Munich-Centre for Advanced Photonics
Ludwig Maximilians Universitaet, Physik Fakultaet Hoersaal
Garching
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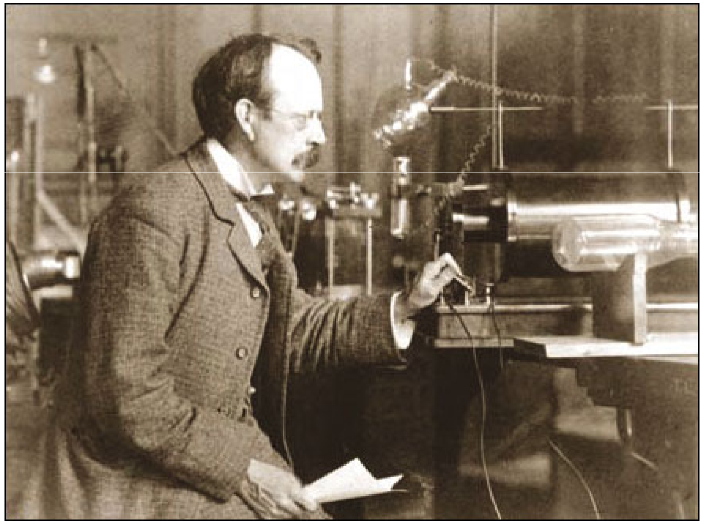
High Field Science Frontier

T. Tajima
LMU and IZEST

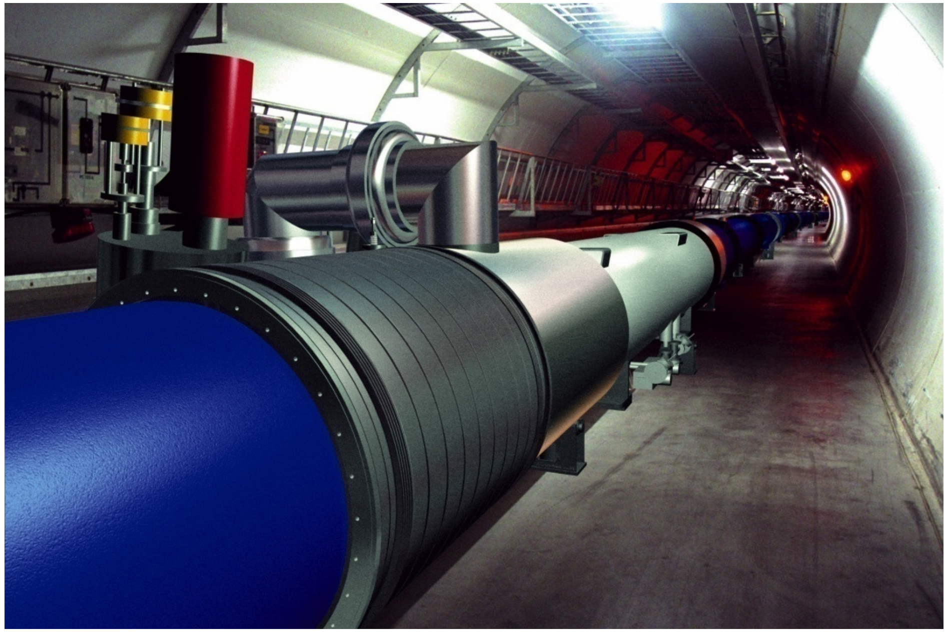
Acknowledgments for Collaboration: G. Mourou, , F. Krausz, T. Ostermayr, W. Leemans, K. Nakajima, K. Homma, M. Kando, S. Bulanov, T. Esirkepov, J. Koga, D. Habs, B. LeGarrec, D. Payne, H. Videau, P. Martin, W. Sandner, A. Suzuki, M. Teshima, R. Assmann, R. Heuer, A. Caldwell, S. Karsch, F. Gruener, M. Somekh, J. Nilsson, W. Chou, F. Takasaki, M. Nozaki, D. Payne, A. Chao, J.P. Koutchouk, Y. Kato, E. Goulielmakis, A. Ipp, 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, M. Yoshida, T. Massard, T. Ebisuzaki, F. Kajino

1. Cultivate the frontiers: Exawatt laser and *IZEST* missions
2. Vacuum nonlinear susceptibility χ
3. Non-collider paradigm of laser acceleration
    - Vacuum texture and synchrotron radiation in high energy
        - Lorentz invariance check
    - Energy frontier at PeV with attosecond metrology
        - without luminosity, ever diminishing emittance
    - Electron acceleration to TeV/PeV
4. Vacuum nonlinearity: QED and beyond
    - phase contrast imaging of vacuum
    - Dark Matter and Dark Energy fields
        - degenerate 4 wave mixing
5. Real-time (as opposed to spectrum) search of vacuum
    - zeptosecond regimes (for CALA):
    - shortest pulses ← highest intensity (Mourou-Tajima Conjecture)

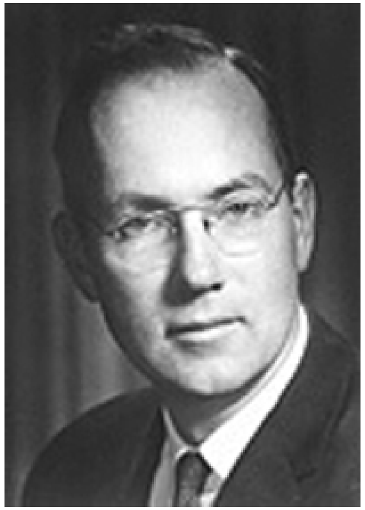
20th Century, the Electron Century
Basic Research Dominated by
Massive and Charged Particles (electronics)



J. J. Thomson

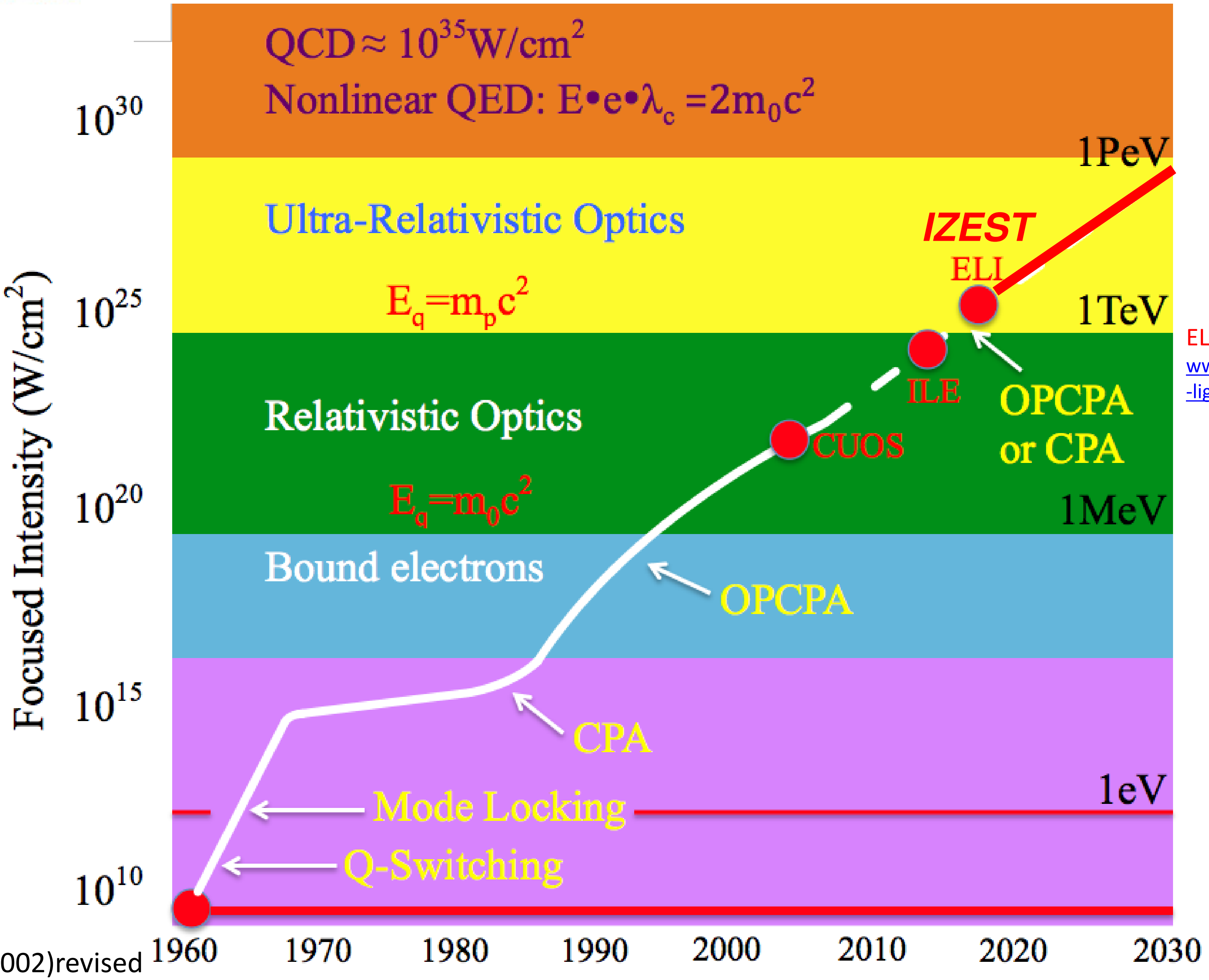


21st Century; the Photon Century
Could basic research be driven
by the massless and chargeless particles;
Photons (photonics)?



C. Townes

Laser Intensity vs. Years

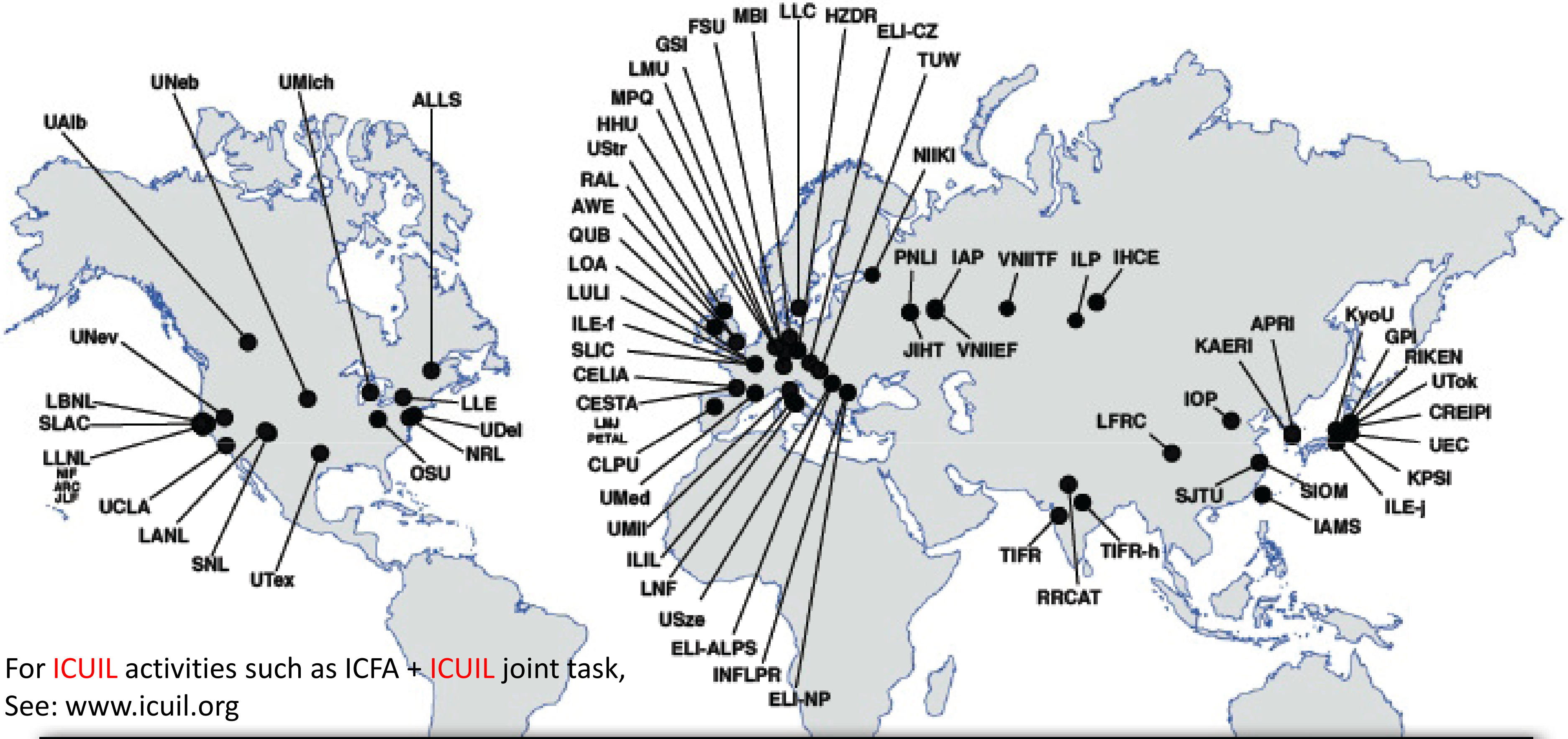


Tajima and Mourou (2002)revised

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

2010 ICUIL World Map of Ultrahigh Intensity Laser Capabilities

IZEST constituency resides in UHIL community



For ICUIL activities such as ICFA + ICUIL joint task,
See: www.icuil.org

- the total peak power of all the CPA systems operating today is ~11.5 PW
- by the end of 2015 planned CPA projects will bring the total to ~127 PWs
- these CPA projects represent ~$4.3B of effort by ~1600 people (no NIF or LMJ)
- these estimates do not include Exawatt scale projects currently being planned

CPJ Barty (barty1@llnl.gov)

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.izest.polytechniqu.edu

Also: Tajima and Mourou PR STAB(2002)

IZEST Associate Laboratories

IZEST's world-wide reach


IZEST Associate Laboratories

LLNL - Lawrence Livermore National Laboratory, Livermore, California, USA ①
PPPL - Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA ②
FERMILAB - Fermi National Accelerator Laboratory, Chicago, Illinois, USA ③
CUOS - Center for Ultrafast Optical Science, Ann Arbor, Michigan, USA ④
ALLS - Advanced Laser Light Source, Montreal, Canada ⑤
TOPS - TeraHertz to Optical Pulse Source, Strathclyde, UK ⑥
JAI - John Adams Institute for accelerator science, Oxford, UK ⑦
HHU - Heinrich Heine Universität, Düsseldorf, Germany ⑧
GSI - Helmholtzzentrum für Schwerionenforchung, Darmstadt, Germany ⑨
CEA - Commissariat à l'Energie Atomique et aux énergies alternatives, Bordeaux, France ⑩
Ecole Polytechnique - Palaiseau, France ⑪

⑫ **CERN** - Organisation Européenne pour la Recherche Nucléaire, Genève, Switzerland
⑬ **CLPU** - Centro de Láseres Pulsados Ultracortos Ultraintensos, Salamanca, Spain
⑭ **ELI-NP** - Extreme Light Infrastructure - Nuclear Physics, Magurele, Romania
⑮ **MEPhI** - Moscow Engineering Physics Institute, Moscow, Russia
⑯ **SIOM** - Shanghai Institute of Optics and Fine Mechanics, Shanghai, China
⑰ **Beijing University** - Beijing, China
⑱ **LeCosPa** - Leung Center for Cosmology and Particle Astrophyics, Taipei, Taiwan
⑲ **GIST** - Gwangju Institute of Science and Technology, Gwangju, Republic of Korea
⑳ **Kyoto University** - Kyoto, Japan
㉑ **KPSI** - Kansai Photon Science Institute, Kansai, Japan
㉒ **KEK** - High Energy Accelerator Research Organization, Tsukuba, Japan

Nonlinear susceptibility of vacuum

$$\chi E = \chi_1 E + \chi_2 EE + \chi_3 |E|^2 E +$$

↑

Zeroeth order:
(not nonlinear)
s.a. possible Lorentz
invariance violation

← birefringence

↑

2nd order:
(nonlinear)
s.a. 4 wave
mixing,
Self-focusing

Vacuum nonlinearity of QED is small in eV regime (only big in MeV).
fortune in disguise

Laser Wakefield (LWFA): nonlinear optics in plasma

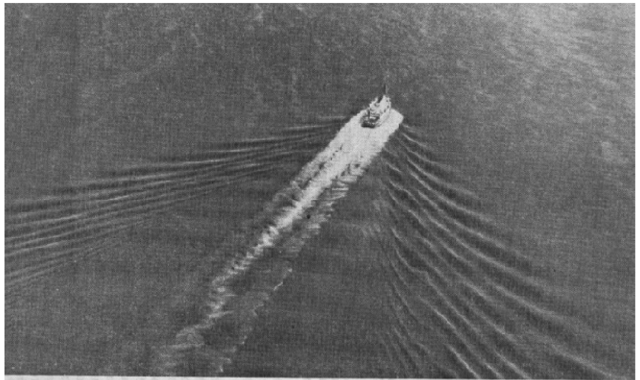
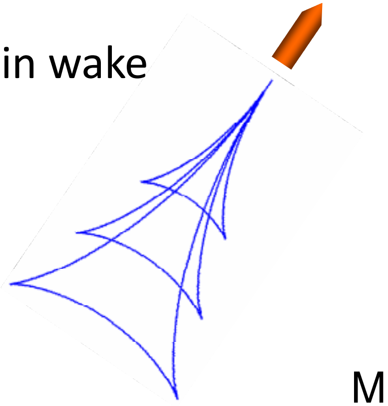
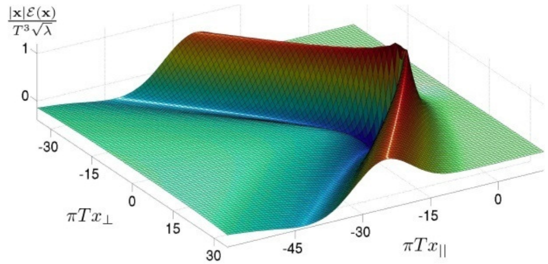


Рис. 71. Наблюдаемая картина корабельных волн. [Любезно предоставлено Aerofilms Ltd.]

