CLEO
San Jose
May 10, 2012

Exawatt-Zettawatt Laser-Based Fundamental High Energy Physics

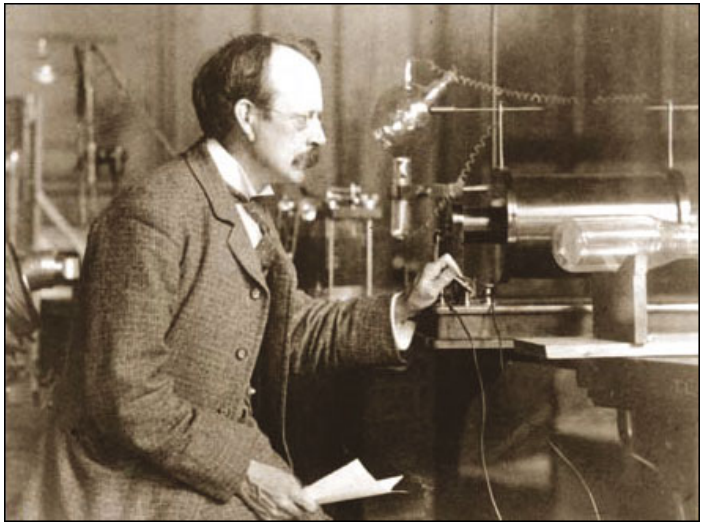
T. Tajima and G. Mourou
IZEST

Acknowledgments for Collaboration: W. Leemans, K. Nakajima, K. Homma, P. Bolton, M. Kando, S. Bulanov, T. Esirkepov, J. Koga, F. Krausz, D. Habs, B. LeGarrec, C.. Barty, D. Payne, H. Videau, P. Martin, W. Sandner, A. Suzuki, M. Teshima, R. Assmann, R. Heuer, A. Caldwell, S. Karsch, F. Gruener, M. Somekh, J. Nilsson, W. Chou, F. Takasaki, M. Nozaki, D. Payne, A. Chao, J.P. Koutchouk, Y. Kato, E. Goulielmakis, X. Q. Yan, C. Robilliard, T. Ozaki, J. Kieffer, N. Fisch, D. Jaroszynski, A. Seryi, T. Kuehl, H. Ruhl, C. Klier, Y. Cao, B. Altschul, T. Seggebrock, K. Kondo, H. Azechi, K. Mima, H. Takabe, A. Ereditato, D. Autiero, M. Yoshida, T. Massard

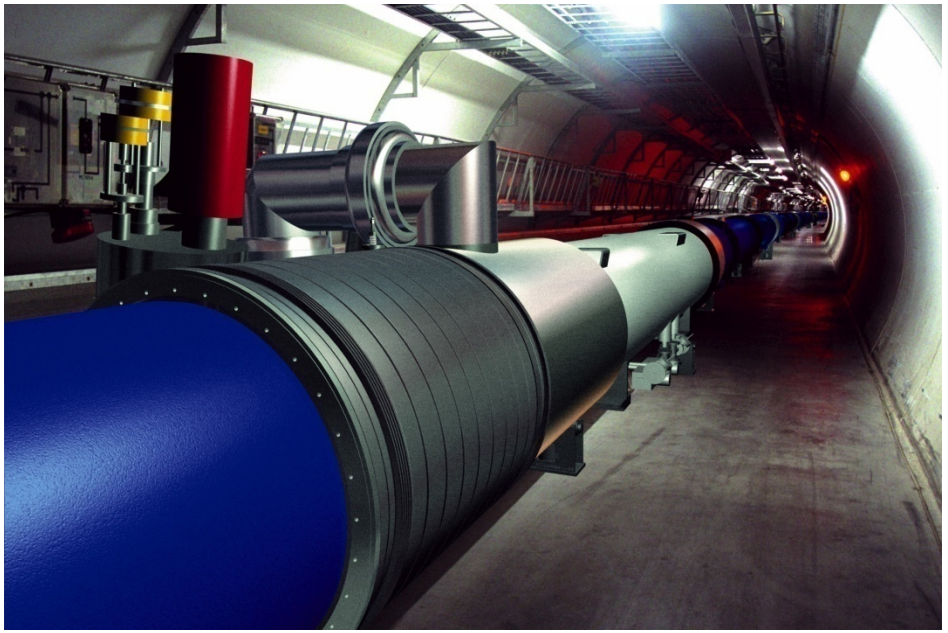
1. Cultivate the frontiers: Exawatt laser toward fundamental physics
2. High energy frontier: compact laser accelerator
   sub-TeV and beyond with EW
   toward LWFA collider at low density regime at *IZEST* (PETAL laser)
3. New compression technique at EW regime:
   Cascaded Compression Conversion (C^3) method
   plasma (instead of solid) as compressor in ultrahigh power regime
4. High average and high efficiency laser at high intensity:
   fiber laser technology
   = CAN (Coherent Amplification Network)
5. *IZEST* missions:
   fundamental physics with high intensity lasers in the world network
   deployment of kJ laser (PETAL etc.) toward EW
   development of 10kW (and beyond) intense laser

IZEST

20th Century, the Electron Century
Basic Research Dominated by
Massive and Charged Particles (electronics)



J. J. Thomson



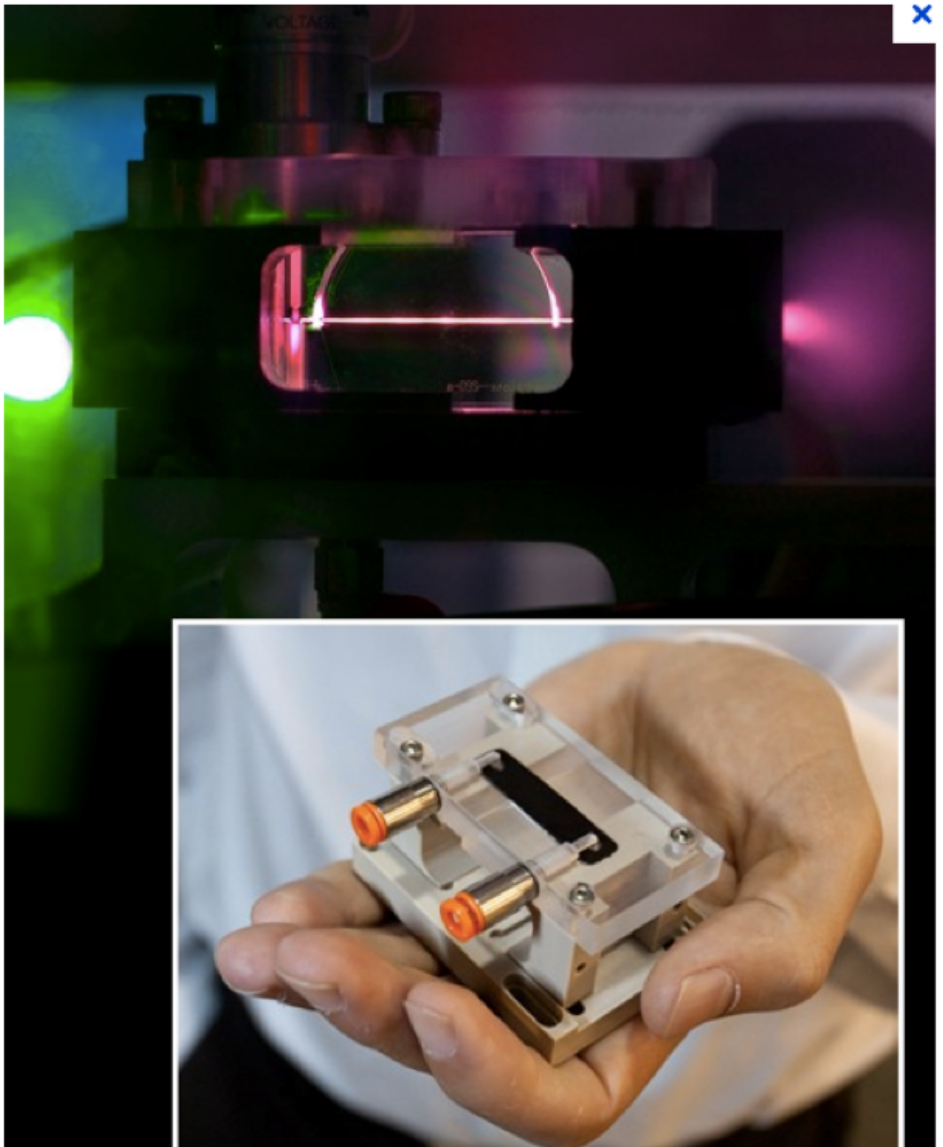
IZEST

21st Century; the Photon Century
Could basic research be driven
by the massless and chargeless particles;
Photons (photonics)?

C. Townes

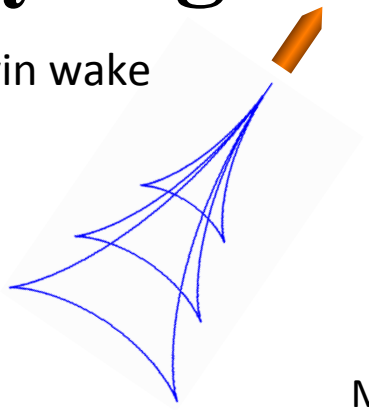
GeV in the Palm

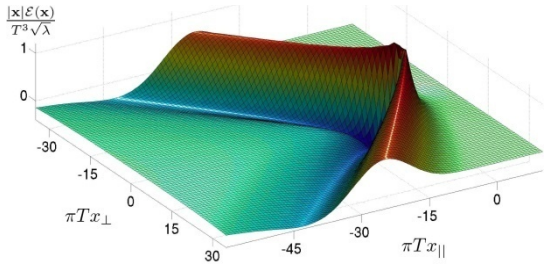
First GeV on few cm
(W. Leemans et al)



Laser Wakefield (LWFA): relativity regulates

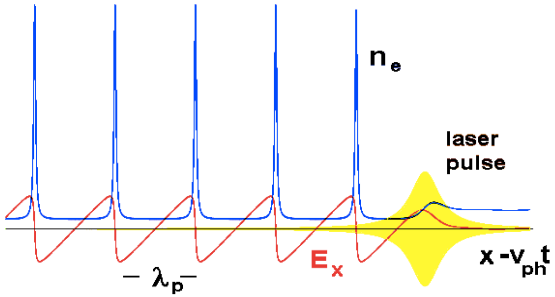
Kelvin wake





Maldacena (string theory) method:
QCD **wake** (Chesler/Yaffe 2008)

No wave breaks and wake **peaks** at v≈c



(The density cusps.
Cusp singularity)

