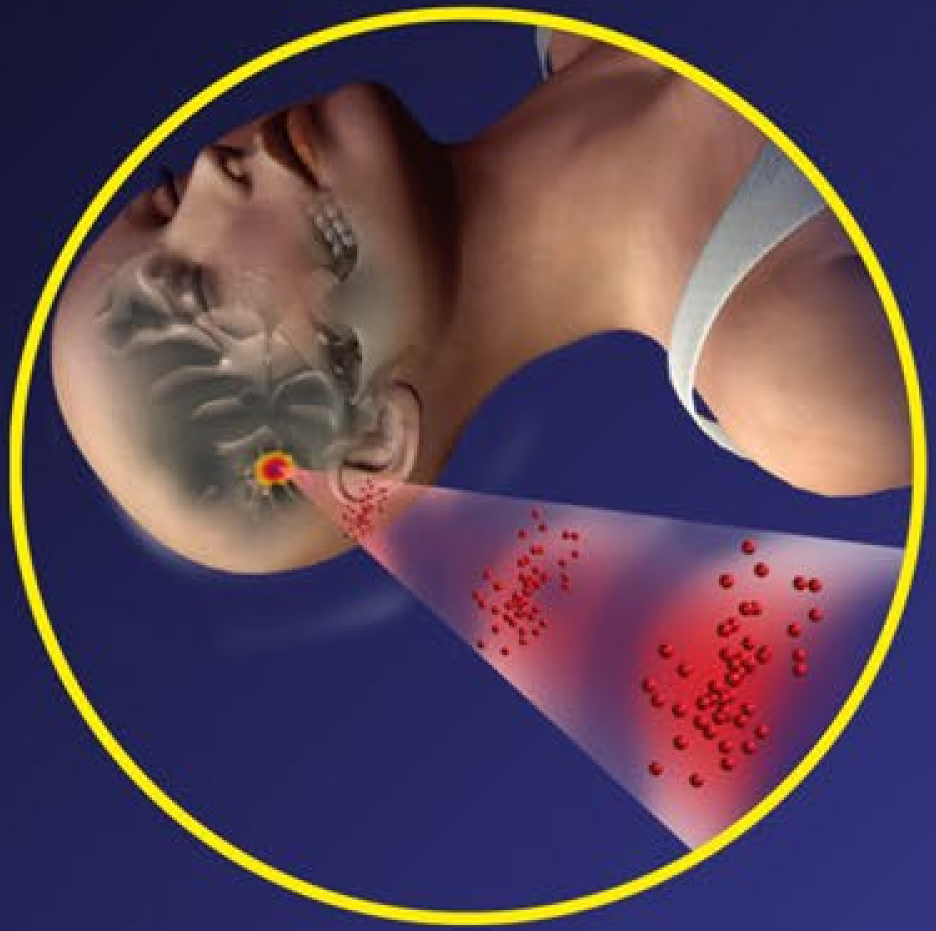
** visible laser induced wakefield*
** about 100 metres long*
** the size of a football pitch*

Beyond tomorrow

** laser induced X-ray wakefield*
** about TeV/cm*
** the size of a microchip*

CPA in Nuclear Medicine

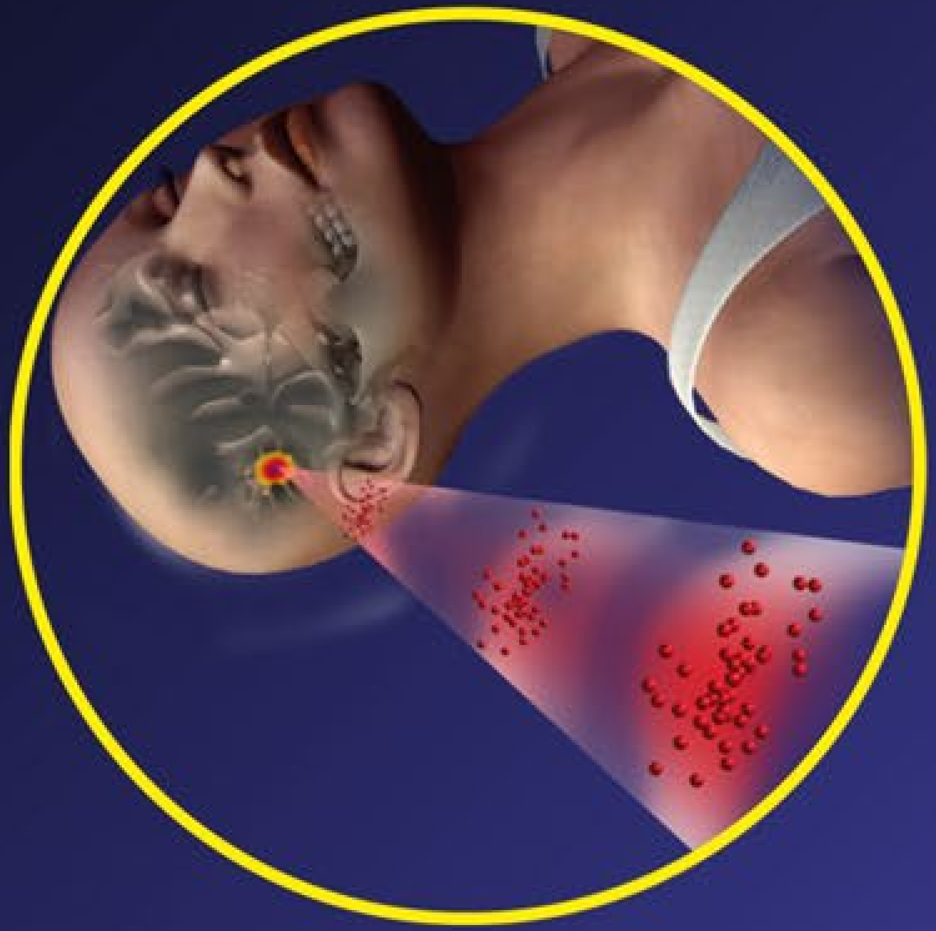
Proton therapy



Extreme light technology will be tens of times more compact, more precise and less expensive

CPA in Nuclear Medicine

Proton therapy



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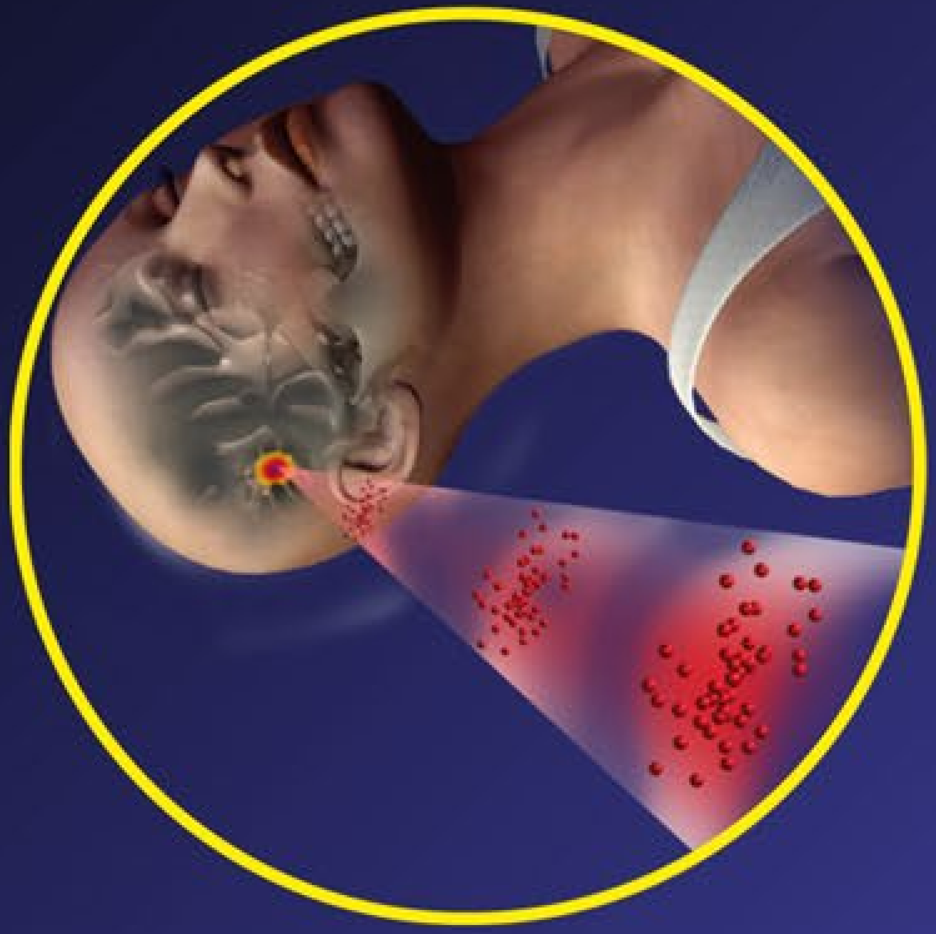
Nuclear therapy

Radionuclides are used to implant radioactive pellets directly into a tumour

CPA in Nuclear Medicine

Proton therapy



Extreme light technology will be tens of times more compact, more precise and less expensive

Nuclear therapy

Radionuclides are used to implant radioactive pellets directly into a tumour

Nuclear diagnostics

When a scanner needs a radioisotope, extreme laser acceleration in the clinic would make this fast and safer

