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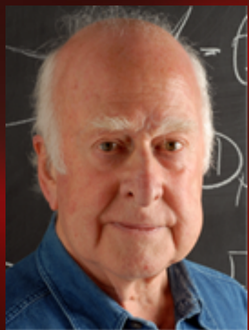
International Zeta-Exawatt Science Technology

Extreme Light: Bridging Optics and Fundamental High Energy Physics, first steps
Towards Zeptosecond and Zettawatt Science



"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

Gérard Mourou

IZEST Ecole Polyetechnique

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Charles Townes 1915-2015

To live a century,

Inventing the laser,

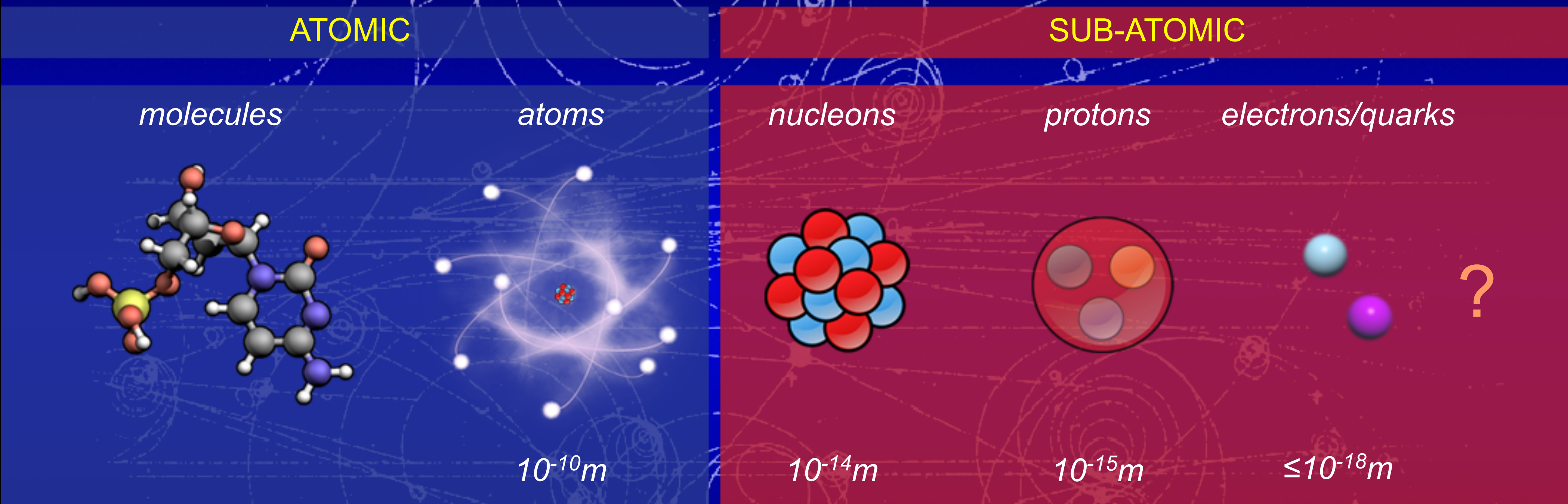
Receiving the Nobel Prize,

Without working a single day.

Contents

- Extreme Light: Overview and Rationales:
  - ✓ Peak Power, Light Pressure, ….
  - ✓ From Atomic to subatomic (nuclear and Particle Physics)
- Route to Zeptosecond-Zettawatt (Z^2) Generation:
  - ✓ Single cycle Generation,
  - ✓ λ^3 Regime, Relativistic Compression
- Applications: Scientific and Societal
  - ✓ Vacuum Physics: Vacuum Polarization, Light Materialization
  - ✓ Societal Application: Transmutation of Nuclear waste

Laser Exploration : from Atomic to Sub-atomic



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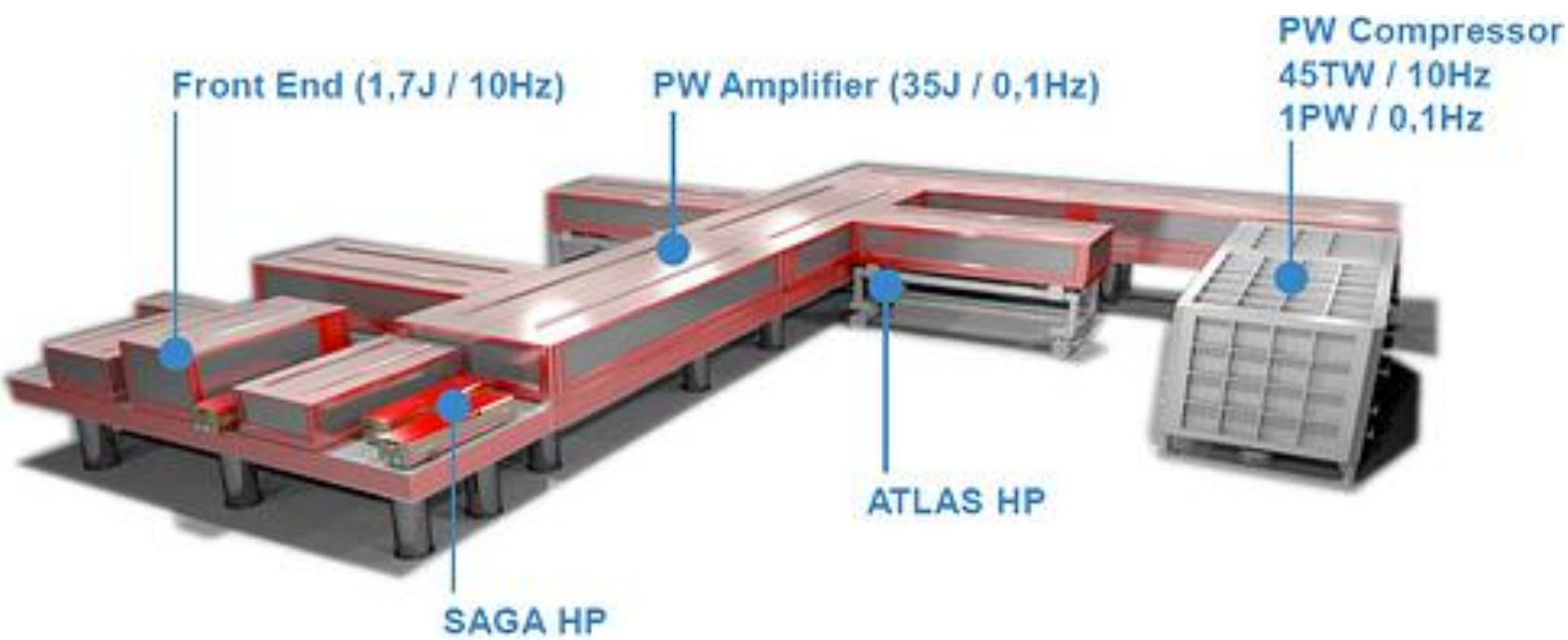
Extreme Light is Produced by Petawatt Laser

1 PW laser = 10^6 Nuclear Power Plants



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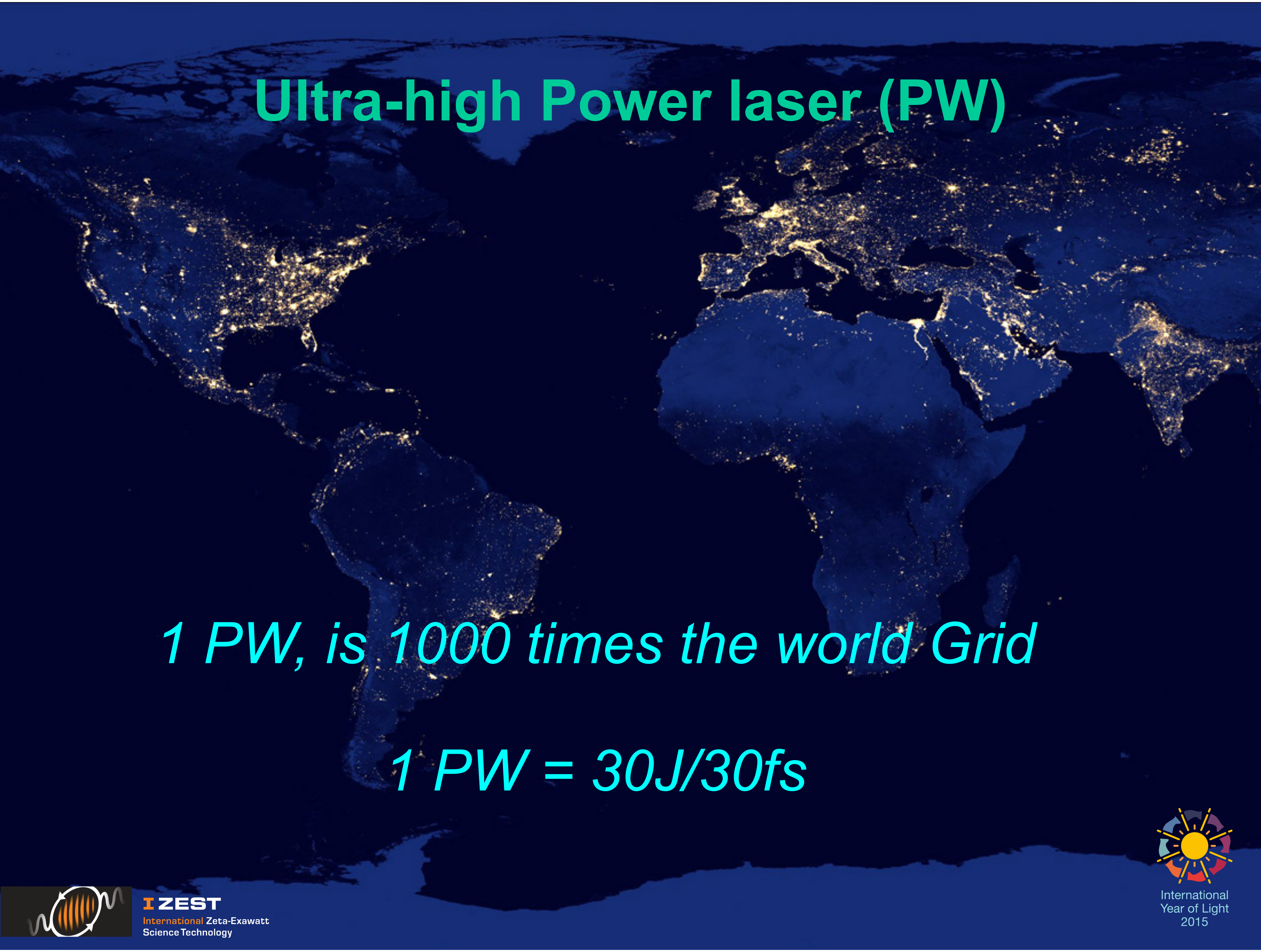
Ultra-high Power laser (PW)



1 PW, is 1000 times the world Grid

1 PW = 30J/30fs

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The Light Pressure= I/c

I = 10²³ w/cm²

10 millions Eiffel Towers on the end of your finger!

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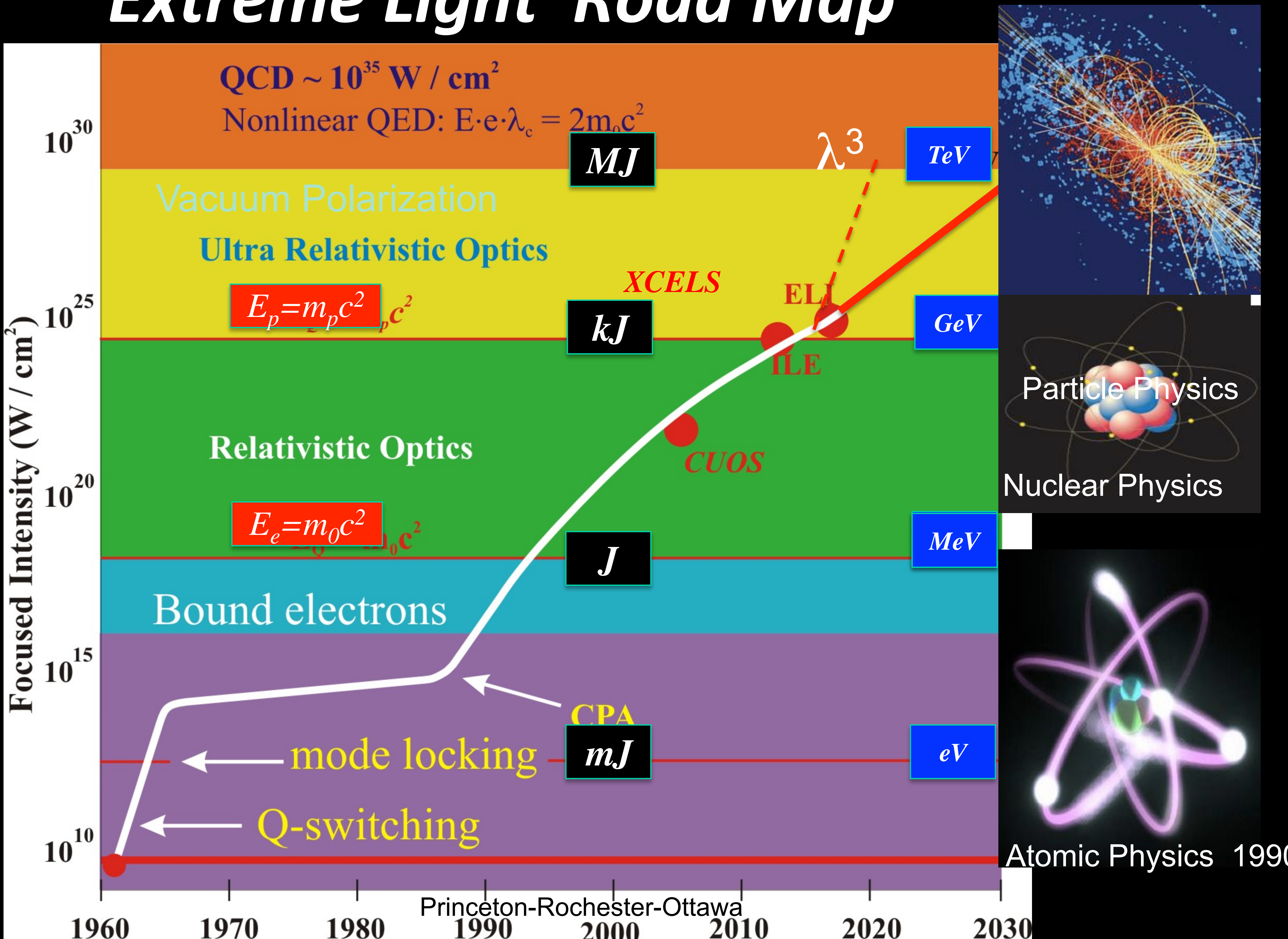
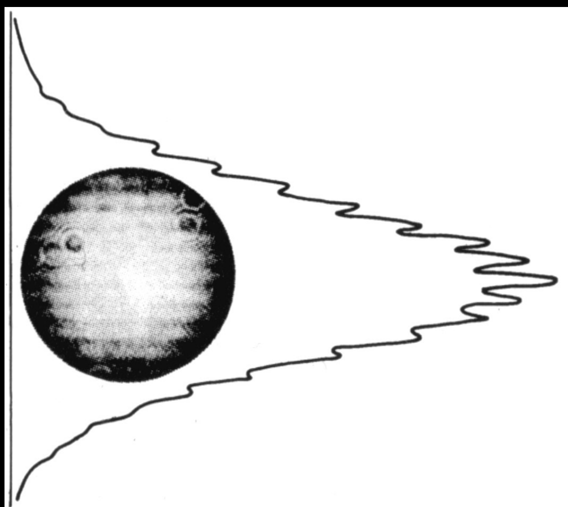
Extreme Light Road Map