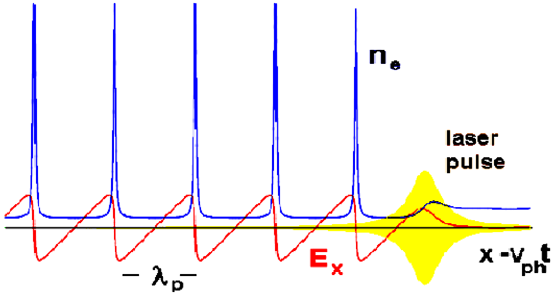
Kelvin wake





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

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



← relativity

regularizes

(*relativistic coherence*)

(The density cusps.
Cusp singularity)

Wave **breaks** at v < c

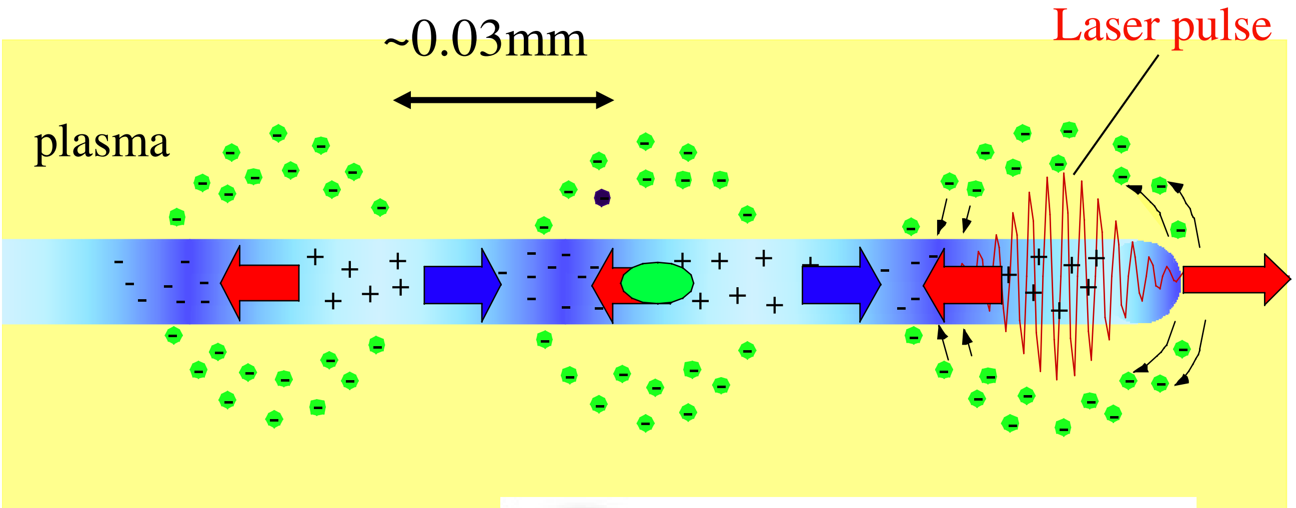
Hokusai

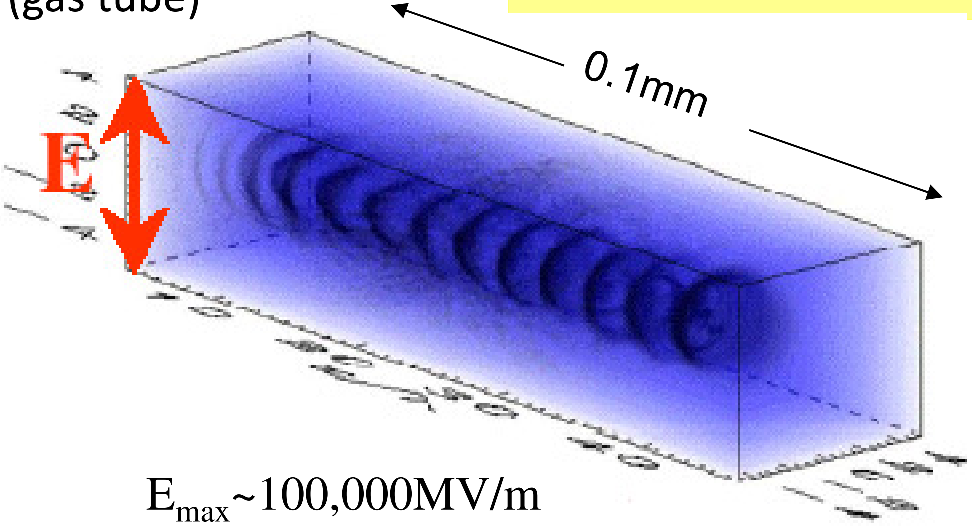
Maldacena

(Plasma physics vs.
String theory)

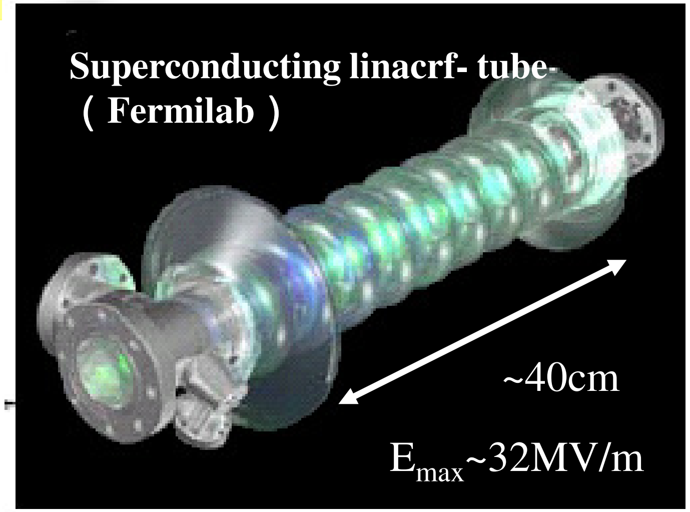
Thousand-fold Compactification

Laser wakefield: thousand folds gradient (and emittance reduction)





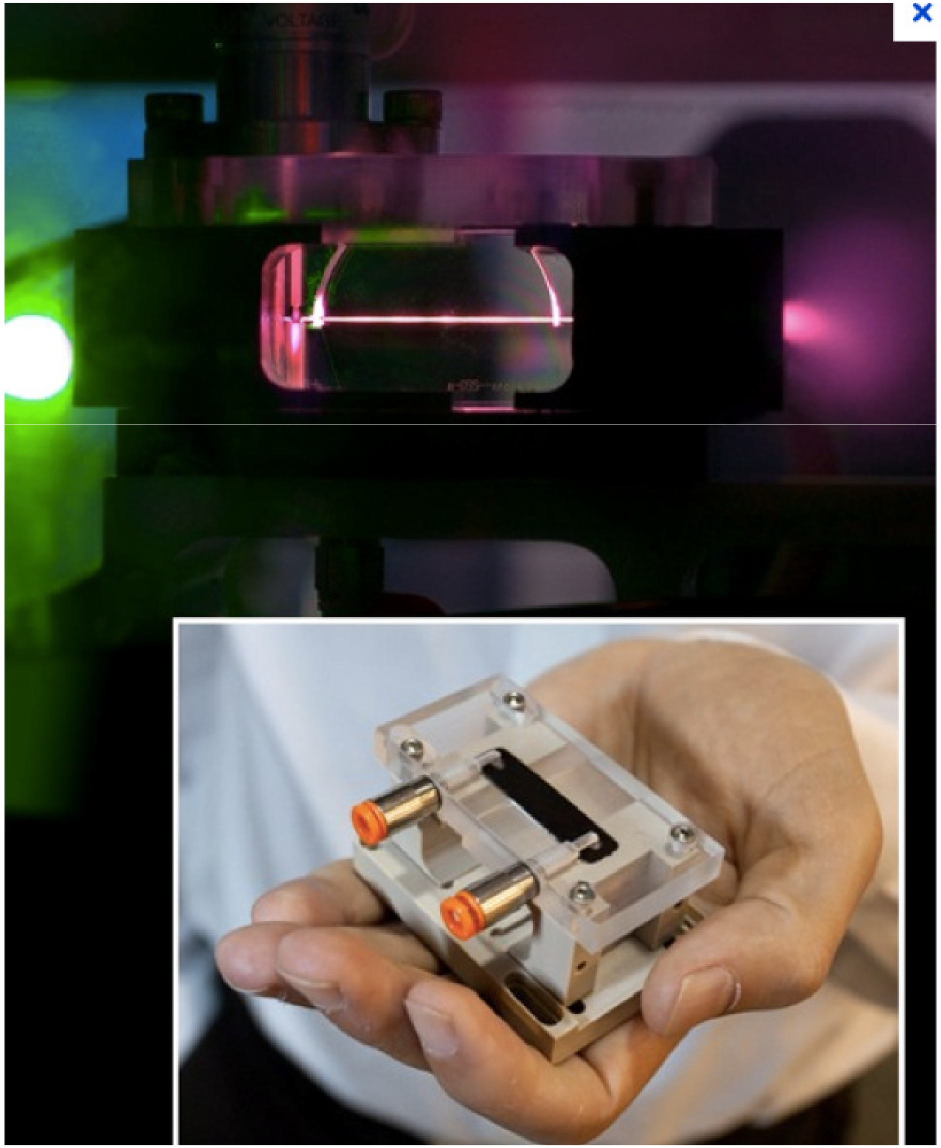
E_{max}~100,000MV/m



GeV in the Palm

First GeV on few cm

(W. Leemans et al)



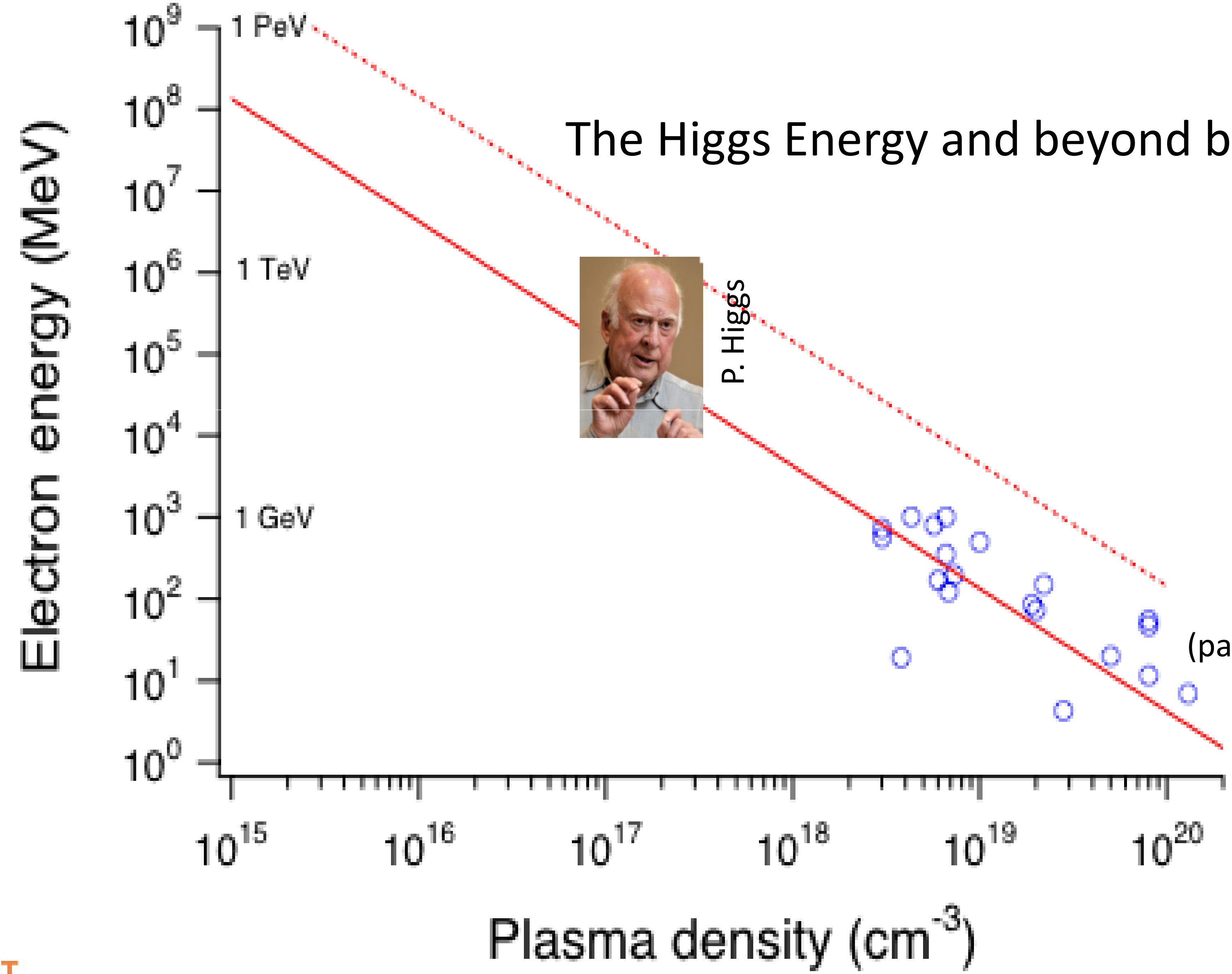
Density scalings of **LWFA** for collider

Accelerating field E_z	$\propto n_e^{1/2}$
Focusing constant K	$\propto n_e^{1/2}$
Stage length L_{stage}	$\propto n_e^{-3/2}$
Energy gain per stage W_{stage}	$\propto n_e^{-1}$
Number of stages N_{stage}	$\propto n_e$
Total linac length L_{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_{avg}	$\propto n_e^{-1/2}$
Wall plug power P_{wall}	$\propto n_e^{1/2}$

(Nakajima, PR STAB, 2011)

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

Laser acceleration energy scaling



The Higgs Energy and beyond by laser

(past exptl data)

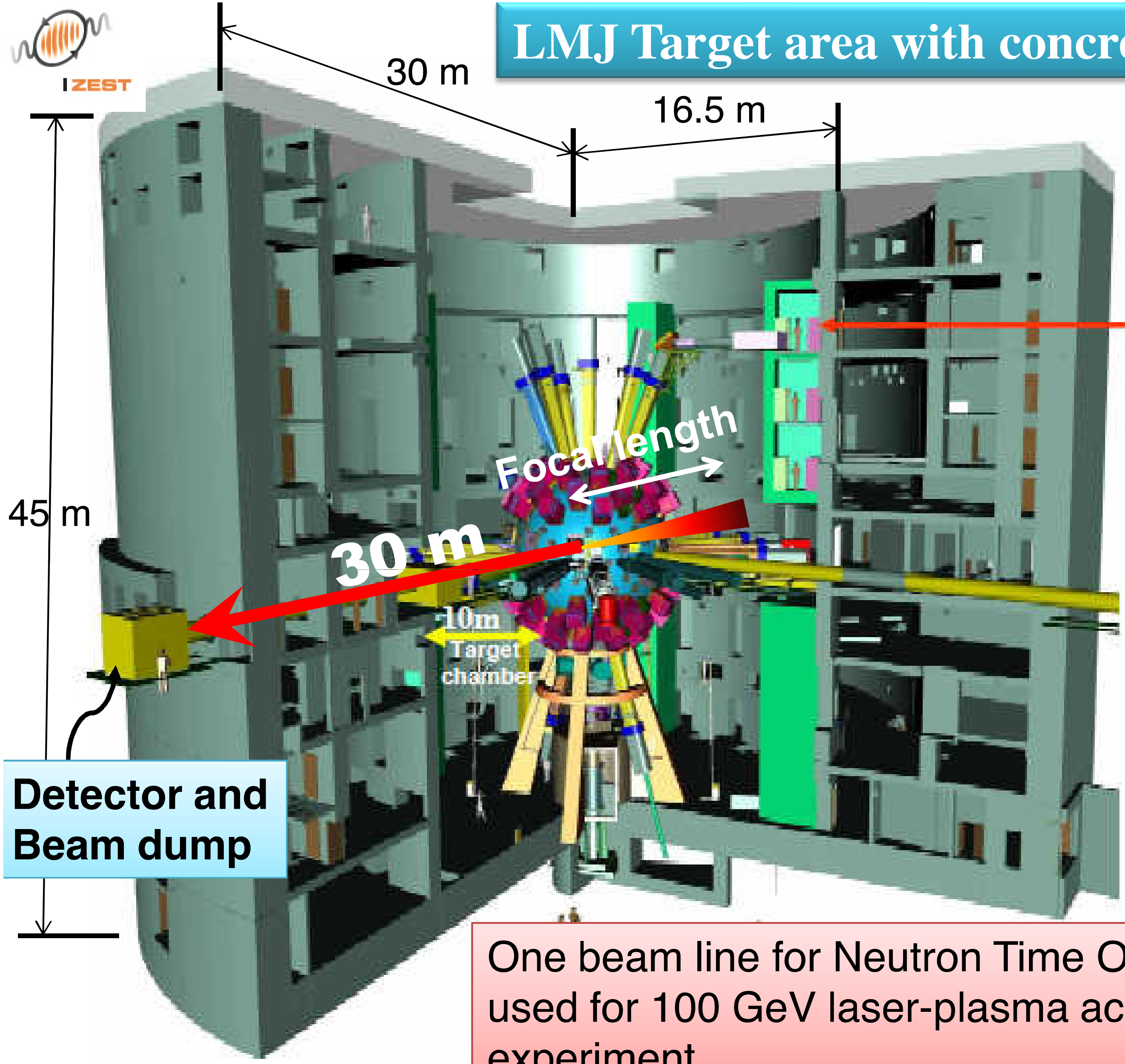
CEA kJ and MJ lasers underpin *IZEST* missions