CPA Mitigating Nuclear waste

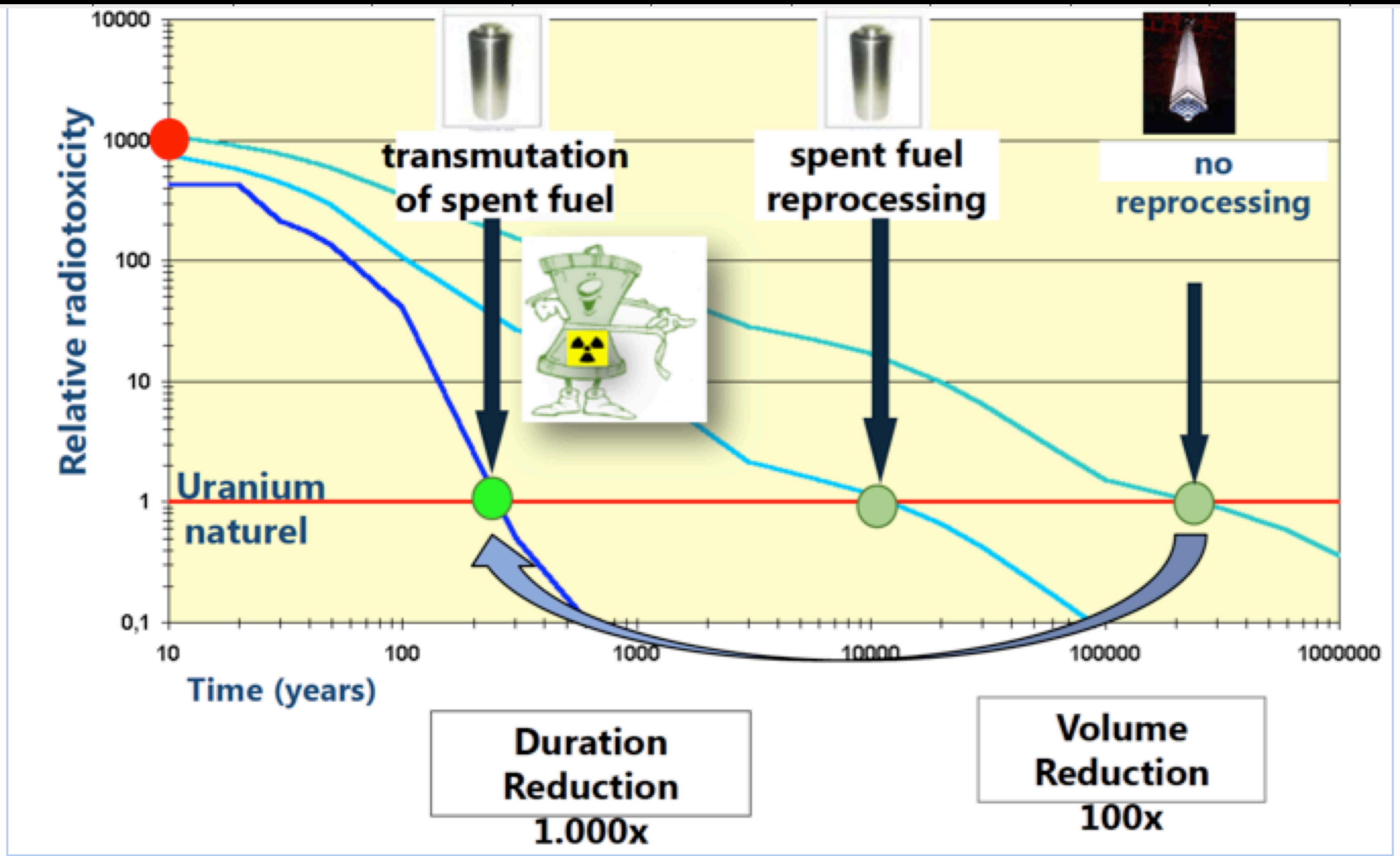
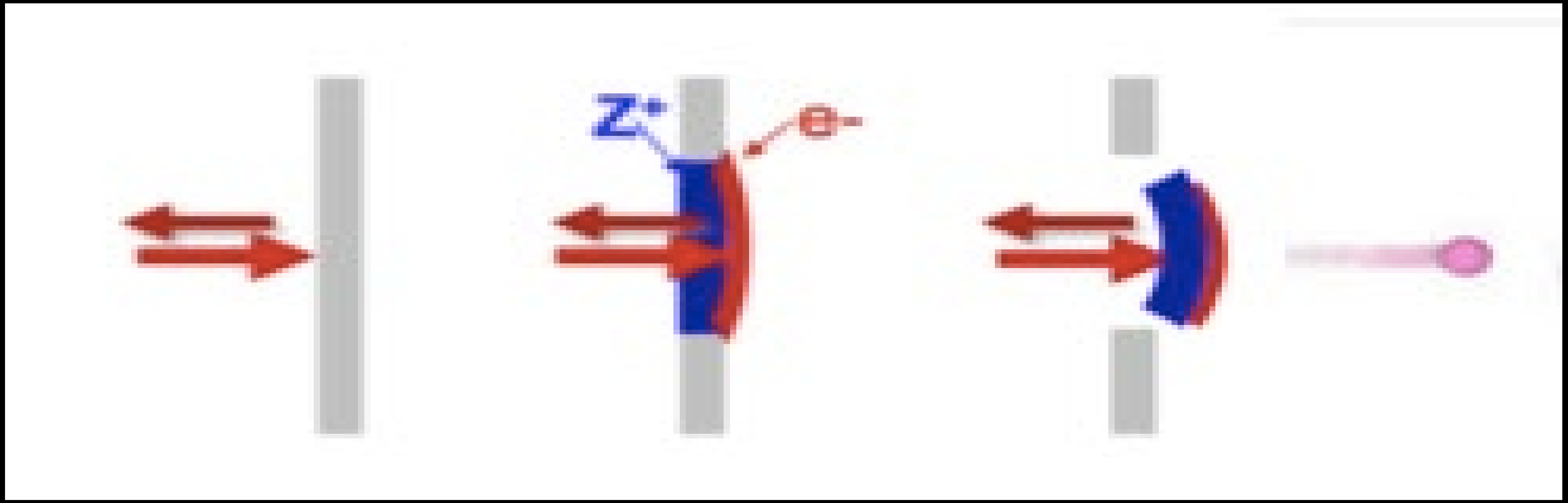


Figure 1: The radiotoxicity of the spent nuclear fuel may be reduced from the level of no reprocessed case to a level reduced by about 1000 times if we transmute the spent fuel. This is why the substantial benefit may be gained by the transmutation. [10],[11]

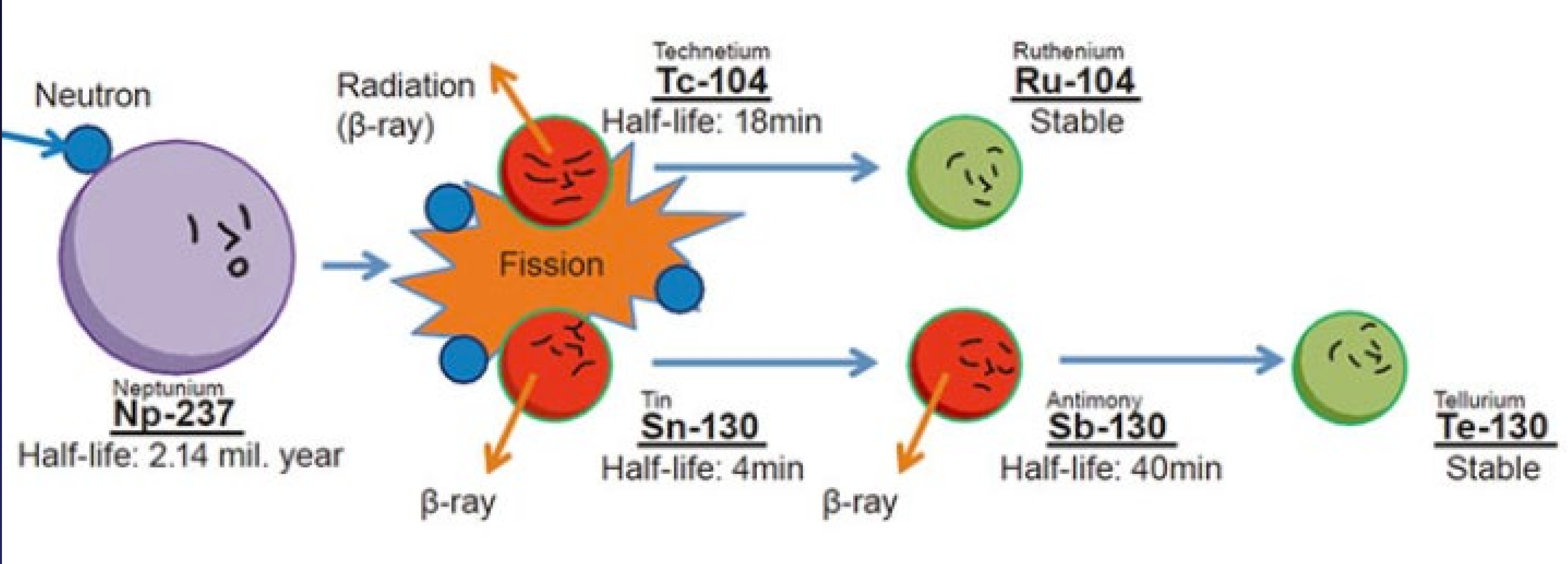
Low Hanging Fruit: High Energy Proton Generation

GeV Proton Generation



MeV-GeV

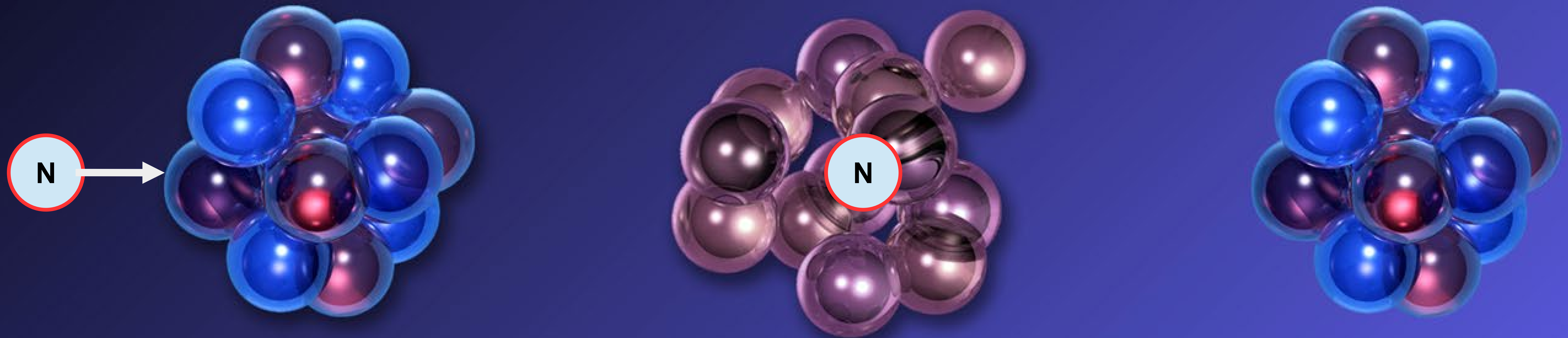
NUCLEAR TRANSMUTATION CONCEPT



CPA Transmutation of Nuclear Waste

For example

** 99Tc (Technetium) half-life of 200 000 years*
** 100Tc has a half-life of 16 seconds*
** it decays to a stable 100Ru (Ruthenium)*