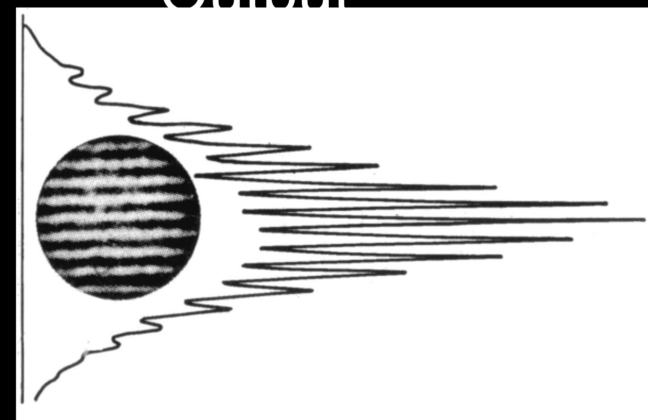
Small-Scale Self-Focusing



Amplifier

$$n = n_0 + n_2 I$$

Output



B-integral < 3 for good beam quality:

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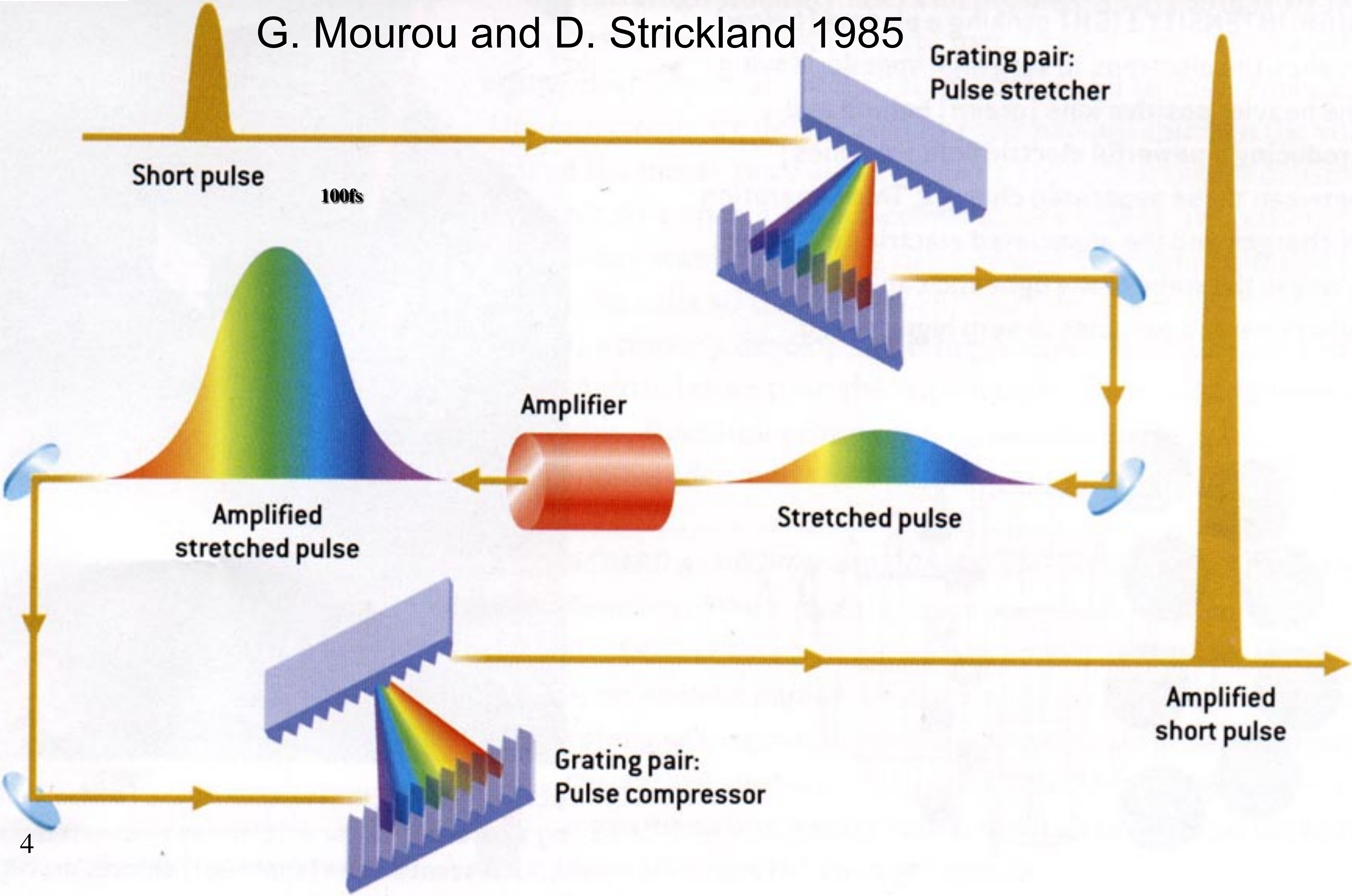
G. Mourou and D. Strickland 1985



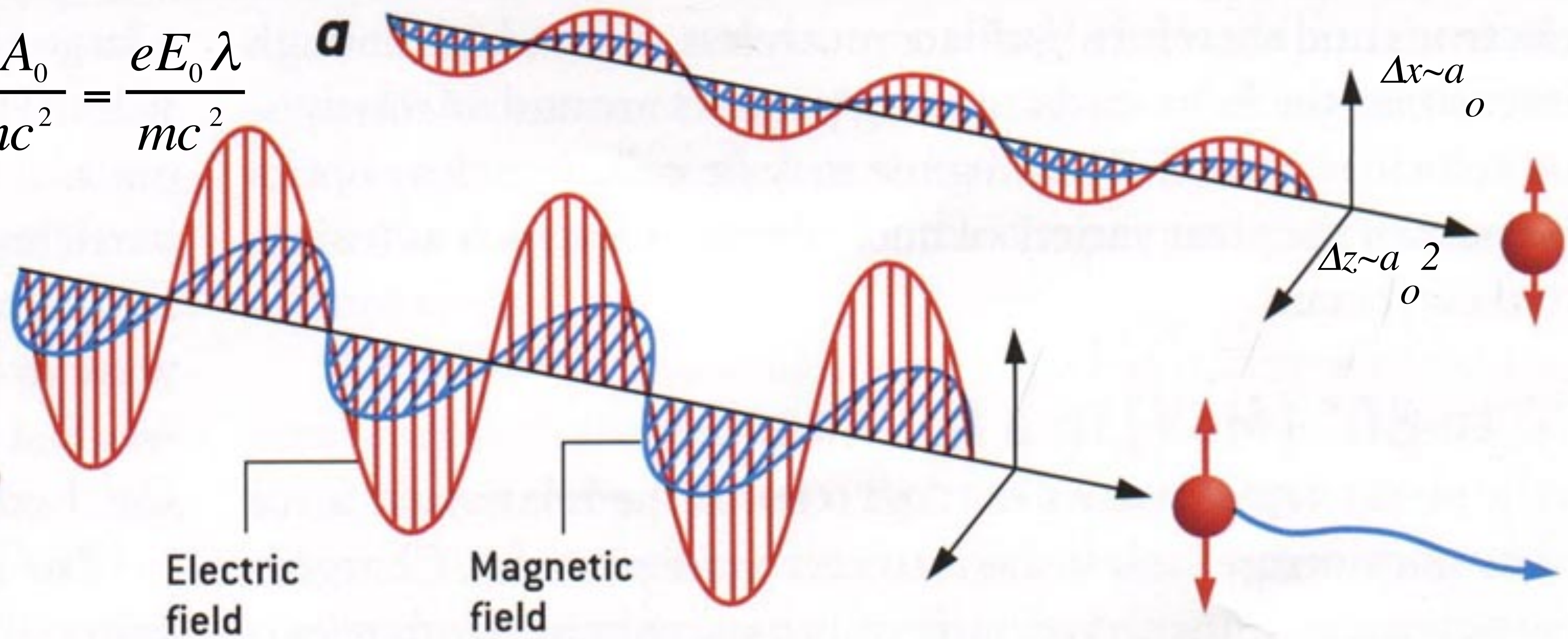
Relativistic Optics

$$\vec{F} = q\left(\vec{E} + \left(\frac{\vec{v}}{c} \wedge \vec{B}\right)\right)$$

a) Classical optics $v \ll c$, $a_0 \ll 1$, $a_0 \gg a_0^2$

b) Relativistic optics $v \sim c$ $a_0 \gg 1$, $a_0 \ll a_0^2$

$$a_0 = \frac{eA_0}{mc^2} = \frac{eE_0\lambda}{mc^2}$$



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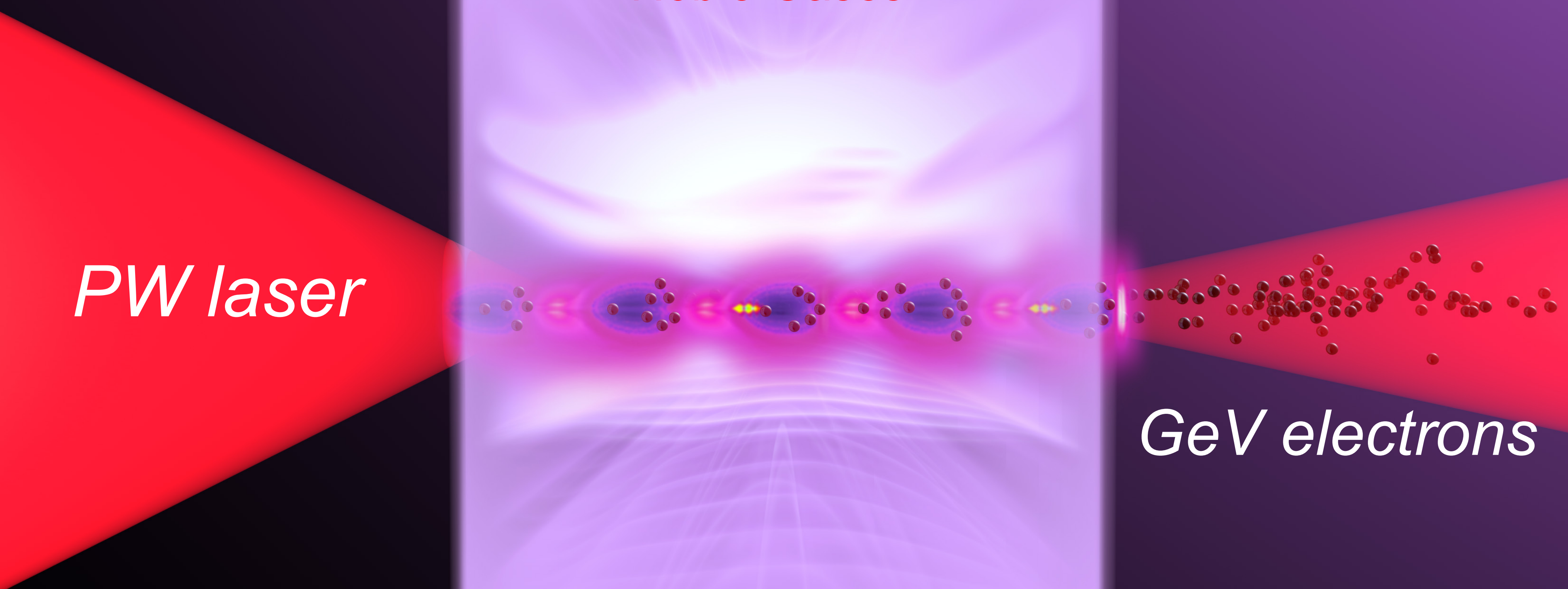
Laser Plasma Acceleration

T. TAJIMA, J. M. DAWSON PRL 1979

Noble Gases



wakefield acceleration in plasma

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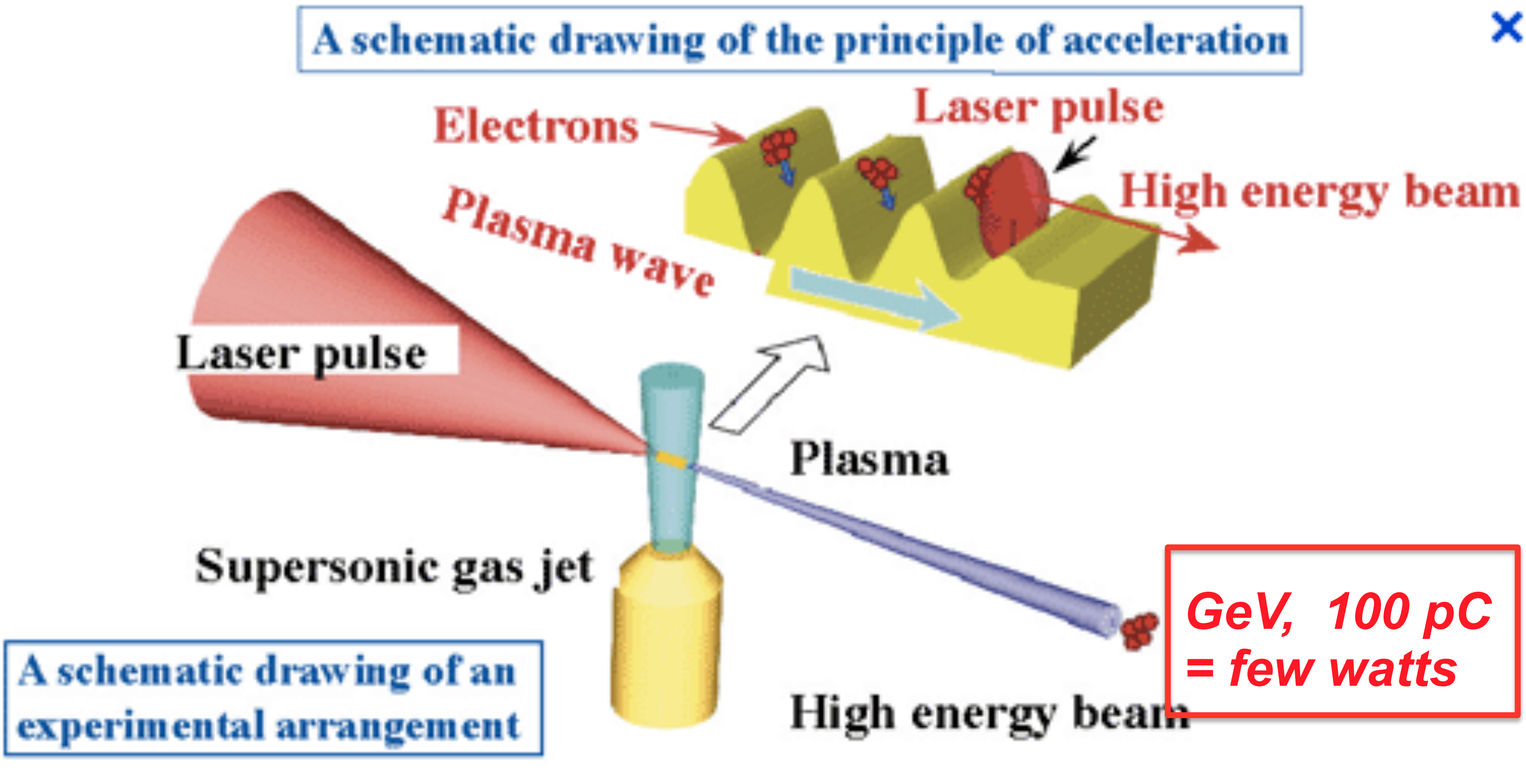

