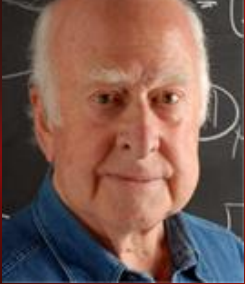




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Science Technology



# Extreme Light Modernistic Applications

## Extreme Light Application Park

*Gérard Mourou,*

*"The discovery of this particle is potentially the beginning of another road, which is to explore what lies beyond the Standard Model"*

- Peter Higgs



*"I realized there would be many applications for the laser, but it never occurred to me that we'd get such power from it!"*

- Charles Townes

*Bucharest July 6 2016*  
*IZEST Ecole Polytechnique*



International  
Year of Light  
2015

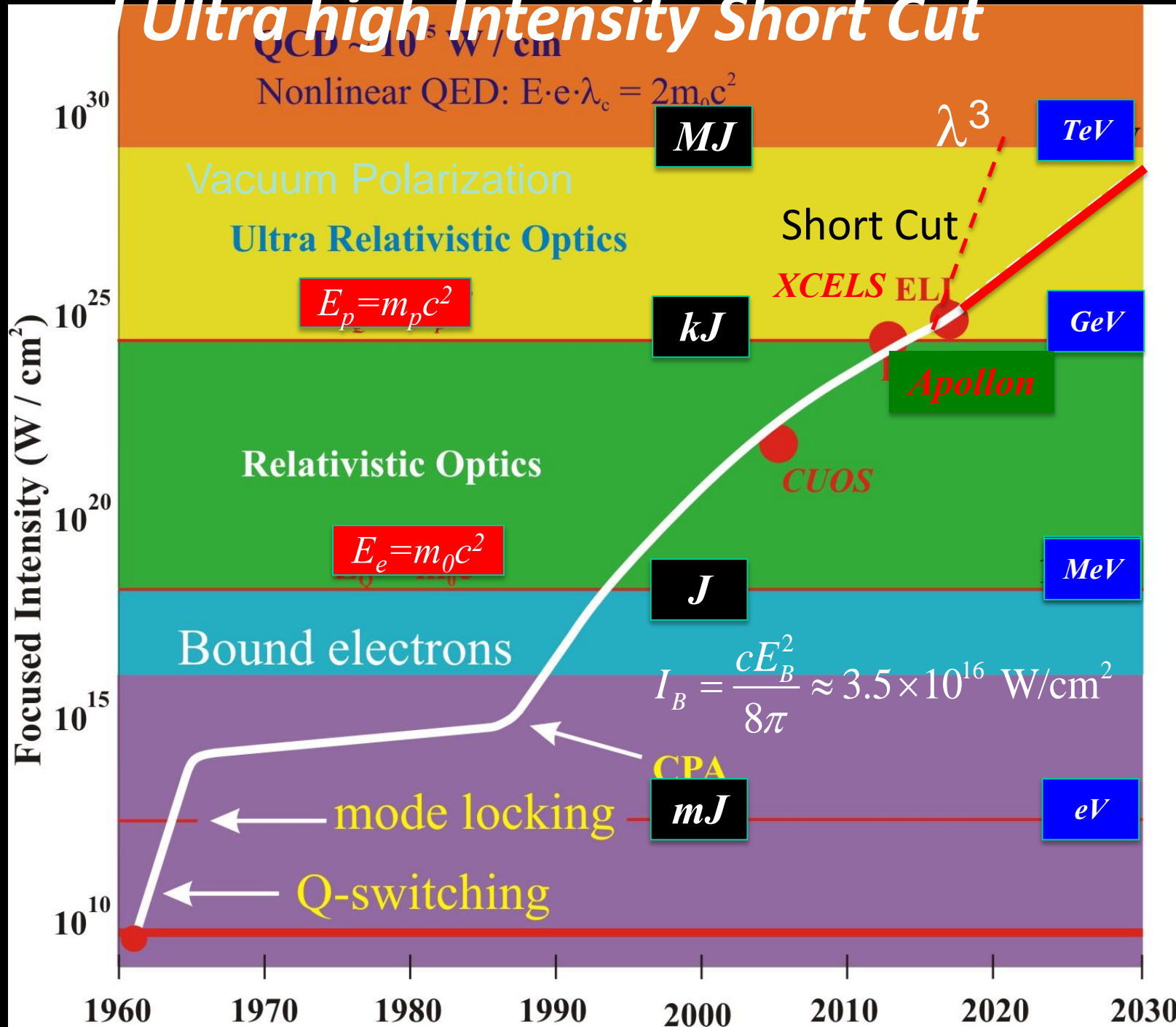
**Extreme Light Application Park (ELAP) will be associated to ELI-NP. ELAP.**

**It will aspire to incubate start-ups derived from the ELI-NP project.**



# Extreme Light Road Map

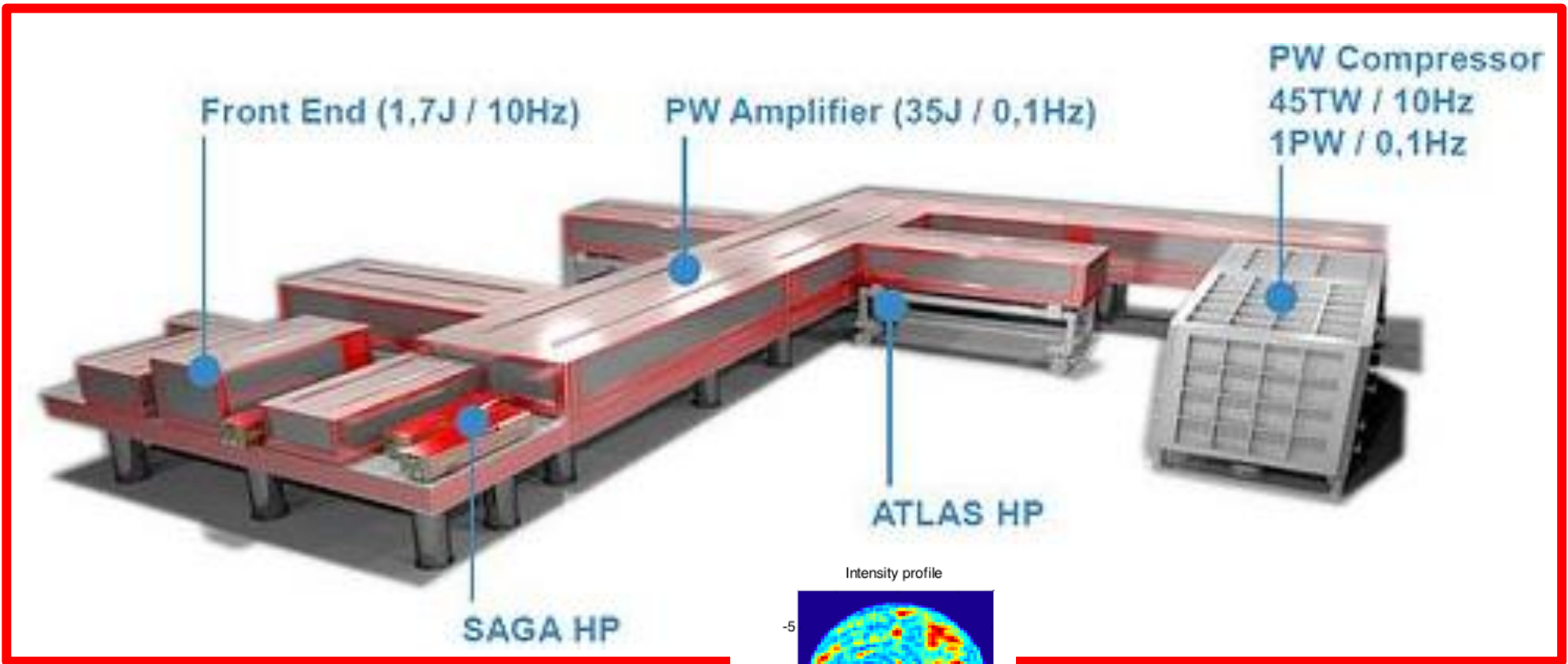
## Ultra high Intensity Short Cut



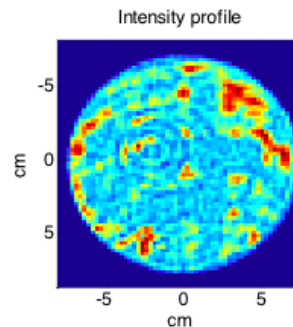
# *Extreme Light Application Park (ELAP)*

1. High Energy Single Cycle Pulse Compression  
in the Visible
2. High field Atto-Zeptosecond pulse  
Compression X-ray,  $\gamma$ -ray Regime
4. Giant Wake Field Acceleration TeV/cm
5. Relativistic Proton Generation
  - a. Proton Therapy
  - B. Nuclear Pharmacology
6. Solving the High Average Power Quandary