← relativity regularizes

Wave **breaks** at v＜c

Hokusai

Maldacen

(Plasma physics vs.
superstring theory)

Density scalings of LWFA for collider

Accelerating field E_z	$\propto n_e^{1/2}$
Focusing constant K	$\propto n_e^{1/2}$
Stage length $L_{\rm stage}$	$\propto n_e^{-3/2}$
Energy gain per stage $W_{\rm stage}$	$\propto n_e^{-1}$
Number of stages $N_{\rm stage}$	$\propto n_e$
Total linac length $L_{\rm total}$	$\propto n_e^{-1/2}$
Number of particles per bunch N_b	$\propto n_e^{-1/2}$
Laser pulse duration τ_L	$\propto n_e^{-1/2}$
Laser peak power P_L	$\propto n_e^{-1}$
Laser energy per stage U_L	$\propto n_e^{-3/2}$
Radiation loss $\Delta\gamma$	$\propto n_e^{1/2}$
Radiative energy spread σ_γ/γ_f	$\propto n_e^{1/2}$
Initial normalized emittance ε_{n0}	$\propto n_e^{-1/2}$
Collision frequency f_c	$\propto n_e$
Beam power P_b	$\propto n_e^{1/2}$
Average laser power $P_{\rm avg}$	$\propto n_e^{-1/2}$
Wall plug power $P_{\rm wall}$	$\propto n_e^{1/2}$

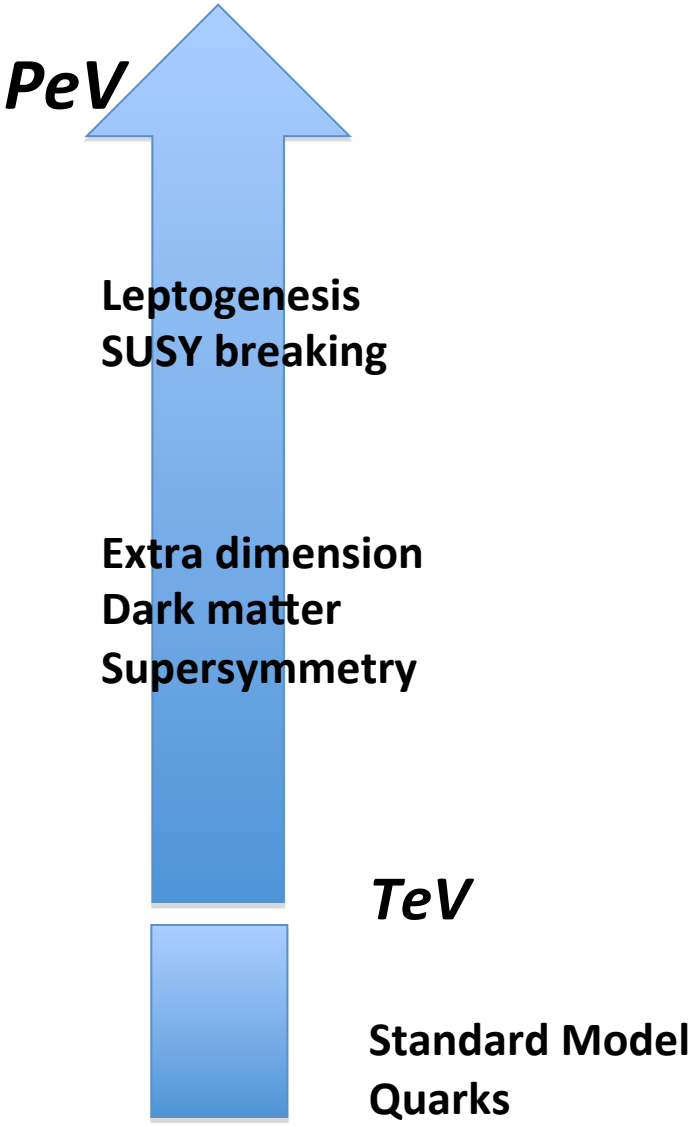
(Nakajima, PR STAB, 2011)

10^{17} /cc (conventional) → 10^{15} /cc

IZEST's Mission: Responding to Suzuki's Challenge

Atsuto Suzuki:
KEK Director General,
former ICFA Chair

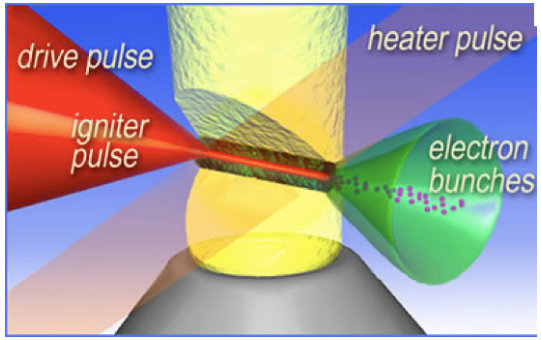
New Paradigm



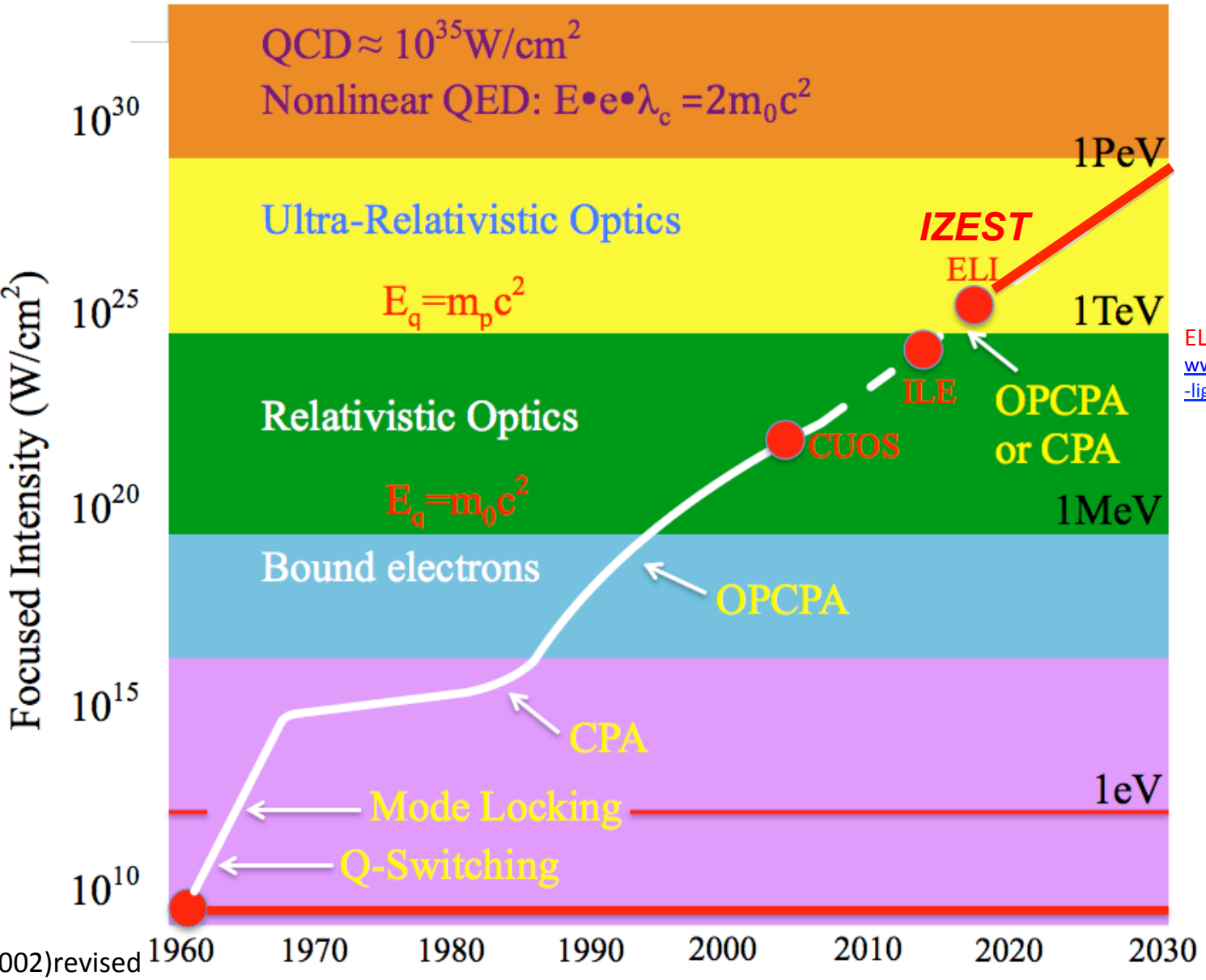
PeV Accelerator

With conventional Technology
The accelerator would Girdle the Earth:
Fermi's vision (1954)

1km laser Plasma accelerator
with LIL or PETAL/LMJ
(Vision 2011)