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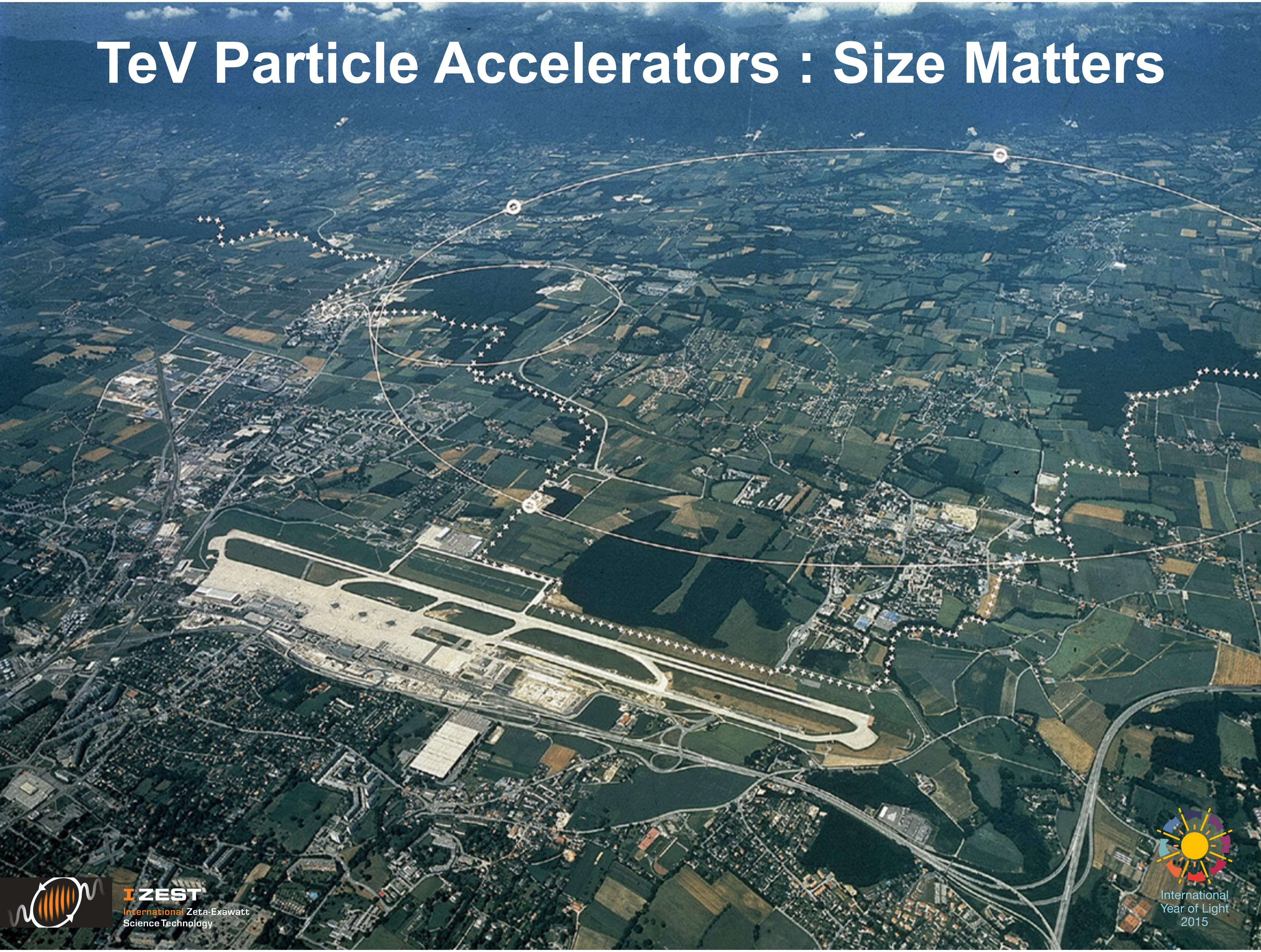
TeV Particle Accelerators : Size Matters



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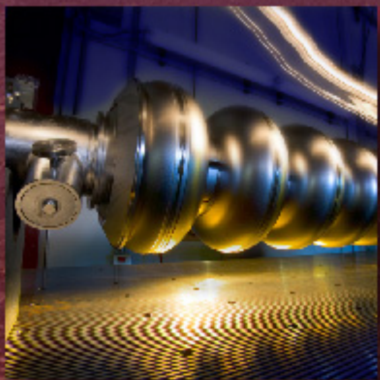

In Existence Now

The Large Hadron Collider (LHC), CERN.

** 27kms toroidal tunnel*

** 175m underground*

** 1 billion proton collisions per second*

** 1 - 14 TeV*

27 kilometres

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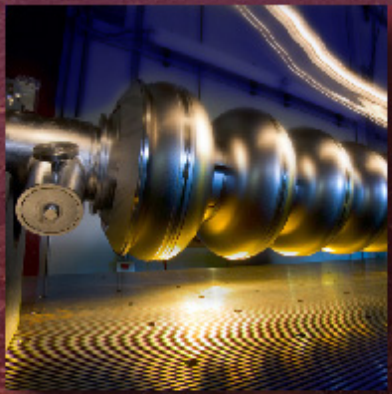

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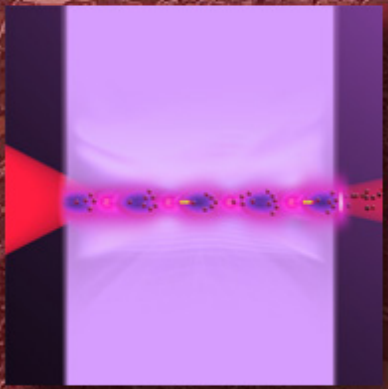


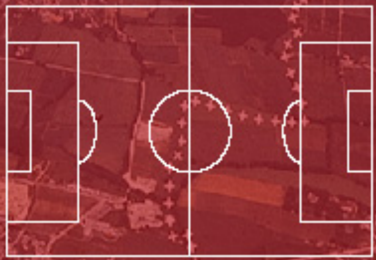
In Development Now

Laser Wakefield Acceleration

** electron/positron collider*

** 100m in length*

** 1 GeV/cm*



100 metres

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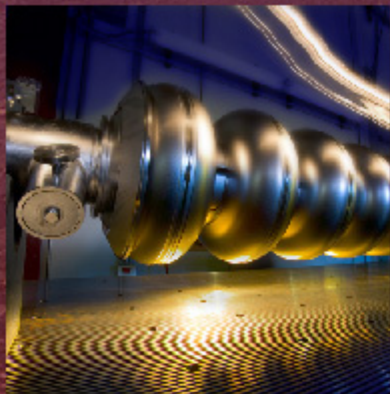
TeV Particle Accelerators : Size Matters



In Existence Now

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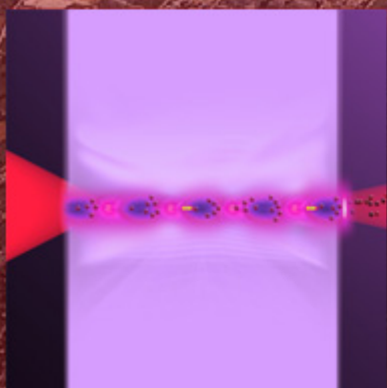

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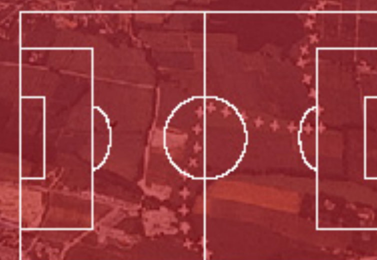
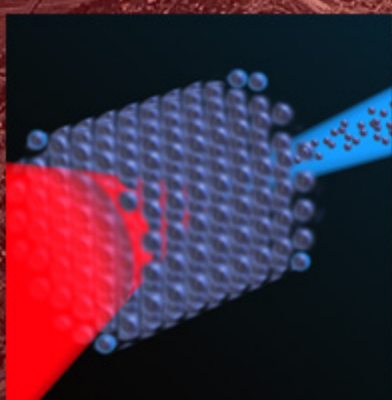


100 metres



In The Future

Zeptosecond X-ray Driver

** laser induced solid crystal wakefield*

** electron, muon, ion collider*

** 1cm in length*

** 1 TeV/cm*

1 centimetre

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Route to Zeptosecond-Zettawatt(Z^2) Physics

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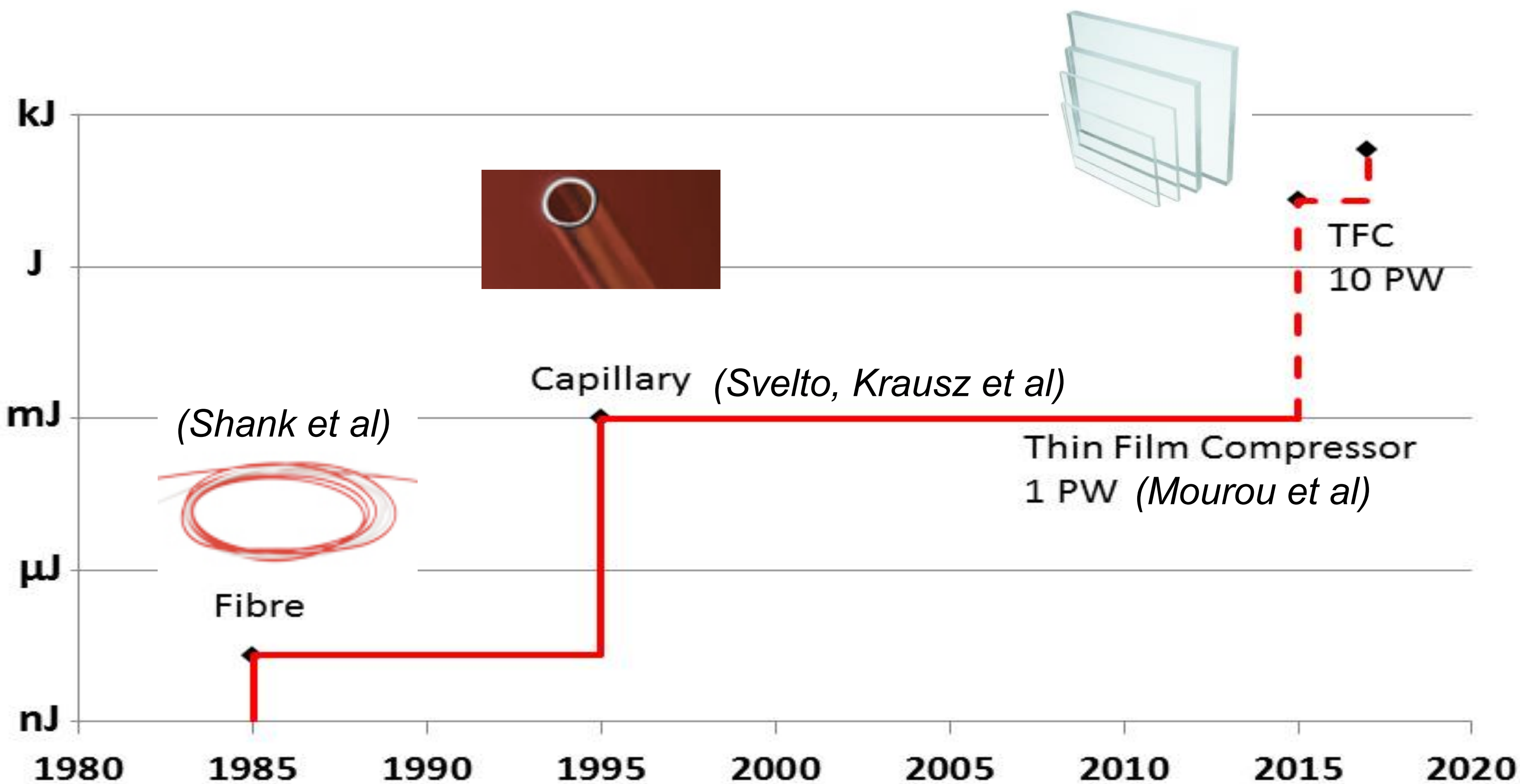
Zeptosecond Generation Steps

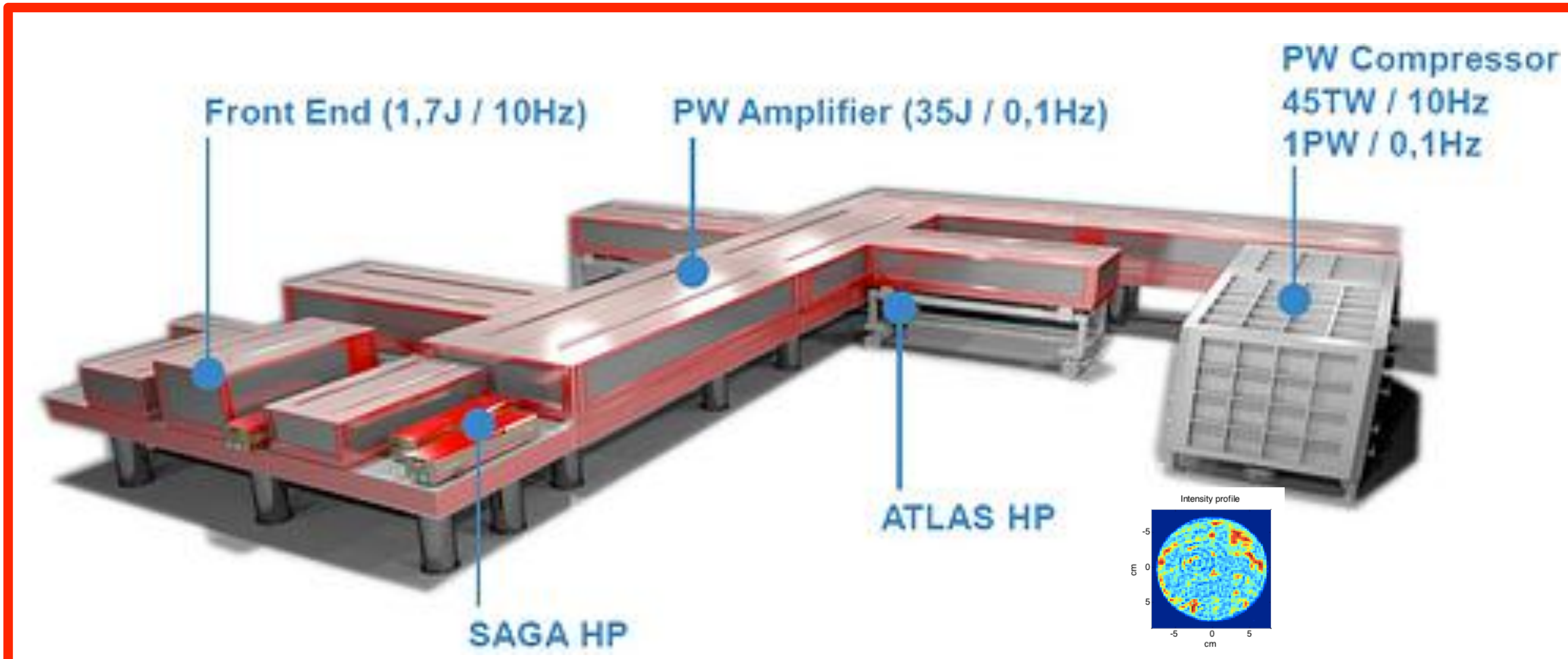
1. First step: Generation of single Cycle 10-100J (10-100PW) pulse
2. Second step: Relativistic Compression from fs to sub-attosecond (zeptosecond)