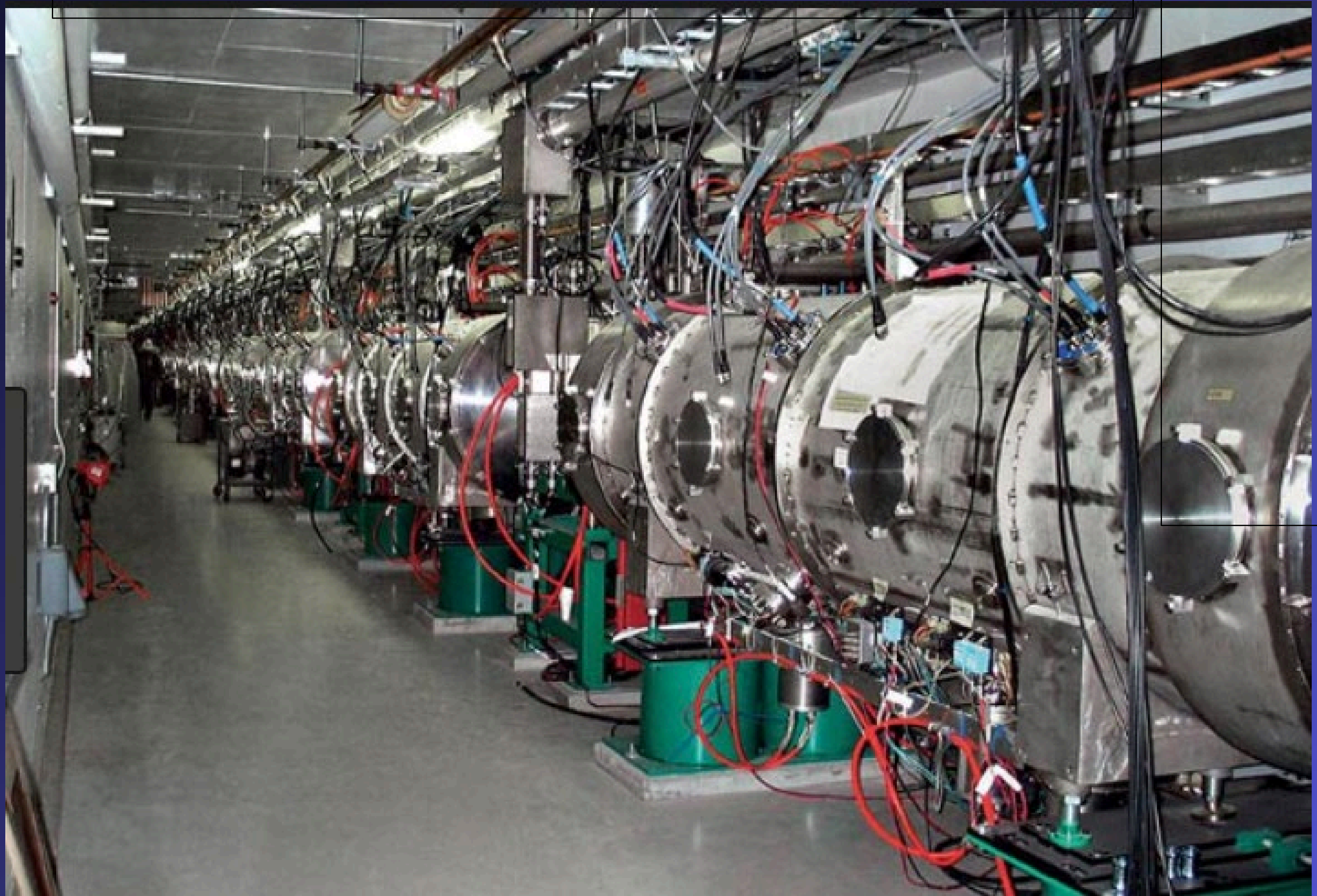


Isotope A
T = 200 000 years

Isotope B
T = 16 secs

Isotope C
no radiation

RELATIVISTIC PROTON ACCELERATOR
for
TRANSMUTATION

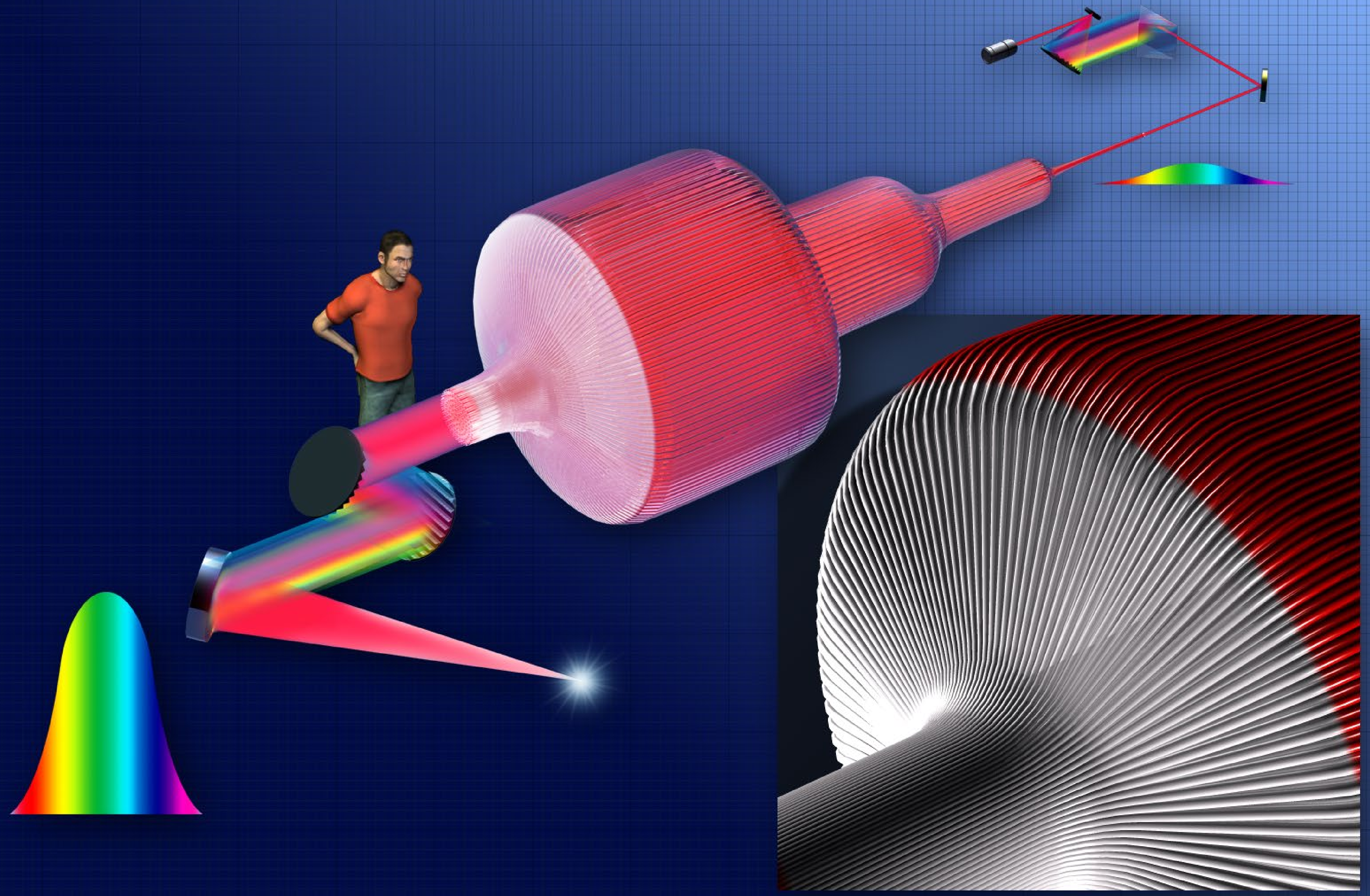


Projet MYRRHA

CAN

Peak Power TW
Average Power MW
Efficiency: 40%

Projet EP-Thales



CONCLUSION

1. La lumière extrême offrent des possibilités considérables, à la recherche, l' innovation mais aussi à l' industrie française et européenne.
2. Elle a eu un énorme impact sur l' industrie française du laser. Elle a permis a celle-ci d' innover et de dominer le marché mondial.
3. Je suis heureux qu'avec le CNRS et la Commission Europeenne nous ayons pu realiser les projets ELI et Apollon et contribuer à l unification de la science dans les pays emergents de l' Union Européenne.
4. Heureux aussi de contribuer au leadership de la recherche Française et Européenne dans le monde.

And the Best is Yet To Come !