# *Petawatt Laser Provides A 10-1000J Uniform wave front in Phase and Amplitude*

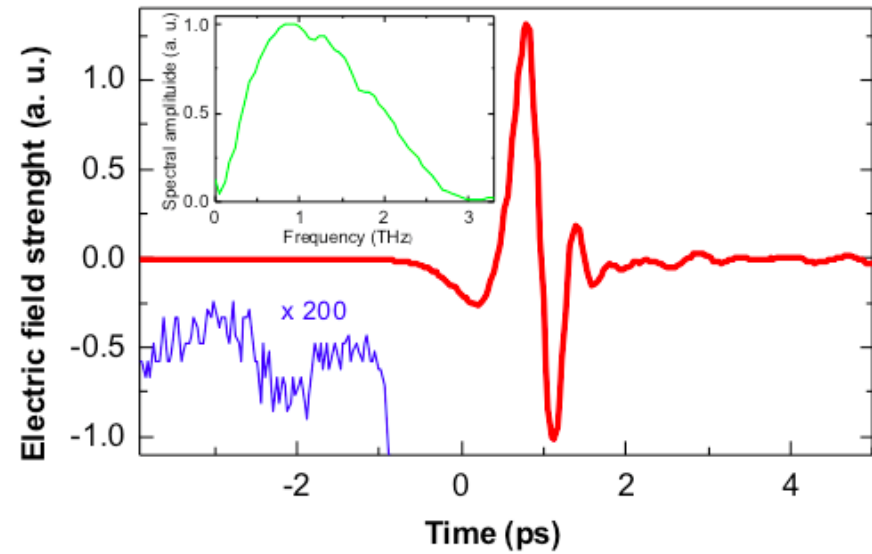
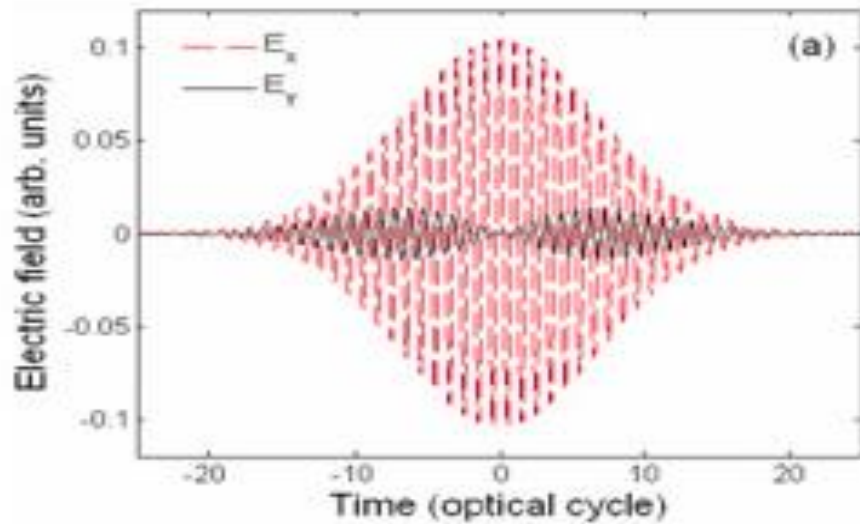


30/08/2016



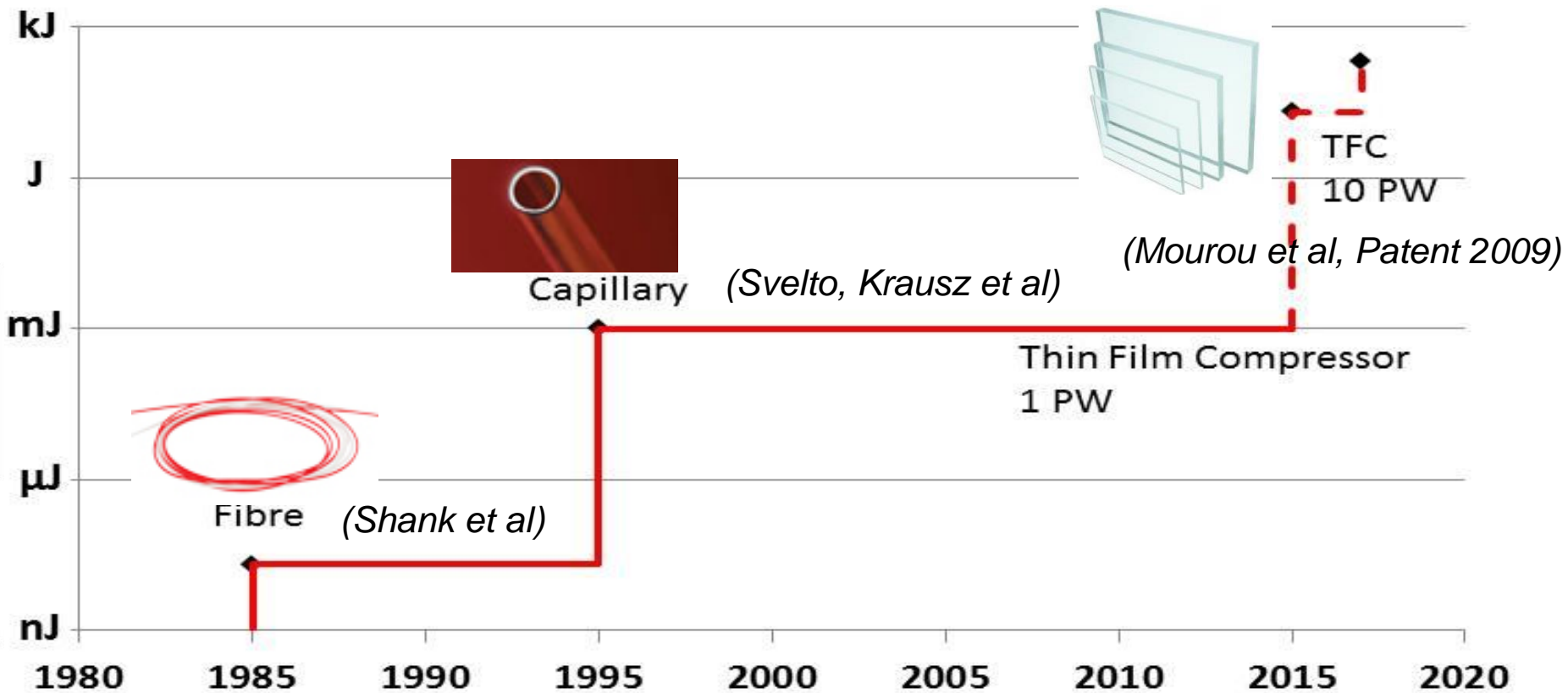
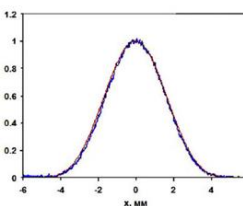
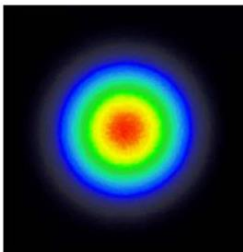
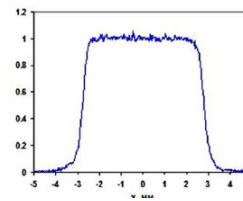
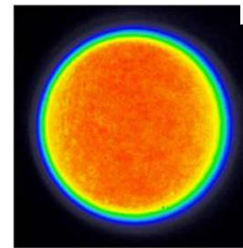
# Optical Pulse

## Single Cycle vs Multi-Cycle pulse



30/08/2016

# Pulse Compression and Single Cycle History





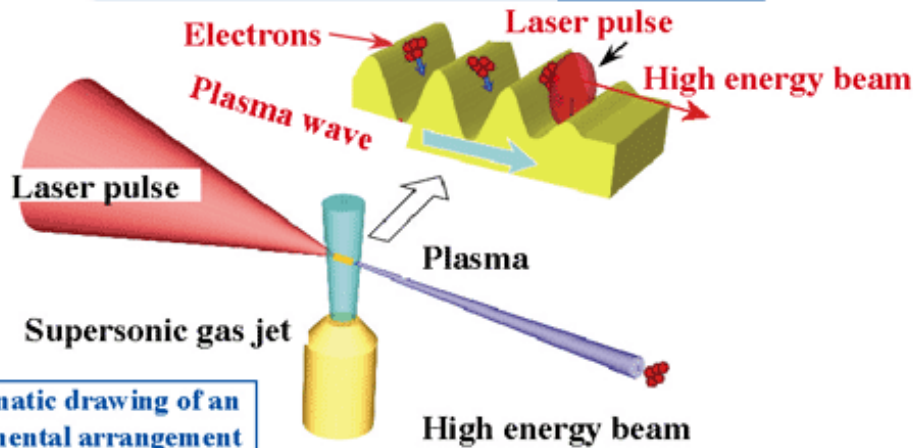
**Grab the Low-  
Hanging Fruit!**



# Giant Wake Field Acceleration in Solid

## Femtosecond Visible Light Driver in Gas *Tajima et Dawson 1979*

A schematic drawing of the principle of acceleration



Plasma Acceleration Energy Gain

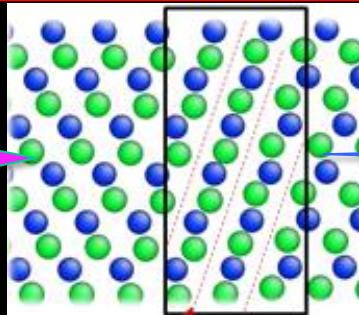
$$G \propto n^{1/2} \text{ eV/cm}$$

$$1 \text{ eV light } n_c \sim 10^{21} \text{ cm}^{-3}$$

$$n_{\text{gas}} = 10^{18} \text{ cm}^{-3}, G \sim 10^9, \text{ GeV/cm}$$

## Atto-zepto, X-ray Driver, Solid, *Tajima et Cavenago 1987*

$$n_{\text{solid}} = 10^{24} \text{ cm}^{-3}, G \sim 10^{12} \text{ eV/cm, TeV/cm}$$