Single Cycle Pulse Compression Pulse: History

Single Cycle Generation History



Petawatt Laser Provides A 10-1000J Flat Top



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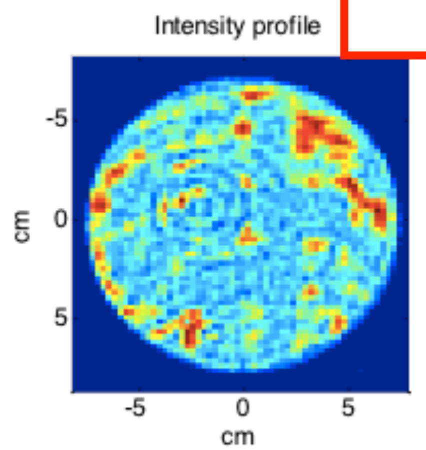
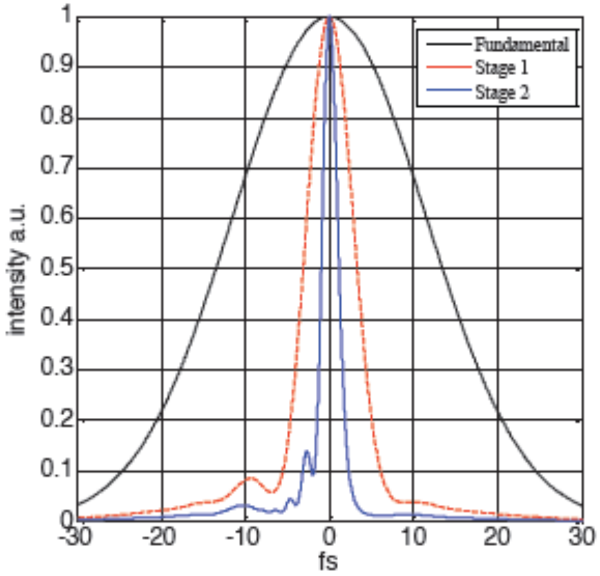
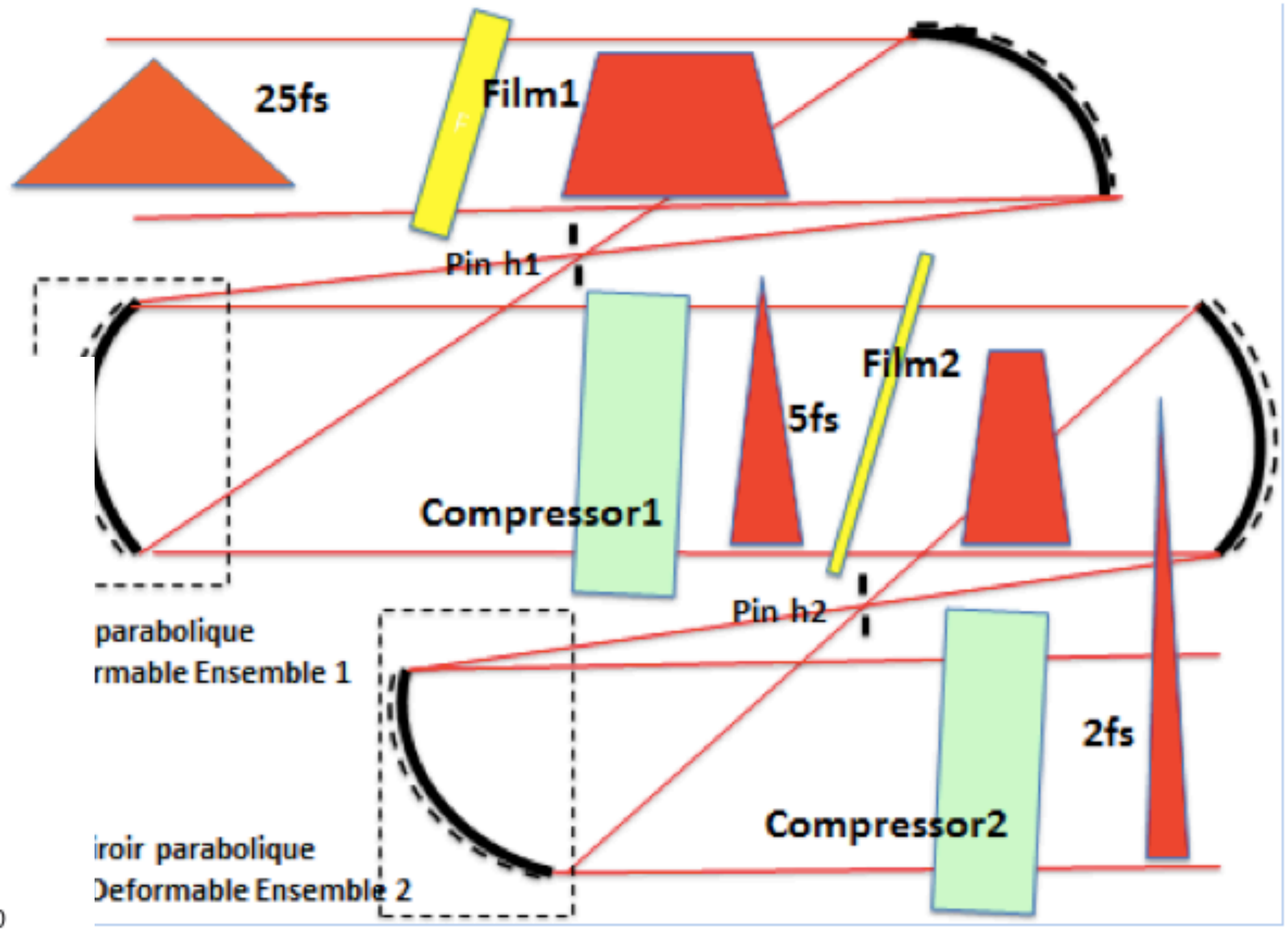
Single Cycle Thin Film Compressor

Laser with Uniform Beam Amplitude and Phase







G. Mourou, S. Mironov, E. Khazanov and A. Sergeev, Single cycle thin film compressor opening the door to Zeptosecond-Exawatt Physics , Eur. Phys. J. Special Topics, 223, 1181(2014)

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

Unlimited size and very low cost

. *Polyethylene terephthalate 0.7mm, 1.5TW/cm², B=4.3*
. Very large aspect ratio, surface over thickness, Unlimited aperture inexpensive.
. Uniformity within a fraction of λ .

Relativistic Compression

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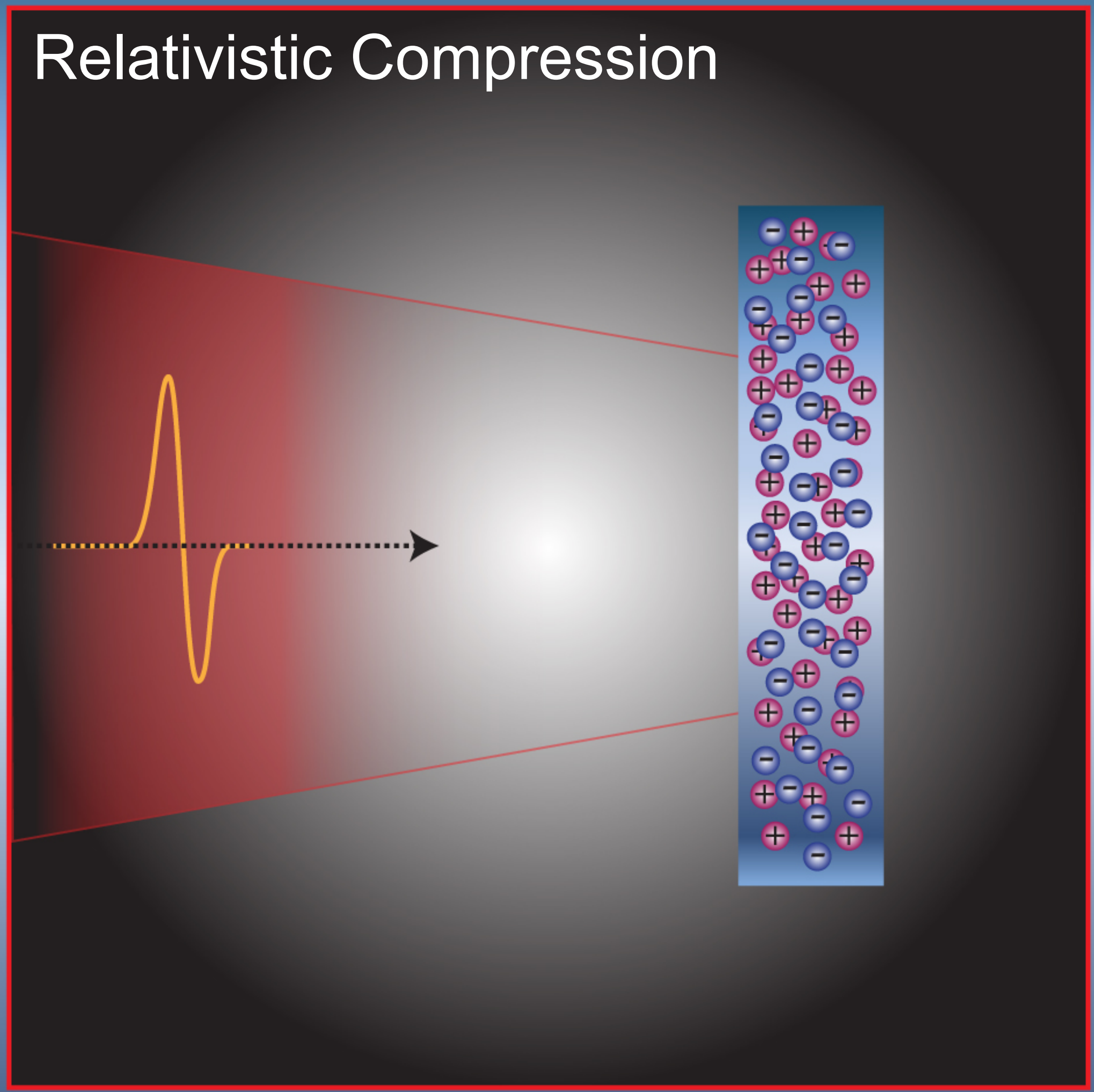

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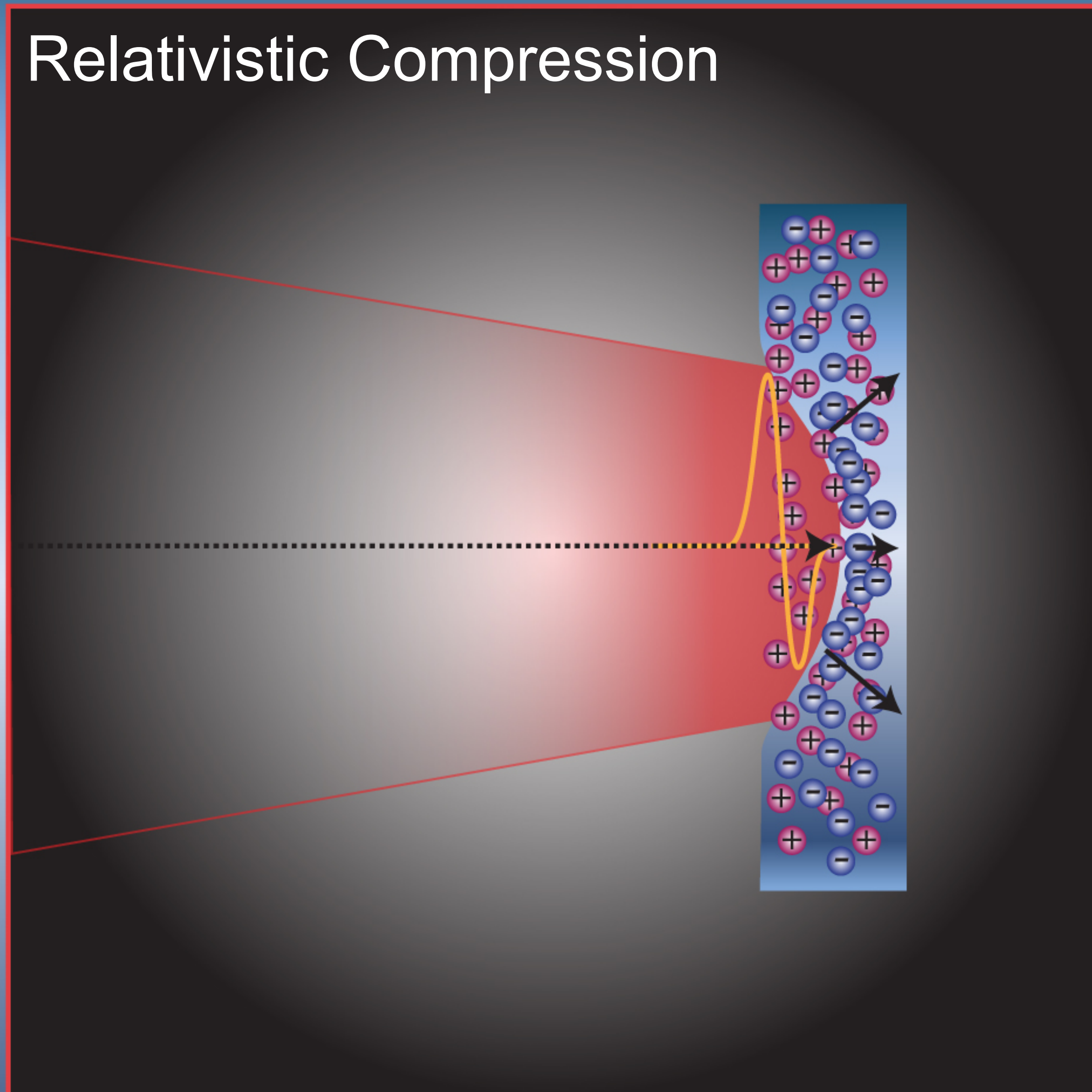