- 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)

LMJ Target area with concrete shielding

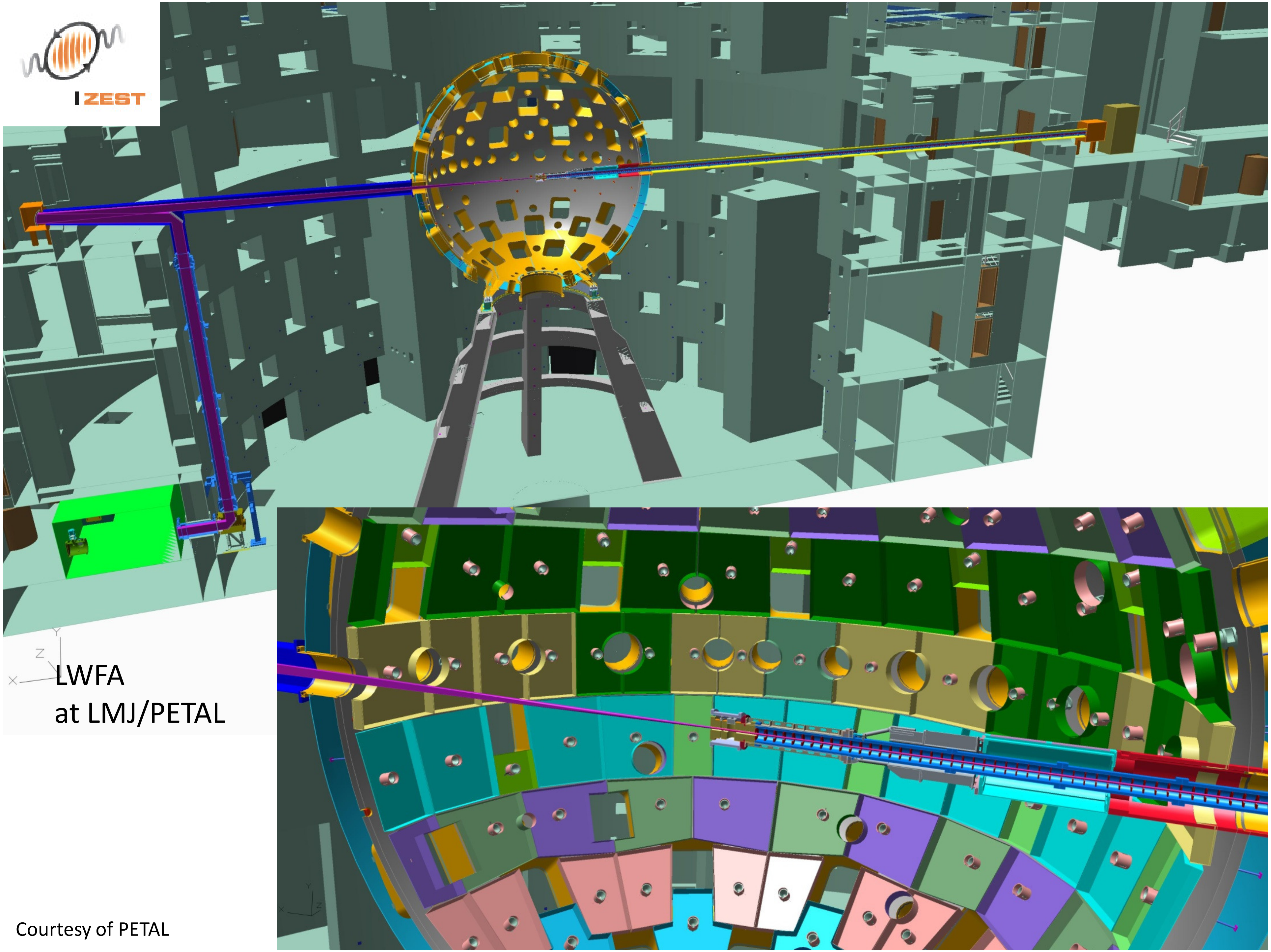
First Workshop on
100GeV IZEST Project:
May 31-June 1, ’12
@ Bordeaux



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

Nakajima, LeGarrec

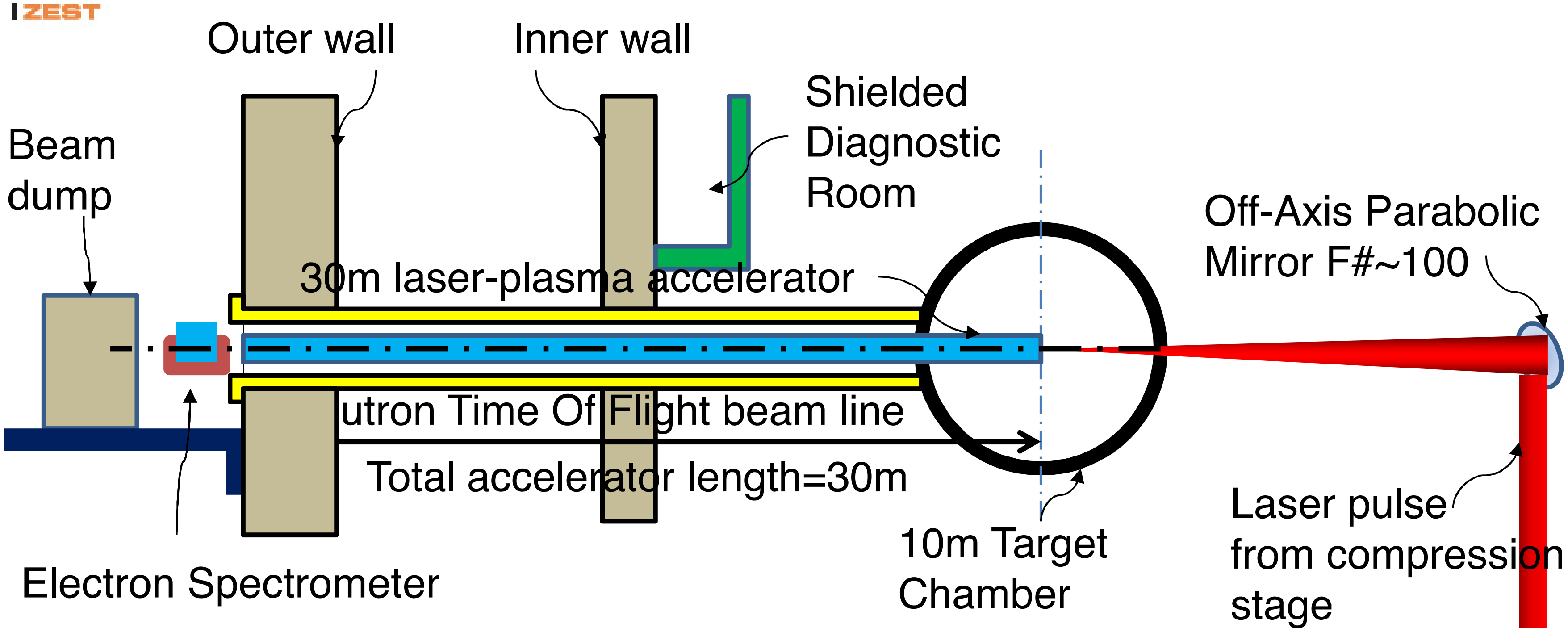
Courtesy of PETAL



LWFA
at LMJ/PETAL

Courtesy of PETAL

A setup design for 100 GeV Laser-Plasma Electron Acceleration



Outer wall

Inner wall

Shielded Diagnostic Room

Beam dump

30m laser-plasma accelerator

Off-Axis Parabolic Mirror F#~100

utron Time Of Flight beam line

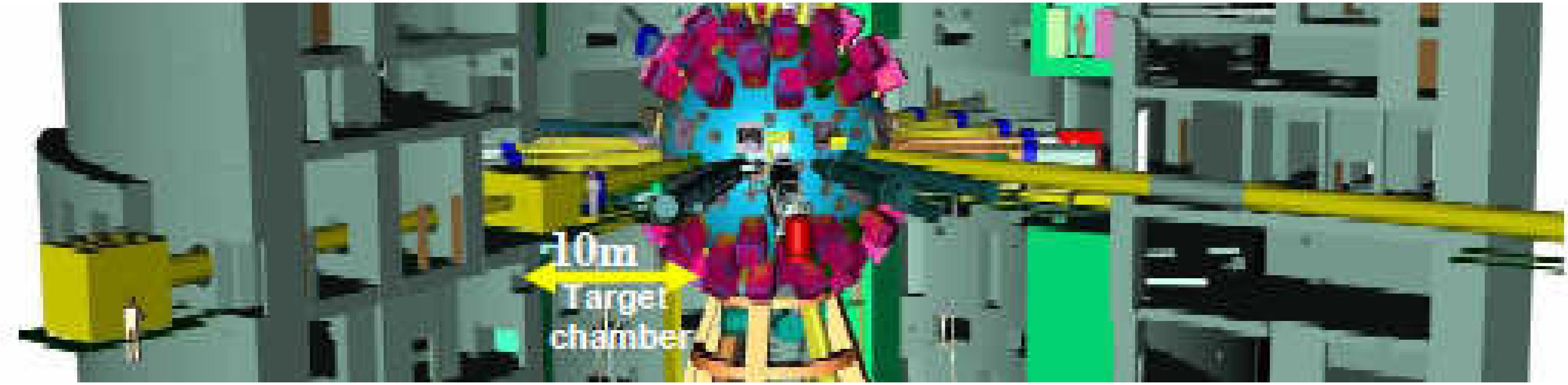
Total accelerator length=30m

Electron Spectrometer

10m Target Chamber

Laser pulse from compression stage

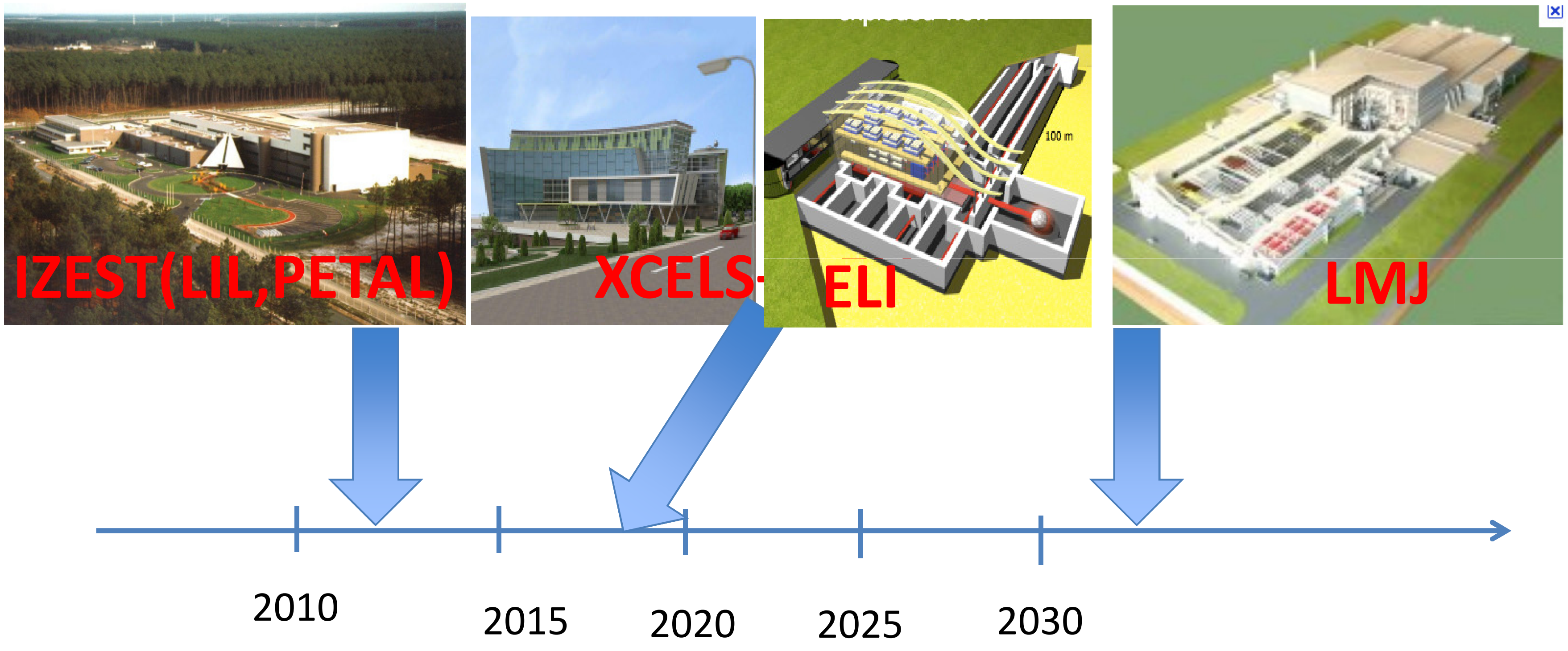
A view of equatorial level of LMJ target chamber



Le Garrec, Nakajima (2012)

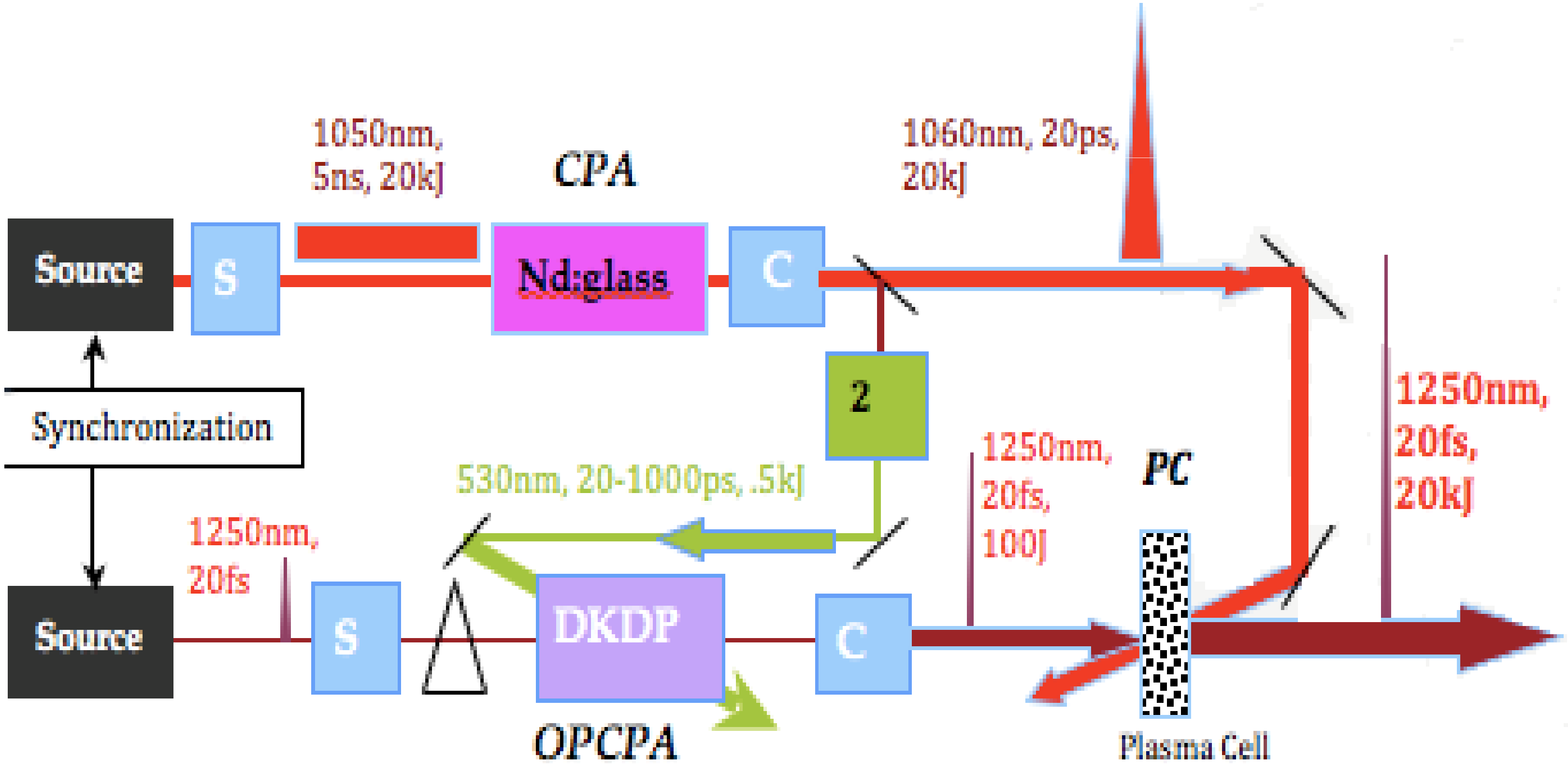
Courtesy of PETAL

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



New Laser Concept C^3
(Cascaded Compression Conversion)
to achieve intensity > 10^{23}W/cm^2