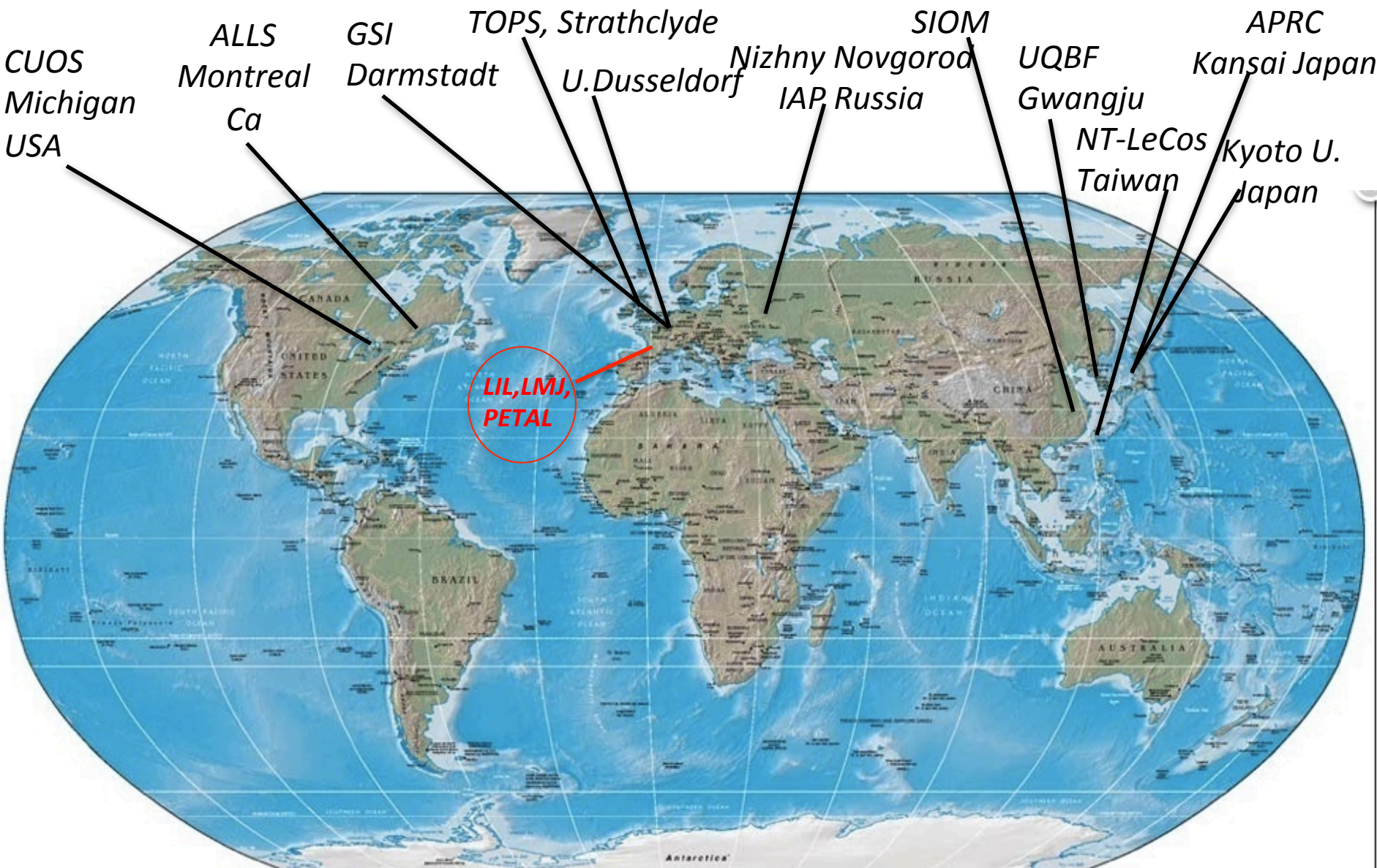
Laser Intensity vs. Years



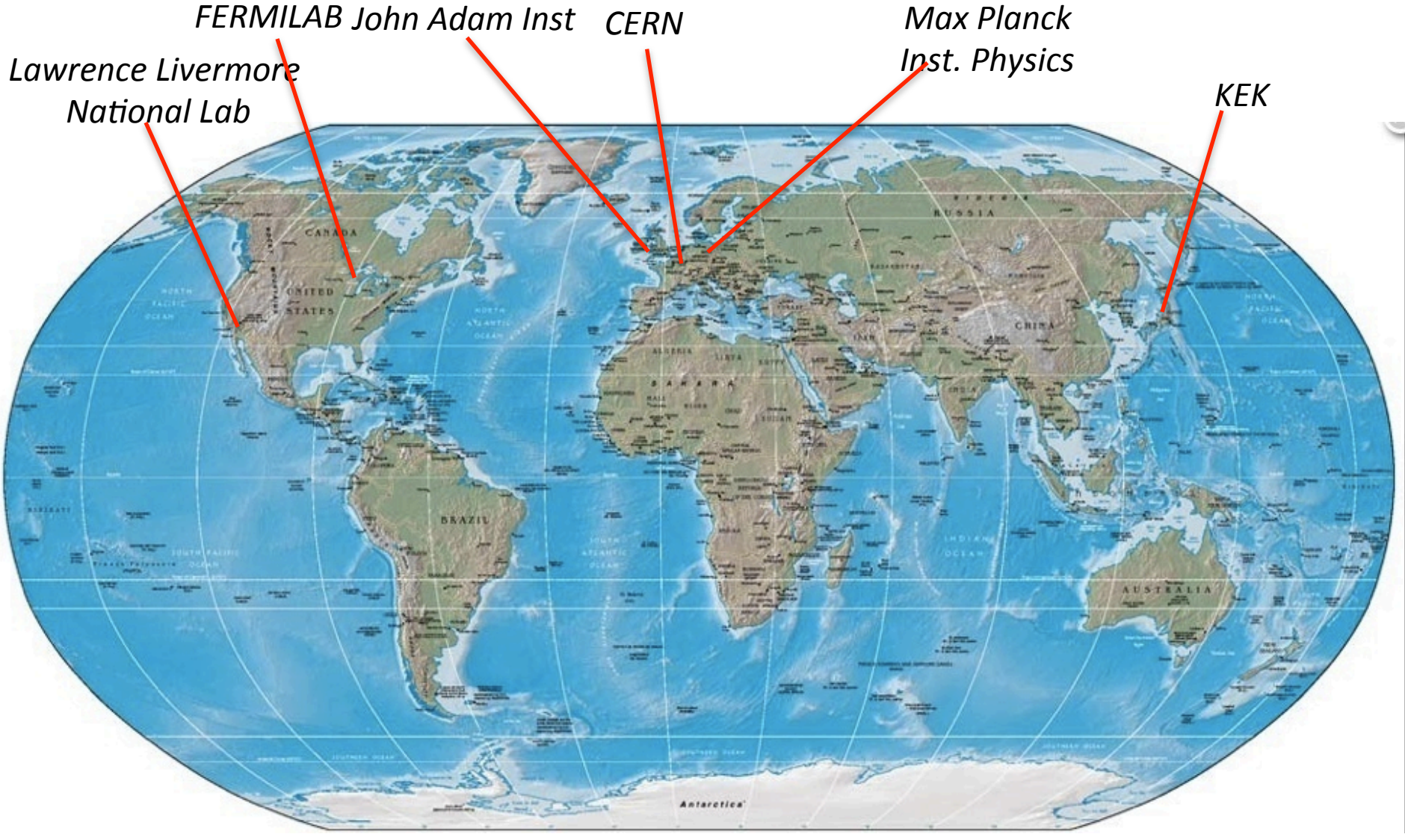
ELI : www.extreme-light-infrastructure.eu/

Tajima and Mourou (2002)revised

IZEST Associate Laboratories



IZEST Support Laboratories



IZEST's Missions

- An international endeavor to unify the high Intensity laser and the high energy / fundamental physics communities to draw

"The Roadmap of Ultra High Intensity Laser"
and apply it to
"Laser-Based Fundamental Physics"

- To form an international team of scientists that can foster and facilitate scientific missions of EW/ZW class lasers comprised from ICFA and ICUIL communities (in collab)

See more:
www.int-zest.com/

Also: Tajima and
Mourou PR STAB(2002)

CEA kJ and MJ lasers underpin *IZEST* missions

PETAL : Main characteristics (One arm of LMJ)

- **Energy > 3 kJ*,**
- **Wavelength > 1053 nm,**
- **Pulse duration between 0,5 and 10 picoseconds,**
- **Intensity on target > 10^{20} W/cm^2,**
- **Intensity contrast (short pulse): 10^{-7} at -7 ps,**
- **Energy contrast (long pulse): 10^{-3}.**

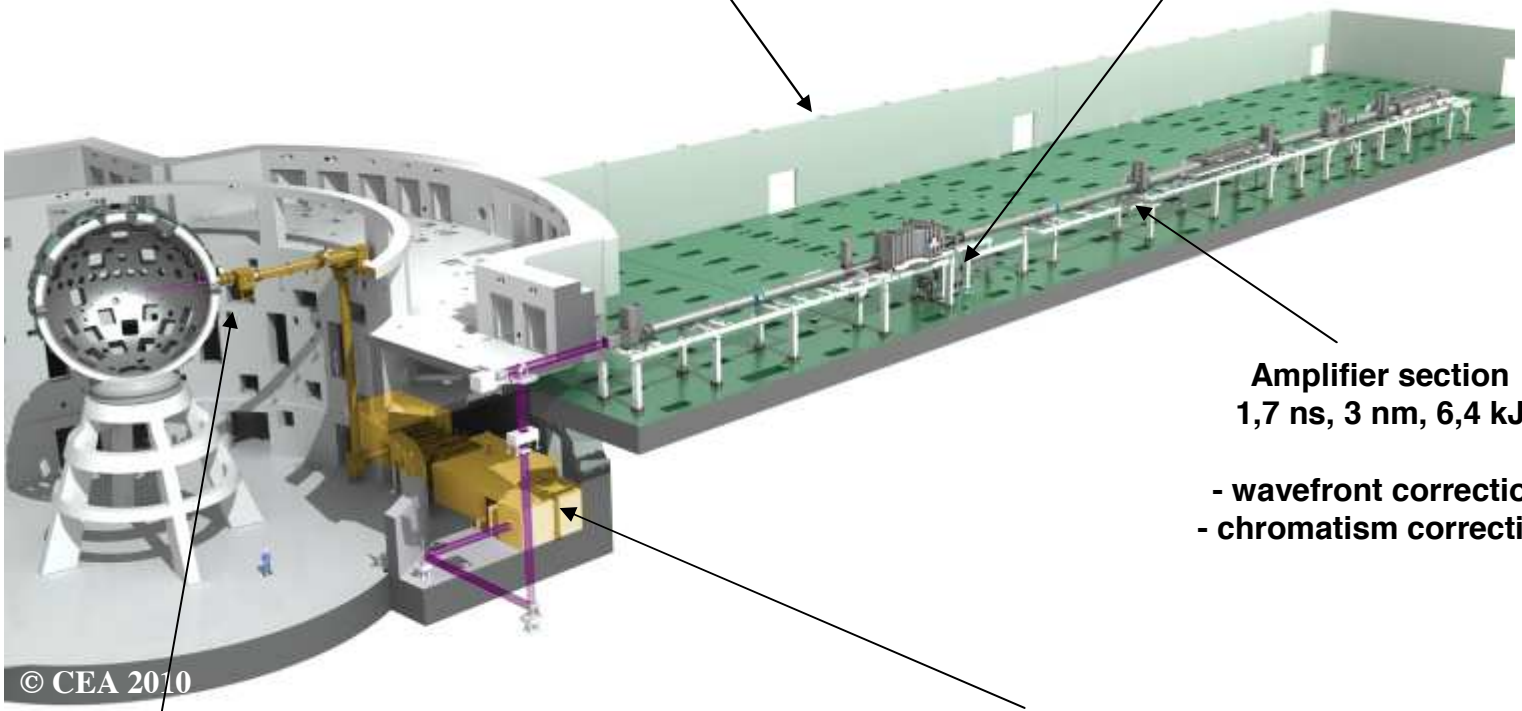
B. LeGarrec (2011)