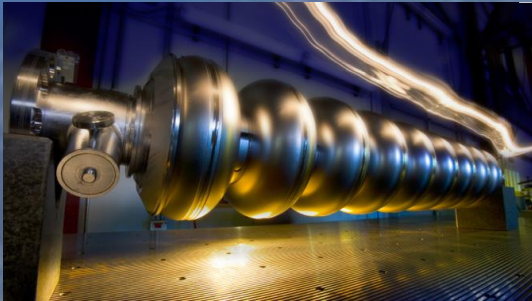


Channeling lower the emittance  
Valid for electron, muons, heavy ions

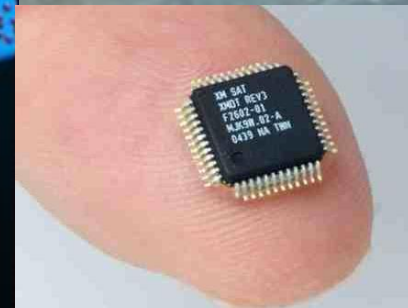
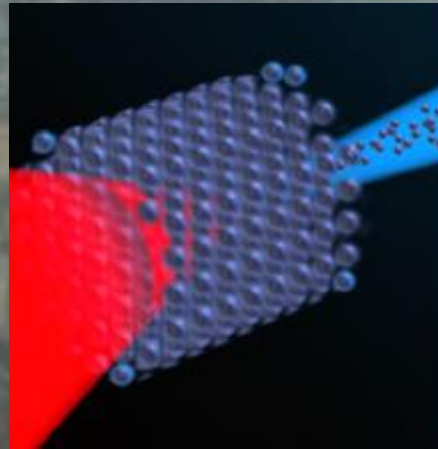
Drive pulse X-Ray,  
600zs + as electron  
pulse