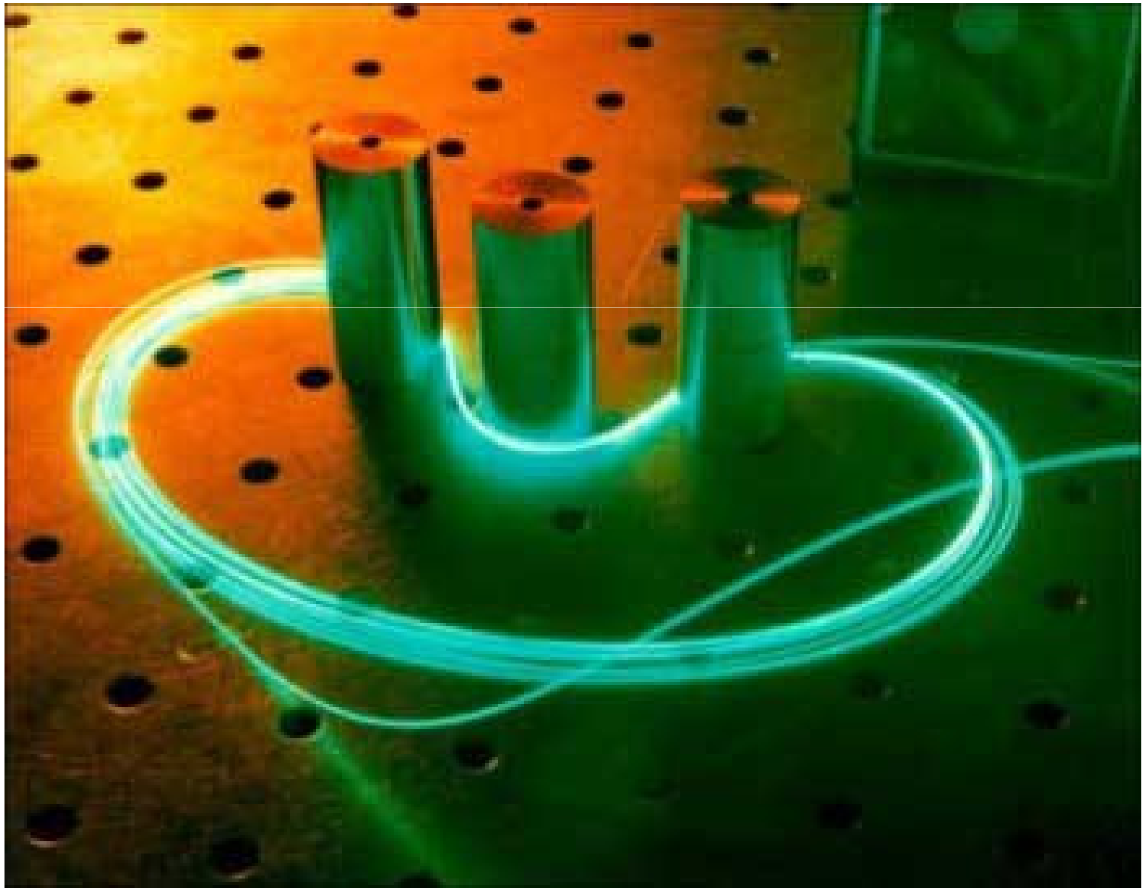
High intensity compressor: material breakdown → plasma compressor
(high intensity accelerator: metallic breakdown → plasma wakefield)



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

Bulk vs. Fiber Lasers (*ICAN*)

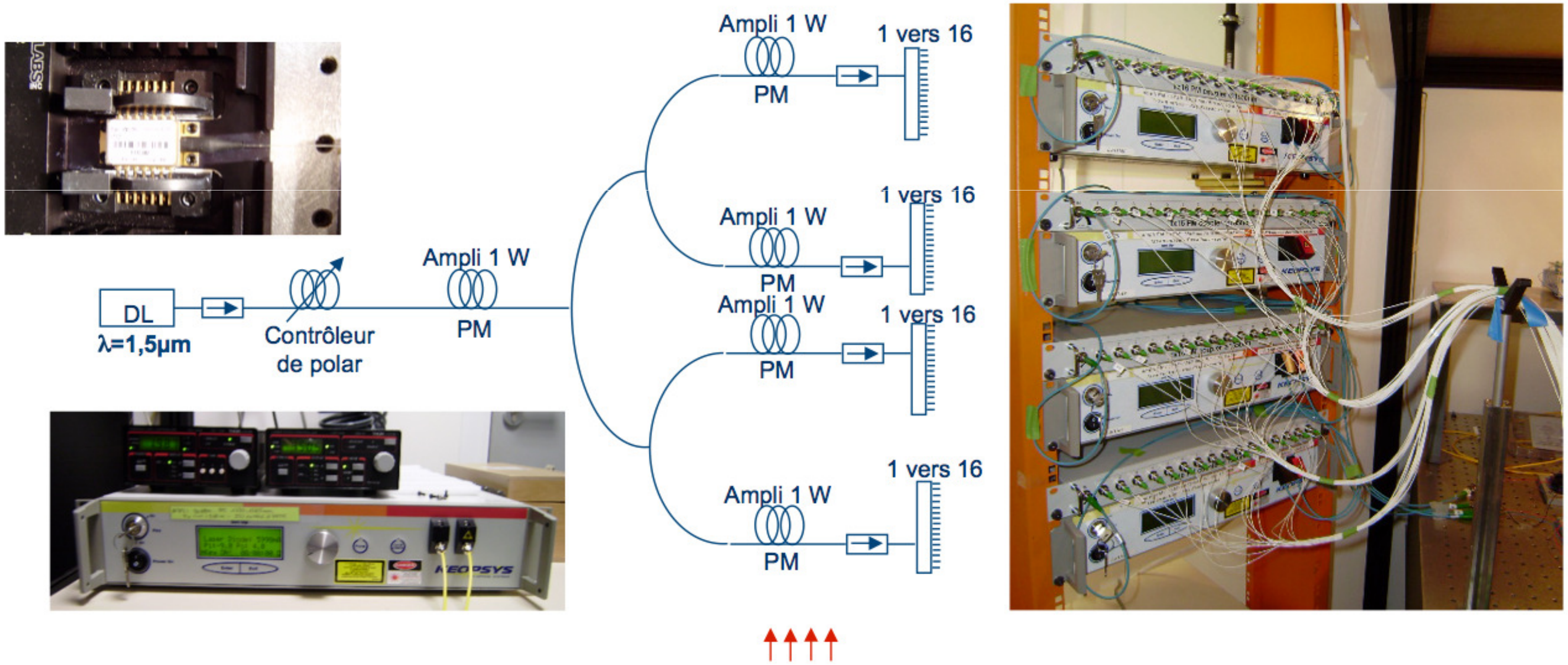
- High Gain fiber amplifiers allow ~ 40% total plug-to-optical output efficiency
- Single mode fiber amplifier have reached multi-kW optical power.
- large bandwidth (100fs)
- immune against thermo-optical problems
- excellent beam quality
- efficient, diode-pumped operation
- high single pass gain
-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



www.izest.polytechnique.edu/izest-hom

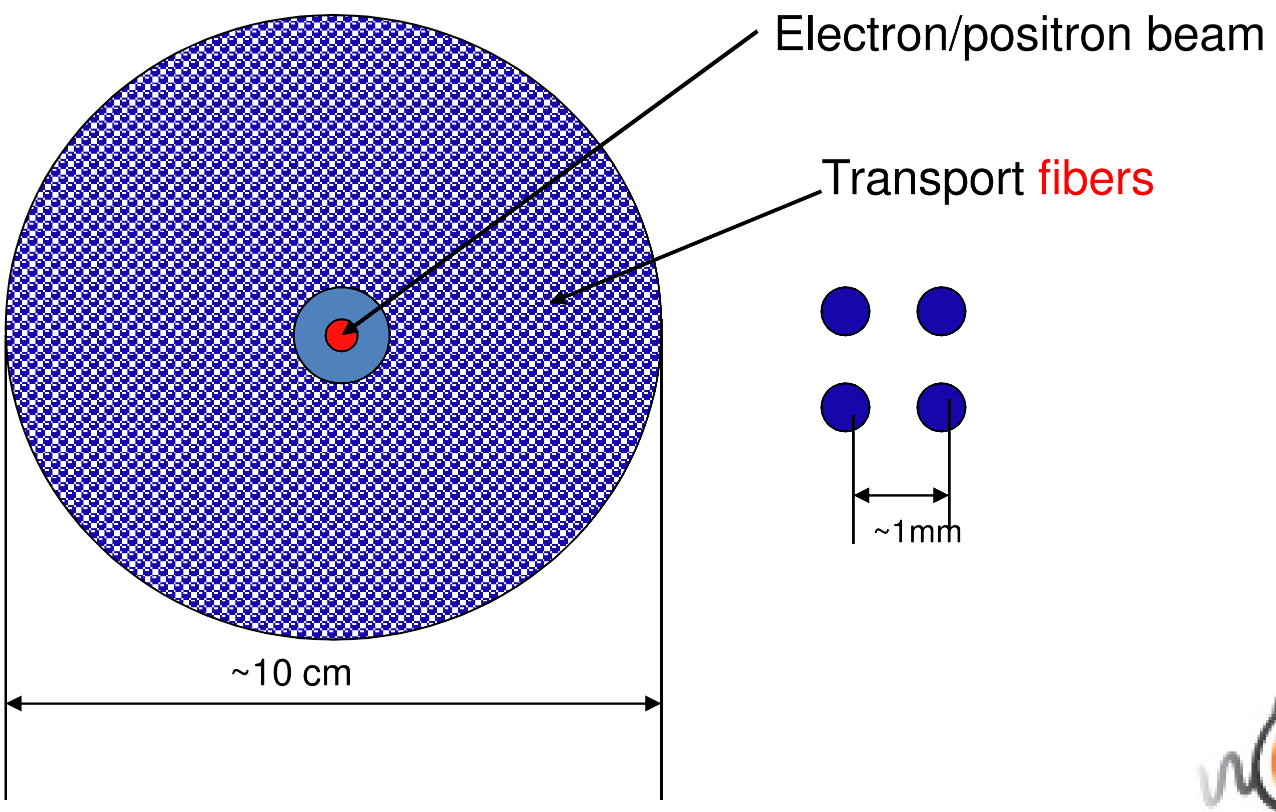
64 fiber coupling

- Génération de 64 faisceaux fibrés



Concept: coherent fiber bundles
toward Avogadro number photons

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



Electron/positron beam

Transport fibers

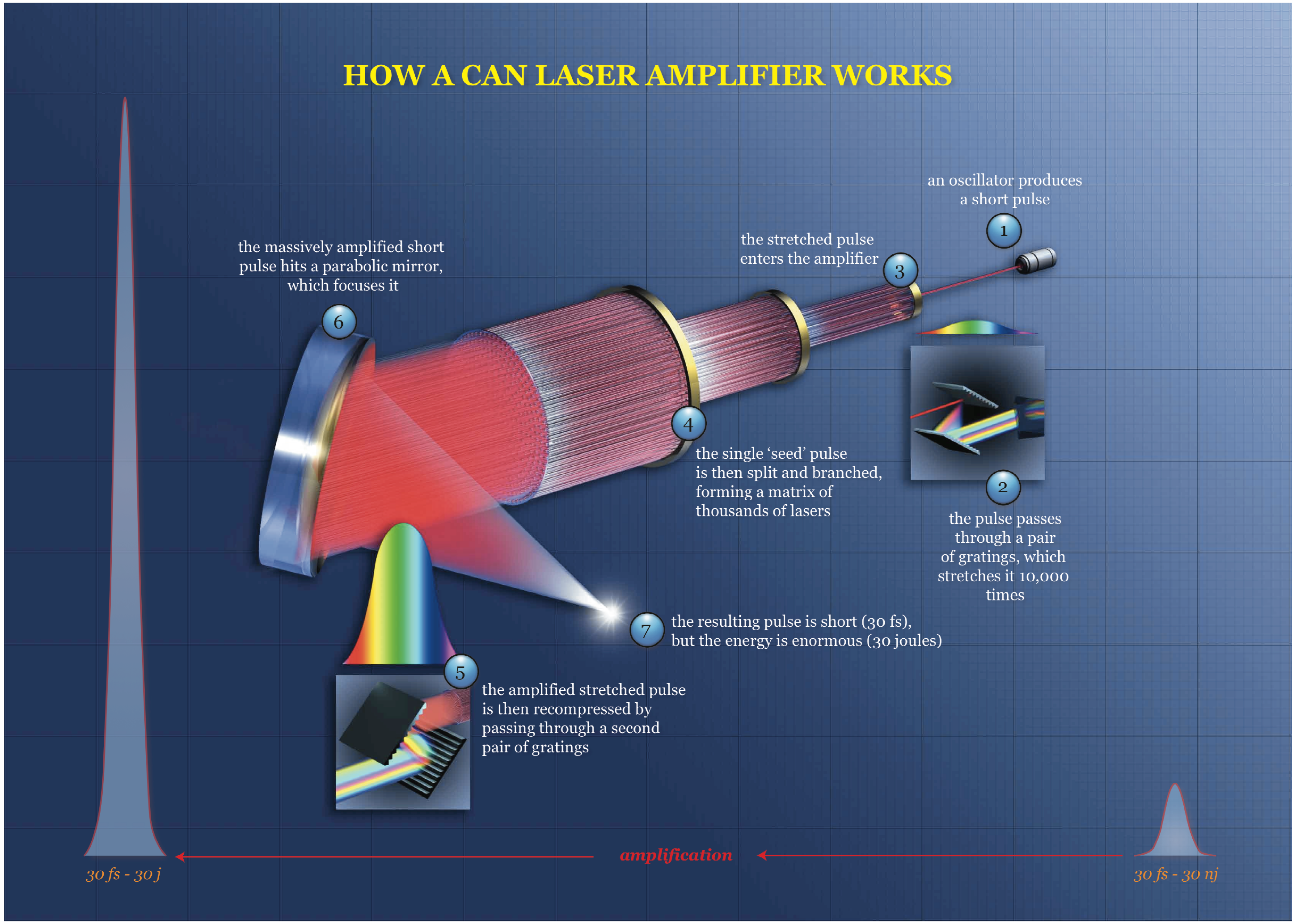
~1mm

~10 cm

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

(Mourou et al)

Toward high-average power lasers: CAN (Coherent Amplification Network)



HOW A CAN LASER AMPLIFIER WORKS

1 an oscillator produces a short pulse

2 the pulse passes through a pair of gratings, which stretches it 10,000 times

3 the stretched pulse enters the amplifier

4 the single ‘seed’ pulse is then split and branched, forming a matrix of thousands of lasers

5 the amplified stretched pulse is then recompressed by passing through a second pair of gratings

6 the massively amplified short pulse hits a parabolic mirror, which focuses it

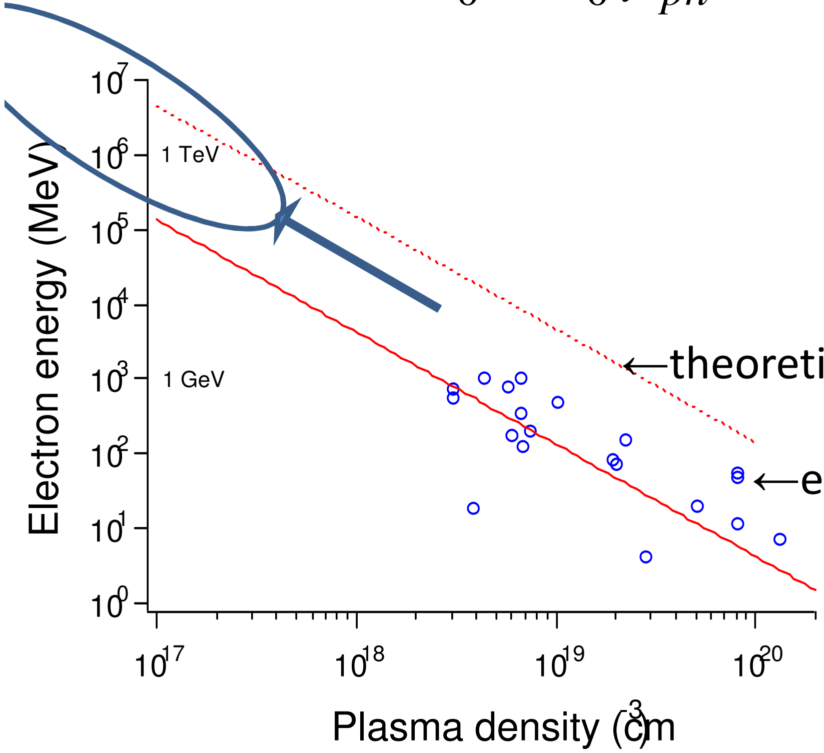
7 the resulting pulse is short (30 fs), but the energy is enormous (30 joules)