IZEST

PETAL in the LMJ Building

Front end (oscillator, Offner)
100 fs → 9ns, 16 nm

Preamplifier Module PAM (OPCPA)
4,5 ns, 8 nm, 100 mJ



Amplifier section
1,7 ns, 3 nm, 6,4 kJ

- wavefront correction
- chromatism correction

Transport / Focusing section: (vacuum)
10^{20} W/cm²

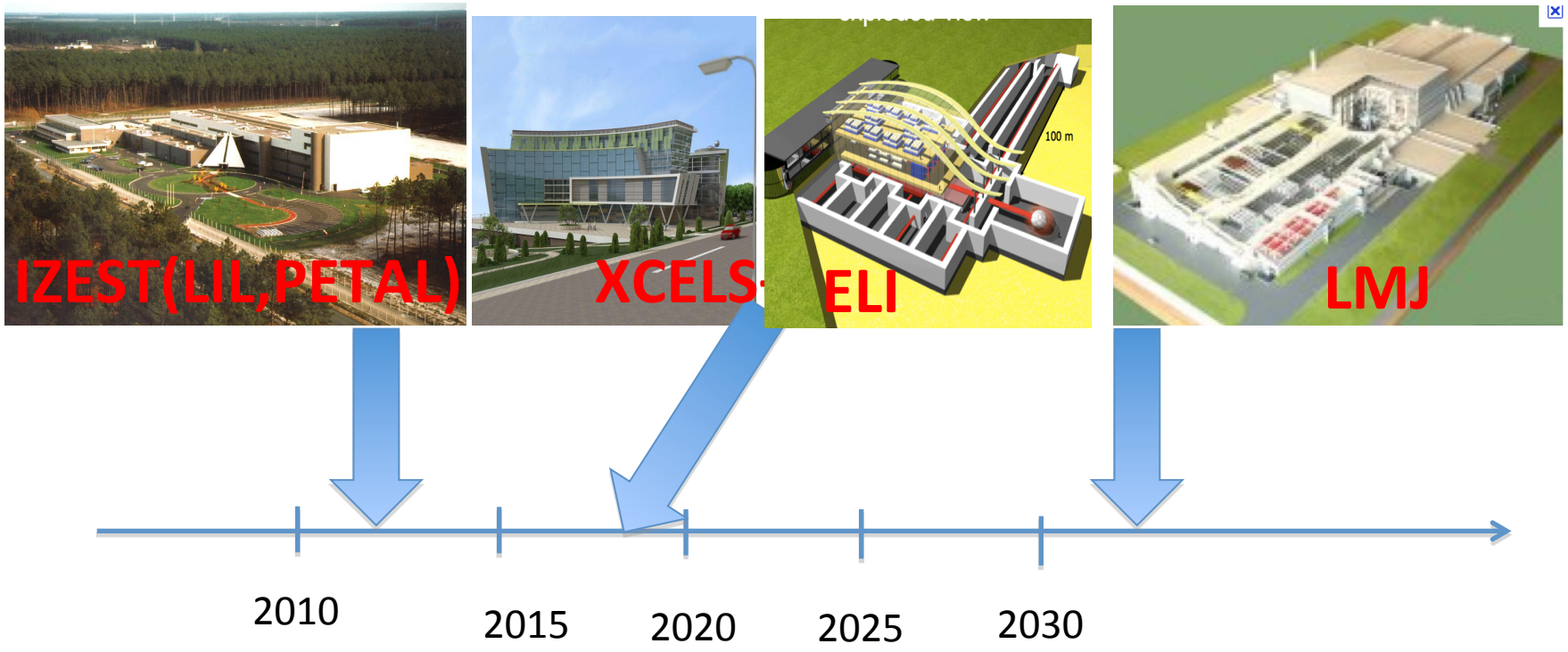
- pointing mirror after parabola
- 90° off-axis parabola

Compression section: 2 stages (air & vacuum)
500 fs, 3 kJ

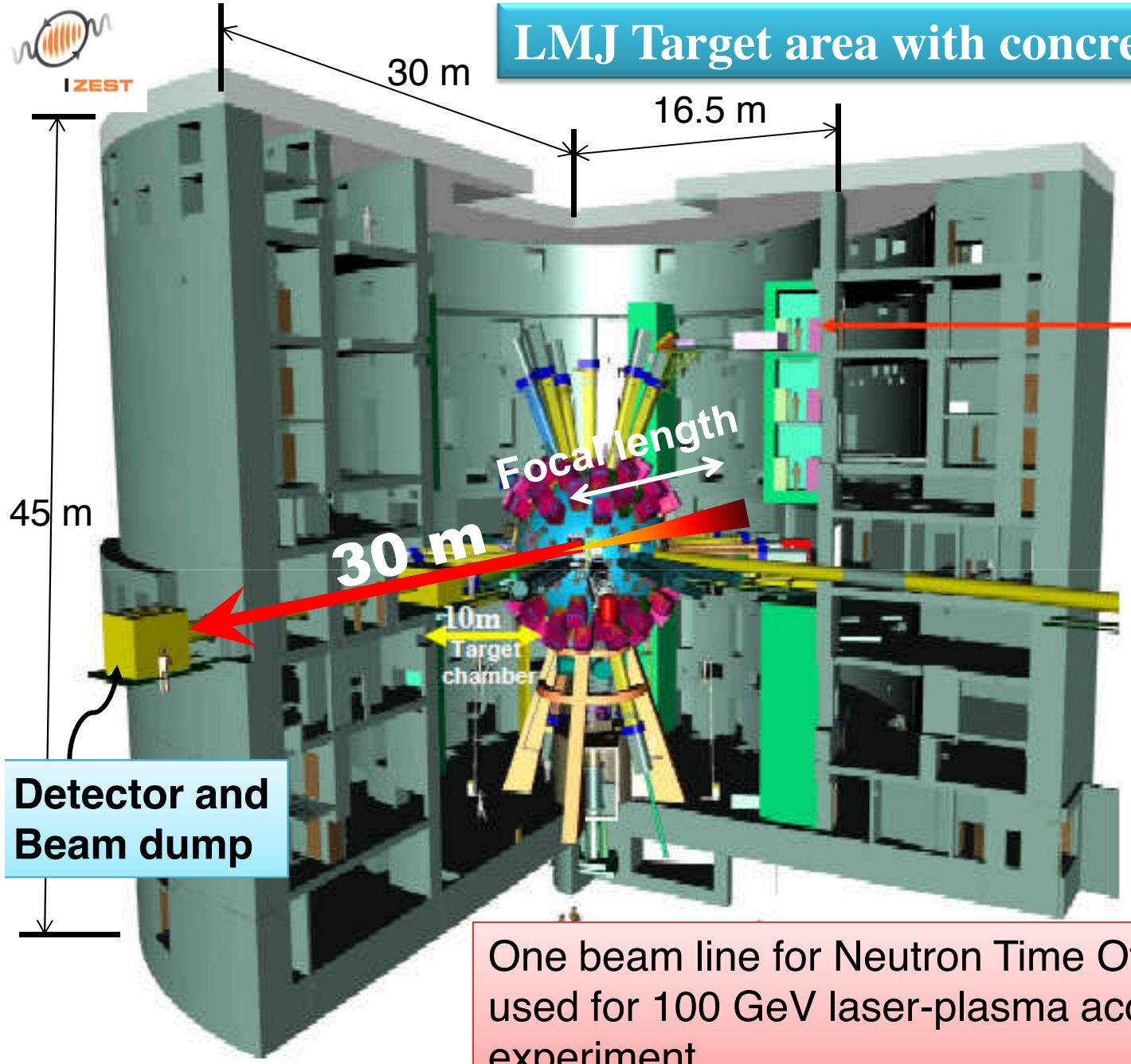
- wavefront correction (gratings deformation)
- beam phasing instead of mosaic gratings

LeGarrec (2011)

Laser-Based High Energy and Fundamental Physics: *Exawatt to Zettawatt*



LMJ Target area with concrete shielding

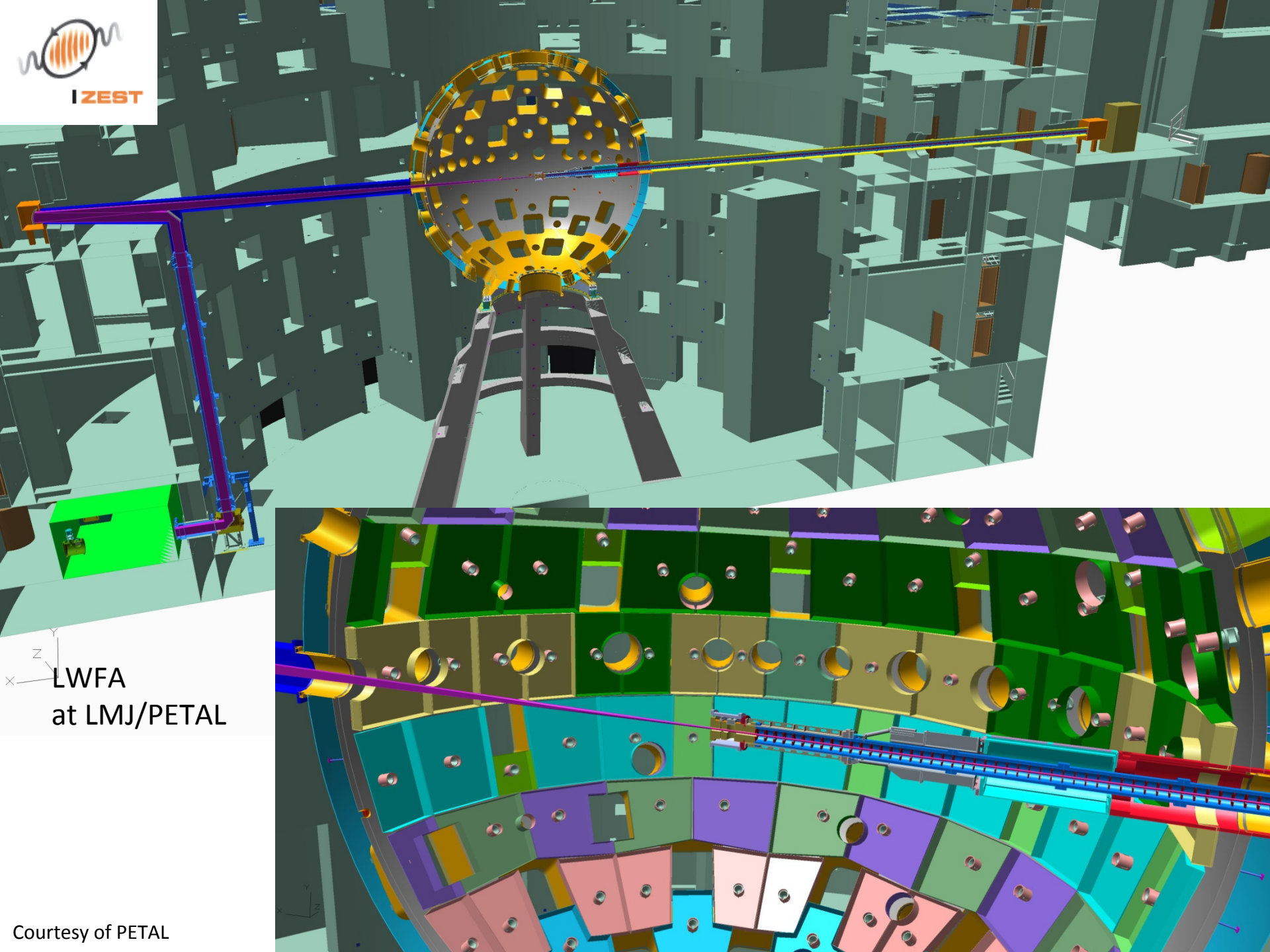


First Workshop on 100GeV IZEST Project:
May 31-June 1, '12
@ Bordeaux

One beam line for Neutron Time Of Flight is used for 100 GeV laser-plasma accelerator experiment.