# LHC CERN 27km, 15B€

Accelerating Cavities MeV /cm

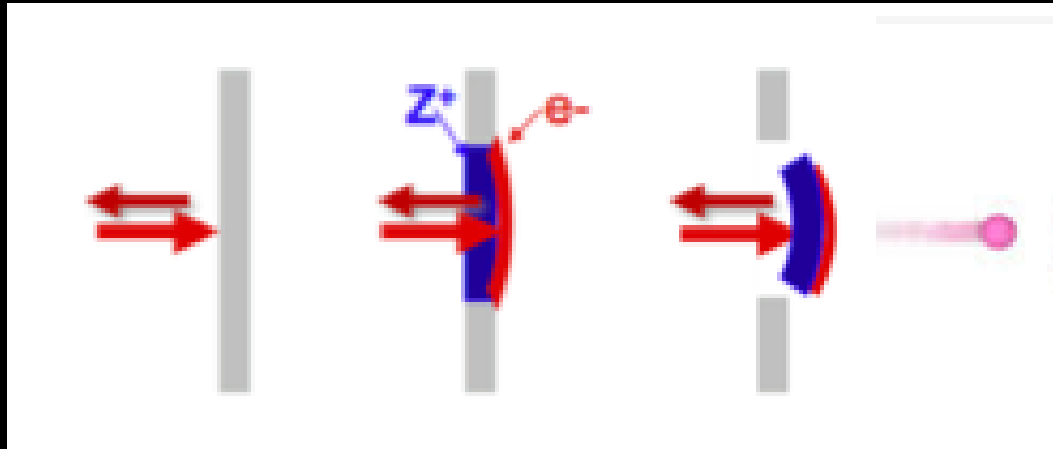


LWA – X-ray  $10^{18}$  Hz, TeV/cm



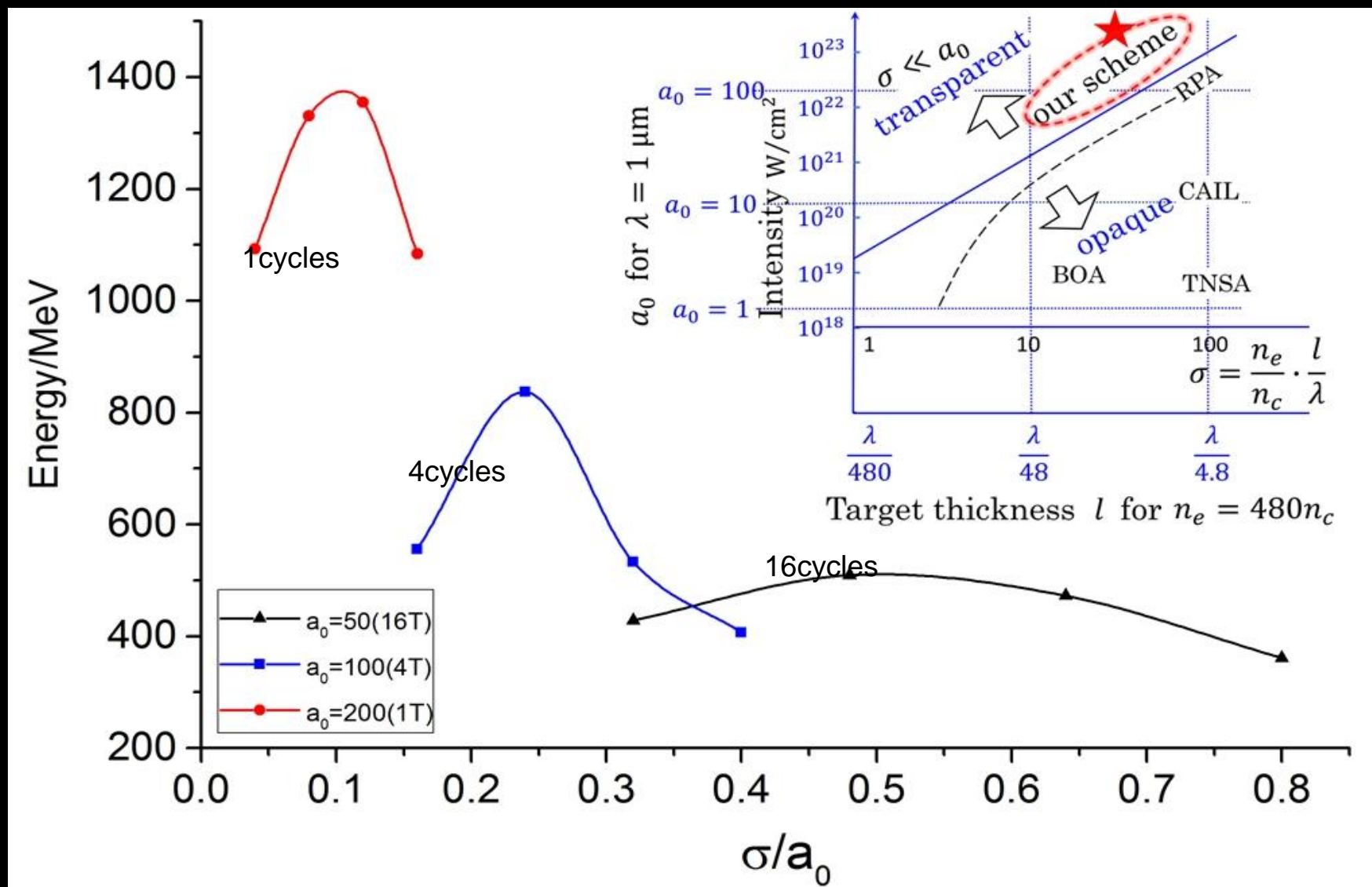
Honoris Causa  
Bucharest 2014

# High Energy Proton Applications



# Applications of Single Cycle to Proton Generation vs $a_0$

M.L. Zhou, X.Q. Yan, G. Mourou, J.A. Wheeler, and T. Tajima, 2016



# ELI-NP Societal

## *Societal Applications*

*Transmutation of Nuclear Waste*

*Under-Critical Reactor*

*Nuclear Pharmacology*

*Proton Therapy*

*Orbital Debris Elimination by Deorbitation*

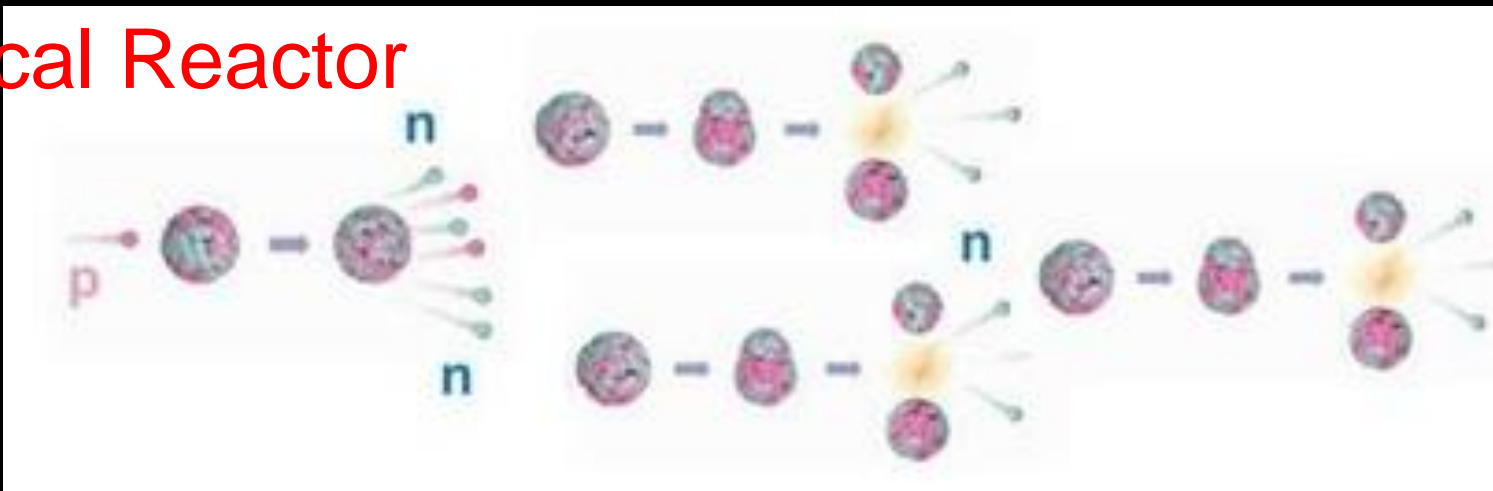
# High Energy Proton Applications

GeV Proton Generation

Neutron source



Subcritical Reactor

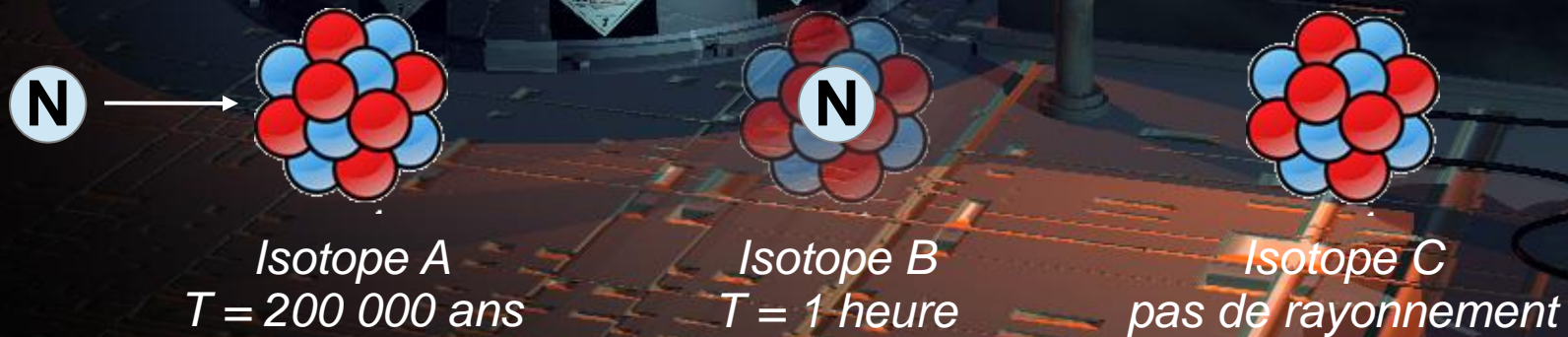


Mourou Korea 2014

# Transmutation Concept

## Example

$^{99}\text{Tc}$  (Technetium) half-life of 200 000 years  
 $^{100}\text{Tc}$  half-life 16s decays to a stable  $^{100}\text{Ru}$  (Ruthenium)

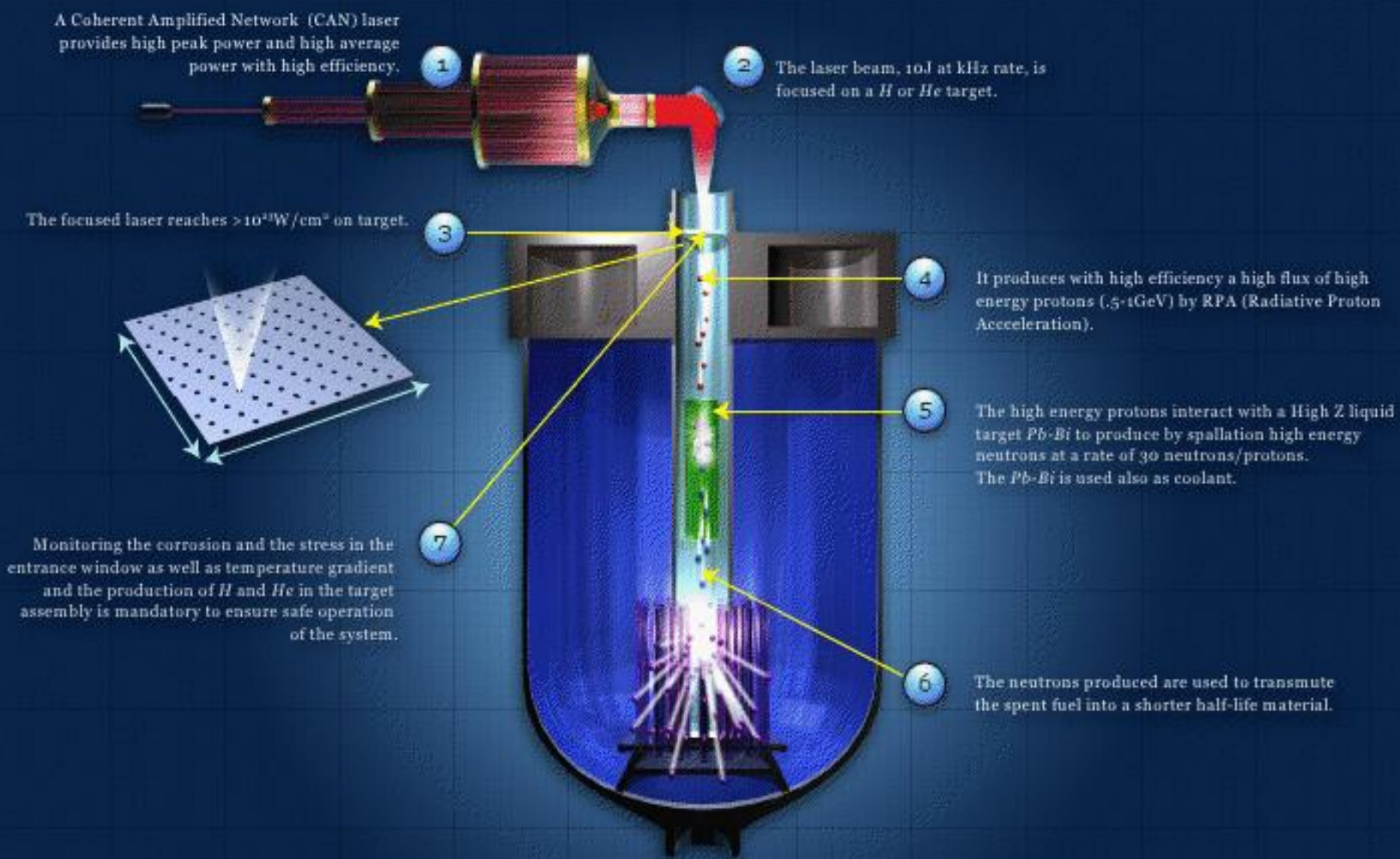


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International  
Year of Light  
2015