Mourou et al.: an IZEST project

https://www.izest.polytechnique.edu/izest-home/ican/ican-94447.kjsp?RF=1332339530225

Theory of wakefield toward extreme energy

$$\Delta E \approx 2m_0c^2a_0^2\gamma_{ph}{}^2 = 2m_0c^2a_0^2\left(\frac{n_{cr}}{n_e}\right),$$ (when 1D theory applies)



In order to avoid wavebreak,

$$a_0 < \gamma_{ph}{}^{1/2},$$

where

$$\gamma_{ph} = (n_{cr}/n_e)^{1/2}$$

$$L_d = \frac{2}{\pi}\lambda_p a_0^2\left(\frac{n_{cr}}{n_e}\right),$$

dephasing length

$$L_p = \frac{1}{3\pi}\lambda_p a_0\left(\frac{n_{cr}}{n_e}\right),$$

pump depletion length

Adopt:

LMJ laser (3MJ)

→ 0.7PeV

(PTP 2011,with Kando, Teshima)

γ-ray signal from primordial GRB

LETTERS NATURE

(Abdo, et al, 2009)

←lower energy

higher→

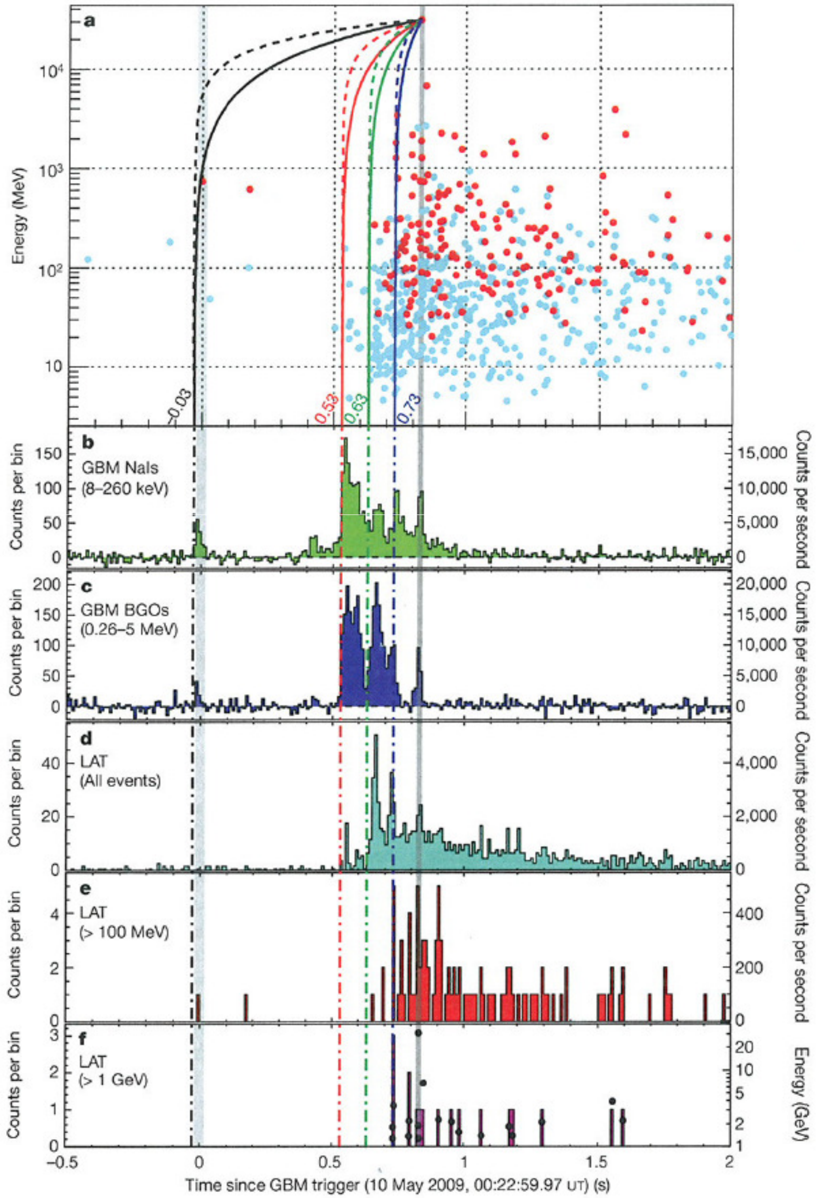


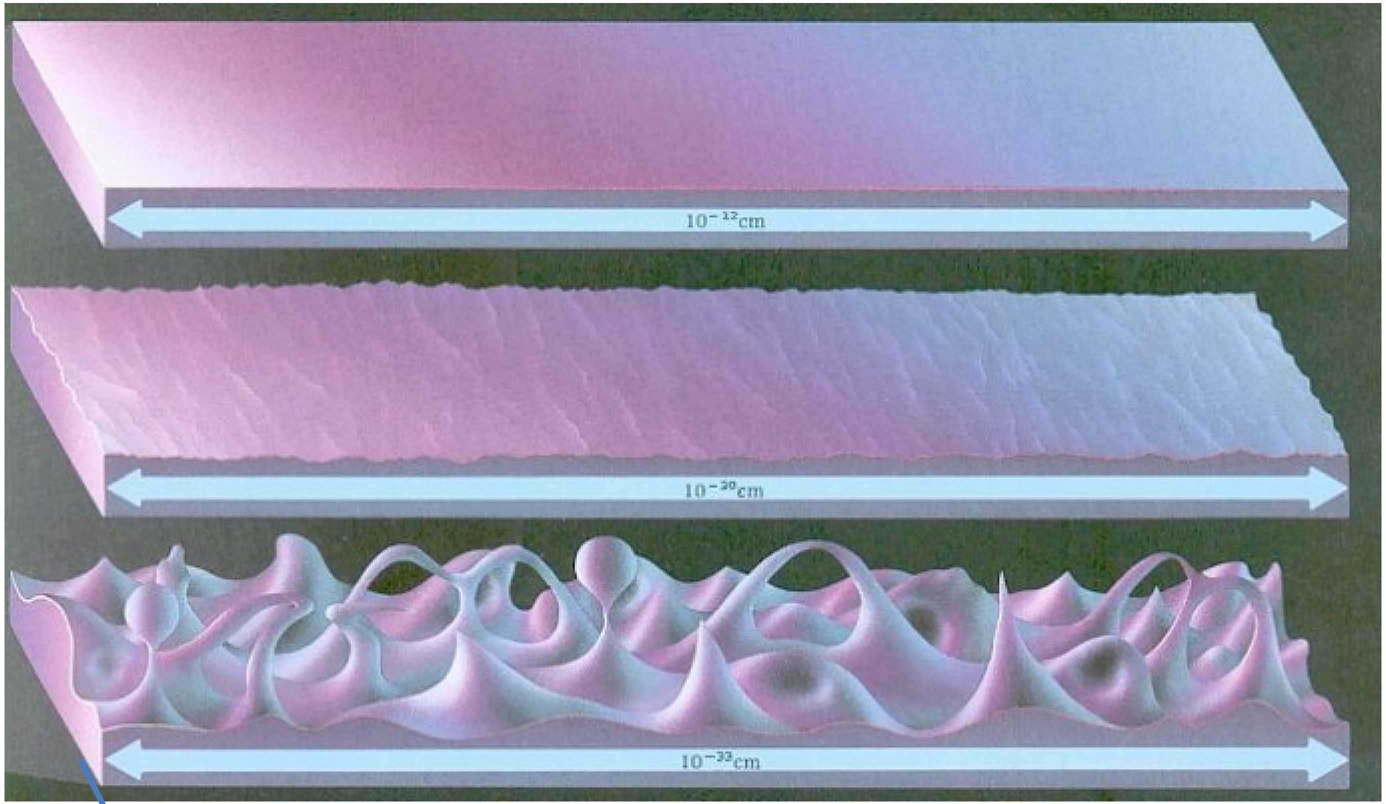
Figure 1 | Light curves of GRB 090510 at different energies. a, Energy … lowest to highest energies. **f** also overlays energy versus arrival time for each

Energy-dependent
photon speed ?
Observation of primordial
Gamma Ray Bursts (GRB)
(limit is pushed up
close to Planck mass)

Lab PeV γ (from e-)
can explore this
with control

Feel vacuum texture: PeV energy γ

Laser acceleration → controlled laboratory test to see quantum gravity texture
on photon propagation (Special Theory of Relativity: c_0)



Coarser,
lower energy
texture

Finer,
higher energy
texture

$c < c_0$

← (0.1PeV)

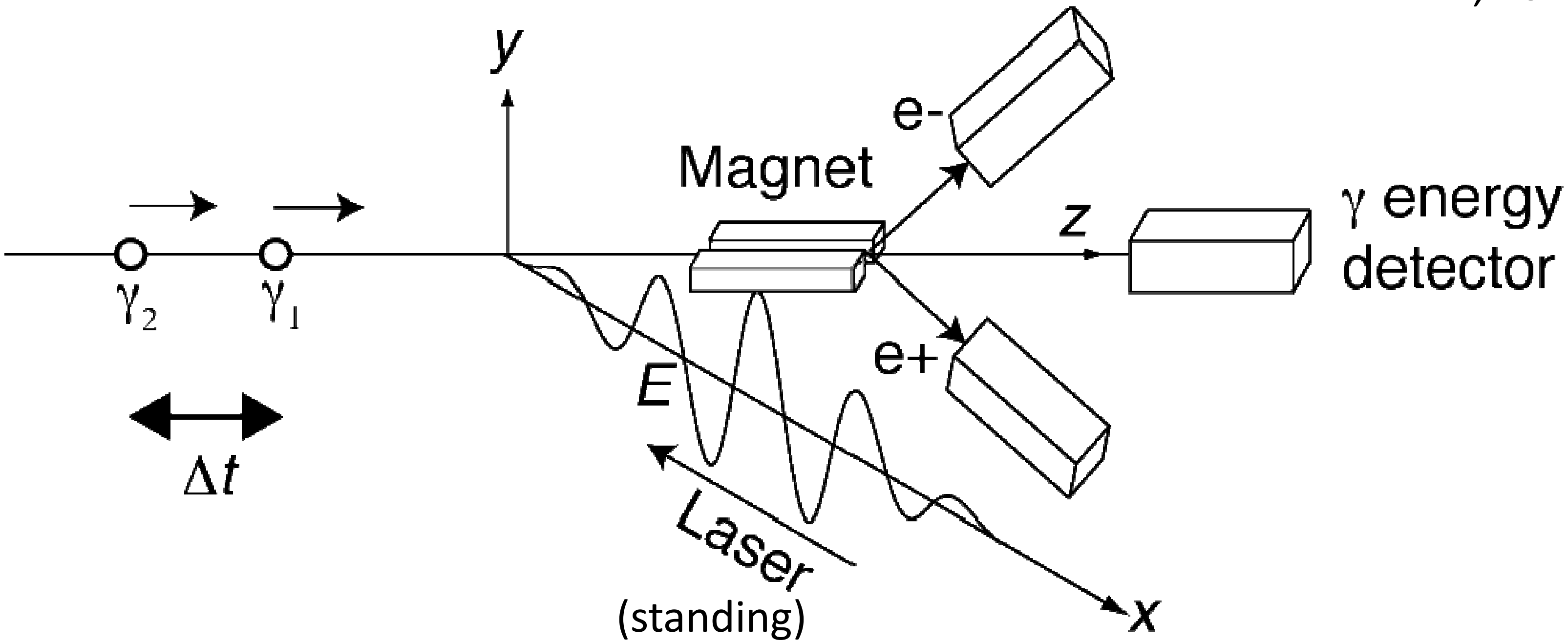
←(1PeV : fs behind)

1km

PeV γ (converted from e^-)

Attosecond Metrology of PeV γ Arrivals

(Tajima, Kando, Teshima
PTP, 2011)



High energy γ- induced Schwinger breakdown
(Narozhny; Nikishov, Ritus)

CEP phase sensitive laser triggers breakdown and results in
electron-positron acceleration

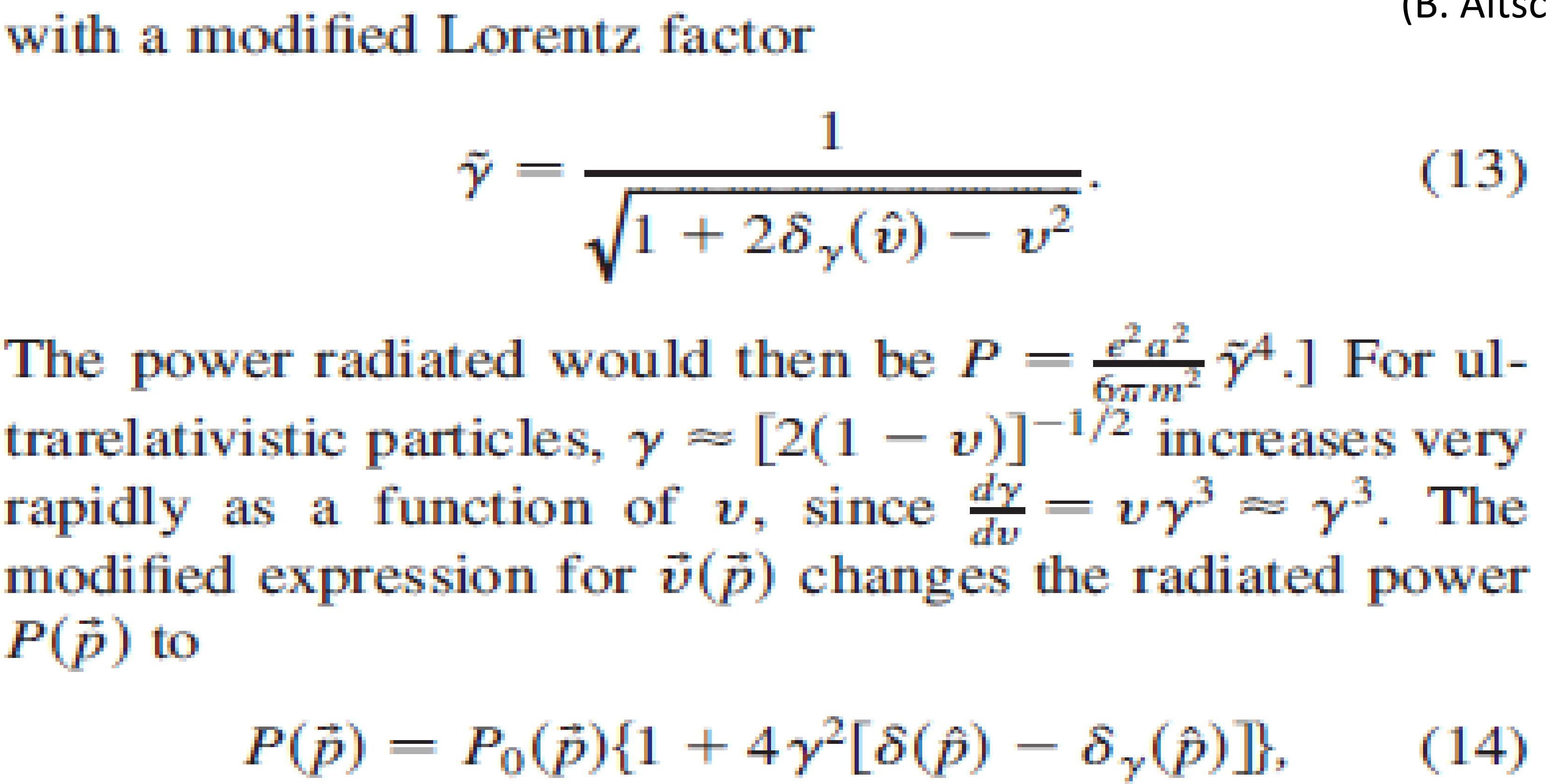
Attosecond electron streaking

γ- energy tagging possible

Extreme High Energy and Synchrotron Radiation

E > 30TeV: untested territory for Lorentz invariance

(B. Altschul, 2008)



with a modified Lorentz factor

$$\tilde{\gamma} = \frac{1}{\sqrt{1 + 2\delta_{\gamma}(\hat{v}) - v^2}}. \qquad (13)$$

The power radiated would then be $P = \frac{e^2 a^2}{6\pi m^2}\tilde{\gamma}^4$.] For ultrarelativistic particles, $\gamma \approx [2(1-v)]^{-1/2}$ increases very rapidly as a function of v, since $\frac{d\gamma}{dv} = v\gamma^3 \approx \gamma^3$. The modified expression for $\vec{v}(\vec{p})$ changes the radiated power $P(\vec{p})$ to

$$P(\vec{p}) = P_0(\vec{p})\{1 + 4\gamma^2[\delta(\hat{p}) - \delta_{\gamma}(\hat{p})]\}, \qquad (14)$$

Synchrotron radiation
radiation

↑ Lorentz violating term (>30TeV)

LWFA (PWFA): Only way to go beyond 30TeV

Beyond 30TeV, rapid cooling, emittance reduction, better beam

→ new regime, new physics

Challenges of the Genesis of EECR

1.Fermi's mechanism: too much energy loss by synchrotron radiation beyond 10^{19} eV
2.Confinement problem: out of range of the Hillas' Diagram, takes too large magnetic field
3.Detachment Problem: Accelerated parti1.cles need to get out that magnetic fields

↓

Paradigm of collective acceleration (and thus much greater accelerating gradient) of ***Laser*** ***Wakefield Acceleration*** (LWFA) or its variants <----- compact astrophysical objects s.a. GRB, AGN, NS-NS collision, etc.