Nakajima, LeGarrec

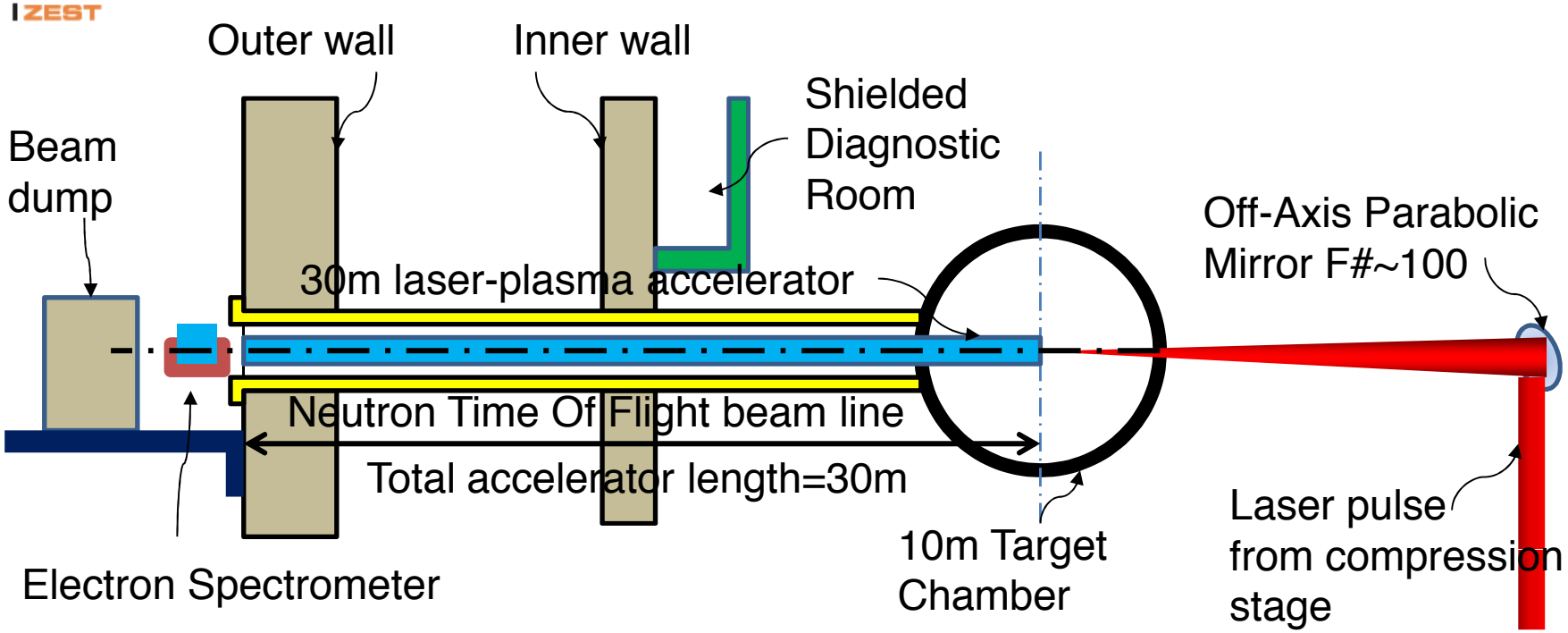
Courtesy of PETAL



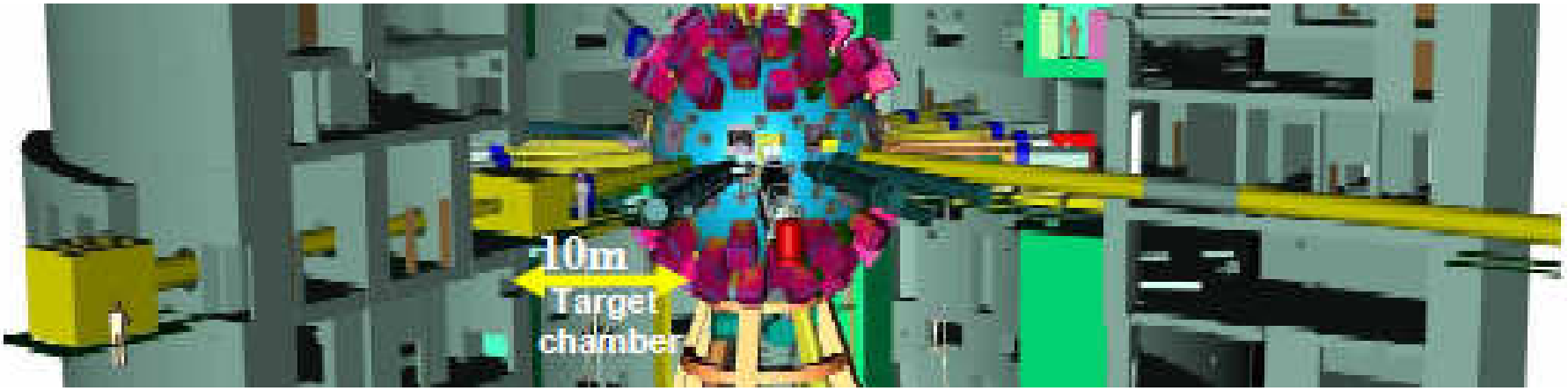
LWFA
at LMJ/PETAL

Courtesy of PETAL

A setup design for 100 GeV Laser-Plasma Electron Acceleration



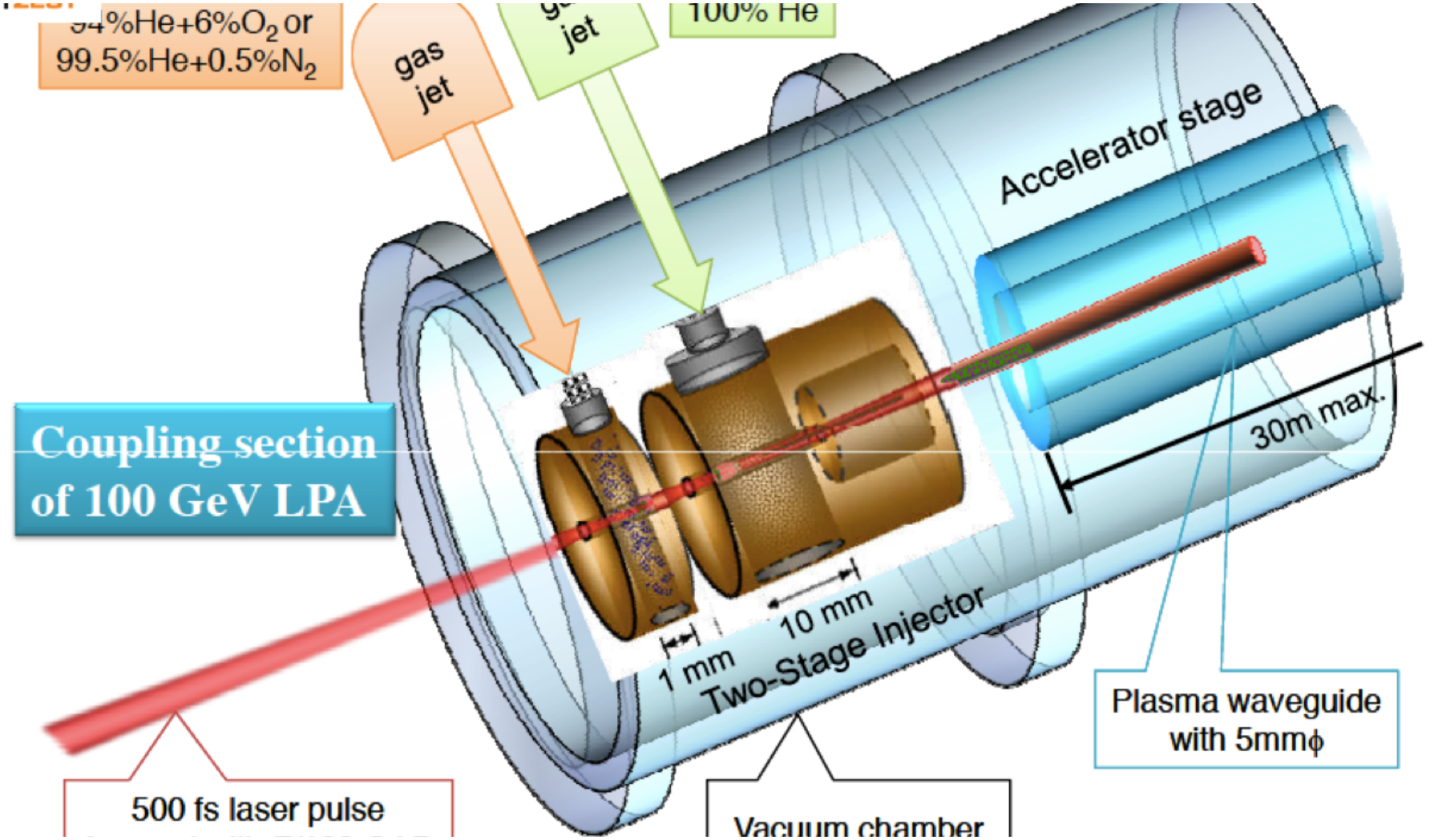
A view of equatorial level of LMJ target chamber



Le Garrec, Nakajima (2012)