# THE LASER DRIVEN TRANSMUTATOR CONCEPT





# Solving the Laser Peak and Average Power Quandary

High Peak Power PW

High Repetition Rate 10kHz

Efficiency 30%

***We need to Power a TGV (10MW)  
TeV, 4nC, 13kHz***



G. Mourou

# Single mode fiber can handle >10kW average Power

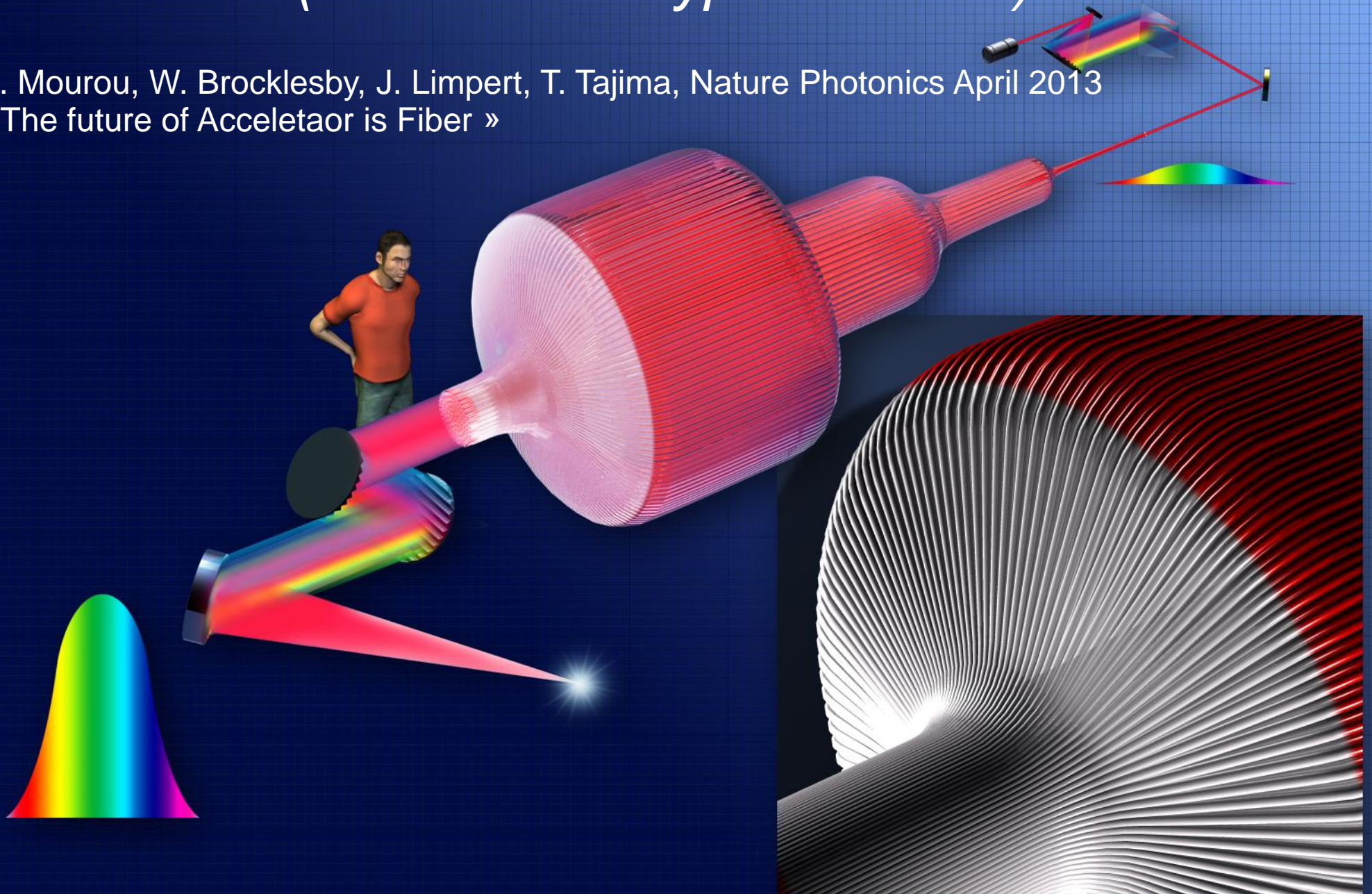
Coherent Amplifying Network

G. A. Mourou, D. Hulin and A. Galvanauskas,  
“The road to High Peak Power and High Average  
Power Laser: Coherent Amplification Network (CAN),  
AIP Conference Proceedings, Third International  
Conference on Superstrong Fields in Plasmas, vol. 827,  
Dimitri Batani and Maurizio Lontano, 152-163 (2006).

Study group sponsors by EC called ICAN to evaluate the  
concept mainly to try to decrease the number of fibers.

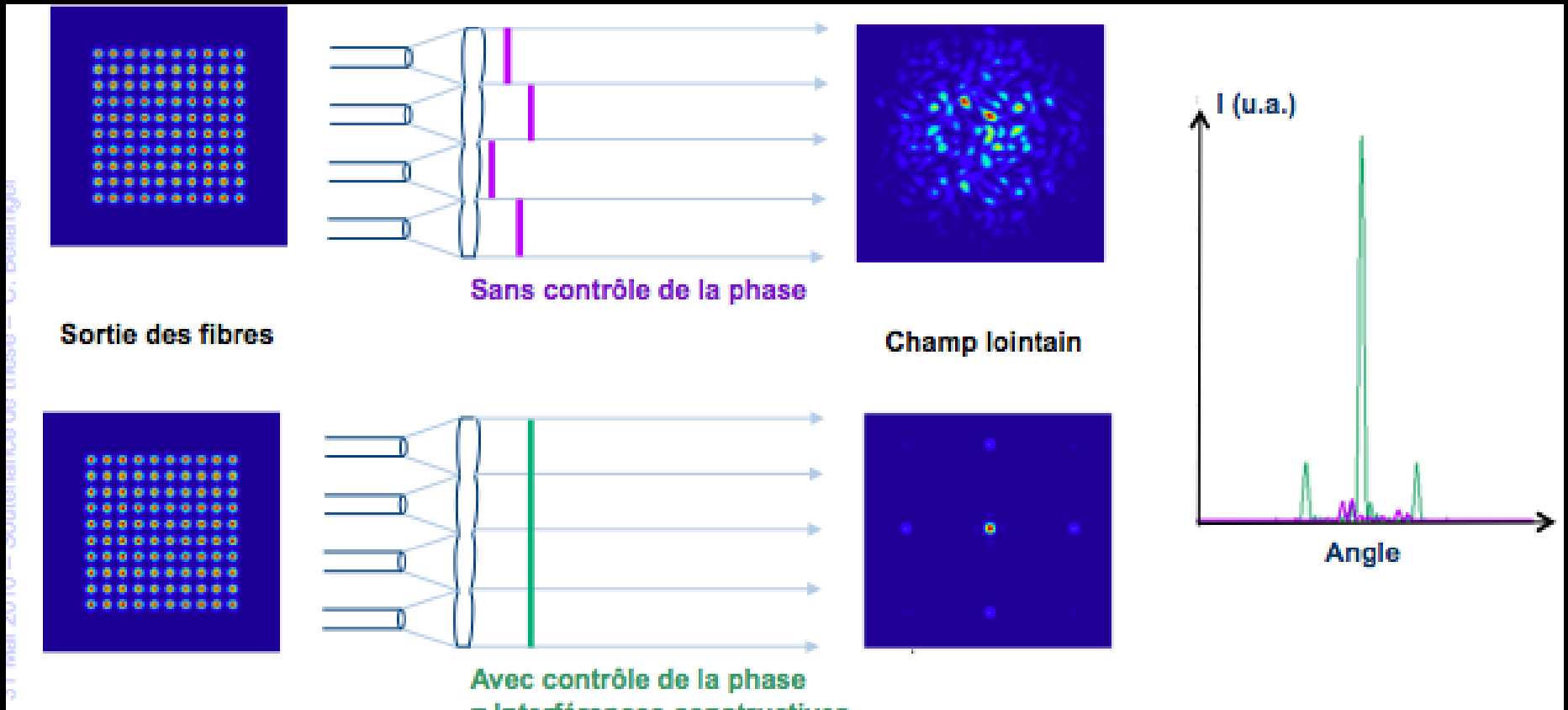
# *CAN Coherent Amplification Network (X-CAN Prototype 61 fibers)*

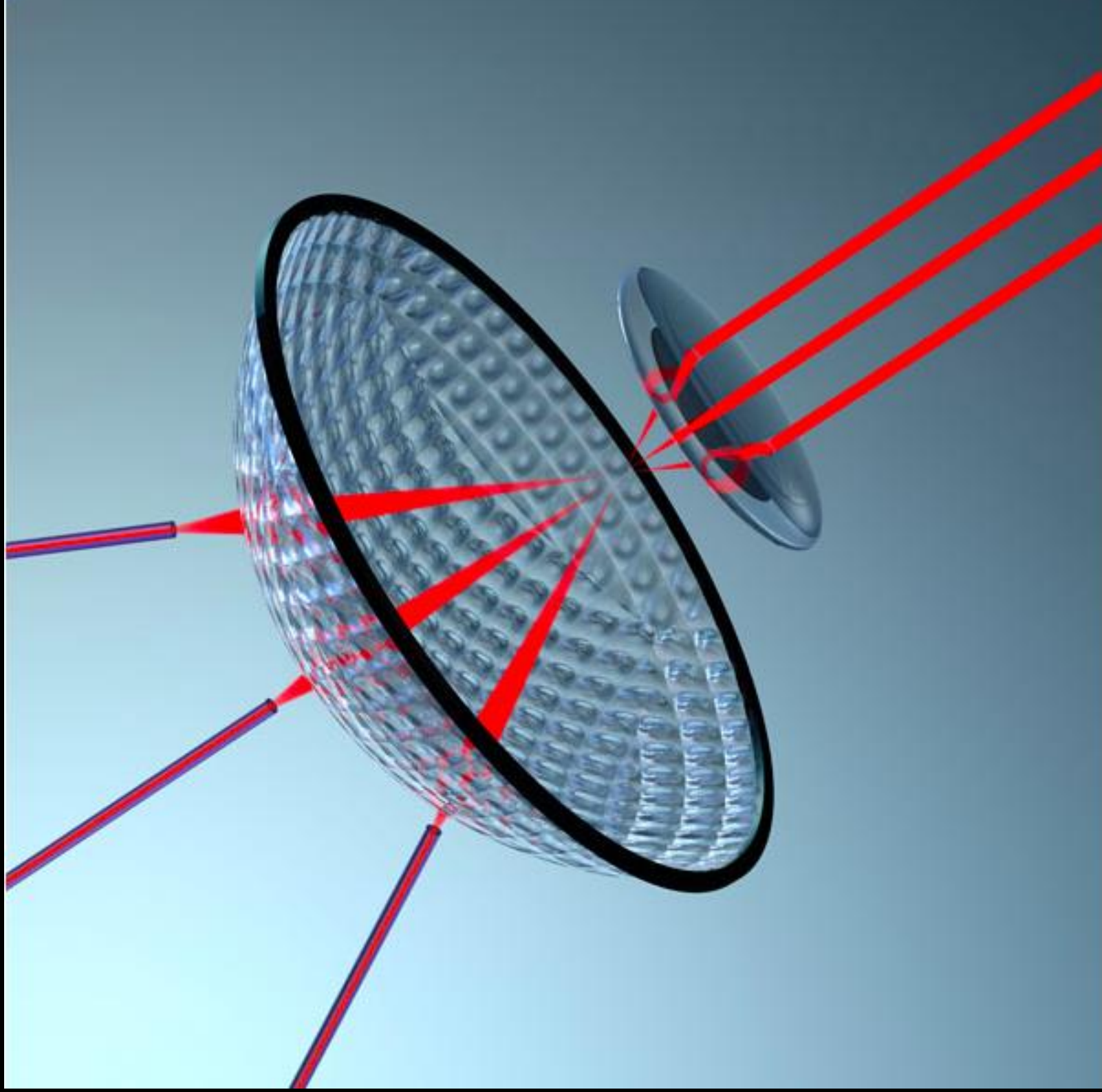
G. Mourou, W. Brocklesby, J. Limpert, T. Tajima, Nature Photonics April 2013  
« The future of Accelerator is Fiber »