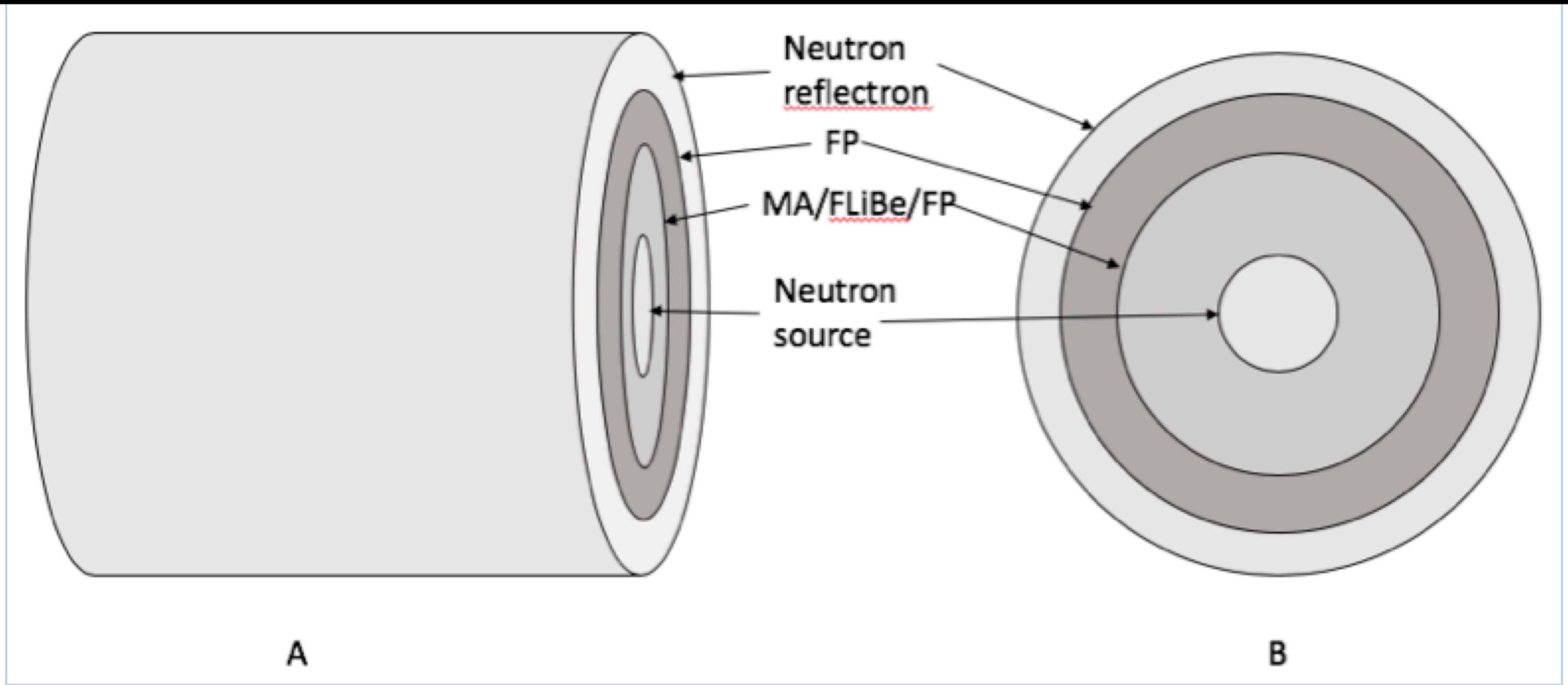
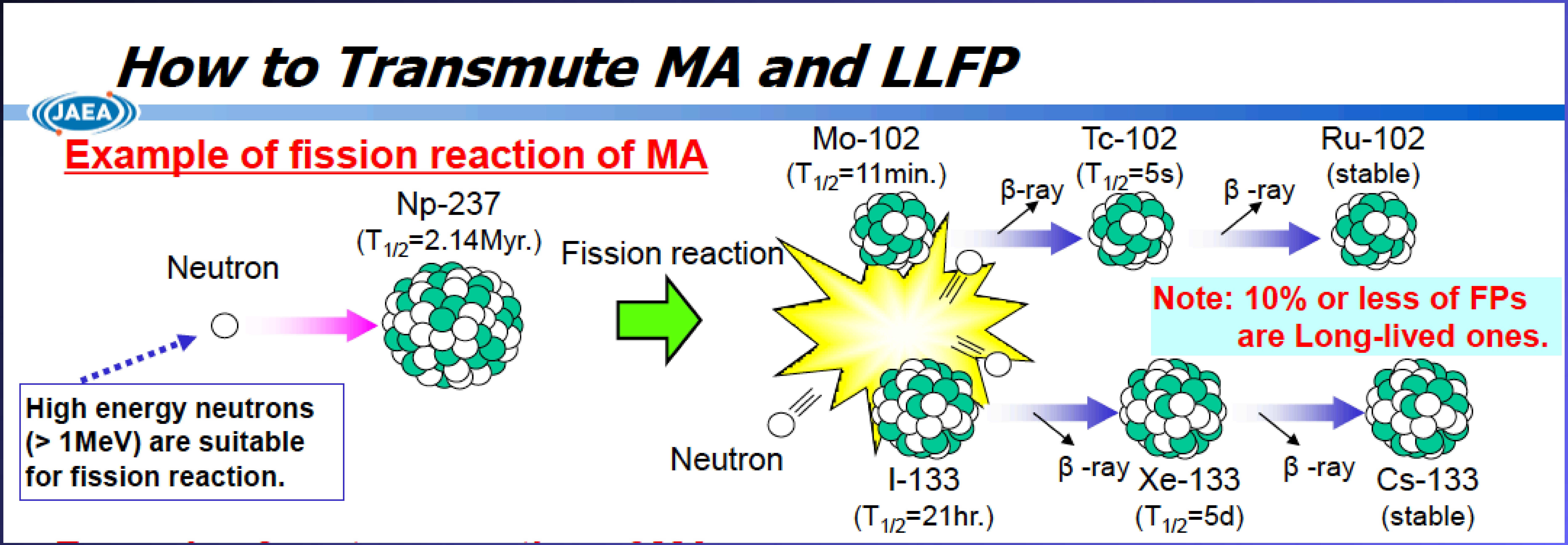
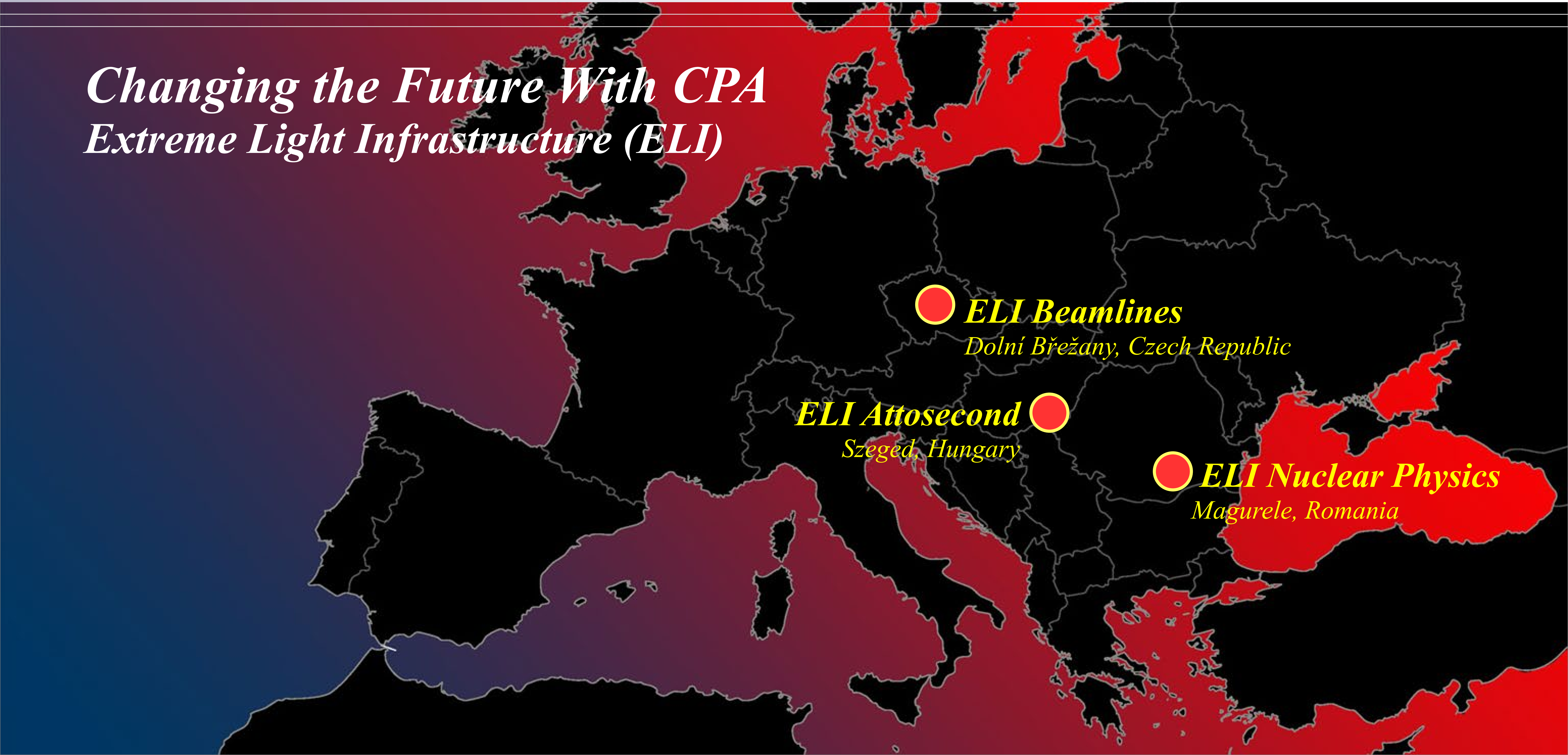


Figure 2. The structure of the liquid state layers of the solution (FLiBe) with TRUand FP surrounding the central fusion neutron source. The schematics, whose more functional details are shown in Fig. 9.

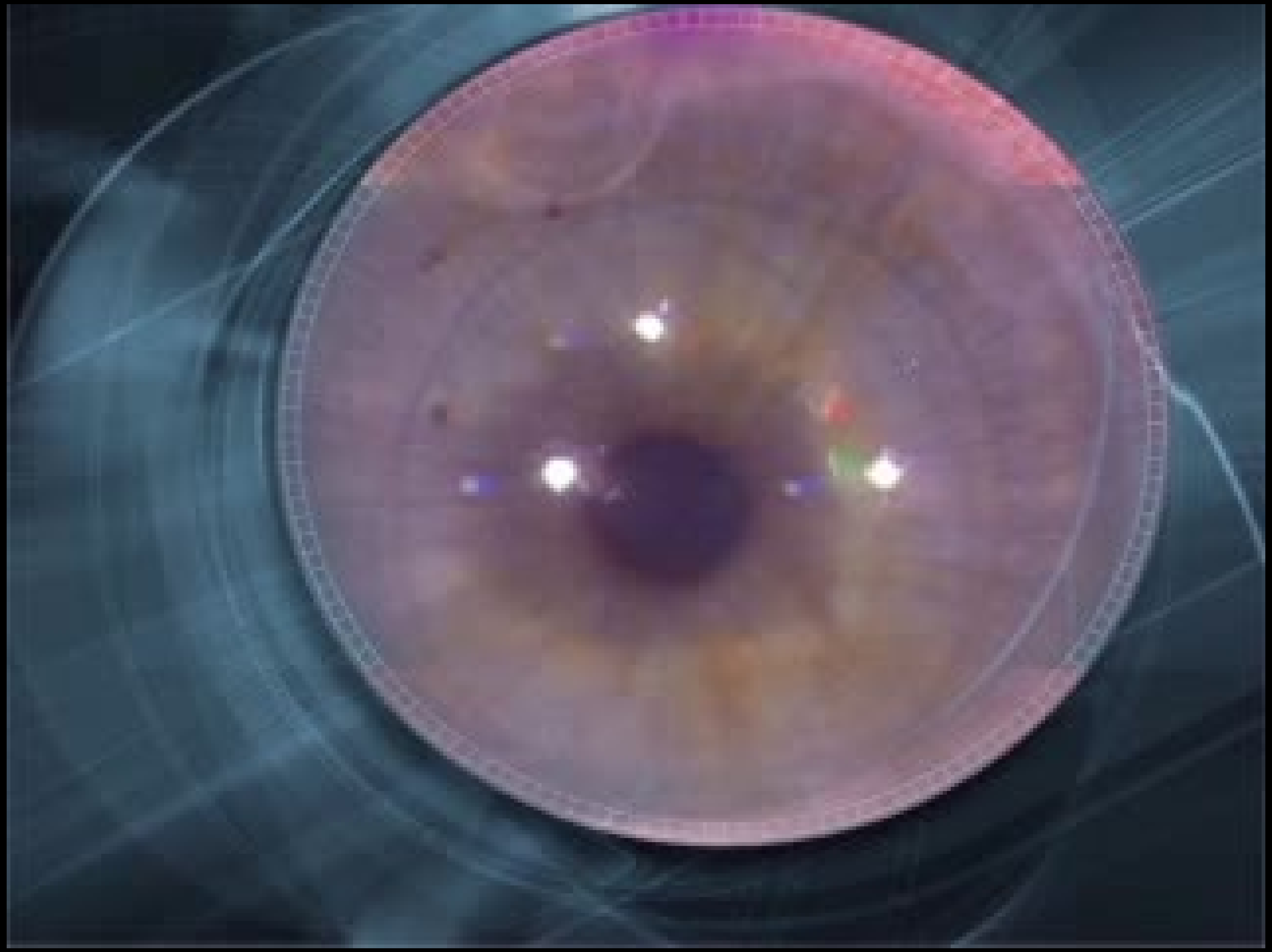
NUCLEAR TRANSMUTATION CONCEPT



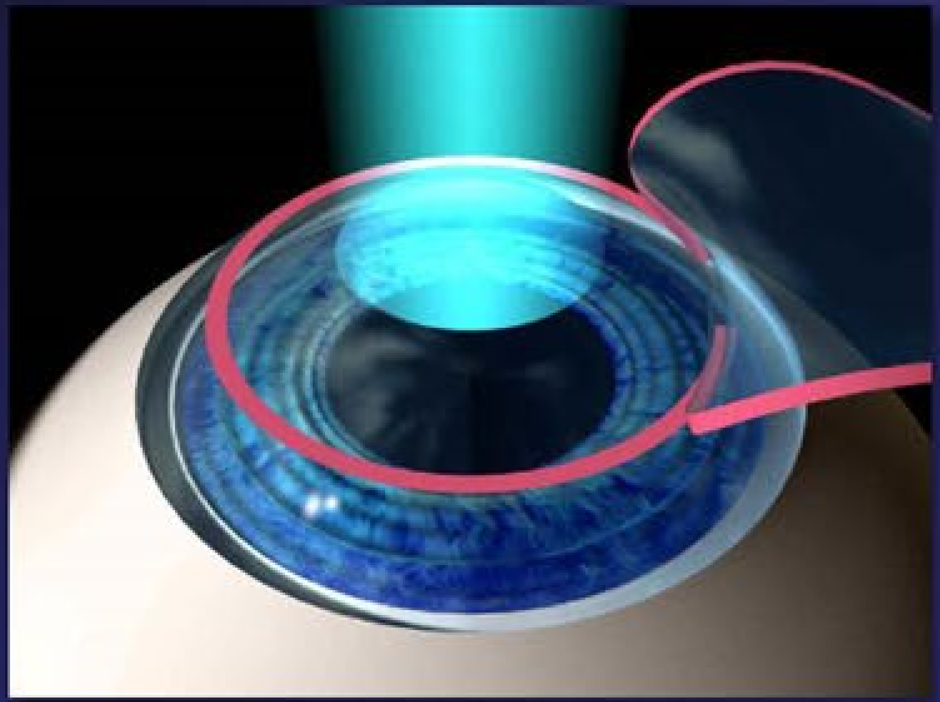
Changing the Future With CPA
Extreme Light Infrastructure (ELI)