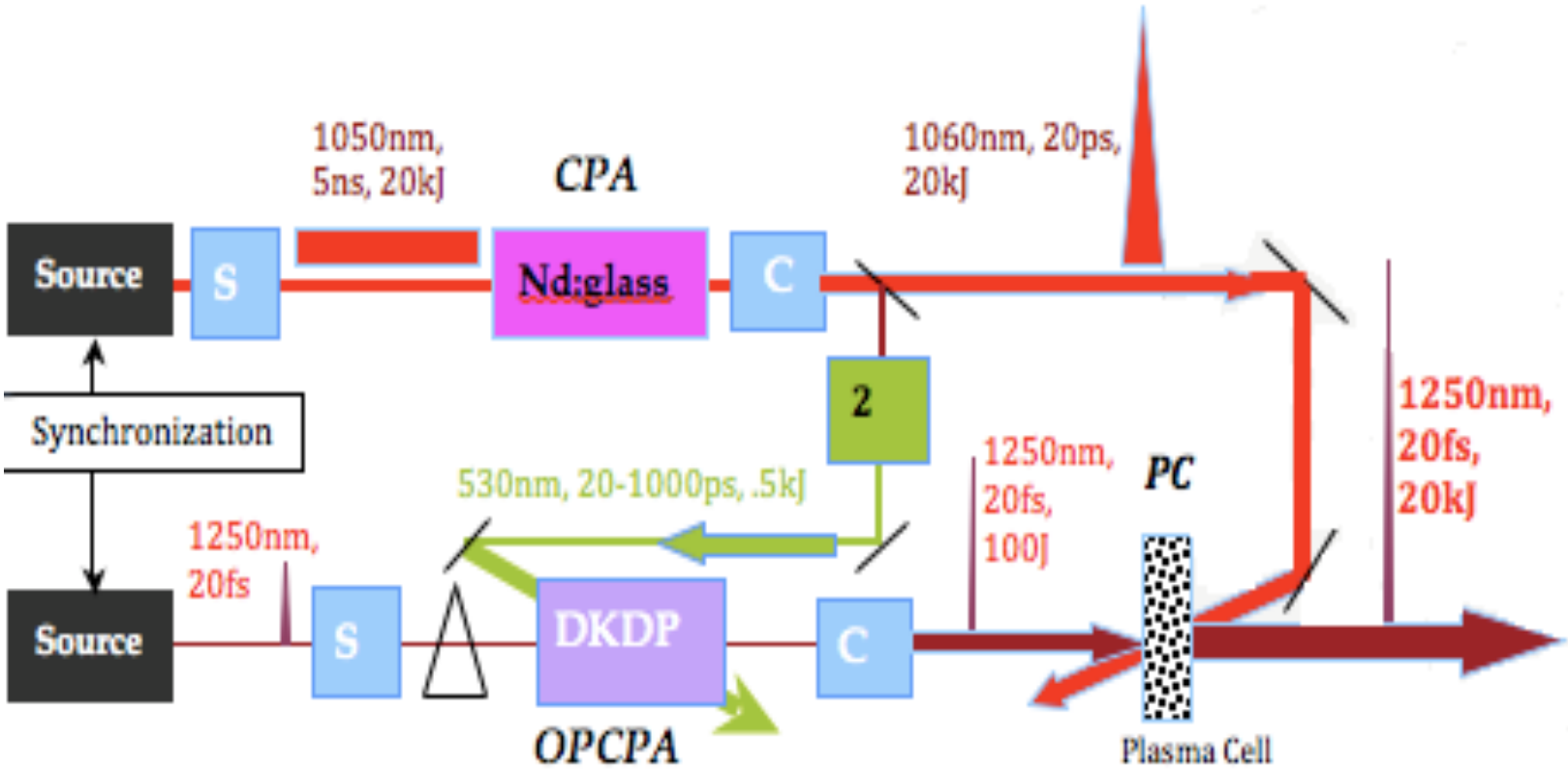
Courtesy of PETAL

Laser coupling section detail: LWFA in PETAL



New Laser Concept C³

(Cascaded Compression Conversion) to achieve intensity > 10^{23} W/cm²



G. Mourou et al. Opt. Comm.(2012)

Plasma Optics

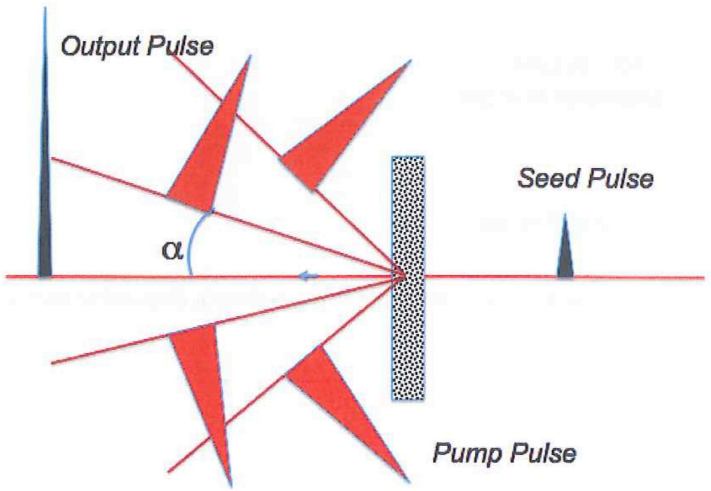
C^3 results from the cascaded actions of the three basic techniques,
CPA, OPCPA, and Plasma Compression(PC).

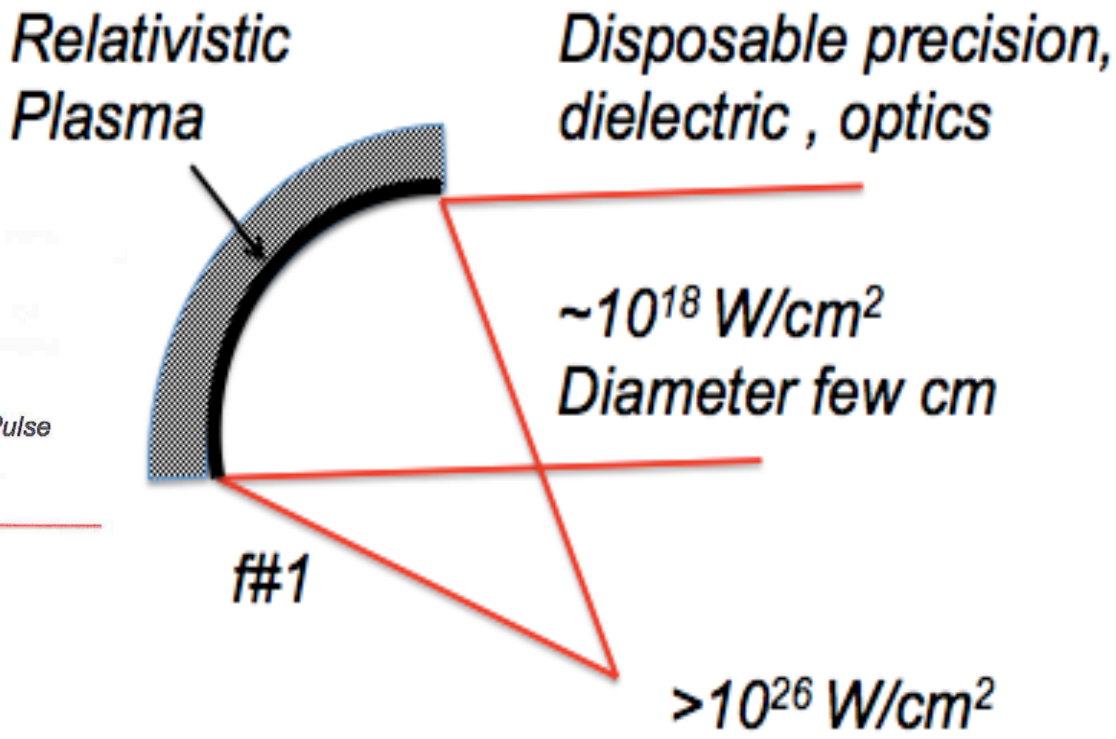
Optics can handle several **kJ/cm²**.

Size reduction by1000 in area.

Disposed after each shot.

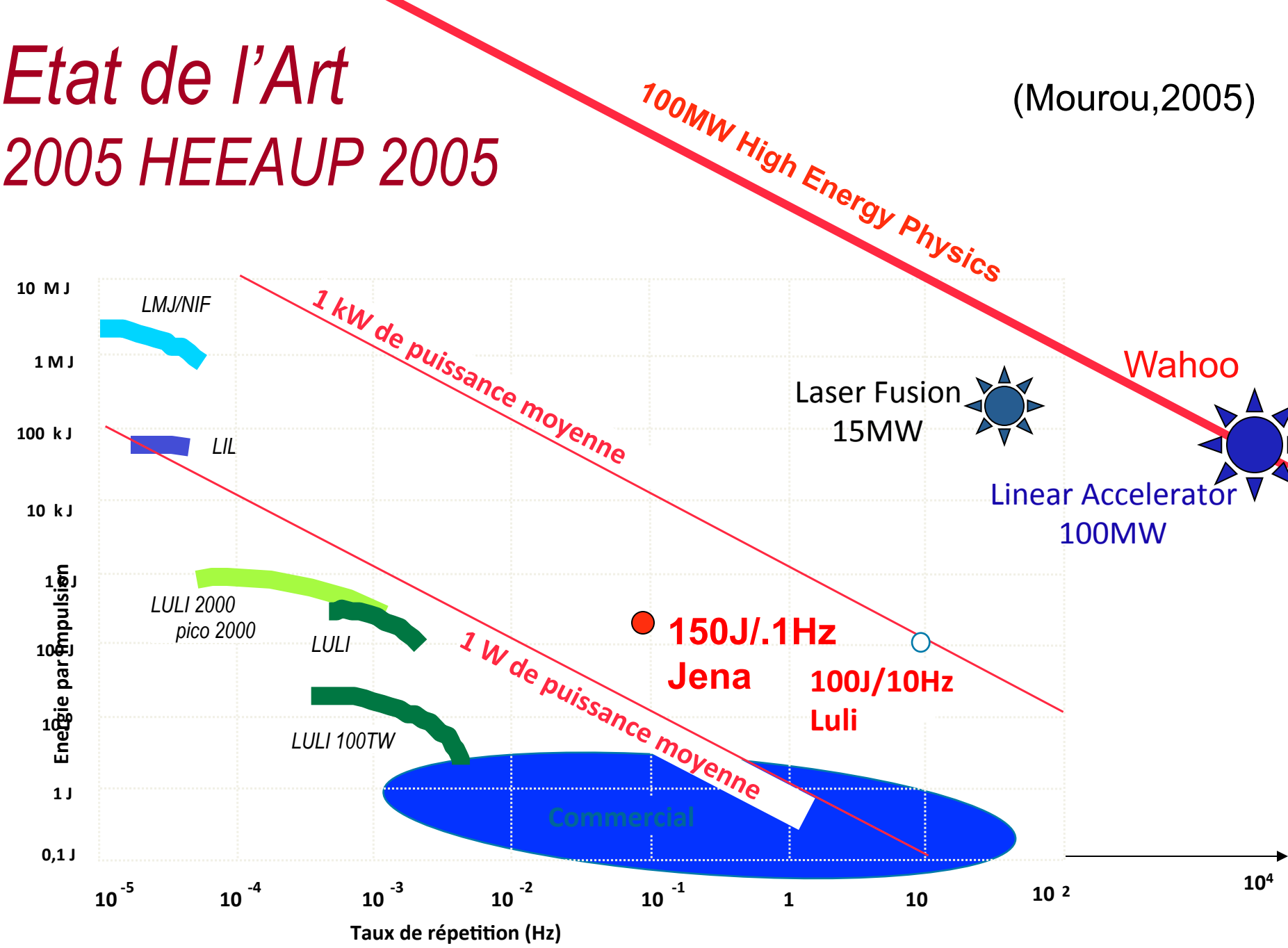
Mourou et al. Opt. Comm (2012)