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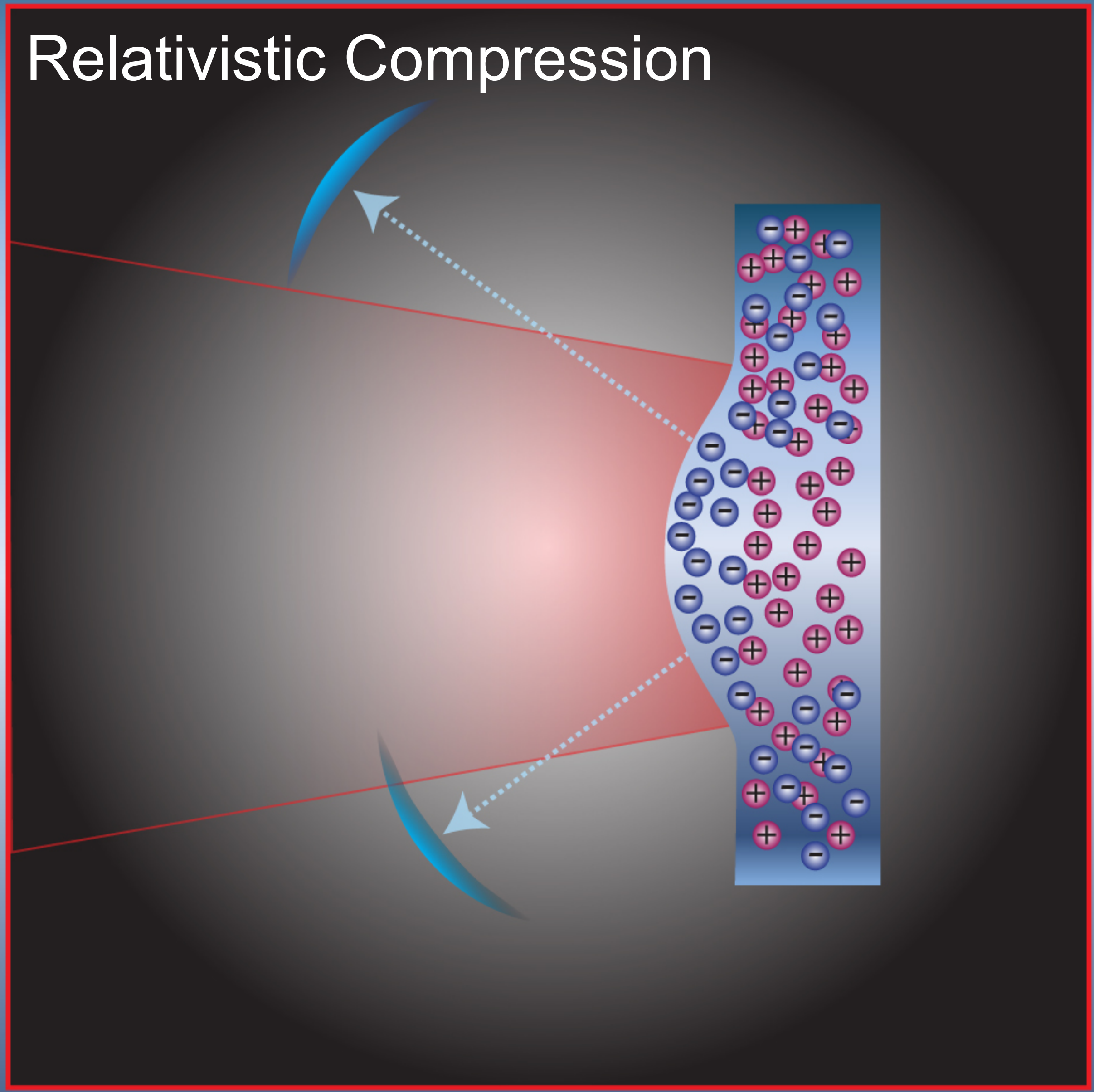

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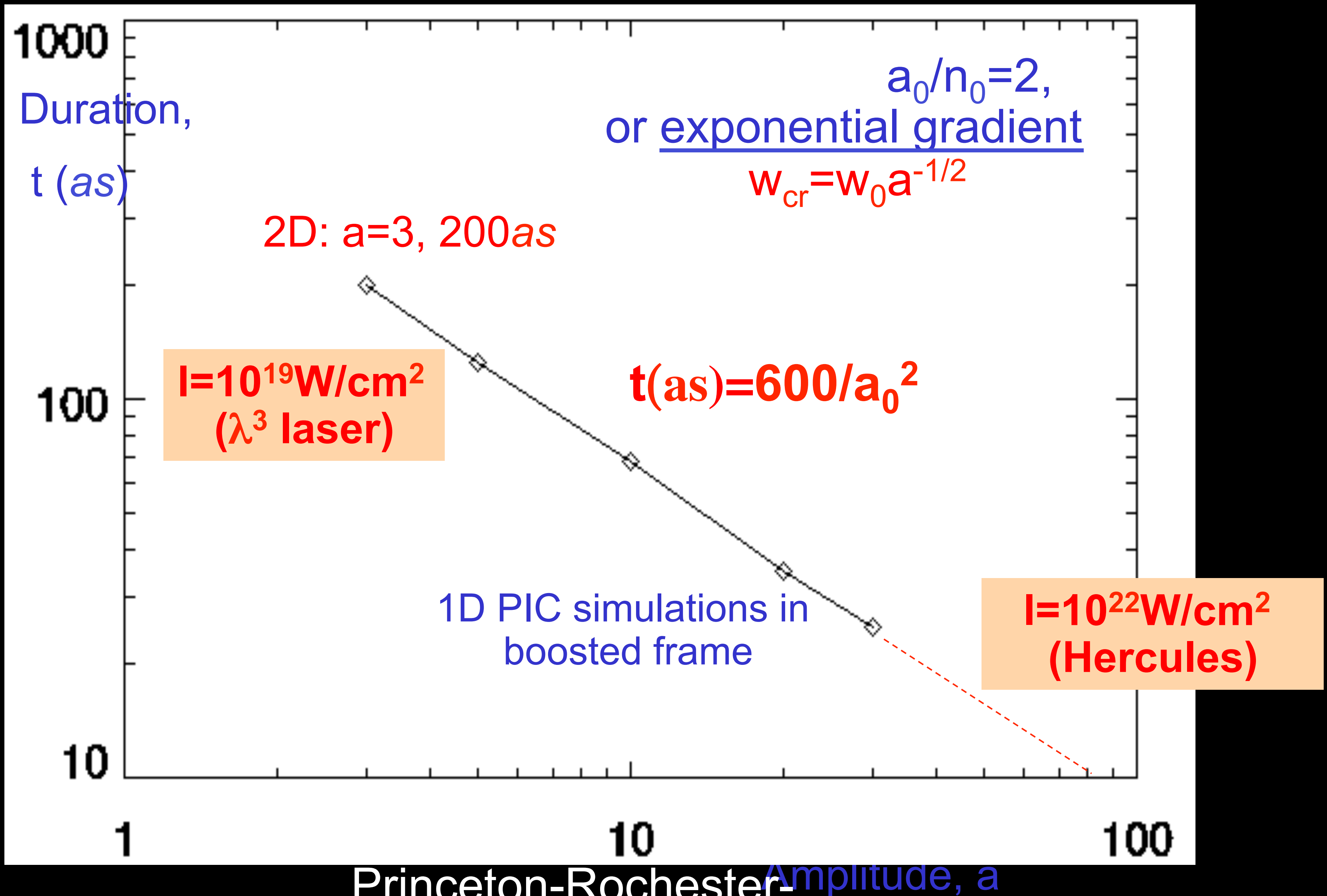
Scalable Isolated Attosecond Pulses

N. M. Naumova, J. A. Nees, I. V. Sokolov, B. Hou, and G. A. Mourou, Relativistic generation of isolated attosecond pulses in a λ^3 focal volume, Phys. Rev. Lett. 92, 063902-1 (2004).



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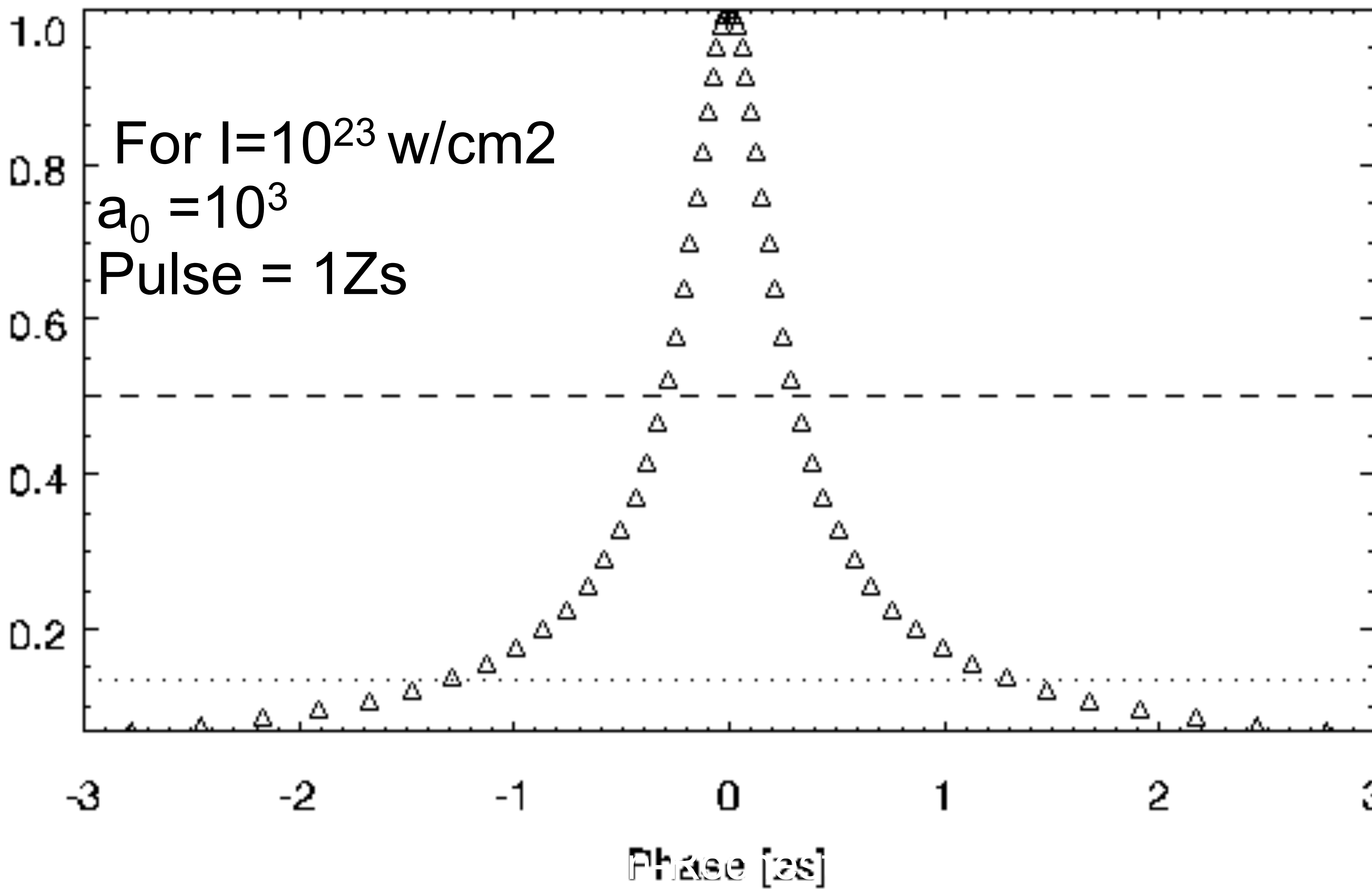
Zeptosecond pulses, (N. Naumova, I. Sokolov, G. Mourou)
(Very Preliminary Result)



But a Zeptosecond pulse is also:

1. 1J in a Zs (10^{-21}s) is a Zettawatt Zw (10^{21}W)
2. A Zs (10^{-21}s) is a 1MeV Coherent Gamma-ray

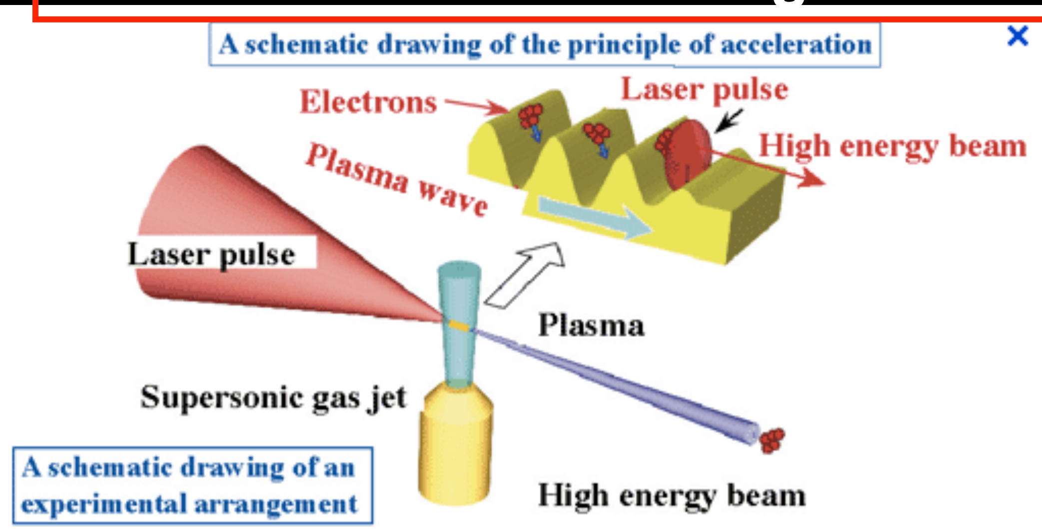
   Giant Laser Acceleration in solid: TeV/cm (CERN on a Dime) towards ZeV

3. 1Zw over λ^2 spot size is 10^{29} W/cm^2 Schwinger Intensity:

   Light Turns into Matter and Antimatter

Zepto-Attosecond X-ray pulse and Giant acceleration

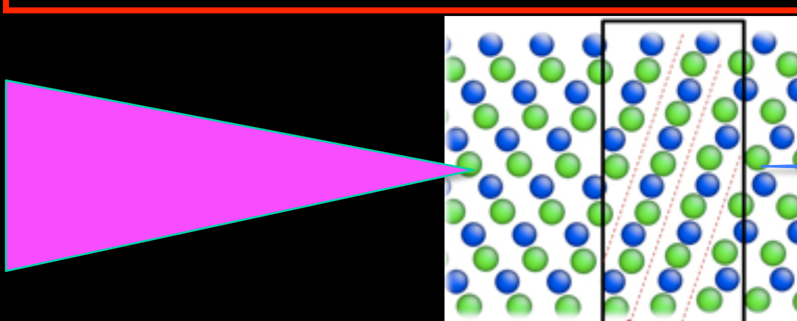
Femtosecond Visible Light Driver, Gas ***Tajima et Dawson 1979***



Plasma Acceleration Energy Gain
$G \alpha \; n^{1/2}$ eV/cm

$n_{gas} = 10^{18} cm^3$, G~ 10^{9}, GeV/cm

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



$N_{solid} = 10^{24} cm^3$, G~ 10^{12} eV/cm. TeV/ cm

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

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

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Extreme Light Grand Challenges: Scientific and Societal Applications