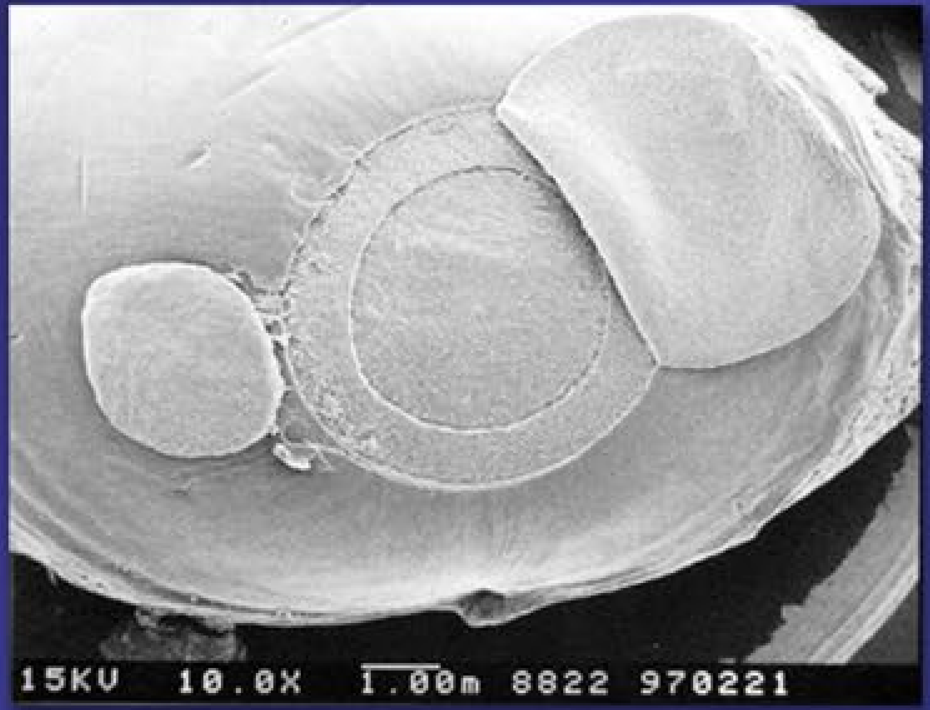


Intralase flap creation

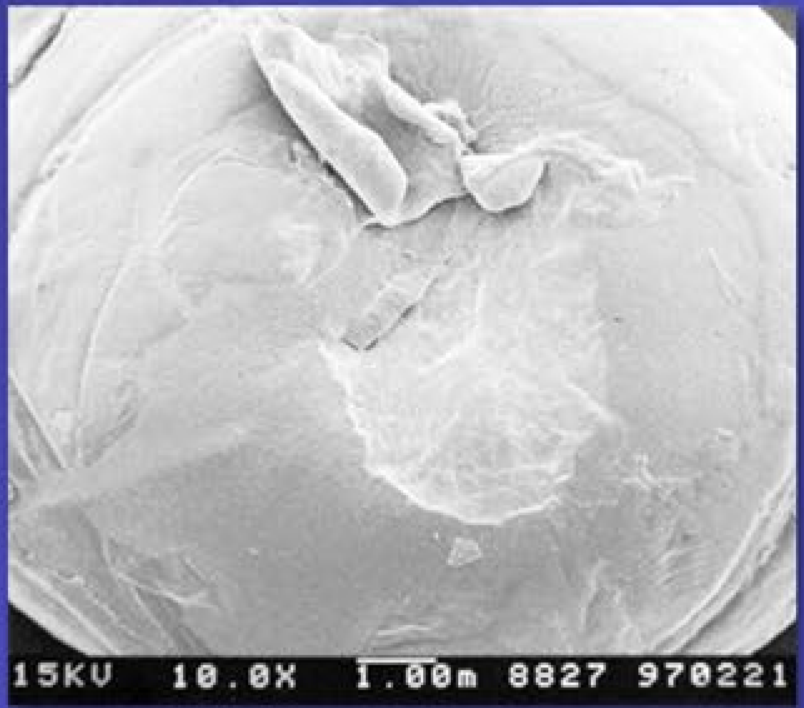


CPA femtosecond lasers revolutionised ophthalmology
24 million eye operations since 2001!





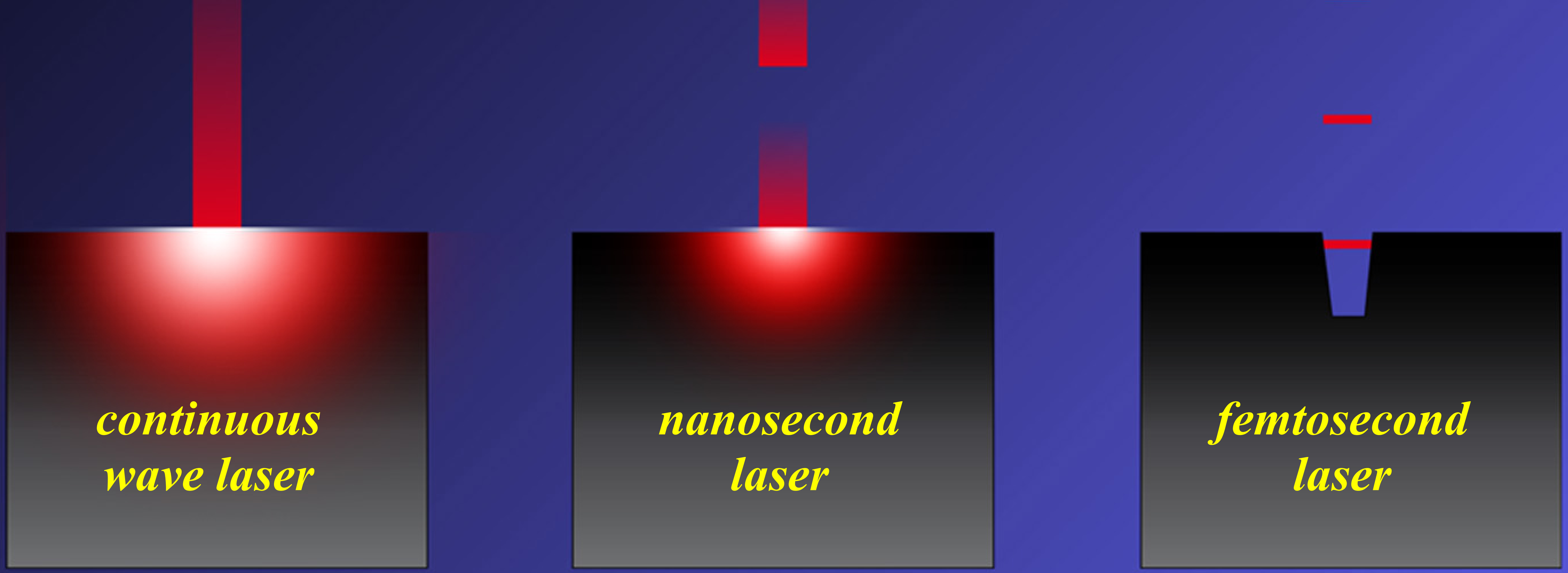
300 femtosecond



50 picosecond

High Precision Micro Machining

A femtosecond (fs) laser will cut the material without damaging it



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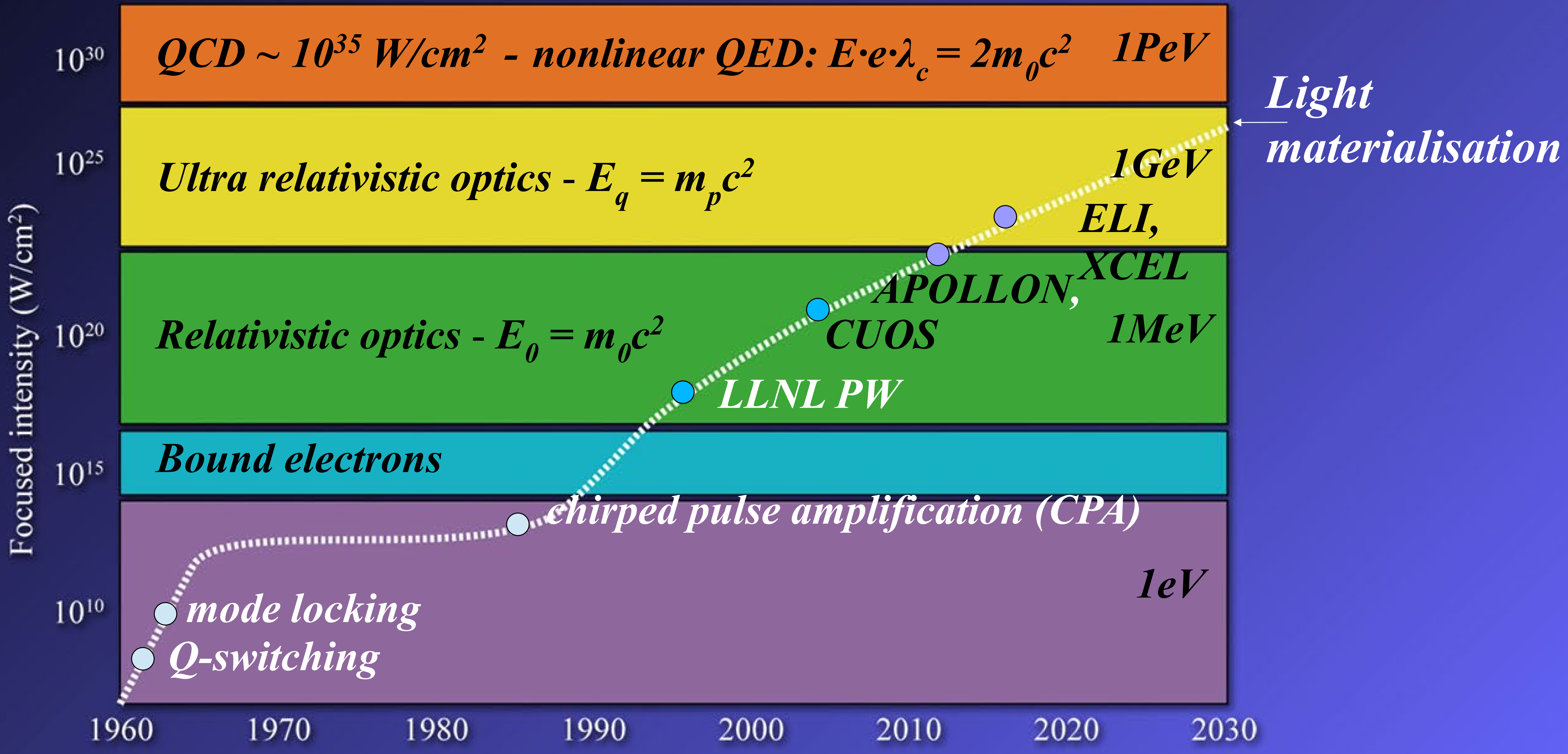
EXCEL