Etat de l'Art
2005 HEEAUP 2005

(Mourou,2005)



Toward high-average power efficient HEP driver laser

(laser community, HEP community, and plasma community)

ICAN, International Coherent Amplification Network

"Solving the efficiency problem in high peak and high average power laser: an international effort"

EU funded ***ICAN***(January, 2012)

European Commission

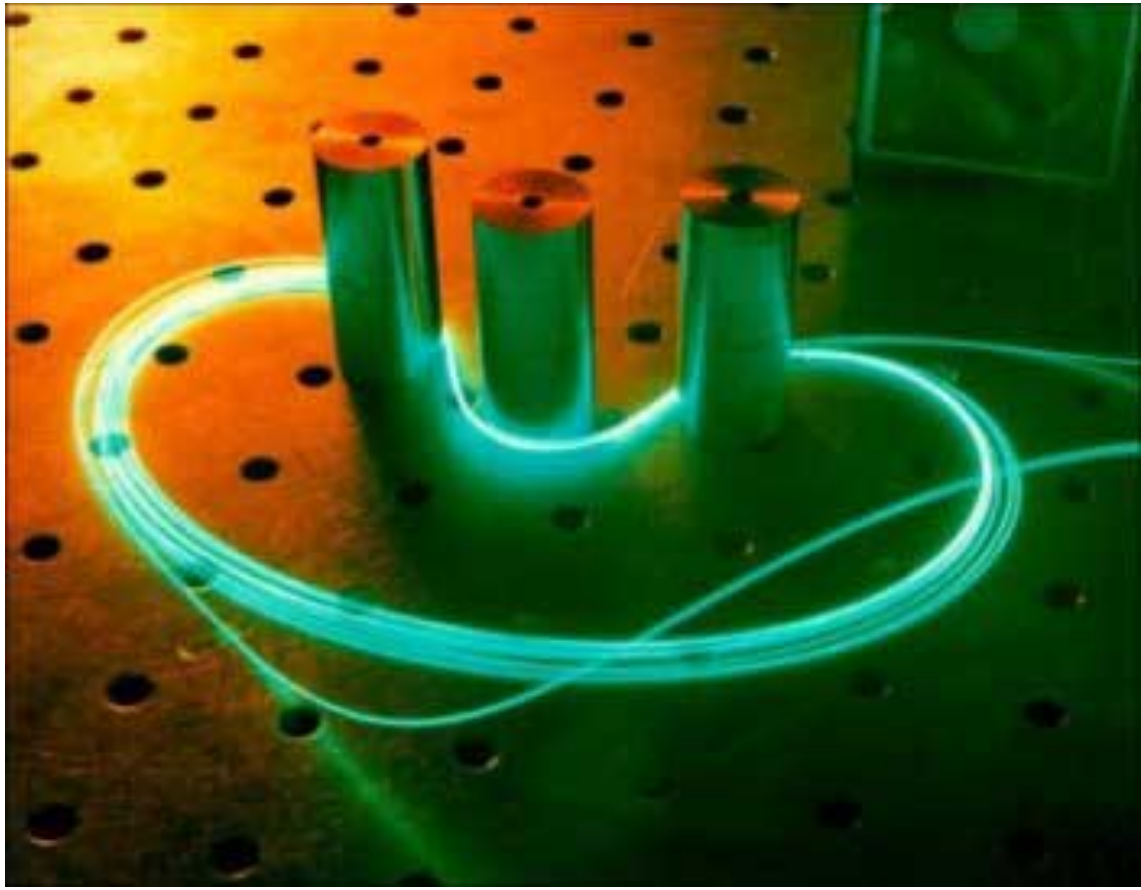
ICAN and FP7

The cold "facts and figures"

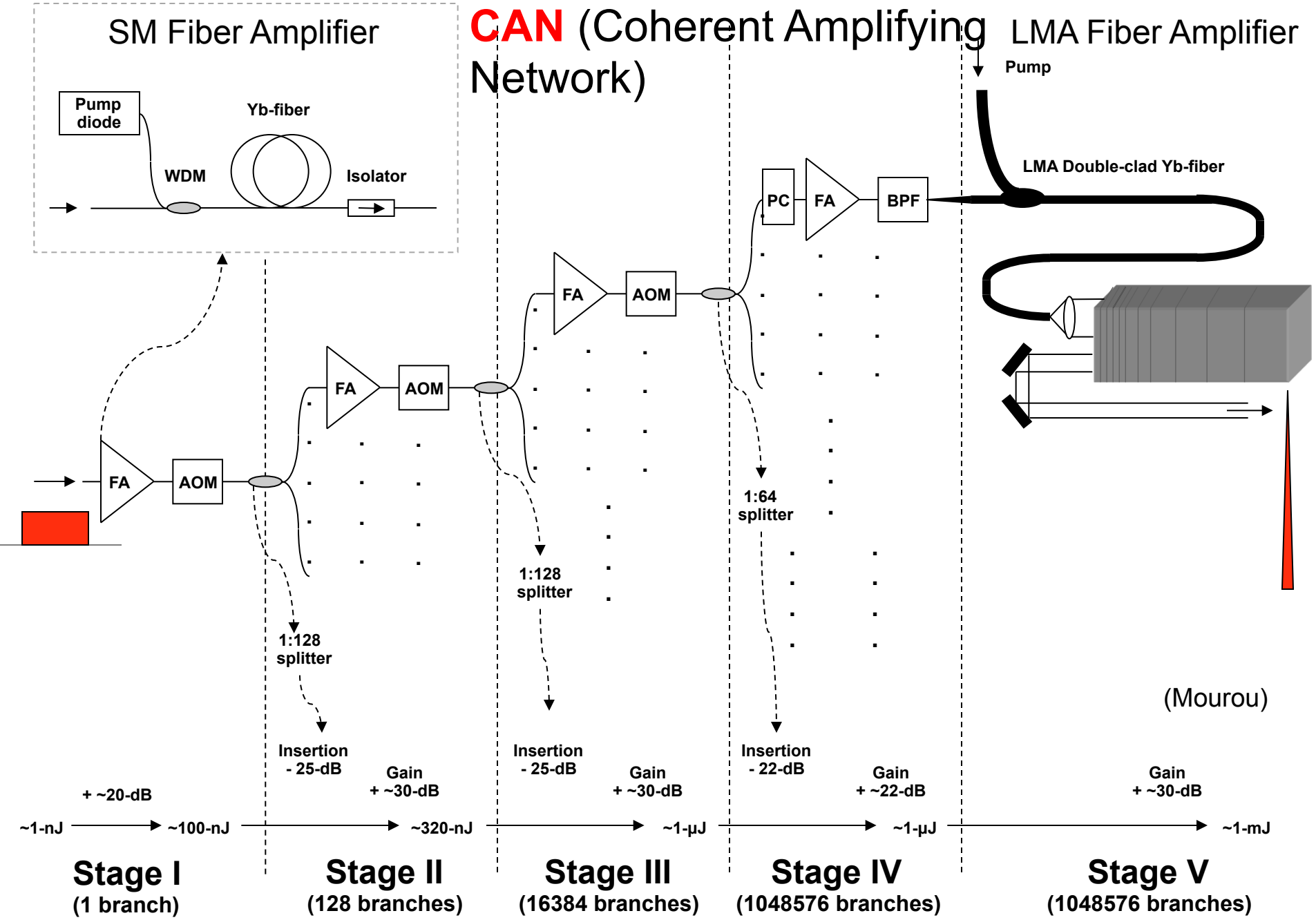
- ICAN — International Coherent Amplification Network
- In "FP7 language", ICAN is a support action responding to a year 2011 call for proposals to *support policy development, including international cooperation, in its field of S & T*
- It was assigned the project number 284437
- It will last 18 months as from 16 January 2012
- The maximum EU contribution is EUR 500,000.00
- 4 beneficiaries form the Consortium

Fiber vs. Bulk Lasers

- High Gain fiber amplifiers allow ~ 40% total plug-to-optical output efficiency
- Single mode fiber amplifier have reached multi-kW optical power.
- large bandwidth (100fs)
- immune against thermo-optical problems
- excellent beam quality
- efficient, diode-pumped operation
- high single pass gain
- mass-produced at low cost.