Scientific Applications

Laser Astrophysics and Cosmology

Polarization of Vacuum, Materialization of Light

Beyond the Standard Model

Higgs Factory

Dark Matter

Societal Applications

Transmutation of Nuclear Waste

Under Critical Reactor

Nuclear Pharmacology

Proton Therapy

Orbital Debris Elimination by Deorbitation

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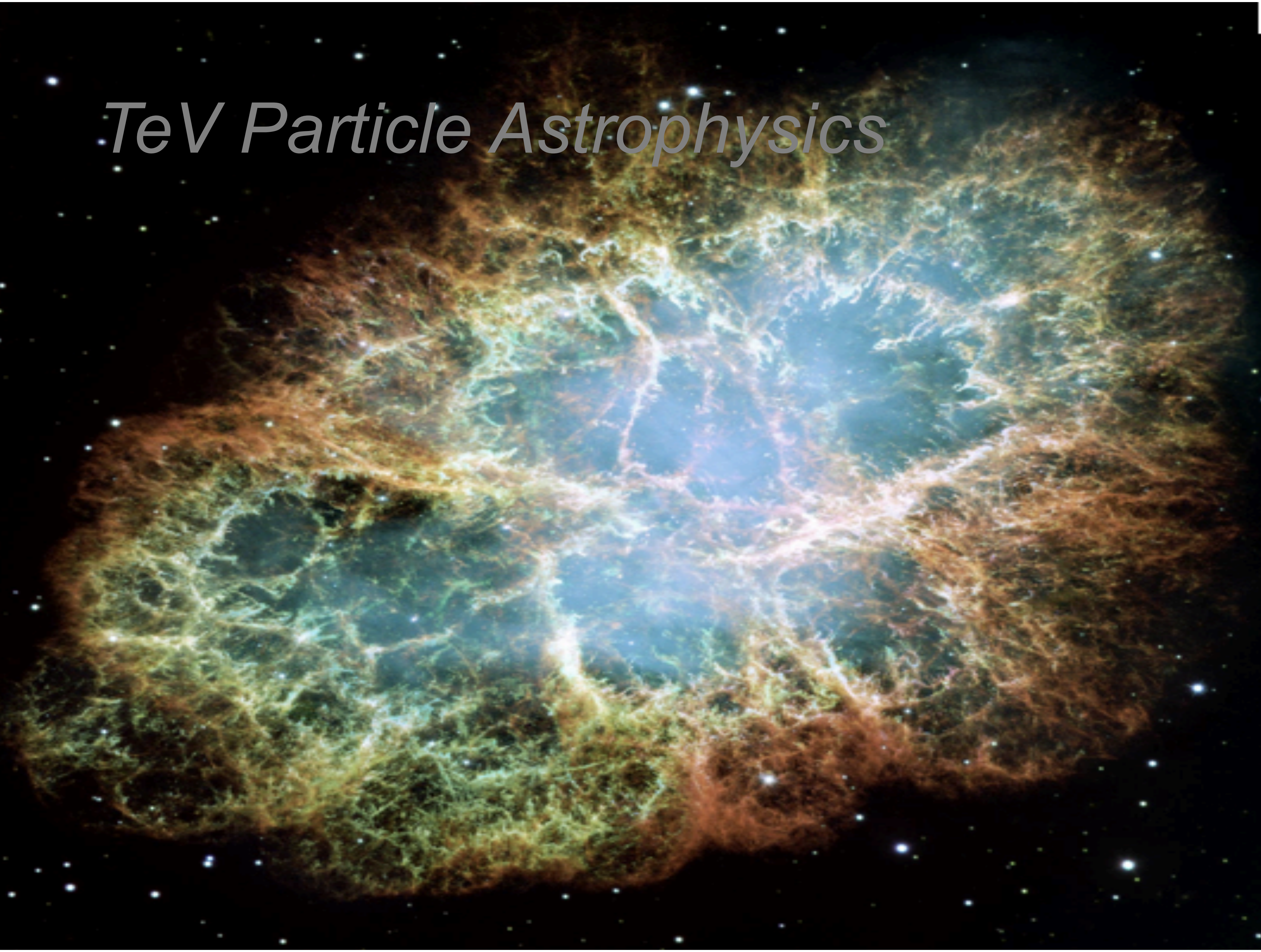
TeV Particle Astrophysics



γLORENTZ INVARIANCE AND GRB

LETTERS NATURE

(Abdo, et al, 2009)

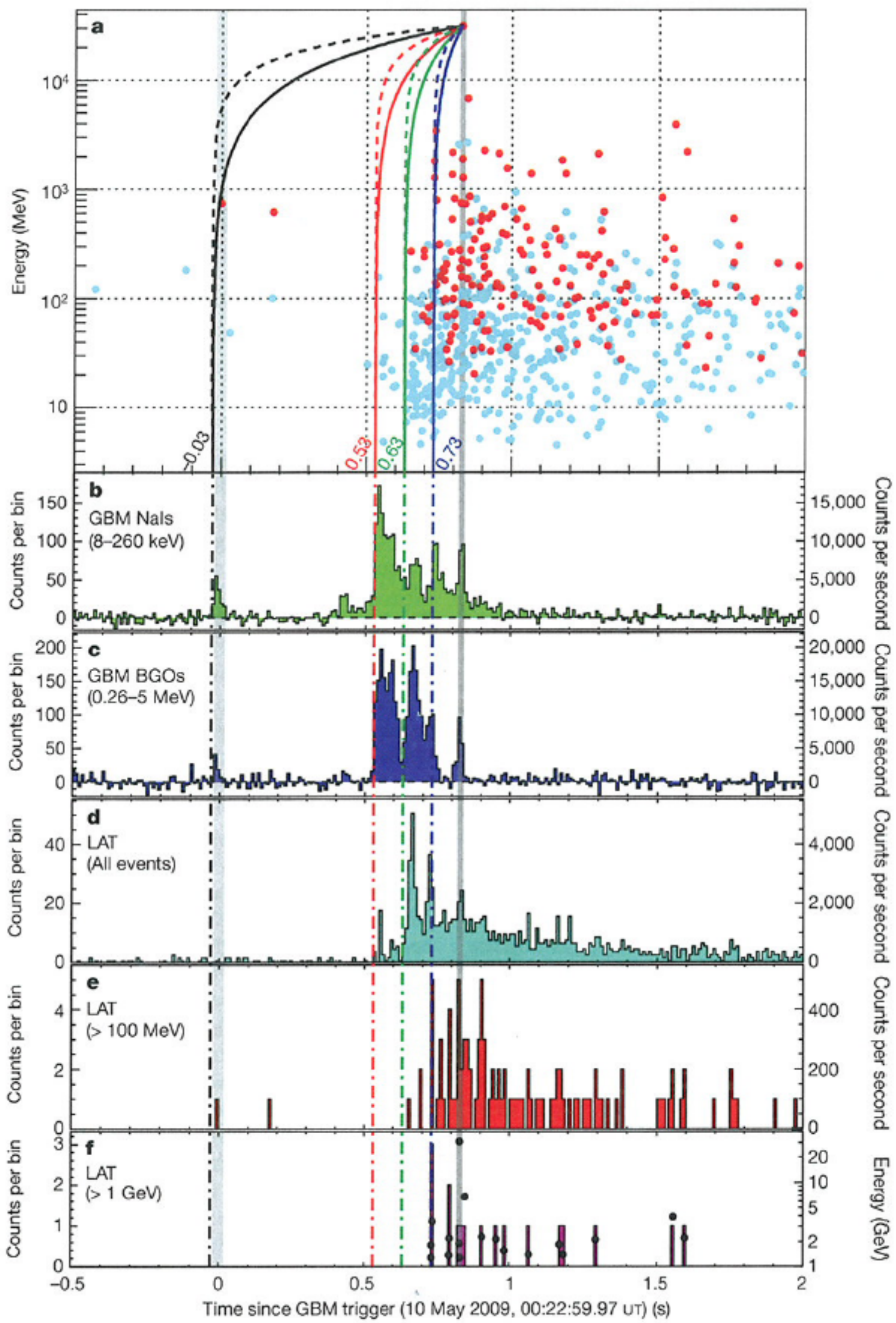
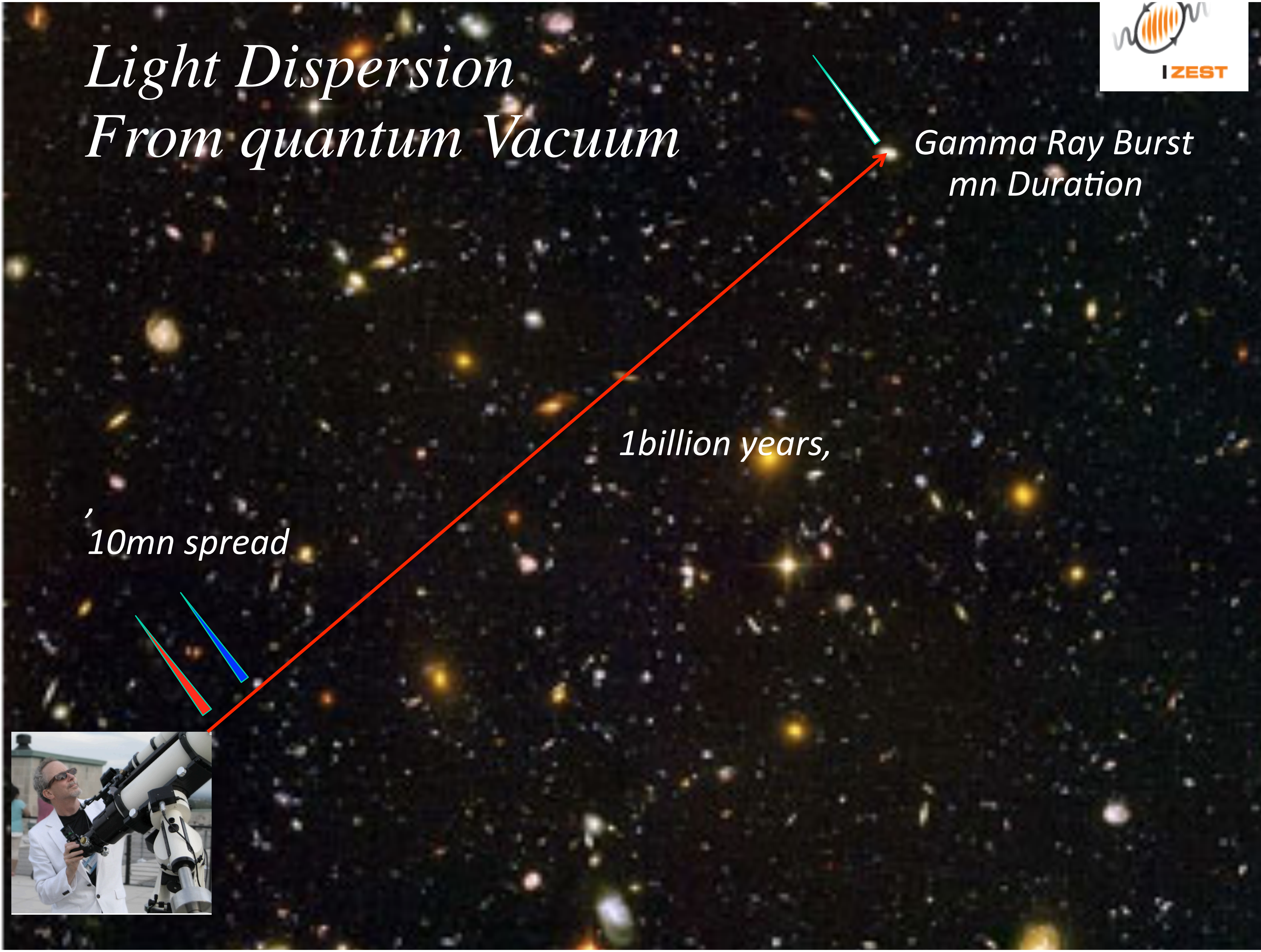


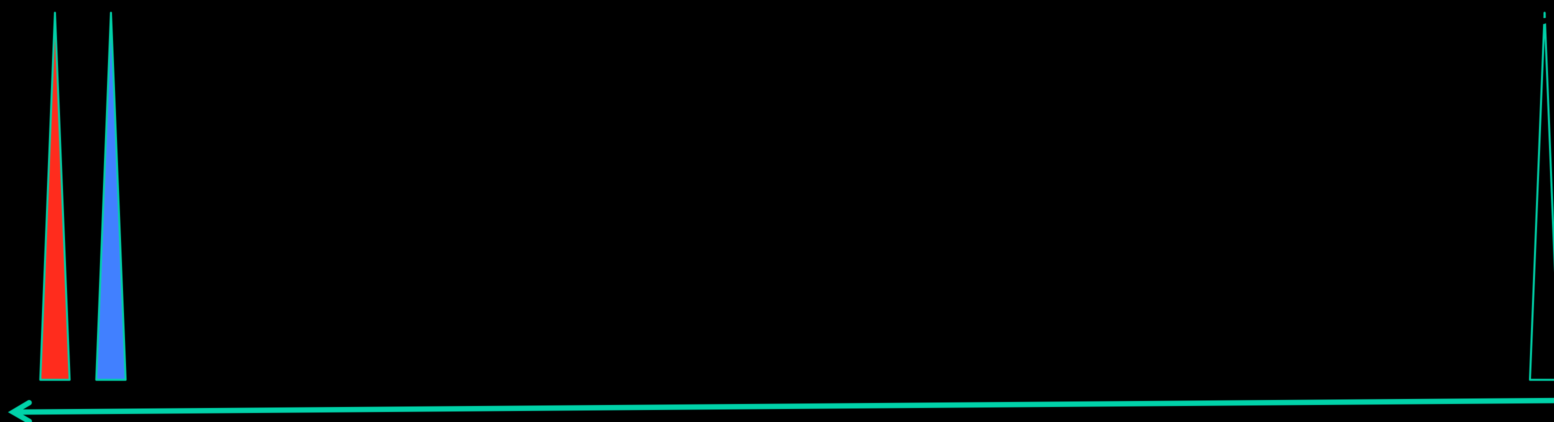
Figure 1 | Light curves of GRB 090510 at different energies. a, Energy lowest to highest energies. **f** also overlays energy versus arrival time for each

***Energy-*[redacted]**
photon [redacted]
Observa[redacted]
Gamma[redacted]
(limit [redacted]
close[redacted]

Lab F[redacted] γ
can[redacted]
wit[redacted]


Light Dispersion
From quantum Vacuum
Gamma Ray Burst
mn Duration
1billion years,
,
10mn spread
IZEST