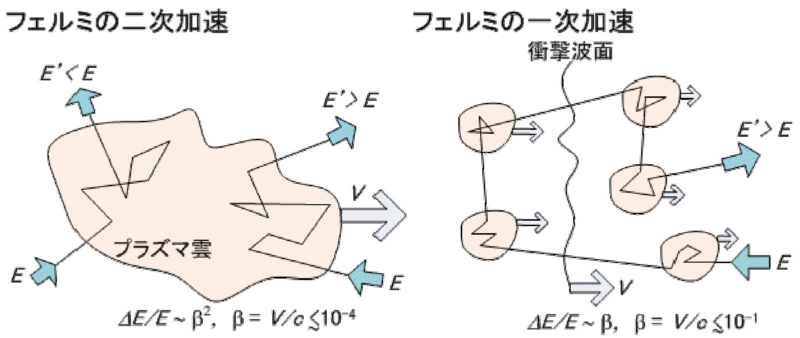
1.Much greater acceleration gradient, no need of multiple stages → compact, no limit from synchrotron rad, linear acceleration
2.No confinement
3.Thus no detachment problem

Wakefield Acceleration

Fermi Acceleration

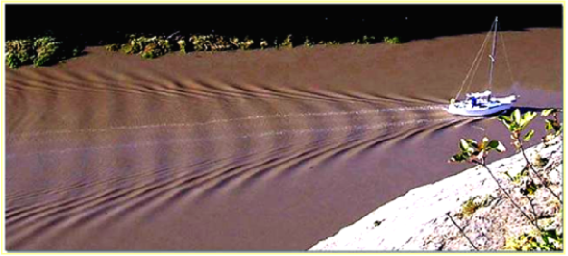
Widely invoked, but not applicable beyond 10^{19}eV
even protons lose energies upon each momentum kick by radiative damping

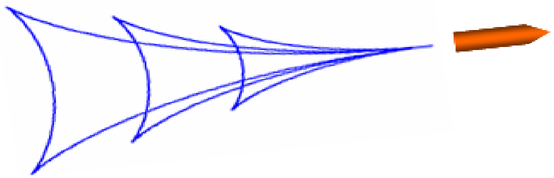
➔ ***prompt linear acceleration***



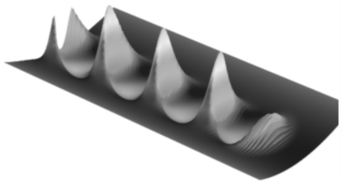
↓

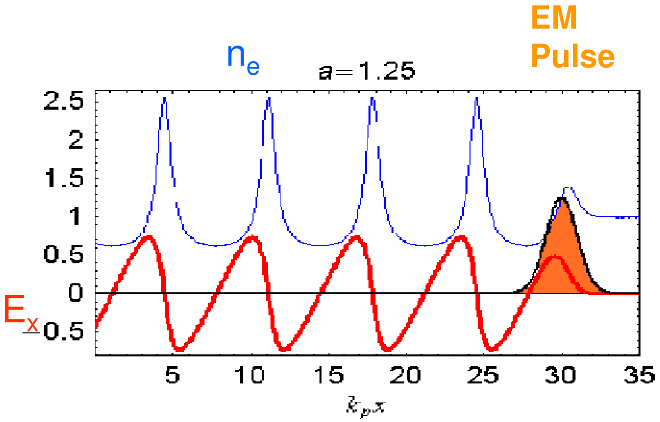
Kelvin's Ship Wake





EM Pulse Wake in Plasma

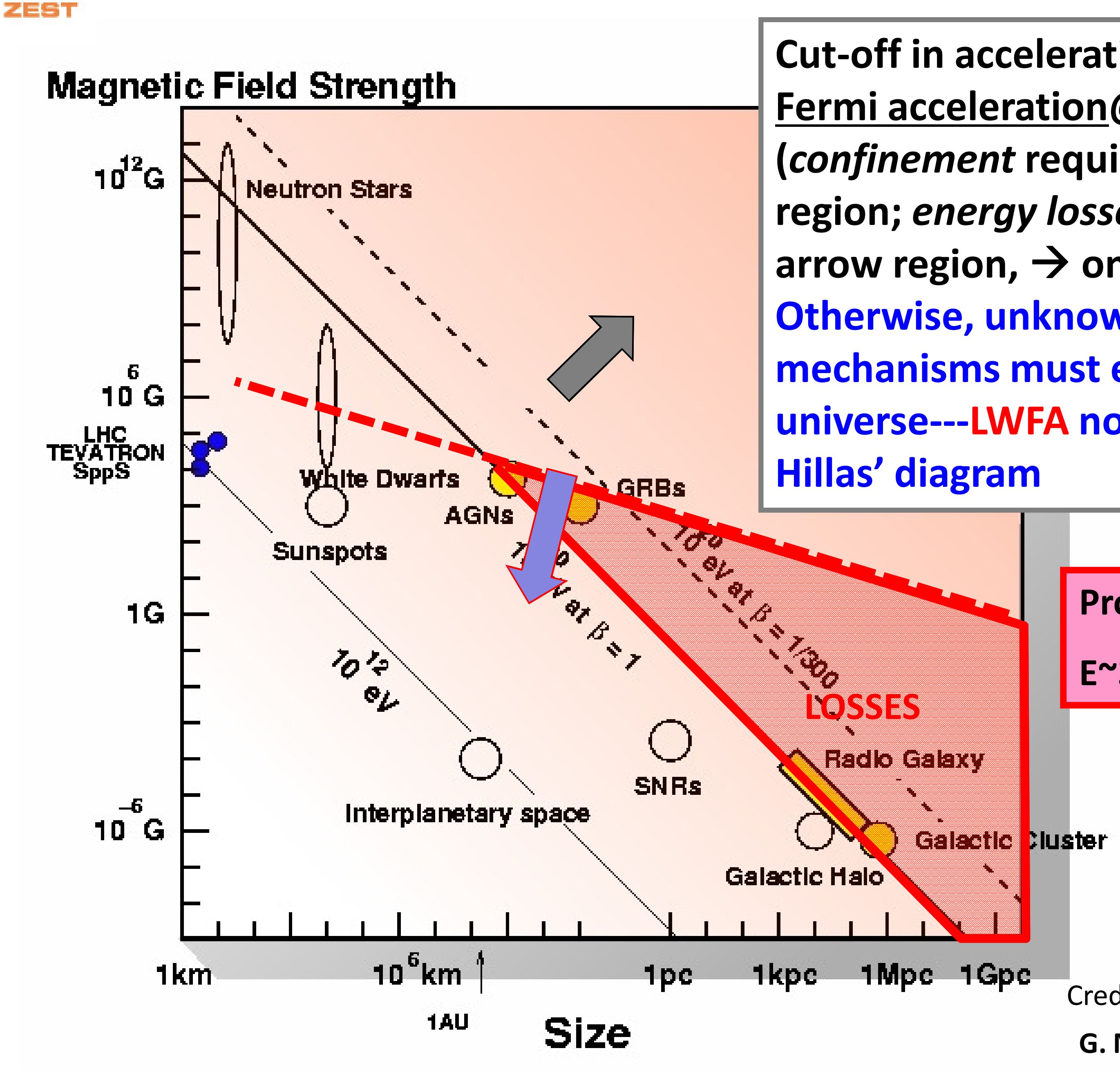




EECR Sources in Hillas' Diagram

Cut-off in acceleration based on the Fermi acceleration@ ~ 10^{20} eV (*confinement* requires the grey arrow region; *energy losses* requires blue arrow region, → only red triangle)

Otherwise, unknown sources or mechanisms must exist in the universe---LWFA not constrained by Hillas' diagram

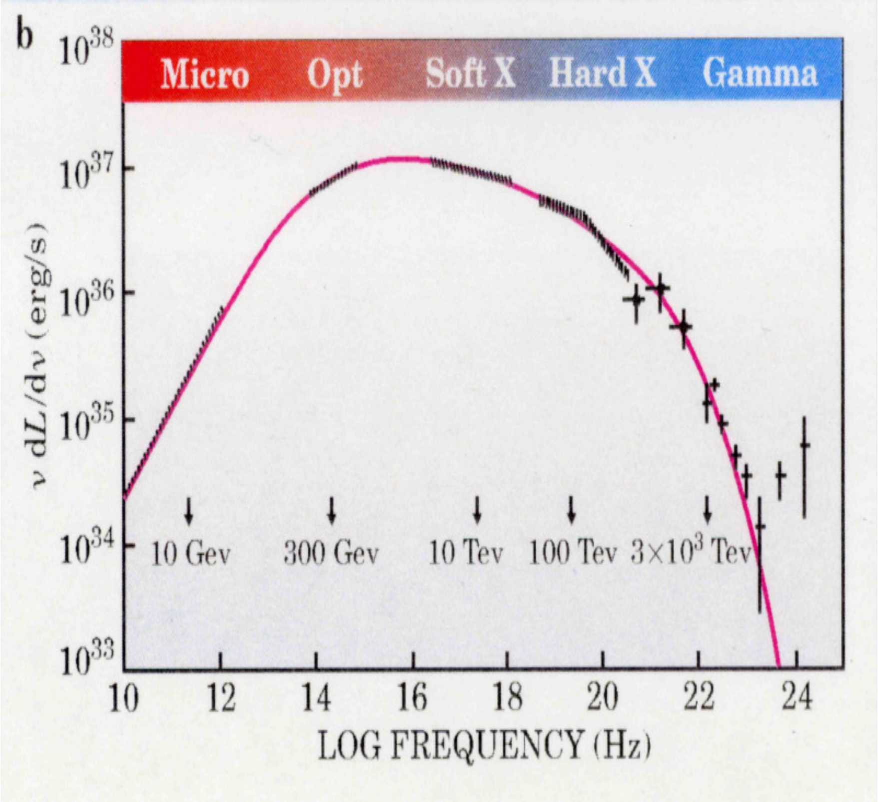


Protons up to

E~3 x 10^{20} eV

Credit:JEM-EUSO collaboration

G. Medina Tanco - ICN/UNAM



The Crab Pulsar, a city-sized, magnetized neutron star spinning 30 times a second, lies at the center of this composite image of the inner region of the well-known Crab Nebula. The spectacular picture combines optical data (red) from the Hubble Space Telescope and x-ray images (blue) from the Chandra Observatory, also used in the popular Crab Pulsar movies. Like a cosmic dynamo the pulsar powers the x-ray and optical emission from the nebula, accelerating charged particles and producing the eerie, glowing x-ray jets. Ring-like structures are x-ray emitting regions where the high energy particles slam into the nebular material. The innermost ring is about a light-year across. With more mass than the Sun and the density of an atomic nucleus, the spinning pulsar is the collapsed core of a massive star that exploded, while the nebula is the expanding remnant of the star's outer layers. The supernova explosion was witnessed in the year 1054

Its core hidden from optical view by a thick lane of dust, the giant elliptical galaxy Centaurus A was among the first objects observed by the orbiting Chandra X-ray Observatory. Astronomers were not disappointed, as Centaurus A's appearance in x-rays makes its classification as an active galaxy easy to appreciate. Perhaps the most striking feature of this Chandra false-color x-ray view is the jet, 30,000 light-years long. Blasting toward the upper left corner of the picture, the jet seems to arise from the galaxy's bright central x-ray source -- suspected of harboring a black hole with a million or so times the mass of the Sun. Centaurus A is also seen to be teeming with other individual x-ray sources and a pervasive, diffuse x-ray glow. Most of these individual sources are likely to be neutron stars or solar mass black holes accreting material from their less exotic binary companion stars. The diffuse high-energy glow represents gas throughout the galaxy heated to temperatures of millions of degrees C. At 11 million light-years distant in the constellation Centaurus, Centaurus A (NGC 5128) is the closest active galaxy.

Takahashi’s Short-Pulse GRB Model (2000)

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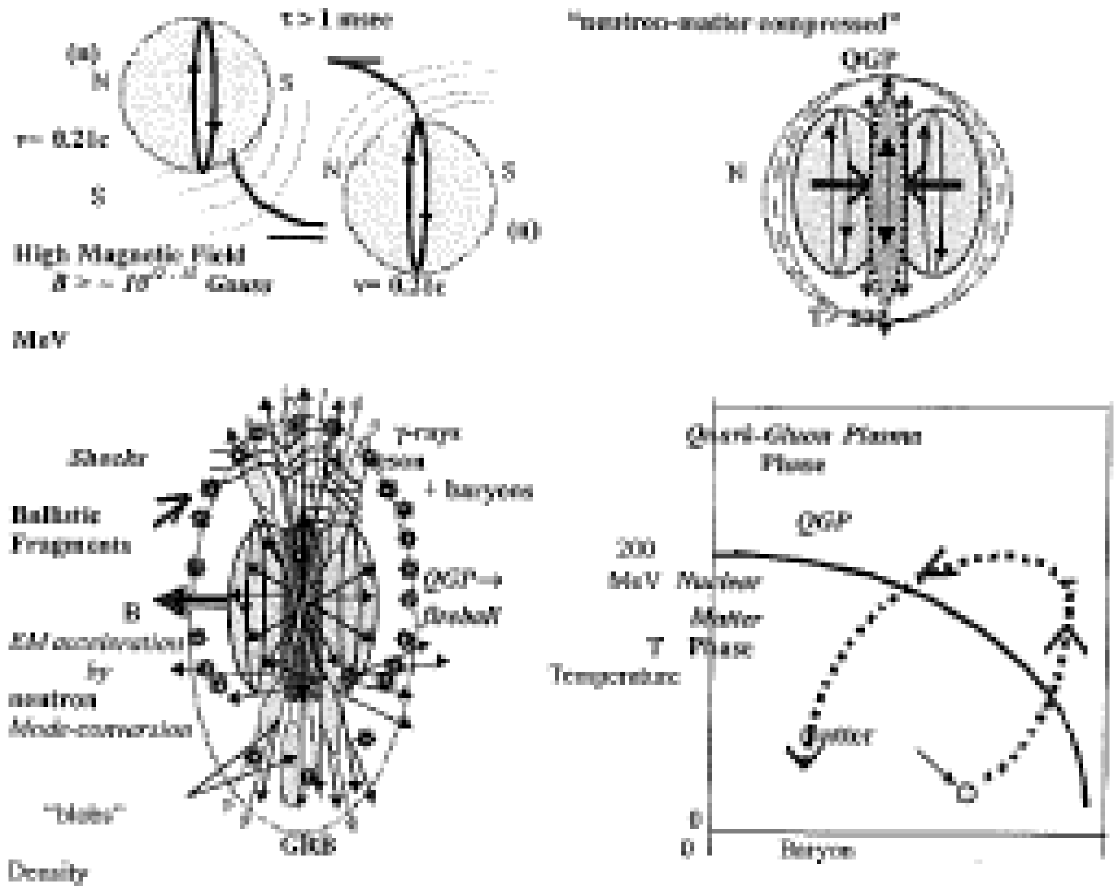

Figure 2. Schematic illustrations of QGP formation in the merge of spinning neutron stars.