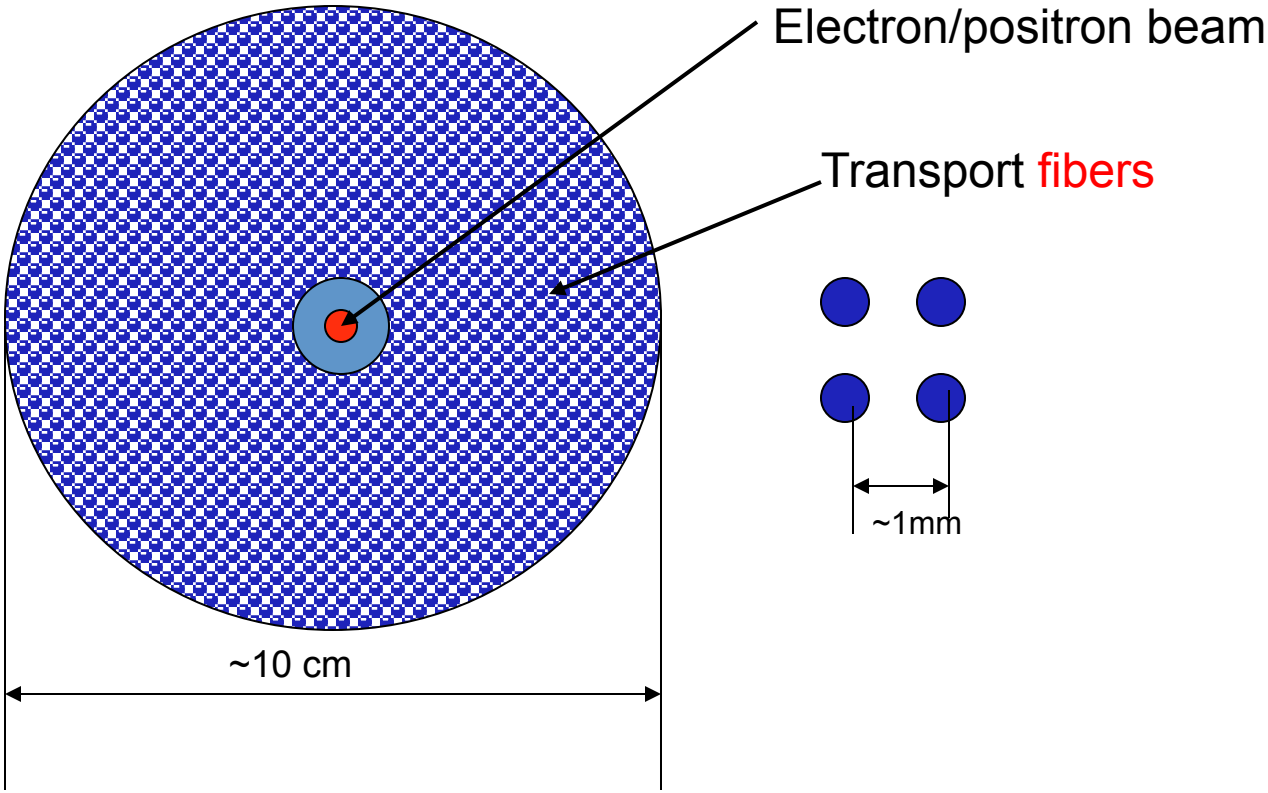


(G. Mourou)


SM Fiber Amplifier
Pump diode
Yb-fiber
WDM
Isolator
CAN (Coherent Amplifying Network)
LMA Fiber Amplifier
Pump
LMA Double-clad Yb-fiber
PC
FA
BPF
AOM
1:64 splitter
1:128 splitter
1:128 splitter
Insertion - 25-dB
Insertion - 25-dB
Insertion - 22-dB
(Mourou)
+ ~20-dB
Gain + ~30-dB
Gain + ~30-dB
Gain + ~22-dB
Gain + ~30-dB
~1-nJ
~100-nJ
~320-nJ
~1-µJ
~1-µJ
~1-mJ
Stage I
(1 branch)
Stage II
(128 branches)
Stage III
(16384 branches)
Stage IV
(1048576 branches)
Stage V
(1048576 branches)

Concept: coherent fiber bundles

Because the transport fibers lossless, assembled in a bundle just before the focusing optics.
all coherently phased.



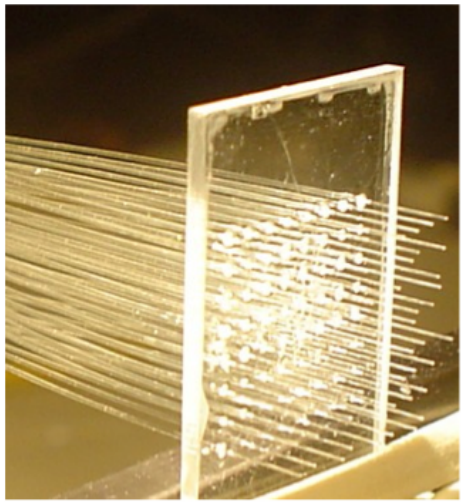
Length of a fiber ~5m Total fiber length~ 5 10^4km

(Mourou et al)

64 fiber alignment

64 Fiber Mock up

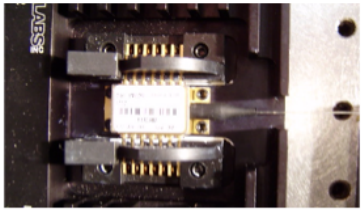
- Insertion des fibres
  - Insertion des 64 fibres, alignement PM (° près), collage
  - Polissage collectif de la surface de sortie des fibres

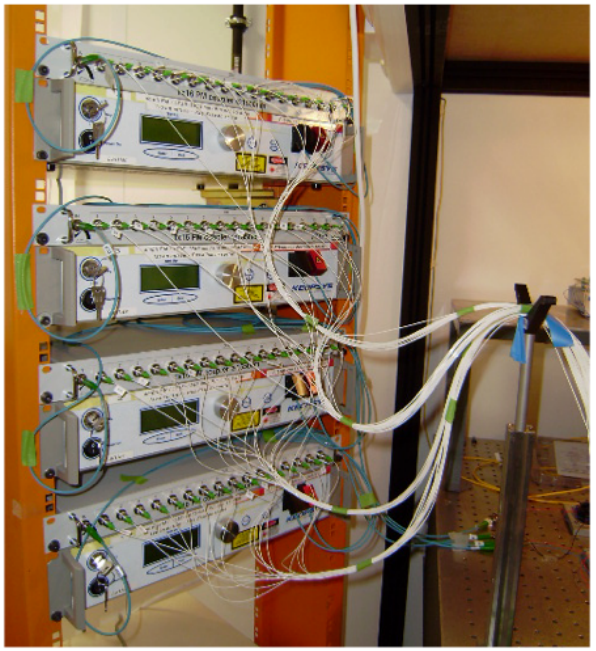


- Composant intégré pour le maintien des fibres

64 fiber coupling

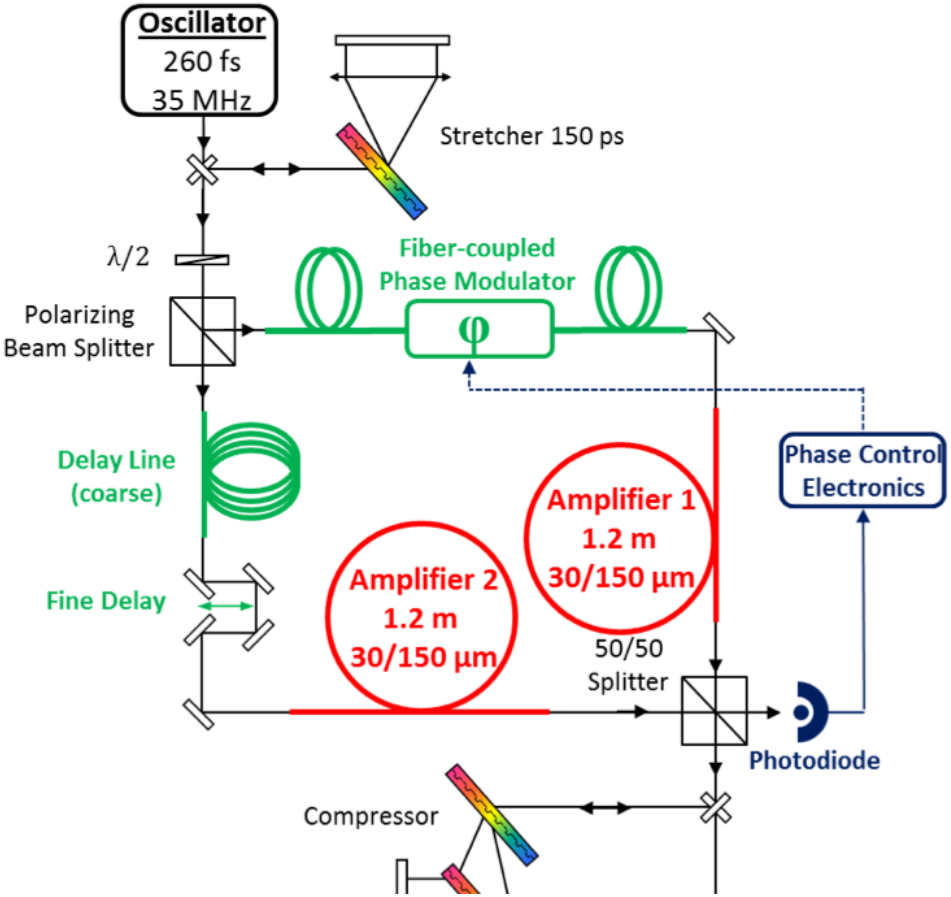
- Génération de 64 faisceaux fibrés





Efficient Amplification of Fiber Laser

In the femtosecond



Combining efficiency > 90%

INSTITUT d'OPTIQUE GRADUATE SCHOOL

L. Daniault, M. Hanna, L. Lombard, D. Goular, P. Bourdon, F. Druon, P. Georges
"Coherent combining of two femtosecond fiber chirped pulse amplifiers"
Oral : Advanced Solid State Photonics, ASSP 2011, Istanbul, Turkey (February 13-16 2011)

Accepted: Optics Letters, L. Daniault et al,
« Coherent beam combining of two femtosecond fiber chirped pulse amplifiers »

Broad applications of high-average Power Fiber Lasers

PW/>10kW/ 10J/kHz/20% efficient

- ***Preliminary conclusion. Design a demonstrator highly relevant to science, engineering that will put europe in leadership position, benefit the industry. It will include 10^4 fibers:***

  >10J, >1kHz, >20% efficient(>10kW capable to produce 10GeV electrons, GeV protons).

- ***Such an infrastructure could validate:***

  1. TeV laser collider concept

  2. Free Electron Laser in the High X-ray regime comparable to LCLS-SLAC but at >1kHz and much more compact.

  3. X-ray, Gamma ray

  4. Proton therapy

  5. Laser Fusion (No need for cophasing)

  6. B-Factory and such.

  6. And the « Summum Bonum »; Accelerator Driven Reactor(ADR)

Conclusions

- GeV electrons in a palm by LWFA
- kJ-MJ energy lasers (such as PETAL) : TeV in low density regime
- *IZEST* with PETAL laser launches 100GeV project ("IZEST 100GeV Ascent Workshop" in Bordeaux, May31-June1, 2012)
- *IZEST* mixes the communities of laser and high energy physics
- *IZEST* develops EW laser system with C^3 amplification
- *ICAN* project launched for high-average power laser technology
- New vigorous way of doing fundamental physics with intense lasers emerging

Crab nebula:
Cosmic PeV accelerating machine

Thank you!