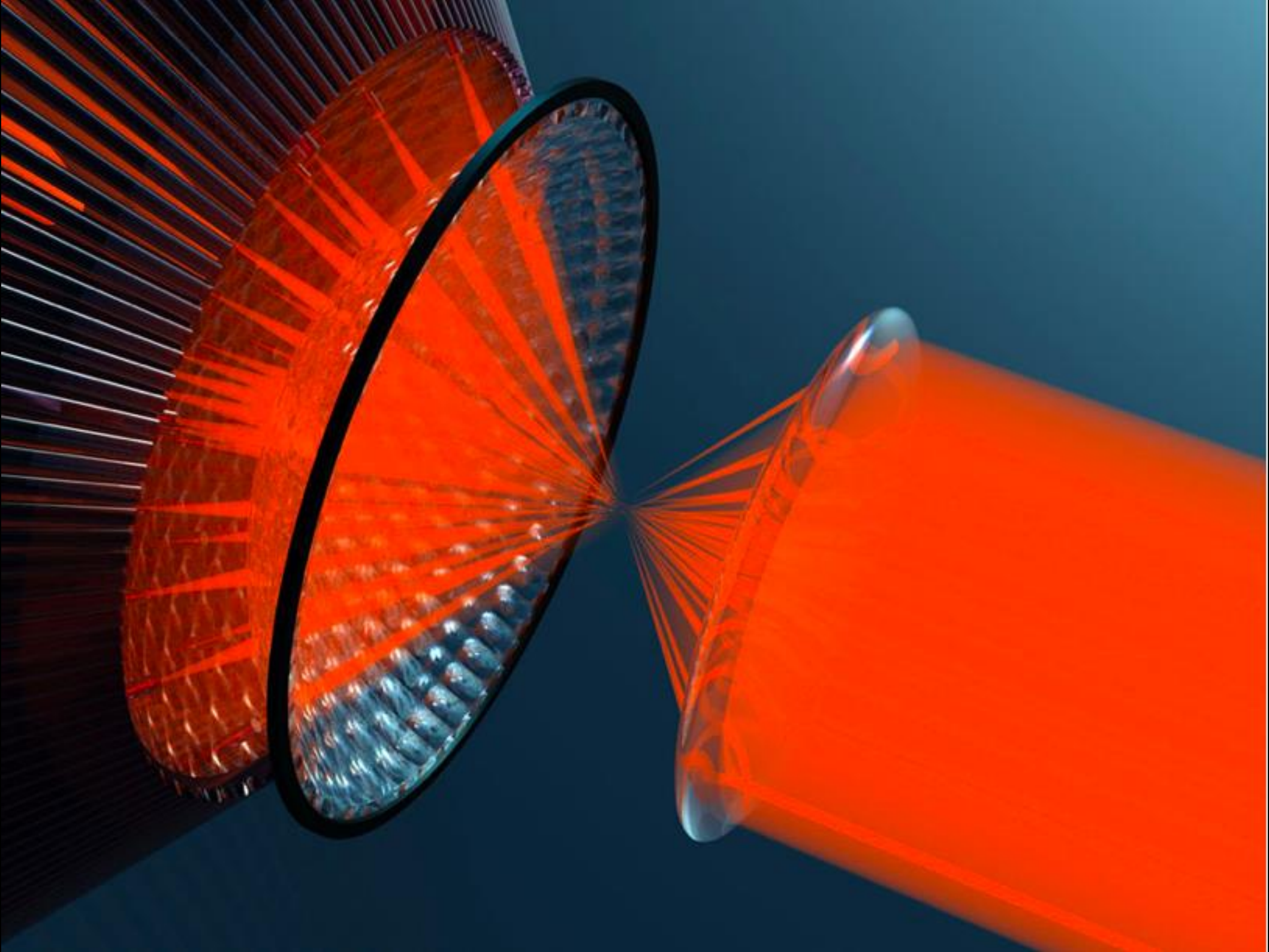


# 64 CW fibers have been phased

(This experiment in fact validates an extension possible to  $>10^4$  phased fibers at 1kHz)



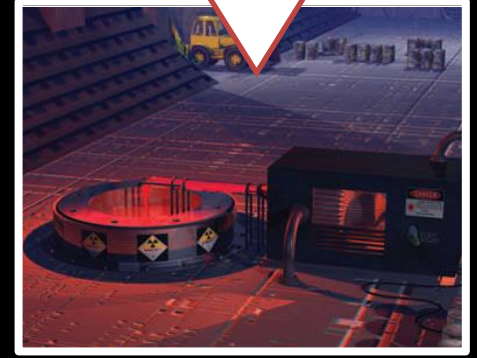
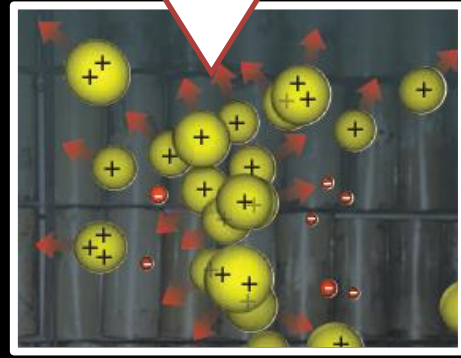
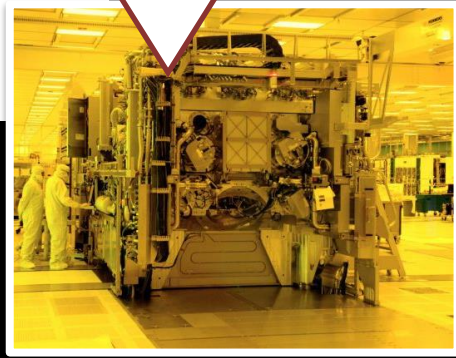
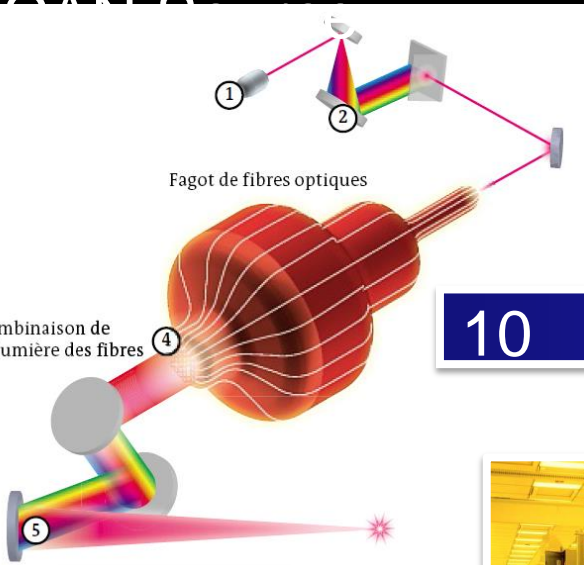
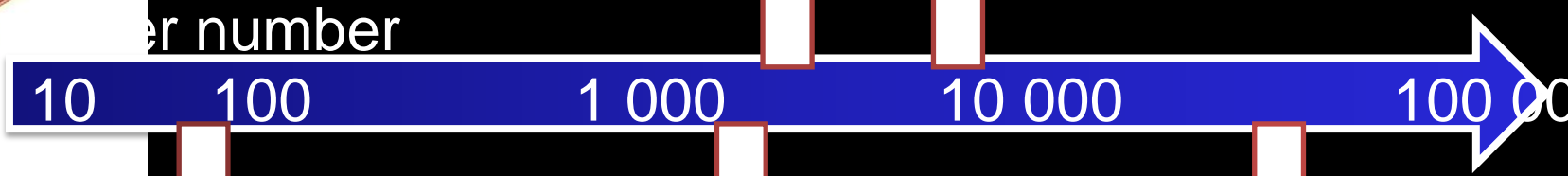
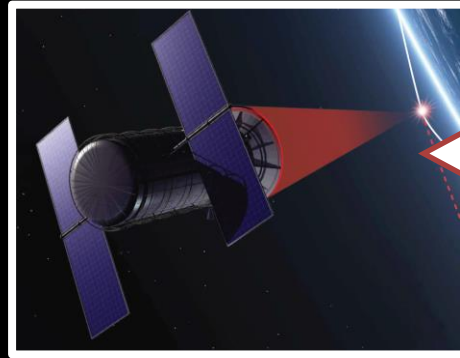




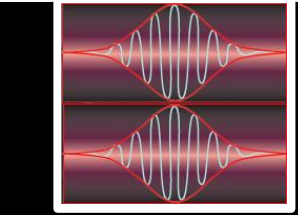
# Orbital debris removal

# Particles

## Acceleration



XUV Photolithography    Chemical agent Neutralization    Nuclear waste transmutation







 Au-delà d'  
can  
Coherent Amplification Network  
POLYTECHNIQUE / THALES

Beyond the laser itself

# From Prototype to Large Scale Applications

X CAN is an Ecole Polytechnique - Thales consortium to demonstrate that the CAN concept is capable to provide:

High Peak Power 100TW

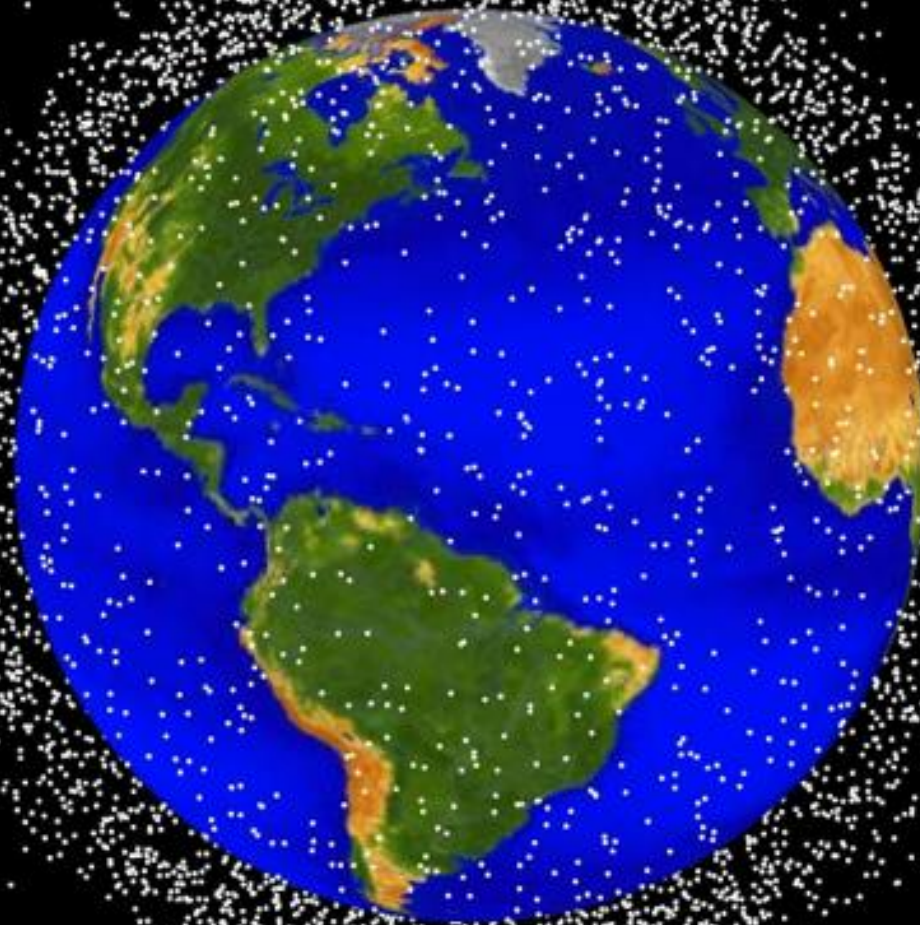
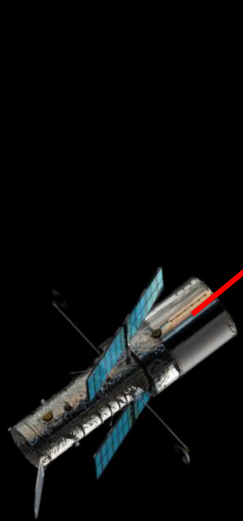
High Average power in the 100kW

High Efficiency >30%

A budget of 3M€ has been allocated to build a 61 high energy fiber prototype that will validate the construction a  $10^4$  fiber unit for grand scale applications.

# ***ICAN Space Debris***

*Millions of orbital debris are cluttering space*



Thank you



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International Zeta-Exawatt  
Science Technology

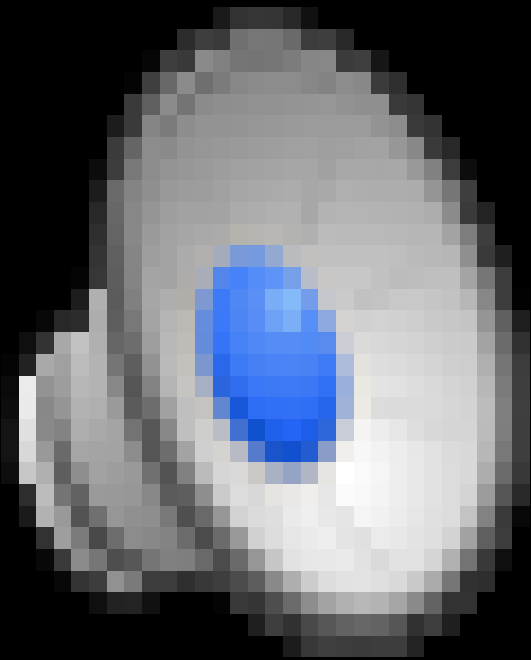


International  
Year of Light  
2015

Conclusion

F. Sinatra

'The Best is yet to come'.



Mourou Korea 2014

# Aknowledgements

**J. Wheeler, G. Cojocaru, R. Ungureanu, R. Gonin, G. Mourou, S. Mironov, E. Khazanov and A. Sergeev, IAP Nizhny Novgorod Russia**

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Sokolov U. of Michigan

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Lech Wiktor Piotrowski a,

YoshiyukiTakizawa a,

MarcoCasolino a,c,

Mario E.Bertaina c,d,

PhilippeGorodetzky e, EtienneParizot e,

Rémi Soulard,



# Ackowlegments

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J. Wheeler IZEST

N. Naumova LOA ENSTA

I. Sokolov U. of Michigan

T. Tajima Univerity of California Irvine

P. Chen Le COSPA Taiwan

S. Mironov, E. Khazanov and A. Sergeev, IAP Nizhny Novgorod Russia



# **CAN Basic Brick**

## ***The Yb-doped Fiber (continued)***

*Yb: fiber transforms efficiently (70%) of low quality inexpensive (\$10/W) light from a diode laser into a high quality single mode light with outstanding beam quality.*

*Fiber provides the highest beam quality with the highest laser efficiency.*

*The fiber can be precisely reproduced and pumped with 0.1% pump power precision/fluctuation*

*Single fiber can produce up to 2mJ, 200fs pulse with an average power ~ 800W, 40kHz (Jena Group)*

*A Phased-Fiber-Array emitting 50J, 50fs will be composed of  $2 \cdot 10^4$  fibers.*

***Is it conceivable?***

Serendipity again!  
Bridging Extreme Light  
and Space Applications

Thin Plastic/Glass Optical Elements Can Have Good Optical Quality And Nonlinear Properties.

Unlimited size and very low cost



- . *Polyethylene terephthalate 0.7mm,  $1.5 \text{ TW/cm}^2$ ,  $B=3-4$*
- . Very large aspect ratio, surface over thickness, Unlimited aperture inexpensive.
- . Uniformity within a fraction of  $\lambda$ .



# ***Phase Noise Measurement with a Quadrilateral Shear Interferometer*** ***( $10^4$ fibers with $\lambda/60$ precision at kHz)***

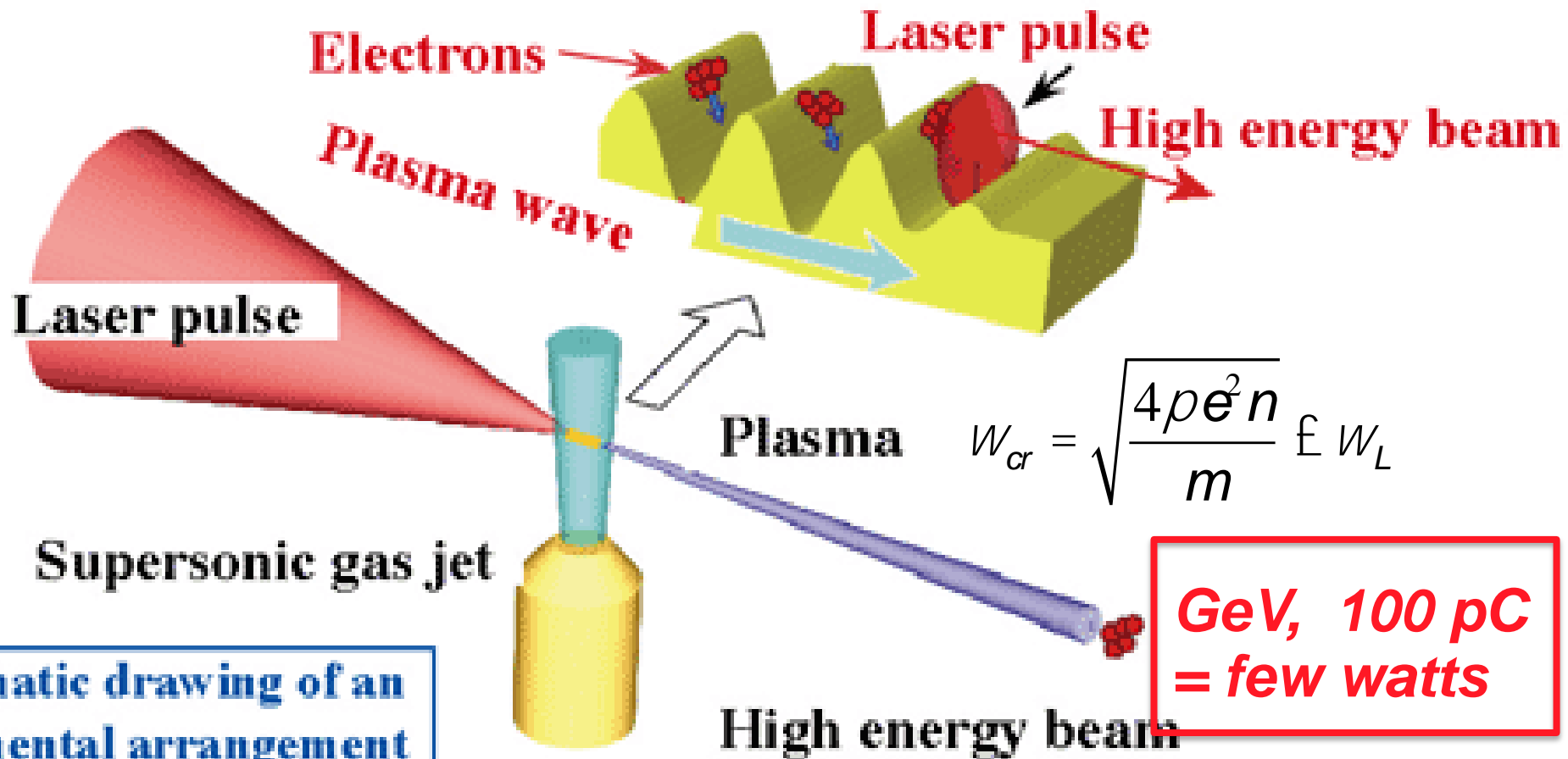
***For  $10^4$  fibers , 6 pixels per fiber for a resolution of  $\lambda/60$  @ 1kHz, off-the-shelf camera with  $10^6$  /1kHz are available.***