Lorentz Invariance Violation Cosmos on the table



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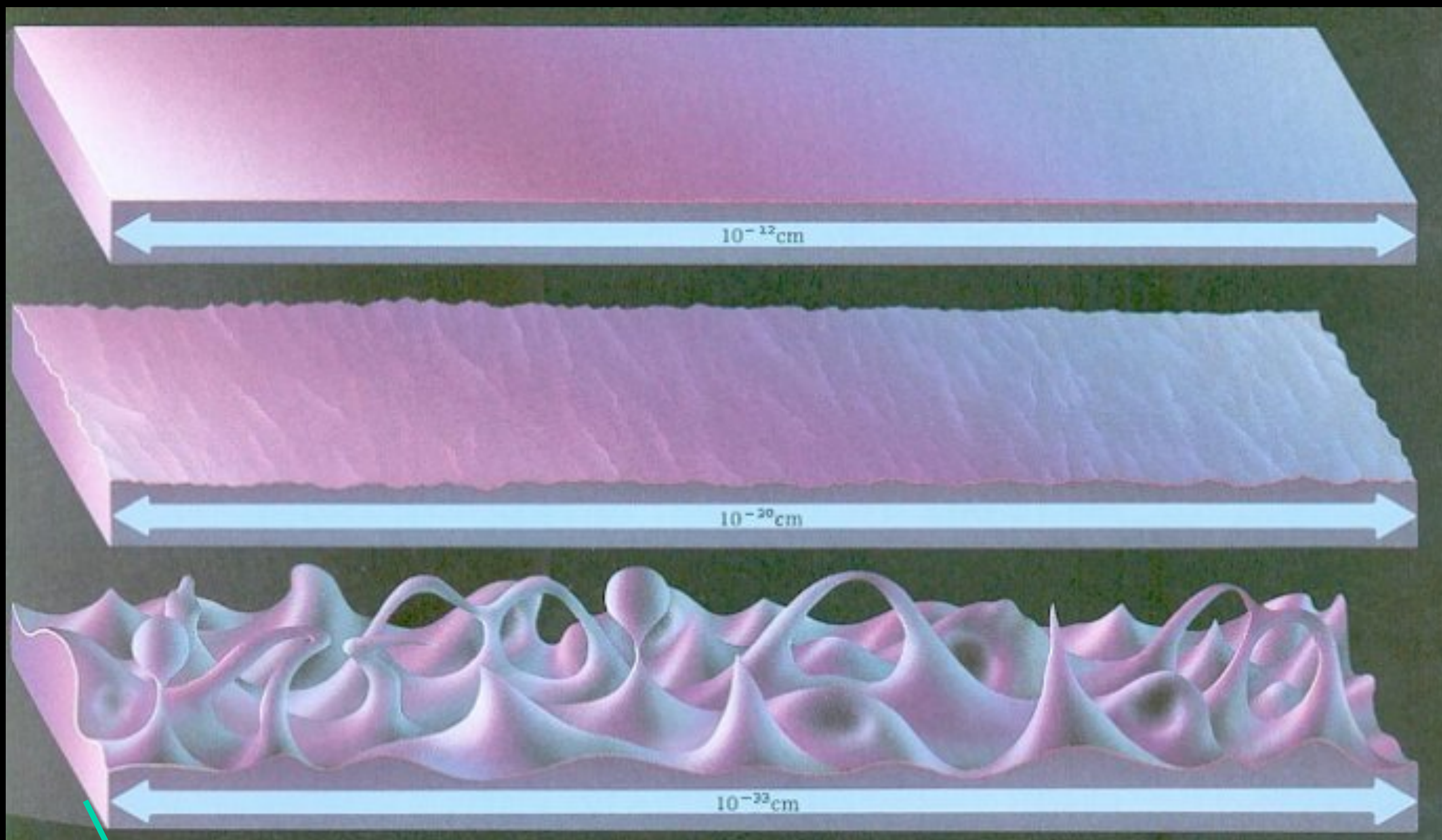
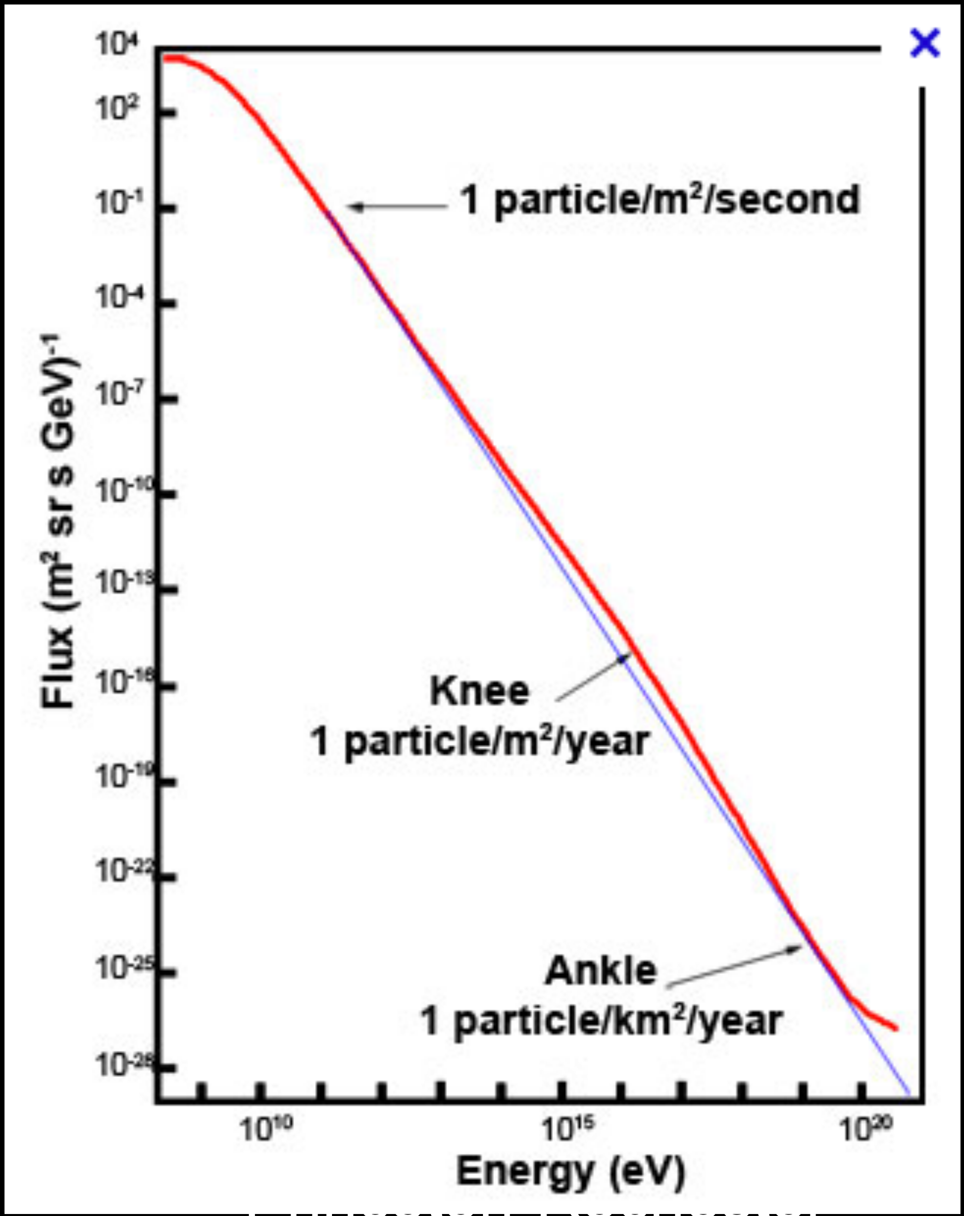
Feel vacuum texture: PeV energy γ

Laser acceleration ⟶ <u>controlled laboratory</u> test to see quantum gravity texture on photon propagation (Special Theory of Relativity: c_0)



γ

Cosmic Ray Spectrum



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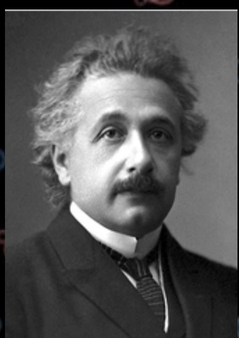
Vacuum is not nothingness but is full of activity i.e Quantum Fluctuations

Fritz Sauter

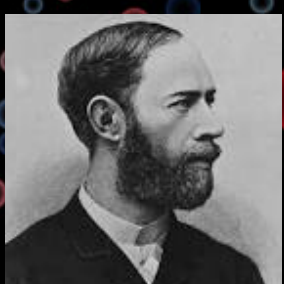
Werner Heisenberg

Julian Schwinger

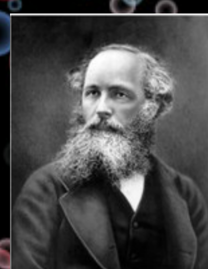


A. Einstein

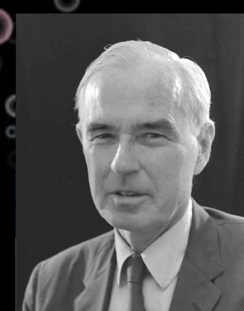
H. Casimir



L. Hertz



J. Maxwell



W. Lamb

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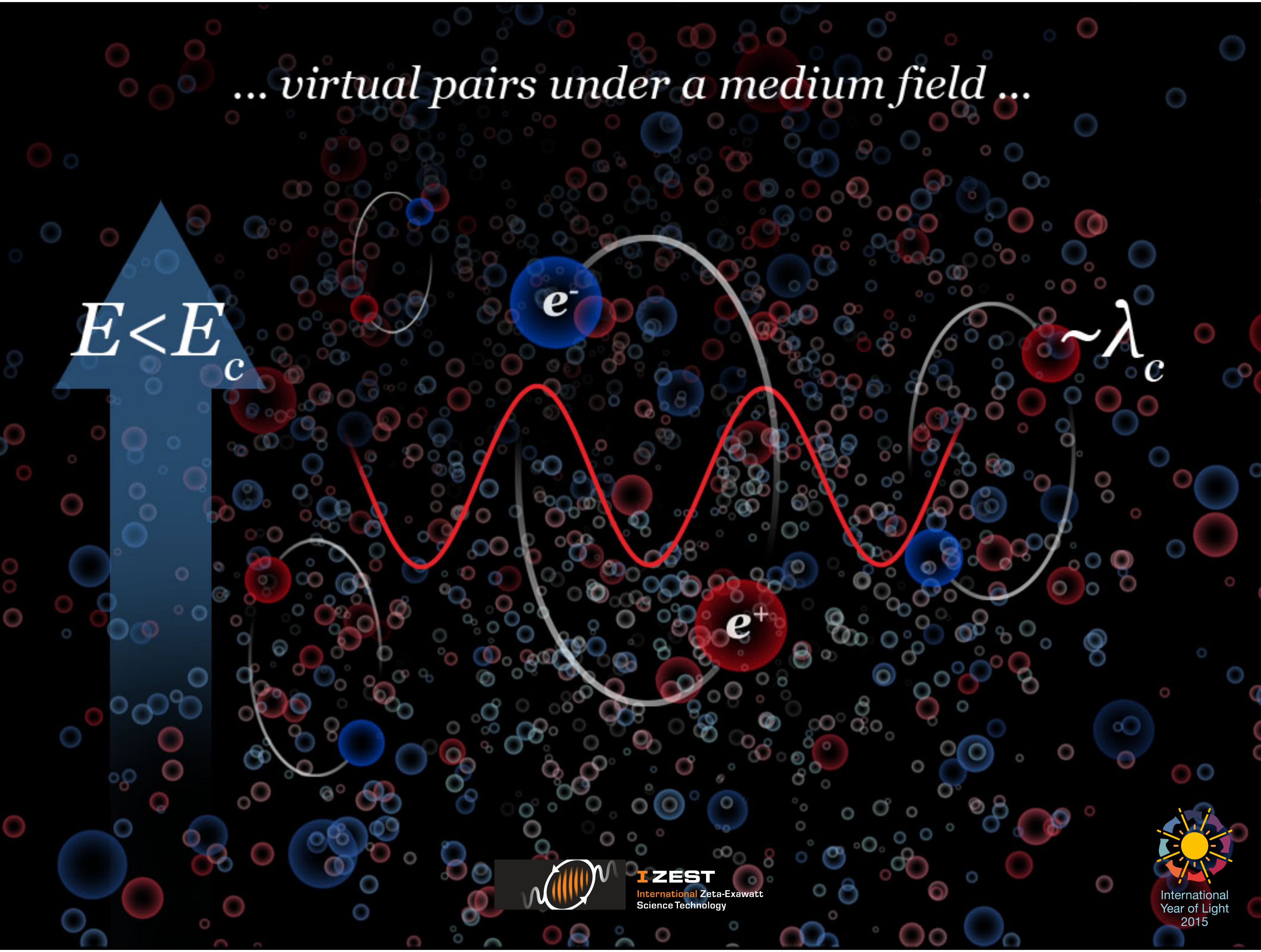
... virtual pairs under a medium field ...
E<E
c
e-
e+
~λ
c
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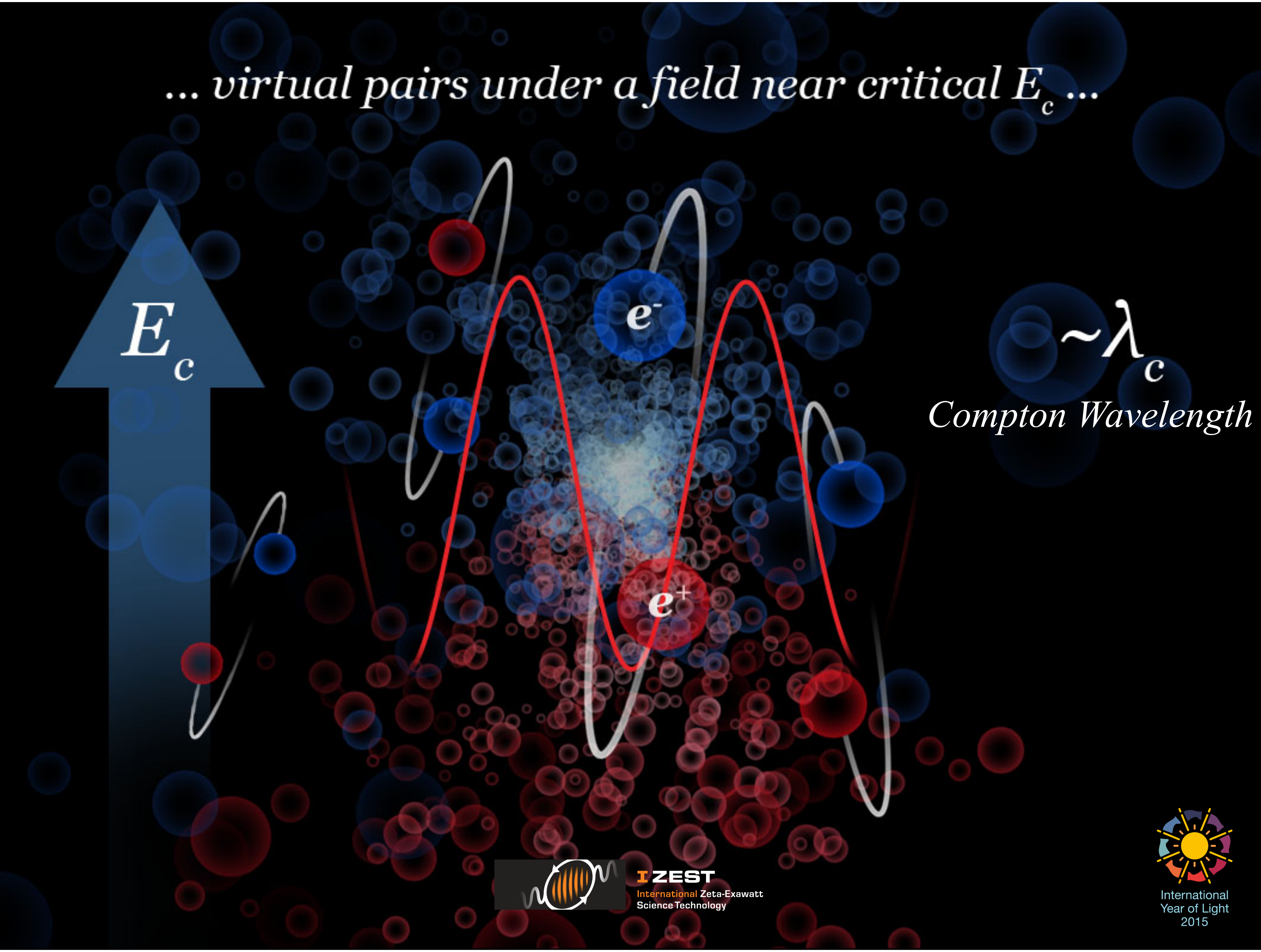
2015



... virtual pairs under a field near critical E_c ...
E_c
e^-
e^+
$\sim\lambda_c$
Compton Wavelength
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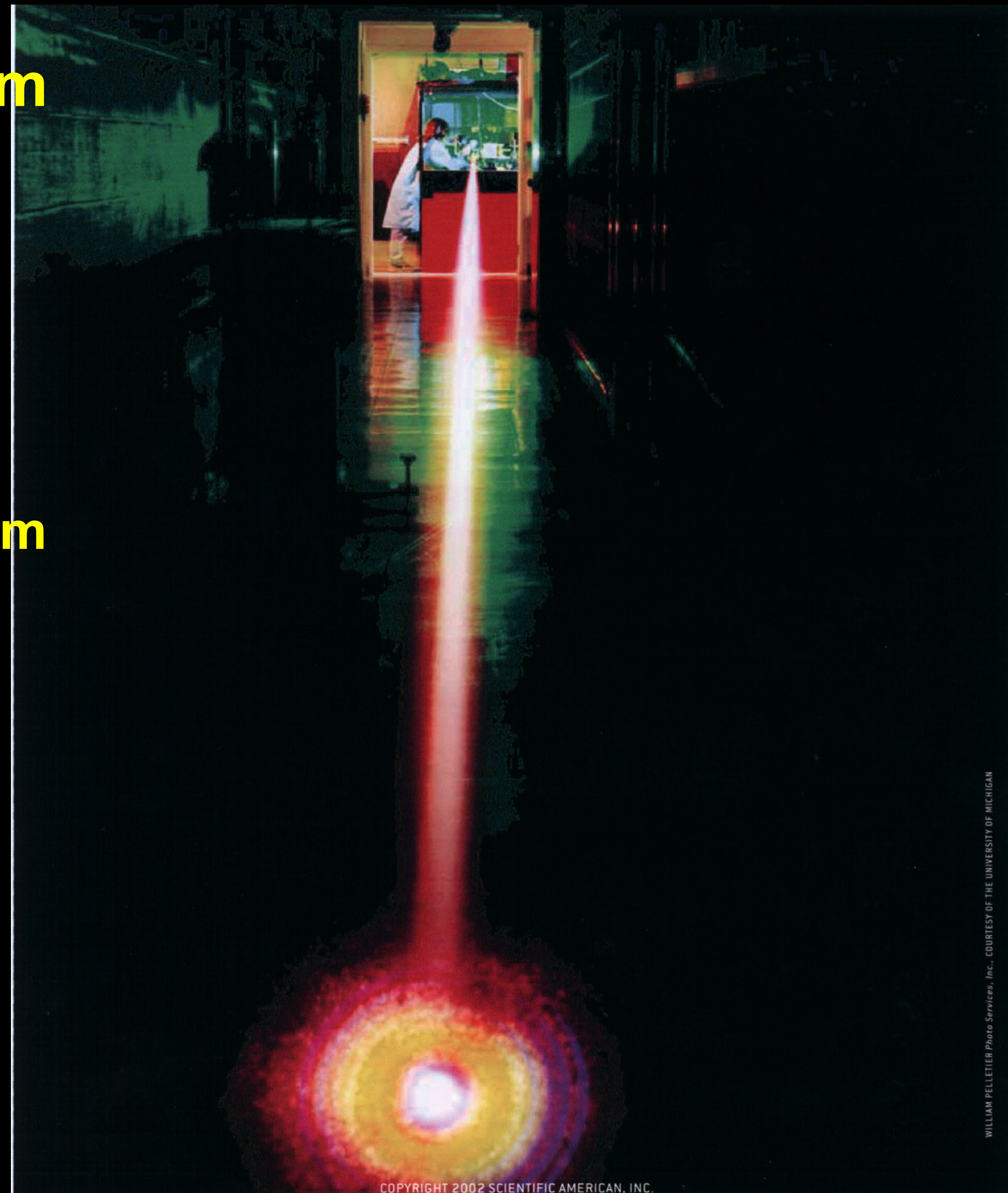
The virtual pairs are turning into a large number of real pairs

At the end of an Extreme Light Laser Beam the vacumm acts as an impenetrable wall stopping the Beam.