Collision of two neutron stars
hot electron-positron plasma
burst of shock propagates out

↓

GRB

Y. Takahashi, L. W. Hillman, and T. Tajima, in *High-Field Science* (Kluwer, NY, 2000) eds. T. Tajima et al.

EM pulse wakefield acceleration in GRB atmosphere

Acceleration in GRB atmosphere

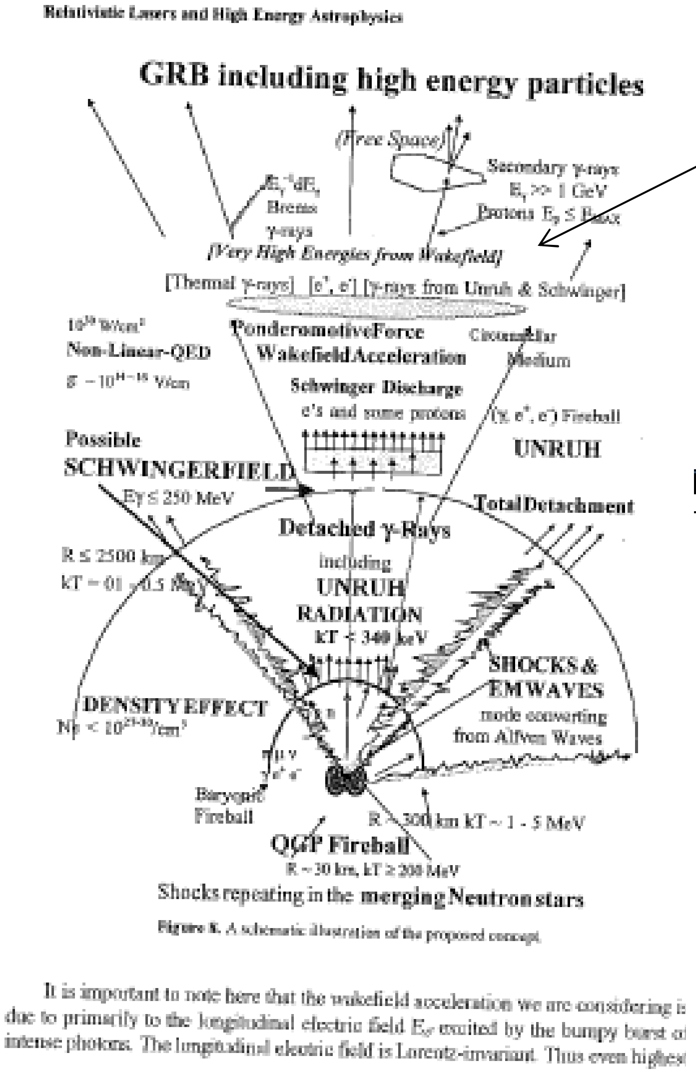

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Figure 8. A schematic illustration of the proposed concept.

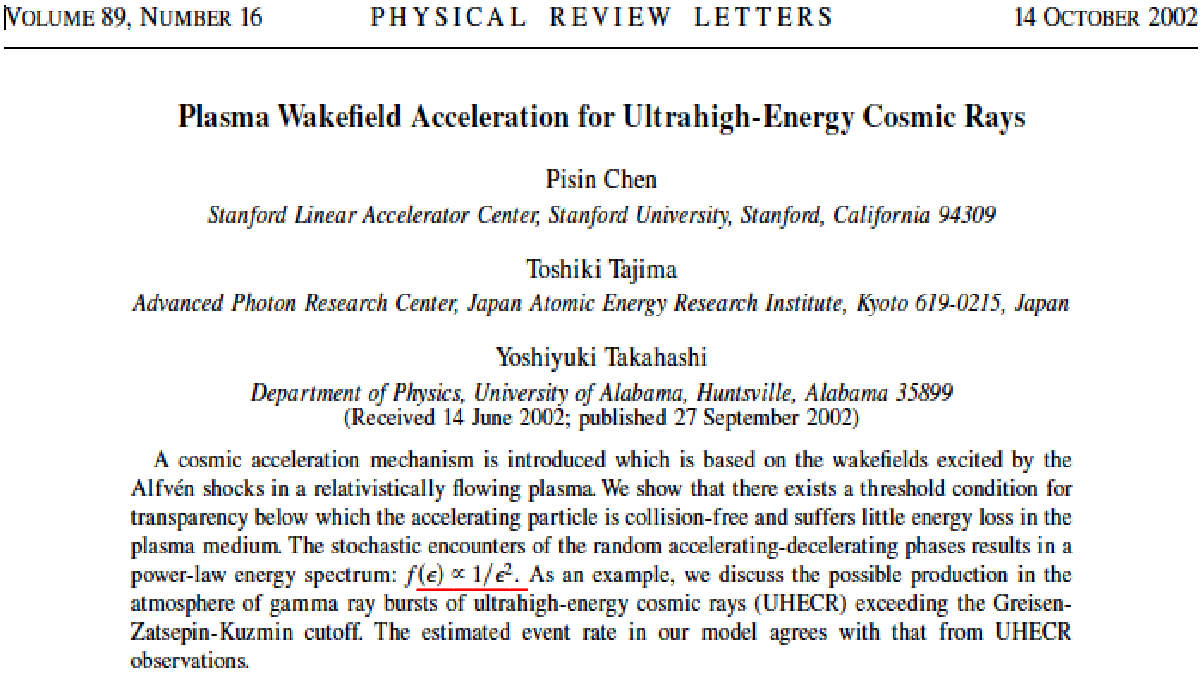
It is important to note here that the wakefield acceleration we are considering i
due to primarily to the longitudinal electric field E_z excited by the bumpy burst o
intense photons. The longitudinal electric field is Lorentz-invariant. Thus even highes

EM shock emerges from the electron-positron fireball into the atmosphere of GRB

EM pulse induces strong wakefields

Immediately accelerates energies beyond 10^{21}eV over 10^3km

→ Energy spectrum of GRB wakefield



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Plasma Wakefield Acceleration for Ultrahigh-Energy Cosmic Rays

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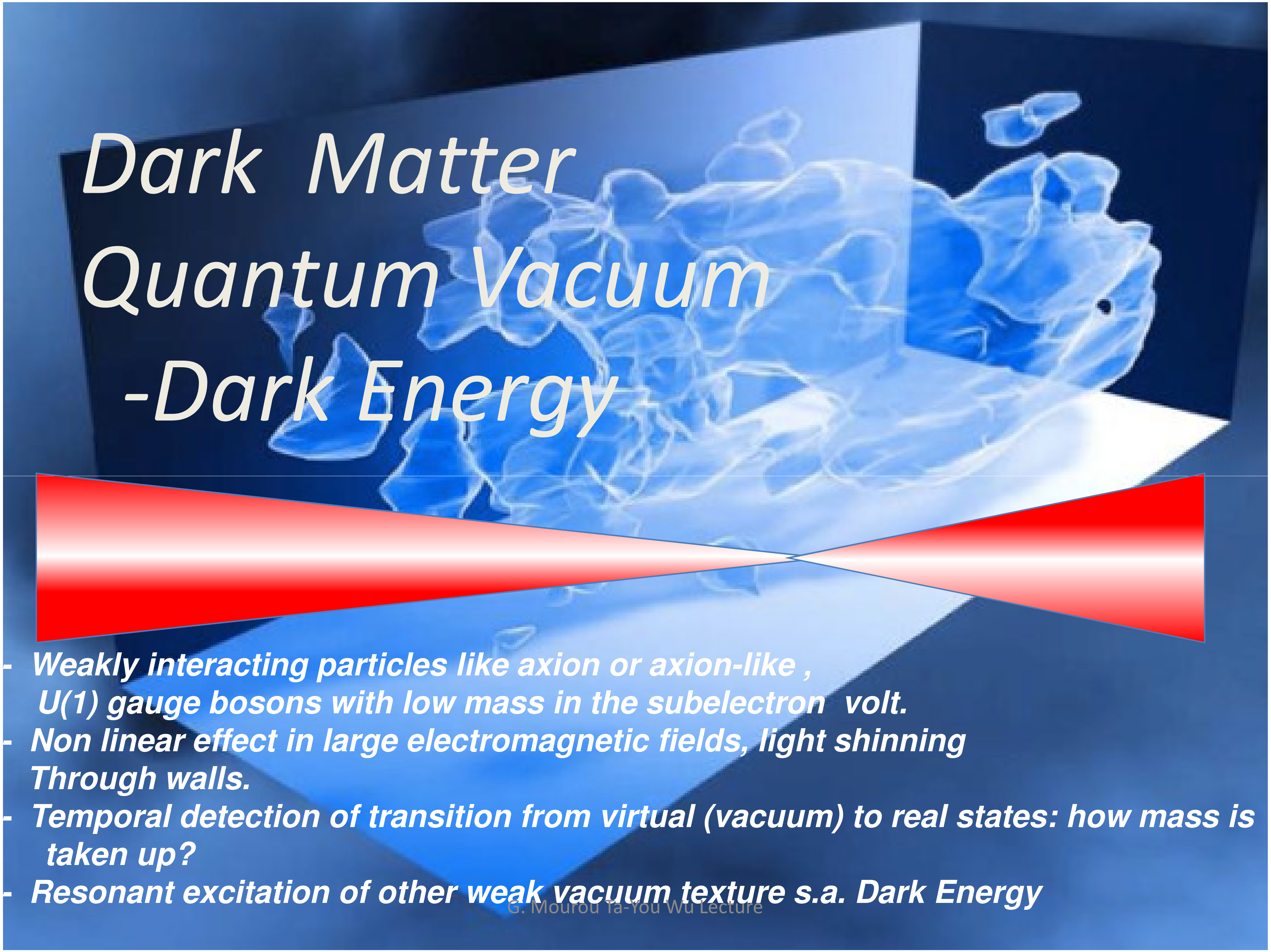
(Received 14 June 2002; published 27 September 2002)

A cosmic acceleration mechanism is introduced which is based on the wakefields excited by the Alfvén shocks in a relativistically flowing plasma. We show that there exists a threshold condition for transparency below which the accelerating particle is collision-free and suffers little energy loss in the plasma medium. The stochastic encounters of the random accelerating-decelerating phases results in a power-law energy spectrum: $f(\epsilon) \propto 1/\epsilon^2$. As an example, we discuss the possible production in the atmosphere of gamma ray bursts of ultrahigh-energy cosmic rays (UHECR) exceeding the Greisen-Zatsepin-Kuzmin cutoff. The estimated event rate in our model agrees with that from UHECR observations.



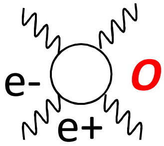
Dark Matter
Quantum Vacuum
-Dark Energy

- *Weakly interacting particles like axion or axion-like ,*
  U(1) gauge bosons with low mass in the subelectron volt.
- *Non linear effect in large electromagnetic fields, light shinning*
  Through walls.
- *Temporal detection of transition from virtual (vacuum) to real states: how mass is*
  taken up?
- *Resonant excitation of other weak vacuum texture s.a. Dark Energy*

Birefringence by QED in eV range

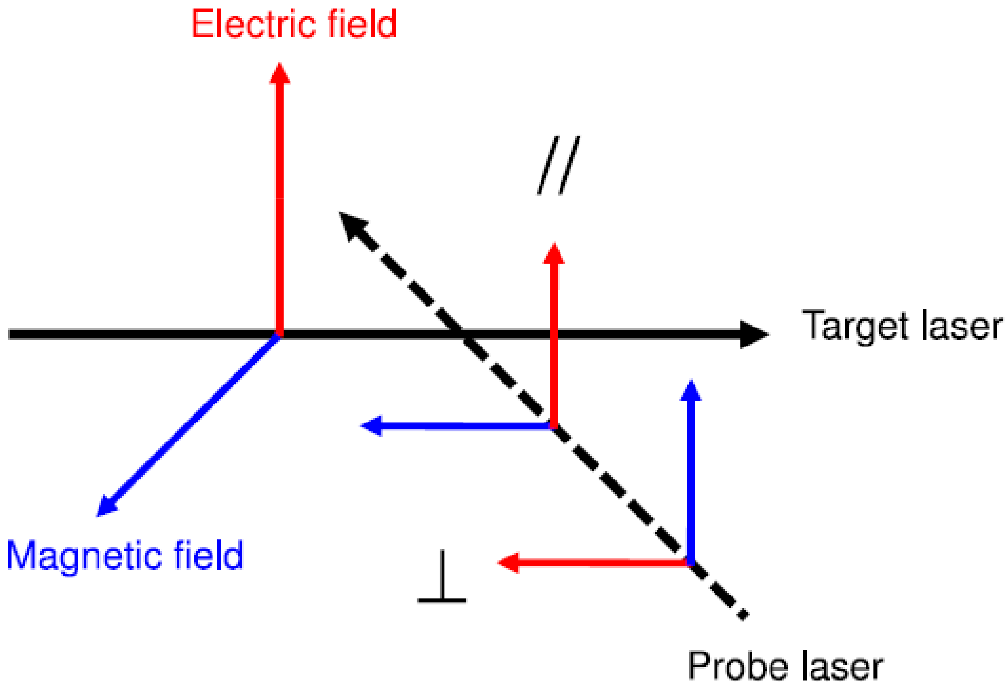
Euler-Heisenberg one-loop Lagrangian

$$L_{QED} = \frac{1}{360}\frac{\alpha^2}{m^4}[4(F_{\mu\nu}F^{\mu\nu})^2 + 7(F_{\mu\nu}\tilde{F}^{\mu\nu})^2]$$



O(10^{-42}b)

Refractive index depends on polarizations



$$n_{\parallel} = 1 + \frac{16}{45}\frac{\alpha^2 U}{U_e}, \quad n_{\perp} = 1 + \frac{28}{45}\frac{\alpha^2 U}{U_e}$$

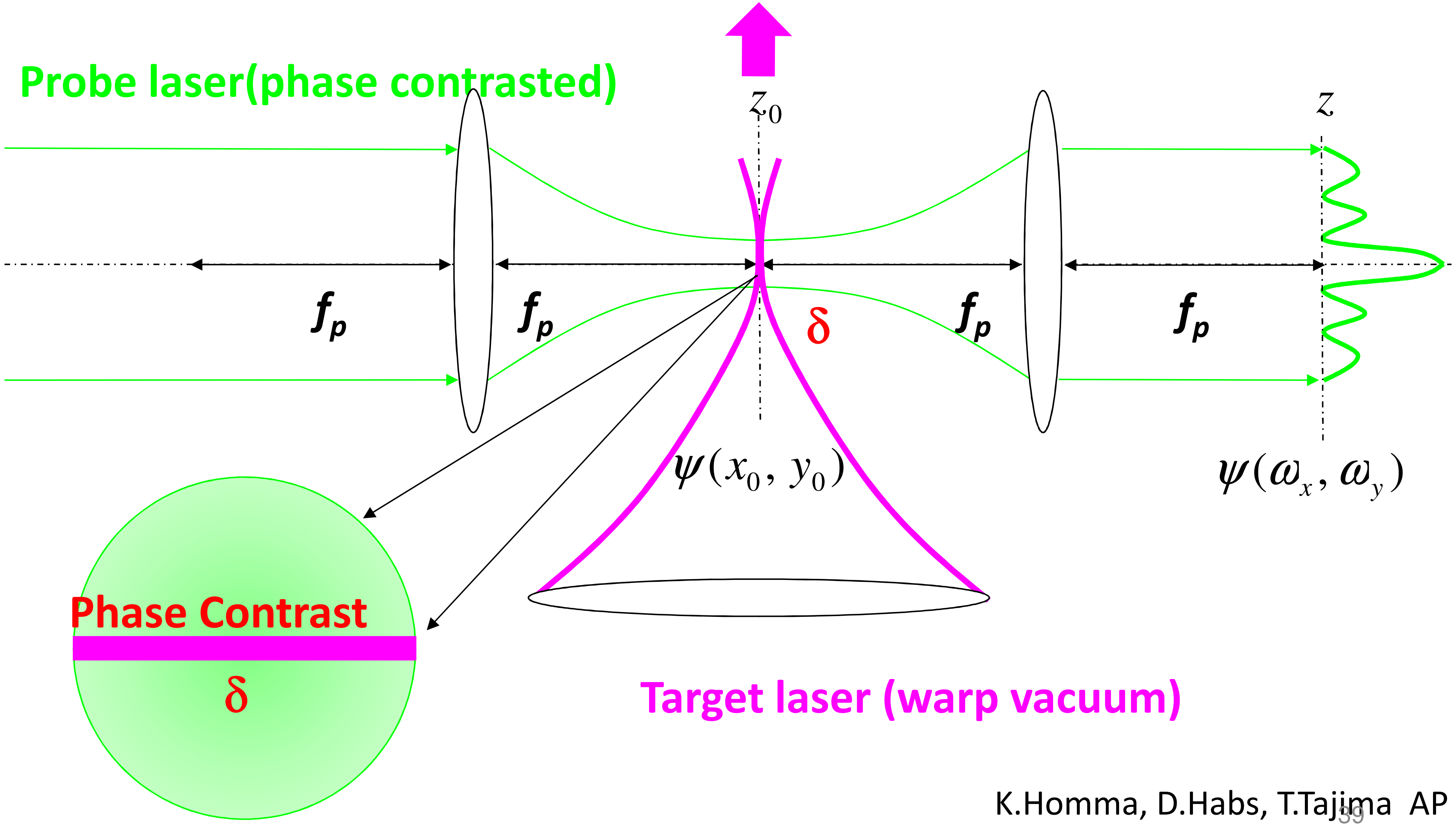
$U_e = m_e^4 c^5 / \hbar^3 \approx$ 1.42x10^6 J/μm^3

ELI(~200J per ~20fs)

can reach Δn~10^{-9}~10^{-10}

(Homma, Habs, Tajima)

Phase contrast imaging of vacuum



Probe laser(phase contrasted)

z_0

z

f_p f_p f_p f_p

δ

$\psi(x_0, y_0)$

$\psi(\omega_x, \omega_y)$

Phase Contrast

δ

Target laser (warp vacuum)