Extreme light ultra high intensity roadmap



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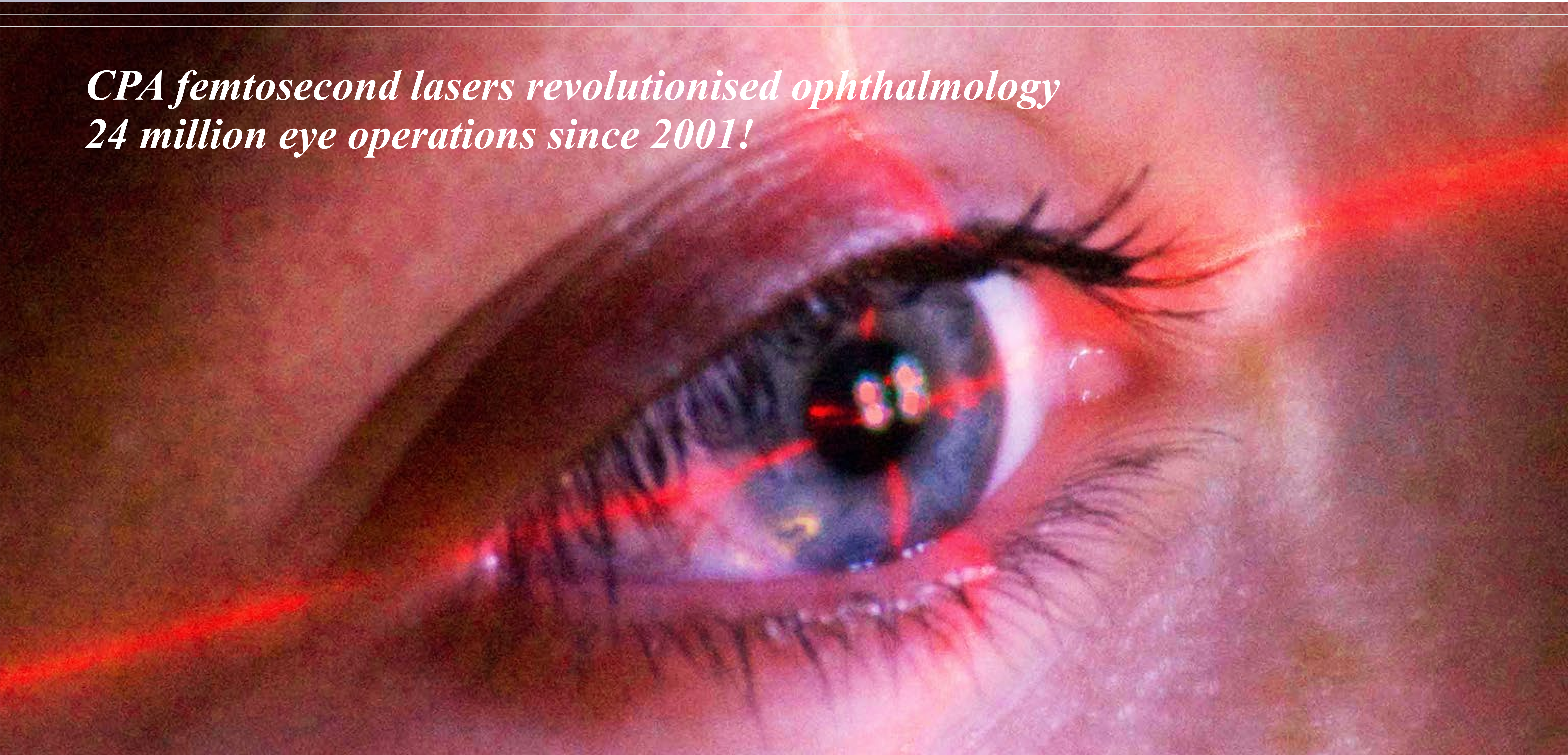

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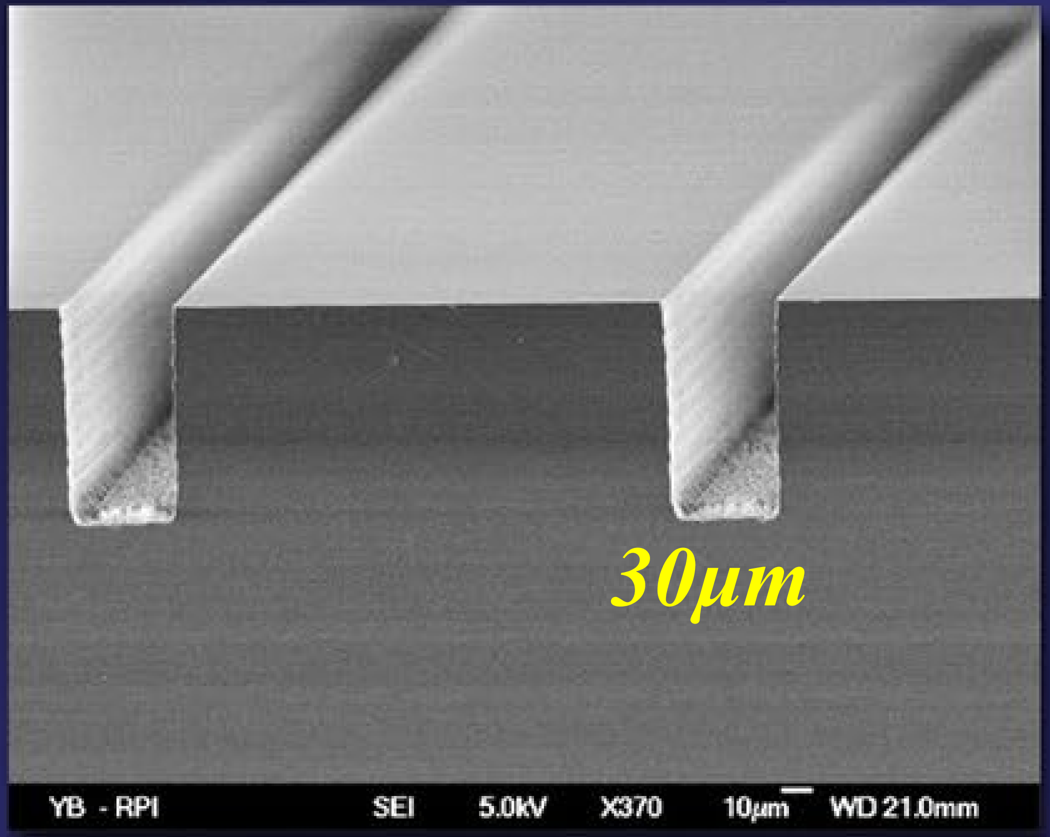

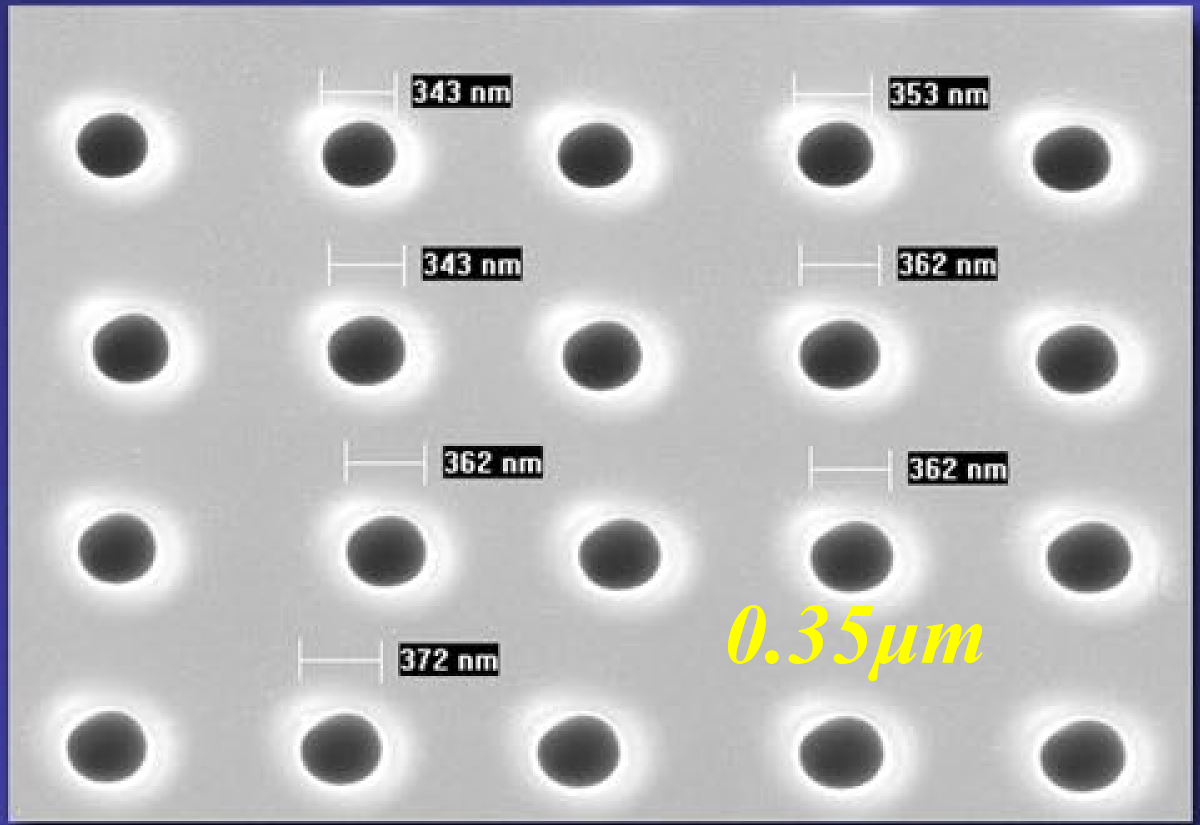


FC BARCELONA
Giant wakefield acceleration in gas
Tajima et Dawson (1979)
This changes the outlook for laser-particle acceleration TeV
Today
* CERN, Large Hadron Collider
* torus - 27 kms long
* 175 metres underground
Tomorrow
* visible laser induced wakefield
* about 100 metres long
* the size of a football pitch