***Algorithm to control the phase distribution of fibers***  
***40Gops Possible with a GPU.***

# Laser Wake Field Acceleration GeV/cm

Tajima and Dawson 1979

A schematic drawing of the principle of acceleration



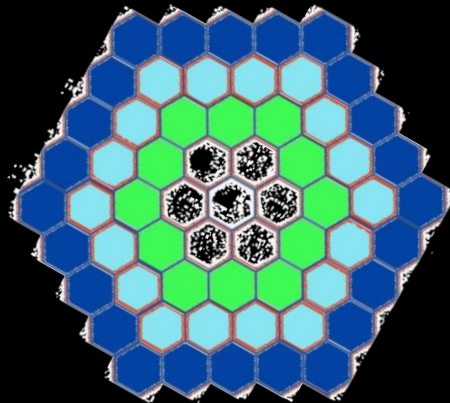
A schematic drawing of an experimental arrangement

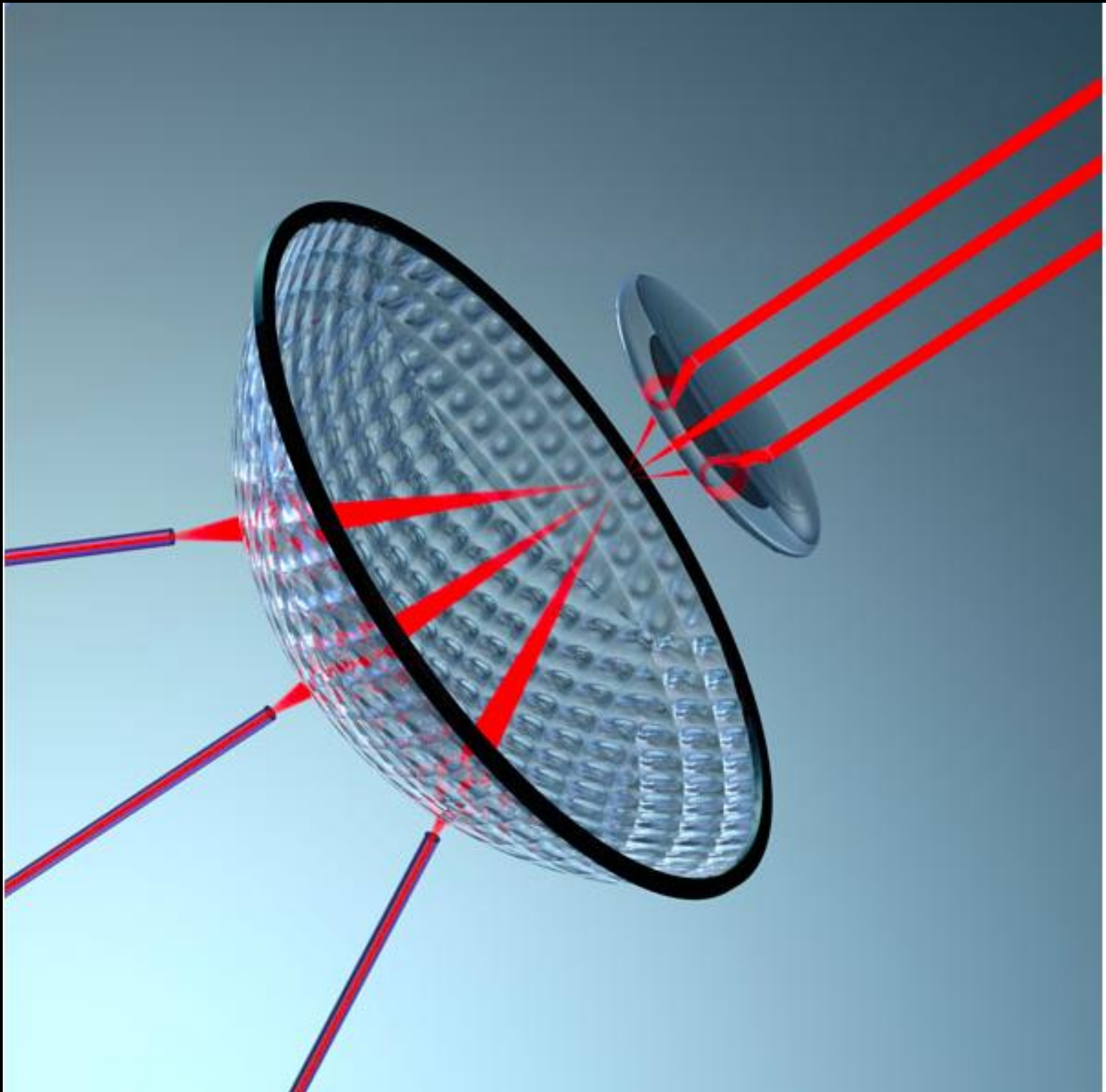
*61 channels*

*350 fs*

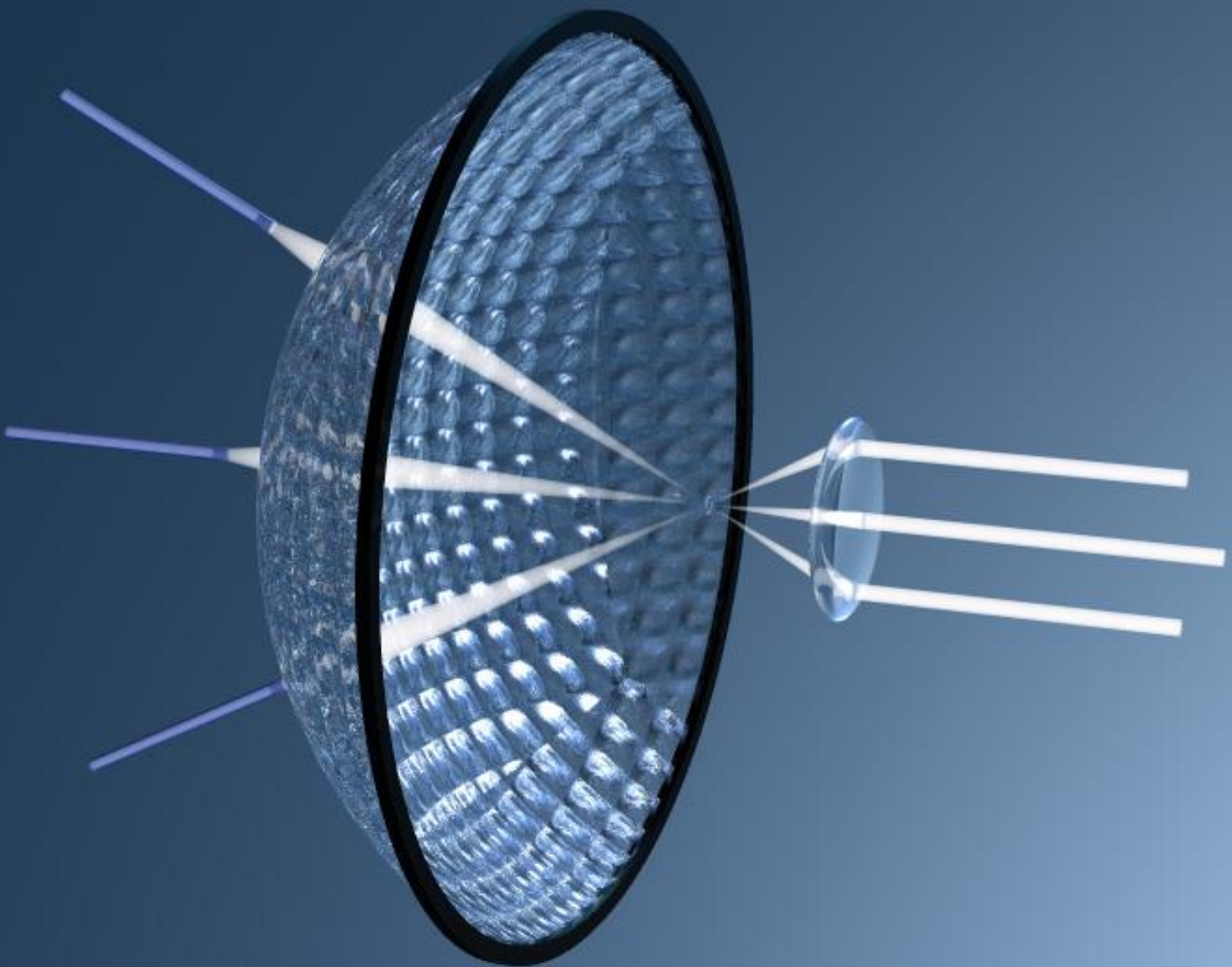
*>10 mJ*

*50 kHz*









# X-ray-Driven Crystal Accelerator

Increase of  $10^6$  in density

$10^3$  in Energy gain