Nonlinear Filament in Vacuum



Critical Power Pc $= \lambda^2/n_2$

For zepto second pulse $\lambda = 10^{-10}$ **cm**

n $_{2vac}$ **10**$^{-18}$ **of n**$_{2\ material}$

Pc $_{vac}$ **=** 10^{14} **W**

Size filament $=\lambda_{compton} = 10^{-10}$ **cm**

Energy per filament= 1 μ**J**

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Extreme Light
Sub-critical Reactor
Transmutation of Nuclear Waste

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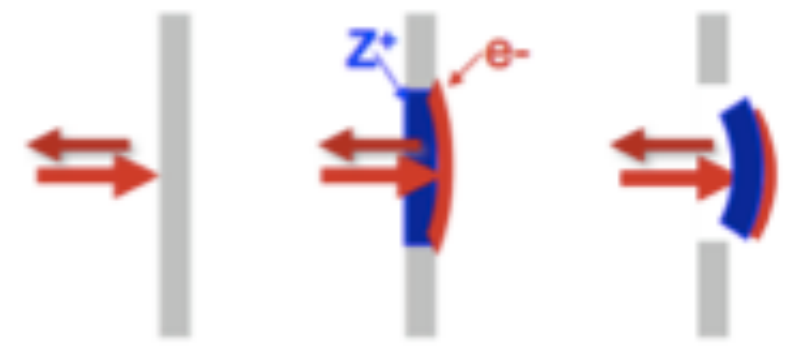
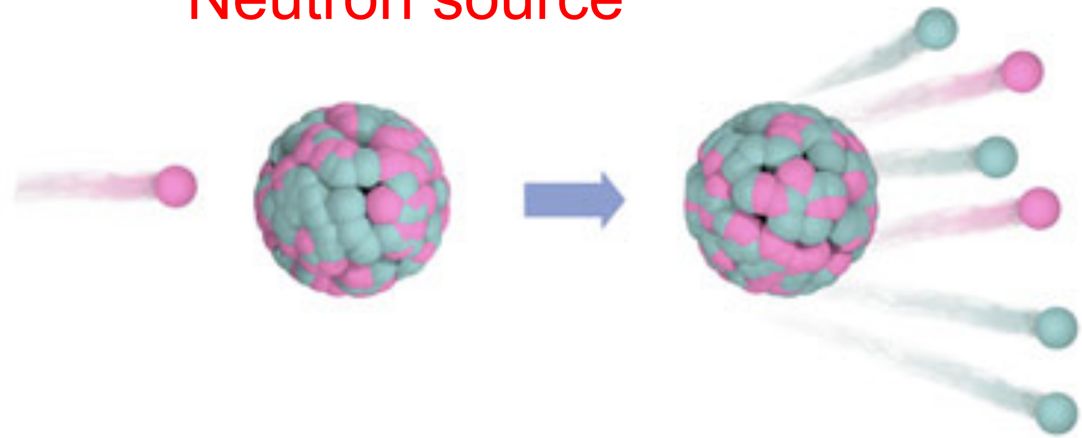
2015

High Energy Proton Applications

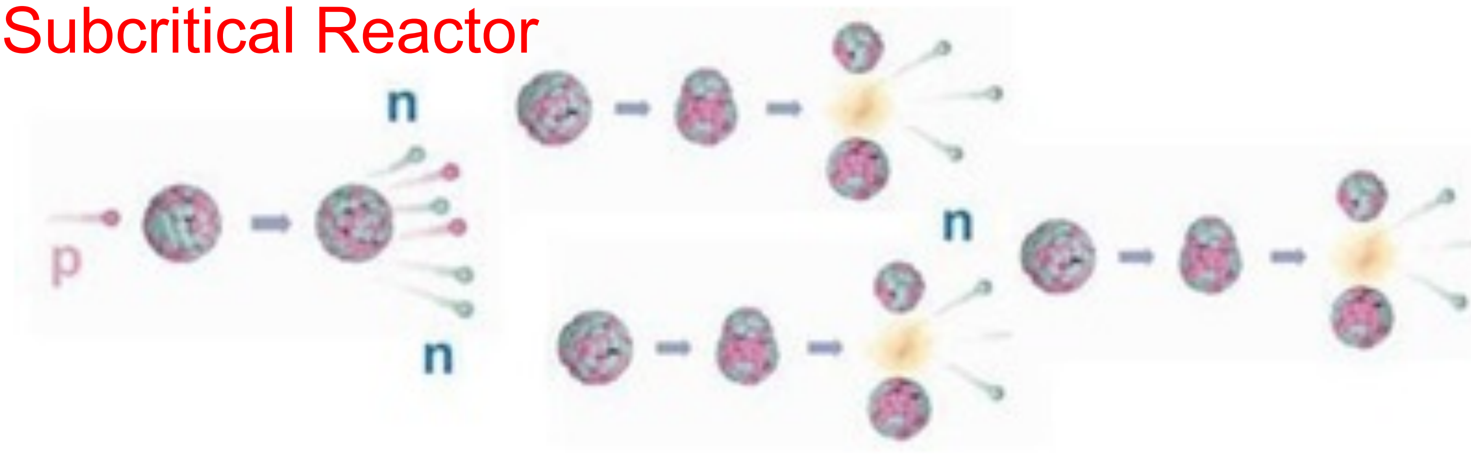
GeV Proton Generation



Neutron source



Subcritical Reactor



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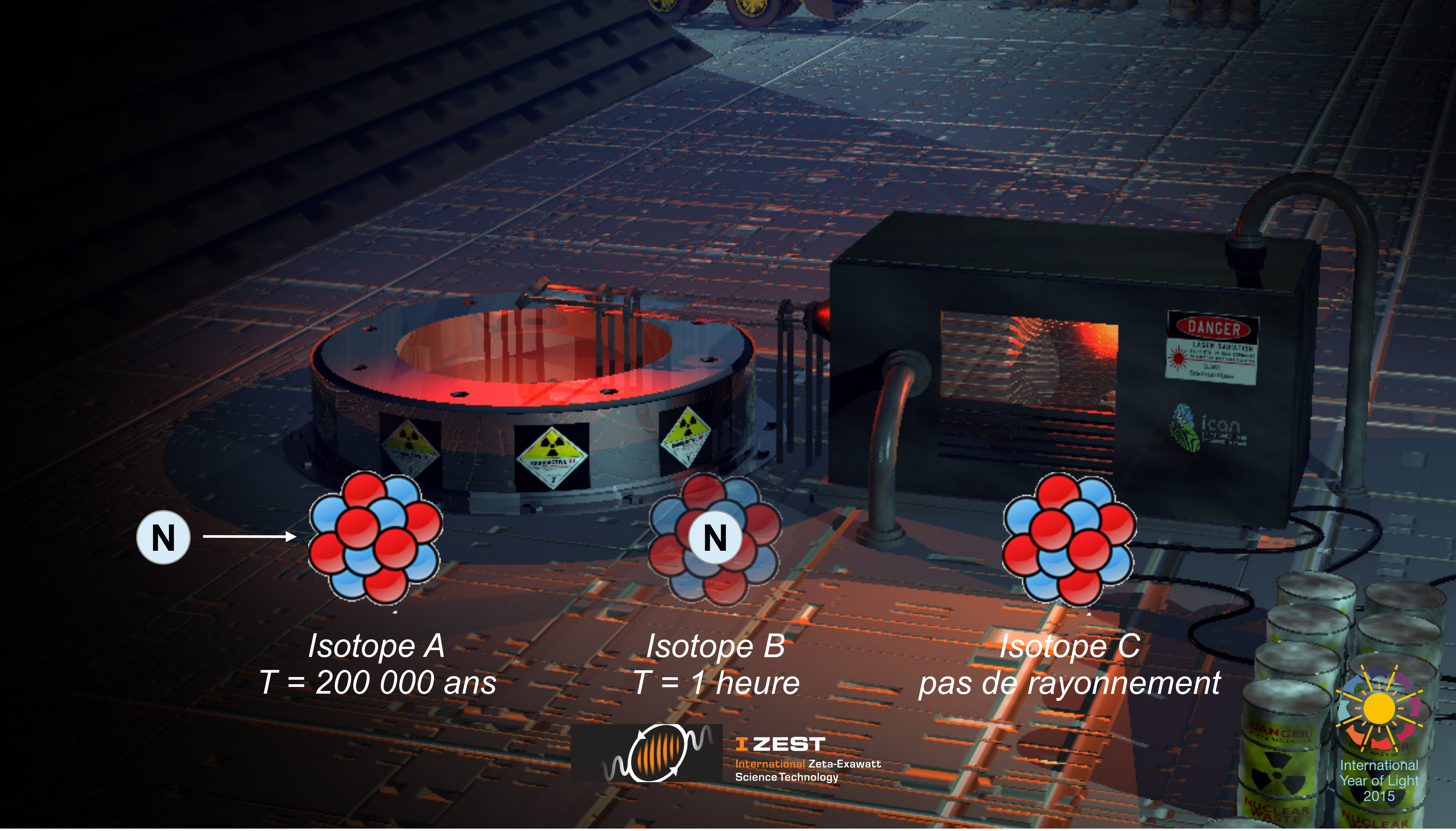
Transmutation Concept

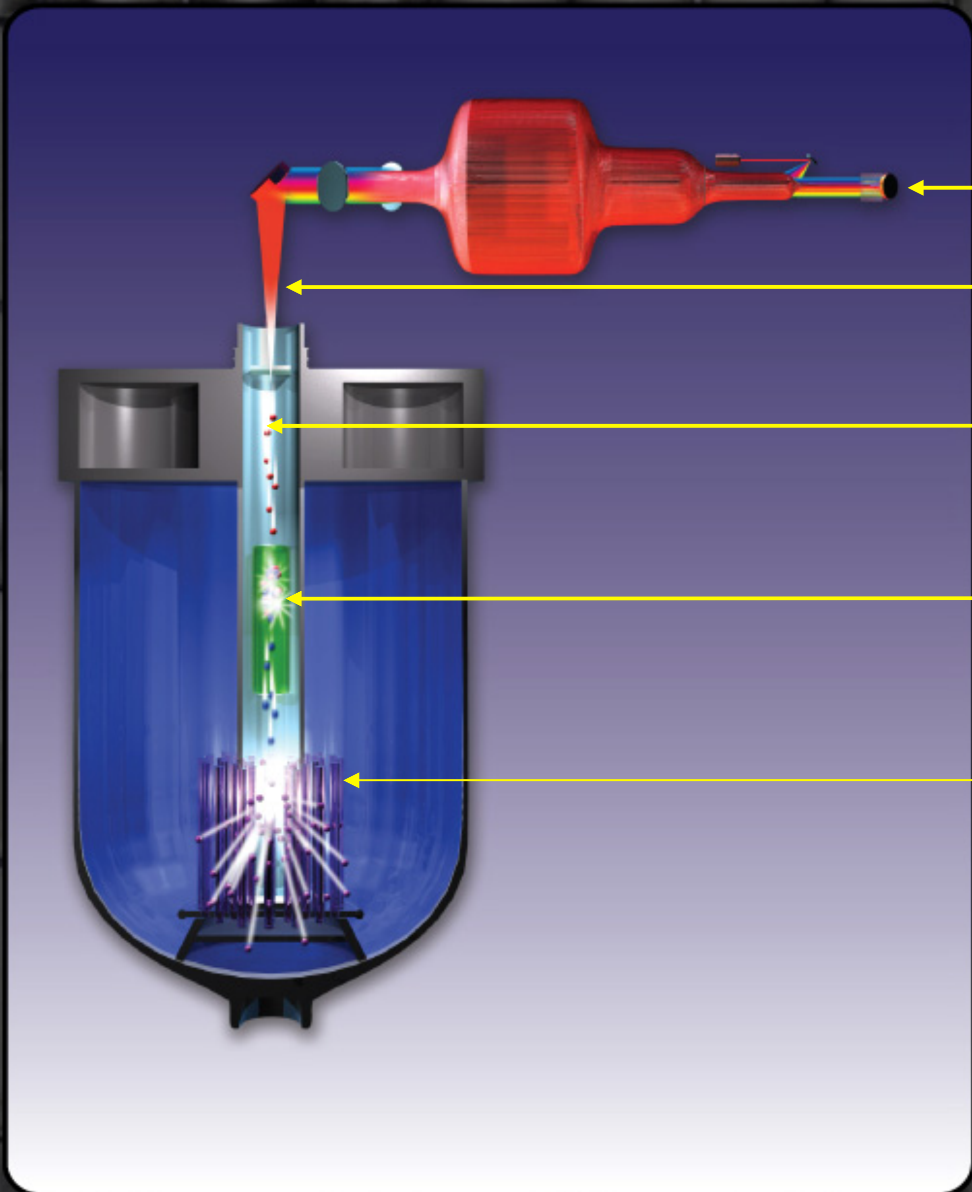
Example

^{99}Tc (Technetium) half-life of 200 000 years

^{100}Tc half-life16s decays to a stable ^{100}Ru (Ruthenium)



The Transmutation Concept



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Conclusion

Extreme Light can become a new Paradigm in Subatomic Science and Application

Scientific Applications

Vacuum Physics, Vac. Polarization,

Materialization of Light

High Energy Physics Beyond the Standard Model(TeV/cm)

*Laser Astrophysics and Cosmology**(Table Top Cosmos**)*

Higgs Factory

Dark Matter

Societal Applications

Transmutation of Nuclear Waste

Under Critical Reactor

Nuclear Pharmacology

ProtonTherapy

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Thank you

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