Giant wakefield acceleration in gas and solid

Tajima et Dawson (1979)

A surfer riding down the face of a wave is accelerated by energy of the wave

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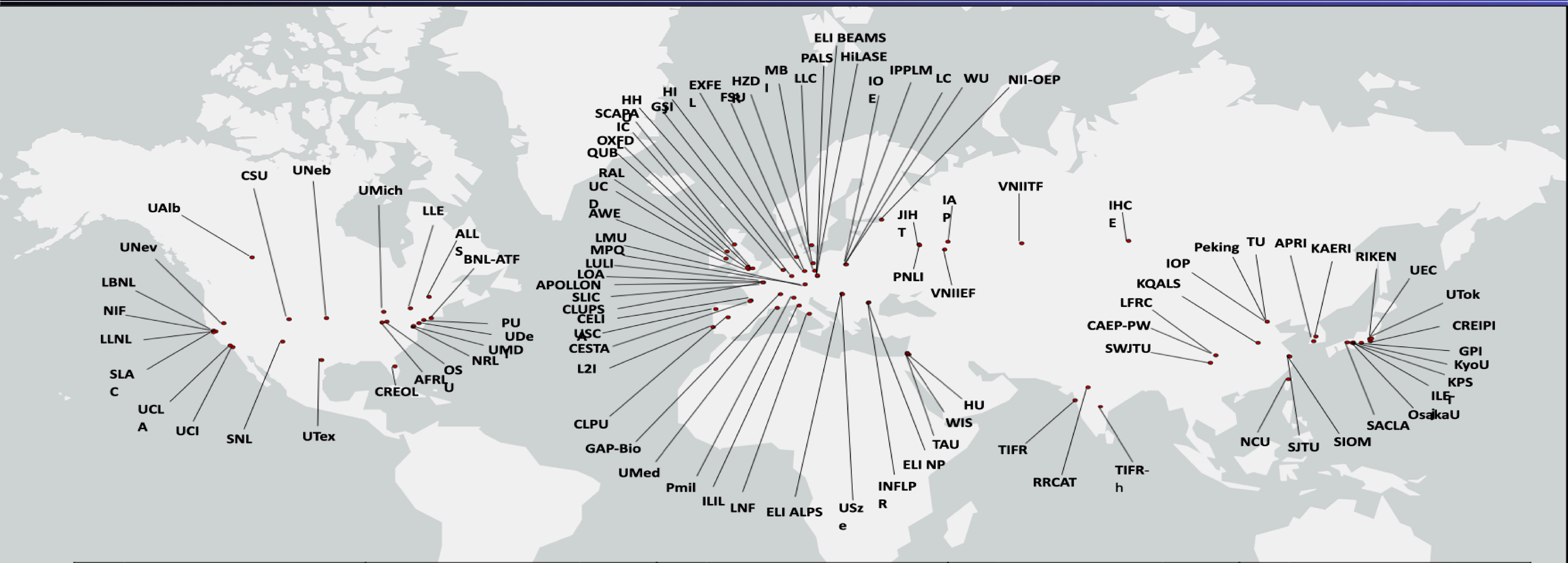


AFRL	Air Force Research Laboratory	Dayton
ALLS	Advanced Laser Light Source	Varennes
APOLLON	APOLLON at Université Paris Saclay	Saclay
APRI	Advanced Photon Research Institute	Gwangju
AWE	Atomic Weapons Establishment	Aldermaston
BNL-ATF	Brookhaven National Lab, ATF	Upton
CAEP-PW	Chinese Academy of Engineering Physics- PW Laser	Mianyang
CELIA	Centre Lasers Intenses et Applications	Bordeaux
CESTA	Centre d'Etudes Scientifiques et Techniques d'Aquitaine	Le Barp
CLPU	Centro de Laseres Pulsados	Salamanca
CLUPS	Laser Center of the University of Paris – Sud	Sud
CREIPI	Central Research Institute of Electric Power Industry	Yokosuka
CREOL	College of Optics & Photonics, UCF	Orlando
CSU	Colorado State University	Fort Collins
ELI ALPS	Extreme Light Infrastructure Attosecond Light Pulse Source	Szeged
ELI BEAMS	Extreme Light Infrastructure Czech Republic	Dolni Břežany
ELI NP	Extreme Light Infrastructure Nuclear Physics	Bucharest
EXFEL	European XFEL, High Energy Density Group	Schenefeld
FSU	IOQ/Friedrich Schiller University of Jena	Jena
GAP-Bio	Université de Genève, GAP-Biophotonics	Carouge
GPI	Graduate School for the Creation of New Photonics Ind.	Hamamatsu
GSI	GSI-Helmholtzzentrum fuer Schwerionenforschung GmbH	Darmstadt
HHU	Heinrich Heine Universität, Düsseldorf	Düsseldorf
HIJ	Helmholtz Institute Jena	Jena
HiLASE	HiLASE	Dolni Břežany
HU	Hebrew University, Arie Zigler Group	Jerusalem
HZDR	Helmholtz Zentrum Dresden- Rossendorf	Dresden
IAP	Institute of Applied Physics, Russian Academy of Sciences	Nizhny Novgorod
ICL	Imperial College London	London
IHCE	Institute of High Current Electronics	Tomsk
ILE-j	Institute for Laser Engineering, Osaka University	Osaka
ILIL	Intense Laser Radiation Laboratory	Pisa
INFLPR	National Institute for Laser, Plasma, and Radiation Phys.	Bucharest
IOE	Instytut Optoelektroniki, Wojskowa Akademia Tech.	Warsaw
IOP	Institute of Physics, Chinese Academy of Sciences	Beijing
IPPLM	Institute of Plasma Physics and Laser Microfusion	Warsaw
JIHT	Joint Institute for High Temperatures	Moscow
KAERI	Korean Atomic Energy Research Institute	Daejoen
KPSI	Kansai Photon Science Institute	Kizugawa
KQALS	Kaifeng Qiyuan Advanced Light Source Research Institute	Kaifeng
KyoU	Kyoto University, Institute for Chemical Research	Kyoto
L2I	Laboratory for Intense Lasers (L2I)	Lisbon
LBNL	Lawrence Berkeley National Laboratory	Berkeley
LC	Centrum Laserowe, Instytutu Chemii Fizycznej	Warsaw
LFRC	Laser Fusion Research Center at the CAEP	Mianyang
LLC	Lund Laser Center	Lund
LLE	Laboratory for Laser Energetics	Rochester
LLNL	Lawrence Livermore National Laboratory	Livermore
LMU	Ludwig Maximilians- Universität München, LEX Photonics	Munich
LNF	Laboratori Nazionali di Frascati, SPARC Lab	Frascati
LOA	Laboratoire d'Optique Appliquée-ENSTA-Ecole Polytech.	Palaiseau
LULI	Laboratoire pour l'Utilisation des Lasers Intenses	Palaiseau
MBI	MAX-BORN-INSTITUT für Nichtlineare Optik und...	Berlin
MPQ	Max Planck Institute for Quantum Optics	Garching
NCU	National Central University	Taoyuan City
NIF	National Ignition Facility at LLNL	Livermore
NII-OEP	Scientific Research Inst. for Optoelectronic Instrum. Engin.	Сосновый Бор
NRL	Naval Research Laboratory	Washington DC
OsakaU	Osaka University	Osaka
OSU	Ohio State University, Scarlet Laser Facility	Columbus
OXFD	University of Oxford	Oxford
PALS	Prague Asterix Laser System Research Centre	Prague
Peking	Peking University	Peking
Pmil	Politecnico Milano	Milan
PNLI	PN Lebedev Institute of Russian Academy of Science	Moscow
PU	Princeton University, Extreme Light-Matter Interactions Lab	Princeton
QUB	Queen's University Belfast, Centre for Plasma Physics	Belfast
RAL	STFC Rutherford Appleton Laboratory, Central Laser Facility	Didcot
RIKEN	RIKEN (from concatenation of Rikagaku Kenkyusho	Tokyo
RRCAT	Raja Ramanna Centre for Advanced Technology	Indore
SACLA	Spring-8 Angstrom Compact Free Electron Laser	Sayo
SCAPA	Scottish Centre for the Appl. of Plasma-based Accelerators	Glasgow
SIOM	Shanghai Institute of Optics and Fine Mechanics	Shanghai
SJTU	Shanghai Jiao Tong University	Shanghai
SLAC	Stanford Linear Accelerator Center	Stanford
SLIC	Saclay Laser-matter Interaction Center	Saclay
SNL	Sandia National Laboratory	Albuquerque
SWJTU	Southwest Jiaotong University	Emeishan
TAU	Tel Aviv Univ., Intense Lasers and Ultrafast Science Group	Tel Aviv
TIFR	Tata Institute of Fundamental Research	Mumbai
TIFR-h	Tata Institute of Fundamental Research New Campus	Hyderabad
TU	Tsinghua University	Beijing
Ualb	University of Alberta	Edmonton
UCD	University College Dublin	Dublin
UCI	University of California, Irvine	Irvine
UCLA	University of California, Los Angeles	Los Angeles
UDel	University of Deleware	Newark
UEC	University of Electro-Communications Inst. for Laser Science	Tokyo
UMD	University of Maryland	College Park
UMed	Université de la Méditerranée, Laboratoire LP3	Marseilles
UMich	University of Michigan, Center for Ultrafast Optical Science	Ann Arbor
UNeb	University of Nebraska- Lincoln, Extreme Light Laboratory	Lincoln
UNev	University of Nevada at Reno, Nevada Terawatt Facility	Reno
USC	University of Santiago de Compostela, L2A2	Santiago
USze	University of Szeged	Szeged
UTex	University of Texas at Austin	Austin
UTok	University of Tokyo, Institute for Solid State Physics	Tokyo
VNIIEF	RFNC- All-Russian Research Institute of Experimental Phys.	Sarov
VNIITF	RFNC- Russian Research Institute of Technical Physics	Снежинск
WIS	Weizman Institute of Science	Rehovot
WU	Warsaw University, Ultrafast Phenomena Lab	Warsaw

Global petawatt facilities

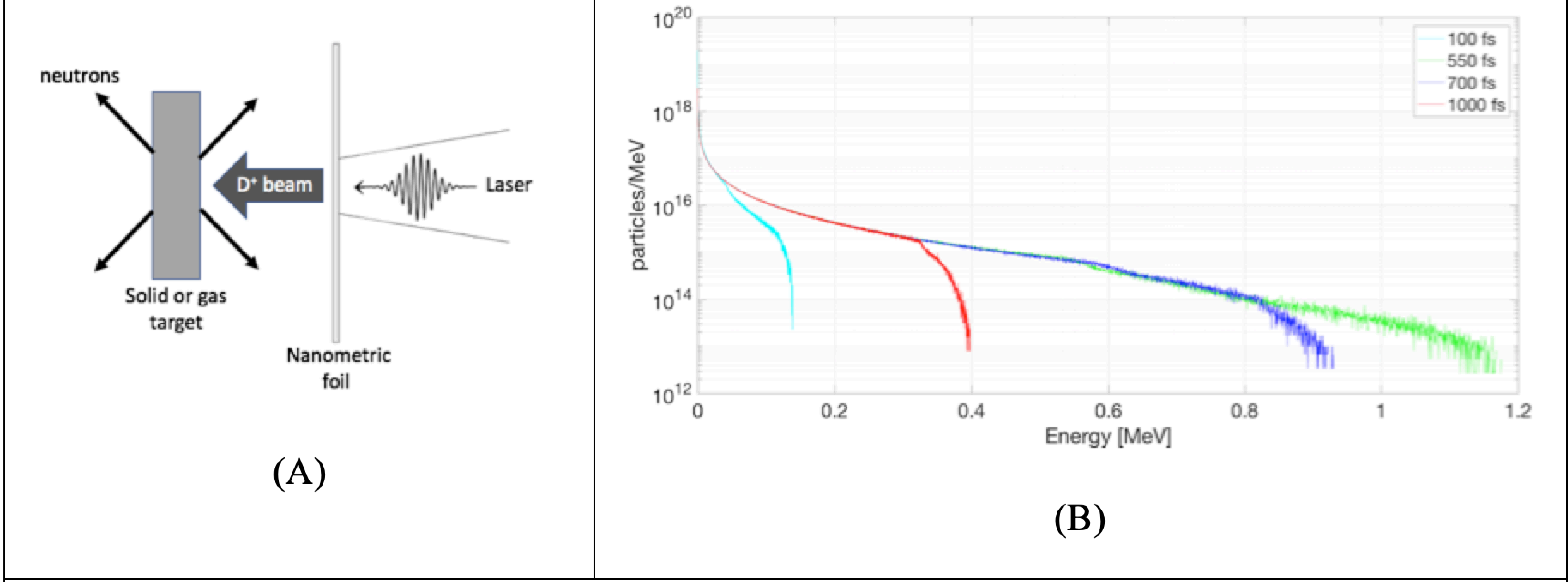
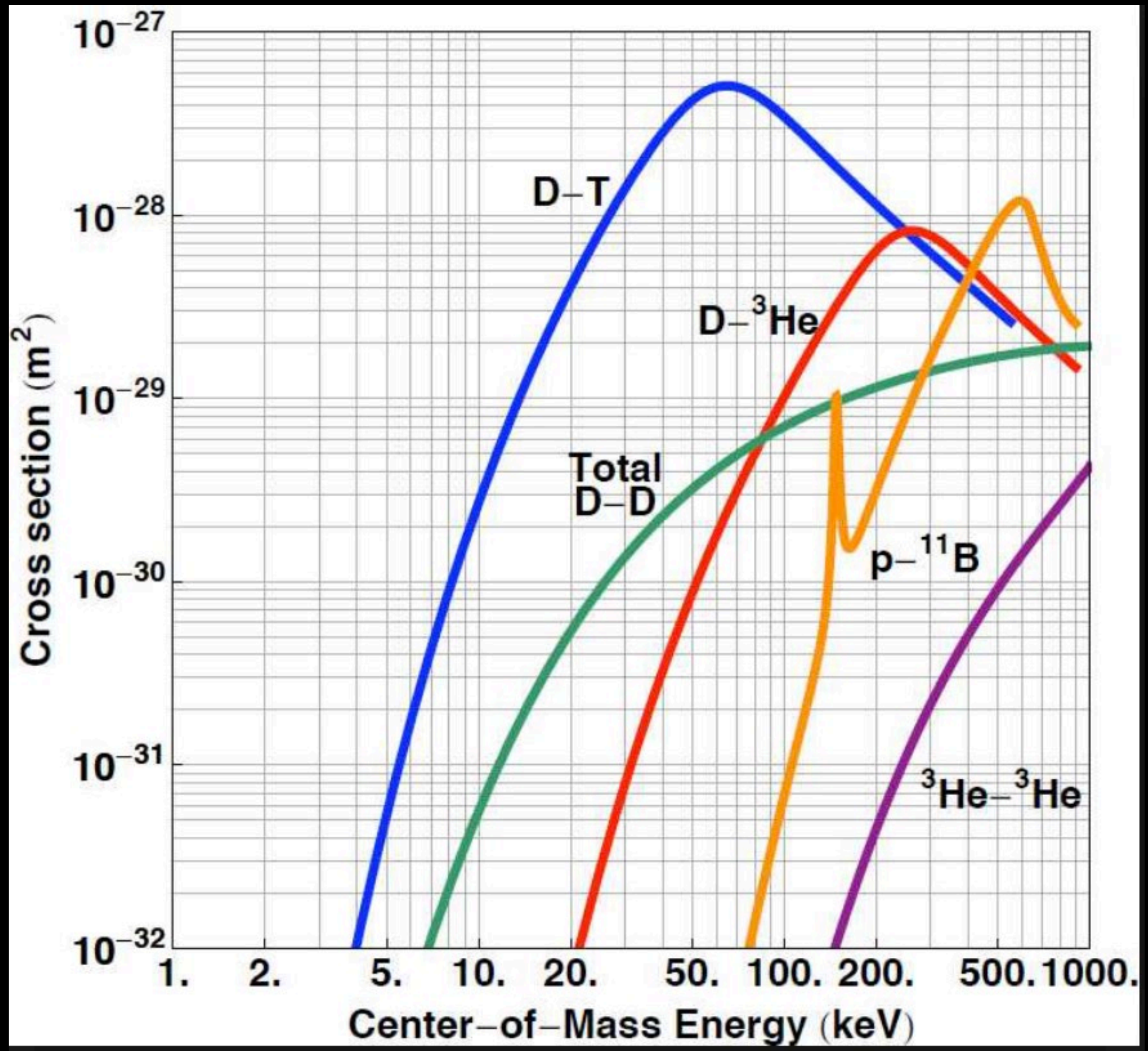
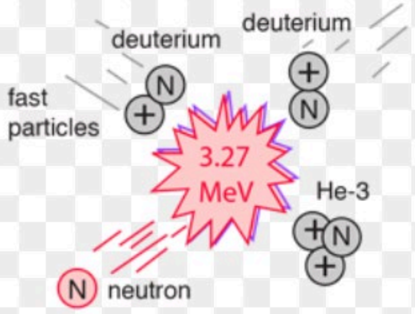


Figure 3: Neutrons are generated by the laser irradiation of a nanometric deuteron foil, deuteron acceleration and interaction with tritiated solid or gas target. (A) Schematic of neutron generation using laser. (B) D+ energy spectrum @ 100 fs, 550 fs, 700 fs and 1000 fs. The average deuteron energy at 550 fs is 100 keV corresponding to ~10% energy efficiency conversion from laser to deuteron.



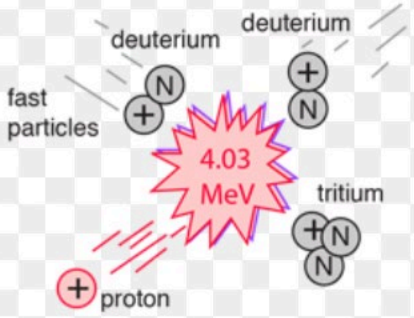
10^−27
10^−28
10^−29
10^−30
10^−31
10^−32
Cross section (m^2)
1. 2. 5. 10. 20. 50. 100. 200. 500. 1000.
Center−of−Mass Energy (keV)
D−T
D−^3He
Total
D−D
p−^11B
^3He−^3He

$$ {}_{1}^{2}H + {}_{1}^{2}H \rightarrow {}_{2}^{3}He + {}_{0}^{1}n + 3.27\,MeV $$



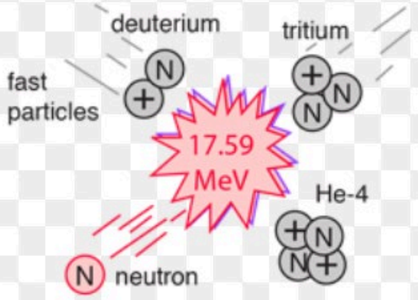
Deuterium-deuterium Fusion

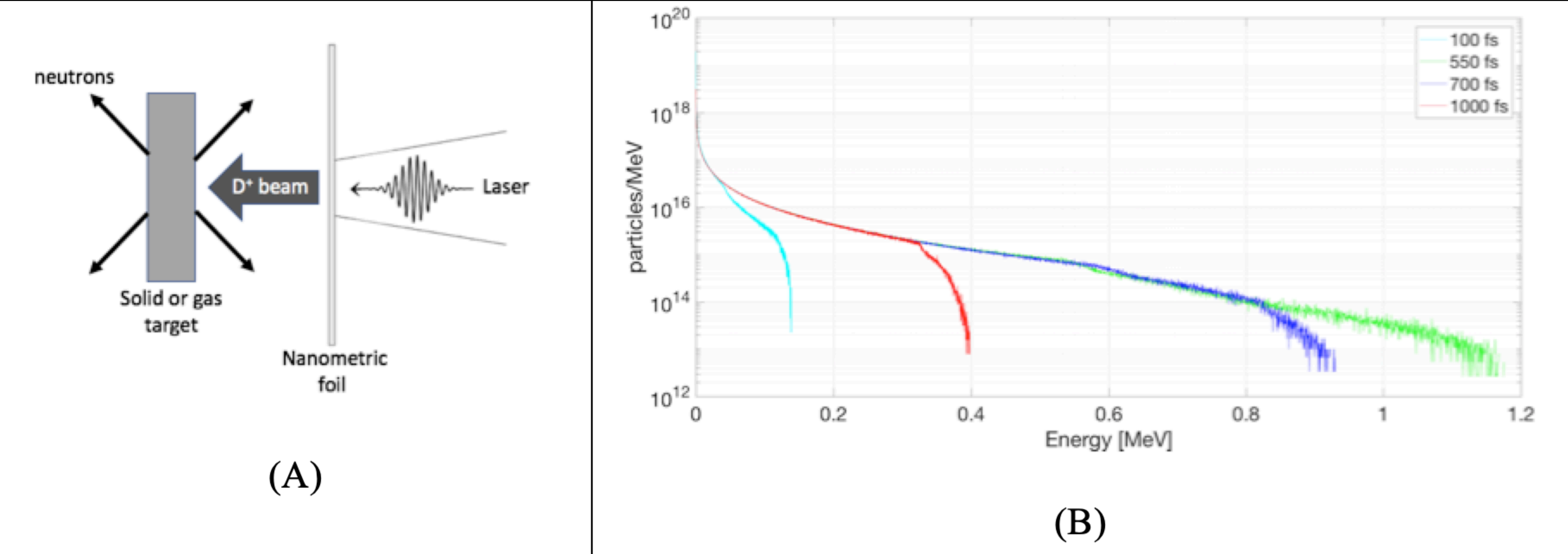
$$ {}_{1}^{2}H + {}_{1}^{2}H \rightarrow {}_{1}^{3}H + {}_{1}^{1}H + 4.03\,MeV $$



$$ {}_{1}^{2}H + {}_{1}^{3}H \rightarrow {}_{2}^{4}He + {}_{0}^{1}n + 17.59\,MeV $$

Deuterium-tritium Fusion





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