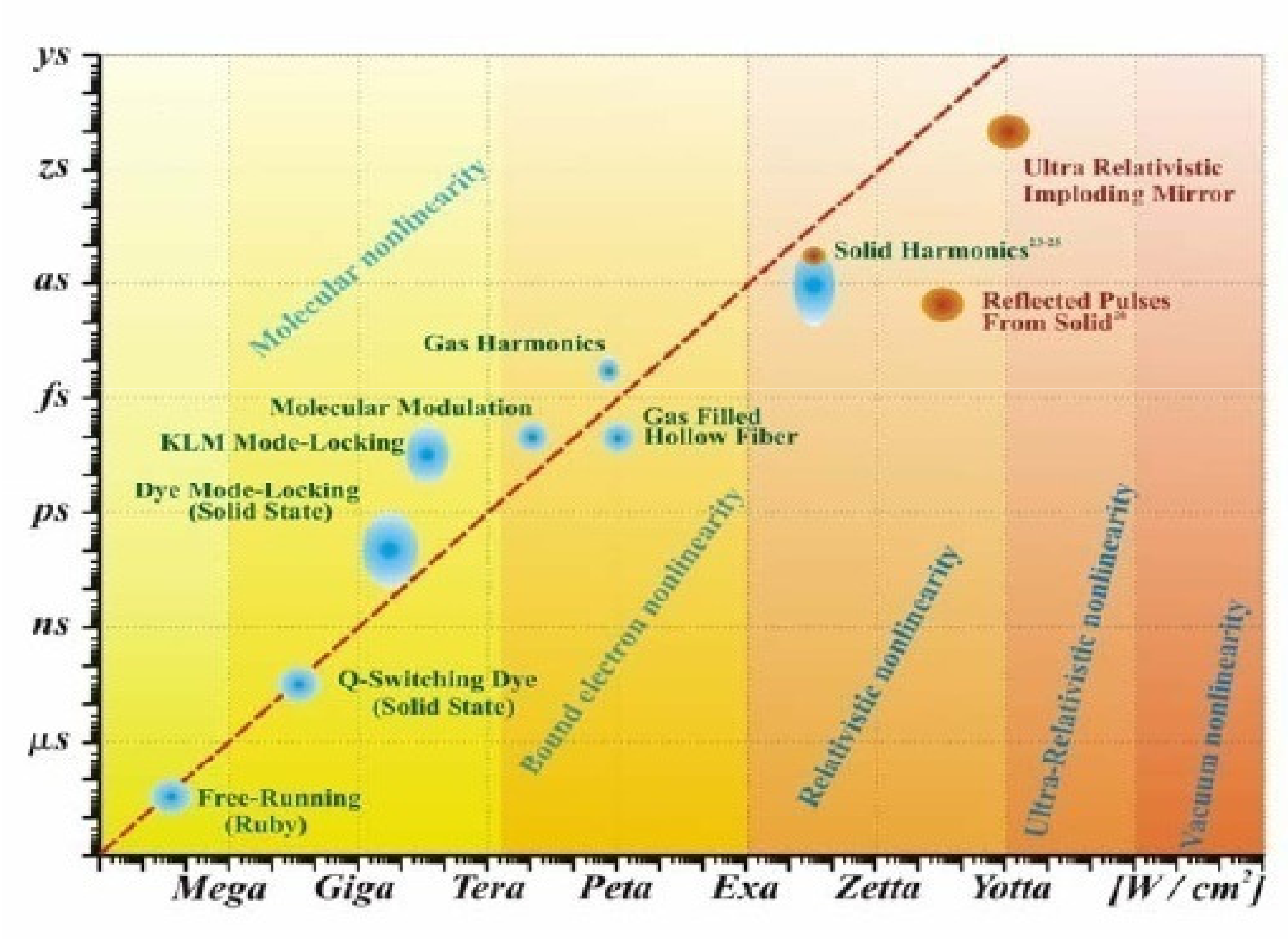
K.Homma, D.Habs, T.Tajima AP B(2011)

The Pulse Intensity-Duration Conjecture

(← physics: “Matter is nonlinear”

“The more rigid nonlinearity, the more intense to manipulate it”; i.e. rigidity vs. pulse length)

Pulse duration



Pulse intensity →

(Mourou / Tajima, Science, 2011)
(Seggebrock et al. 2012)

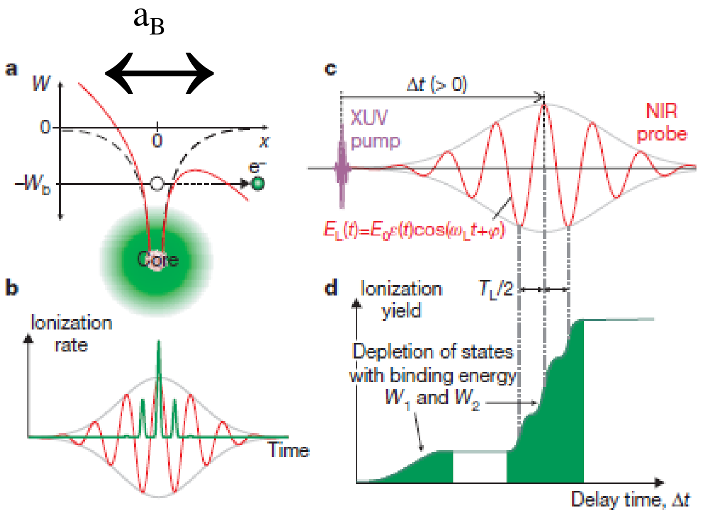
Streaking Vacuum

(from atomic physics to QED vacuum physics)

atom

XUV photon ionization
Laser streaking
→ attosecond dynamics

$\mathrm{a_B}$



Uiberacker et al. (2007)

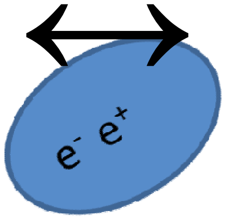
vacuum

Gamma photon 'ionization'
XUV streaking
→zeptosecond dynamics

$$E_S/E_K = \alpha^{-3};\quad P_{c\ vac}/P_c = \alpha^{-6}$$

size

$\lambda_C = \alpha\, a_B$



depth of potential

$\Phi = \alpha^{-2} W_B$

$$R_{e^+e^-} \propto \exp\left(-\left(\frac{8}{3}\right)\left(\frac{m}{\omega}\right)\left(\frac{E_S}{E}\right)\right)$$

Nikishov(1964)

Nonperturbative:

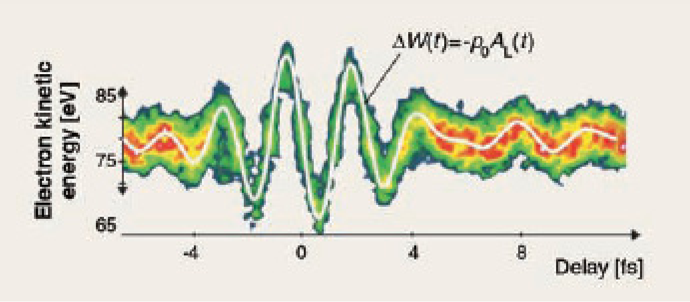
$$W(f,\varkappa) \approx \left(\frac{3}{2}\right)^{3/2} \frac{e^2 m^2}{32\pi k_0}\, \varkappa e^{-8/3\varkappa}\left(1-\frac{64}{15}\frac{f}{\varkappa^3}\right).$$

Multiphoton: Power law dependence of the argument

γ-photon induced vacuum streaking by lasers

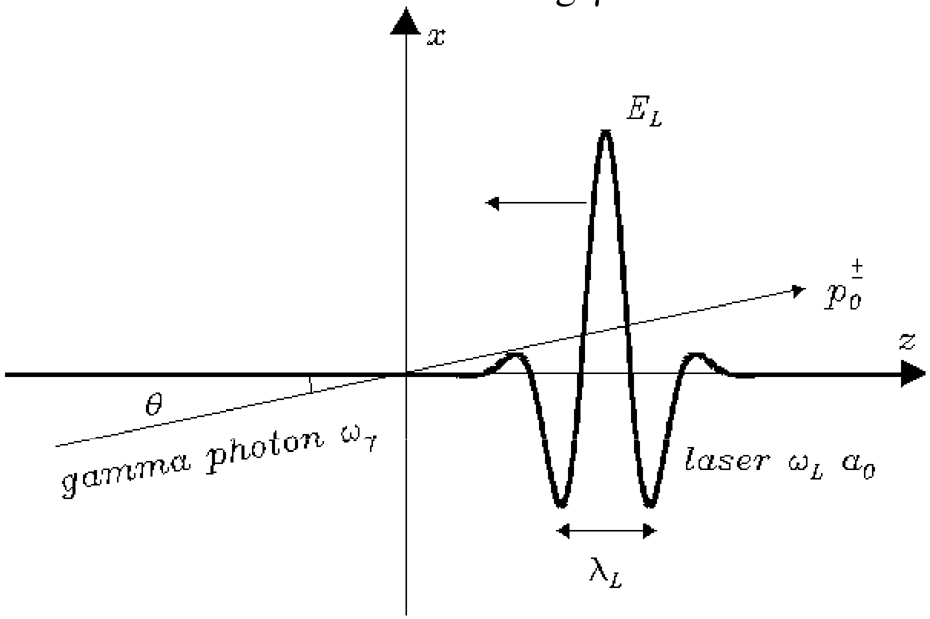
Tajima, Goulielmakis, Krausz, Klier, Ruhl, et al. (in preparation)

Atomic as streaking



Goulielmakis(2008)

Laser field is compressed by factor $(h\nu/mc^2) \sim 10^{3\text{-}4}$ with the counterstreaming γ



QED vacuum zs streaking

$$E_L'/E_L = \tau_L/\tau_L' = \gamma_N = h\nu_\gamma/mc^2$$

counterstreaming laser field: enhanced by γ_N

" " pulse length: compressed by $1/\gamma_N$

need to near threshold to avoid cascade noise

Temporal evolution of nonlinear QED: emergence of pair from virtual into real particles

origin of mass (renormalization)

application to that of QCD in even higher intensity (yoctosecond)

Beyond QED photon-photon interaction

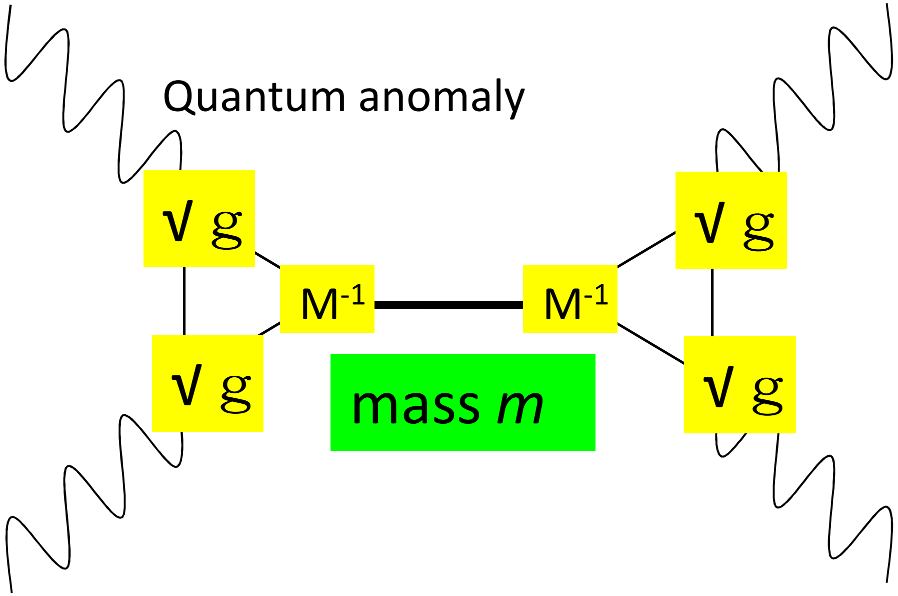
$$L_{QED} = \frac{1}{360}\frac{\alpha^2}{m^4}\left[4(F_{\mu\nu}F^{\mu\nu})^2 + 7(F_{\mu\nu}\tilde{F}^{\mu\nu})^2\right]$$

$$\Updownarrow \qquad\qquad \Updownarrow$$

$$\phi F_{\mu\nu}F^{\mu\nu} \qquad \sigma F_{\mu\nu}\tilde{F}^{\mu\nu}$$

Away from 4 : 7 = QCD , low-mass scalar ϕ, or pseudoscalar σ
(unlike Higgs, which is heavy fields for photon-photon interaction,)

Resonance in quasi-parallel collisions in low cms energy



Quantum anomaly

√ g

√ g

M^{-1}

M^{-1}

√ g

√ g

mass *m*

If $M \sim M_{Planck}$, Dark Energy

$$\boxed{g M^{-1} F^{\mu\nu} F_{\mu\nu} \phi}$$

arXiv:1006.1762 [gr-qc]
Y. Fujii and K.Homma

QCD-instanton, Dark Matter

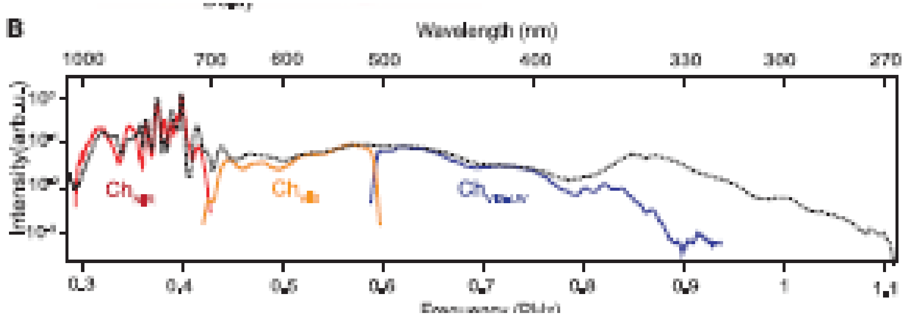
$$\boxed{g M^{-1} F^{\mu\nu} \tilde{F}_{\mu\nu} \sigma}$$

K.Homma, D.Habs,
T.Tajima (2011)

Degenerate Four-Wave Mixing (DFWM)

Laser-induced nonlinear optics in vacuum (cf. Nonlinear optics in crystal)

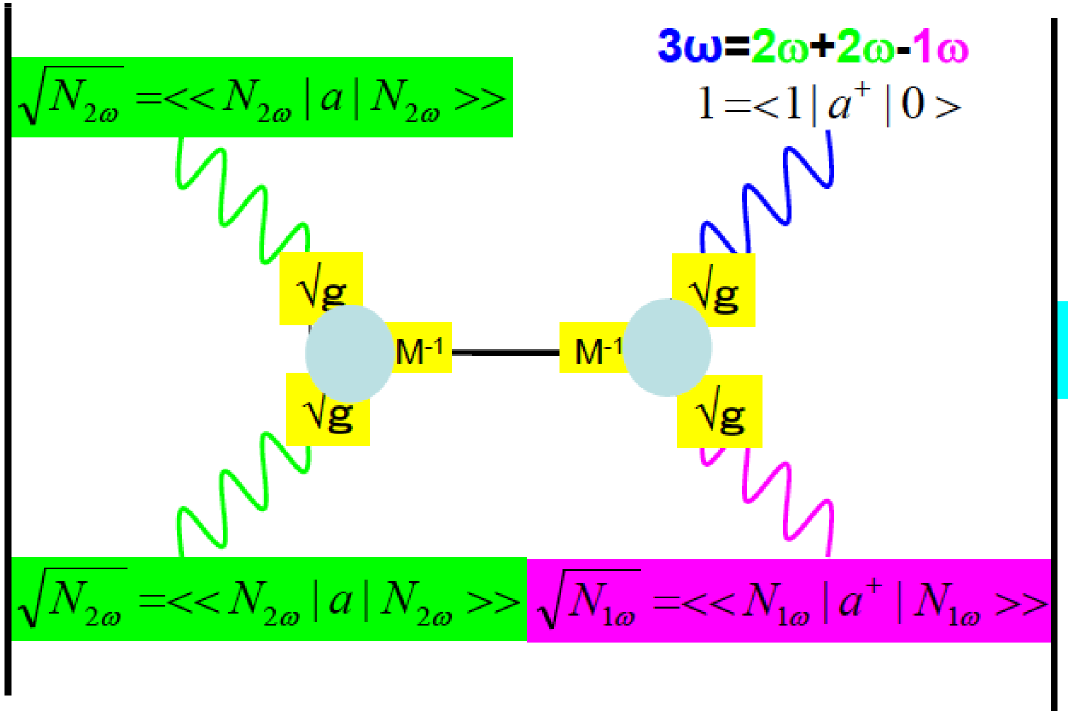
Decay into (4-x)ω can be induced by frequency-mixing



Wirth et al. (Science 2011: synthesized light transients)

Sweep by arbitrary frequency **xω**

e.g. xω = 1ω



3ω=2ω+2ω-1ω

$1 = <1|a^+|0>$

$\sqrt{N_{2\omega}} = << N_{2\omega}|a|N_{2\omega}>>$

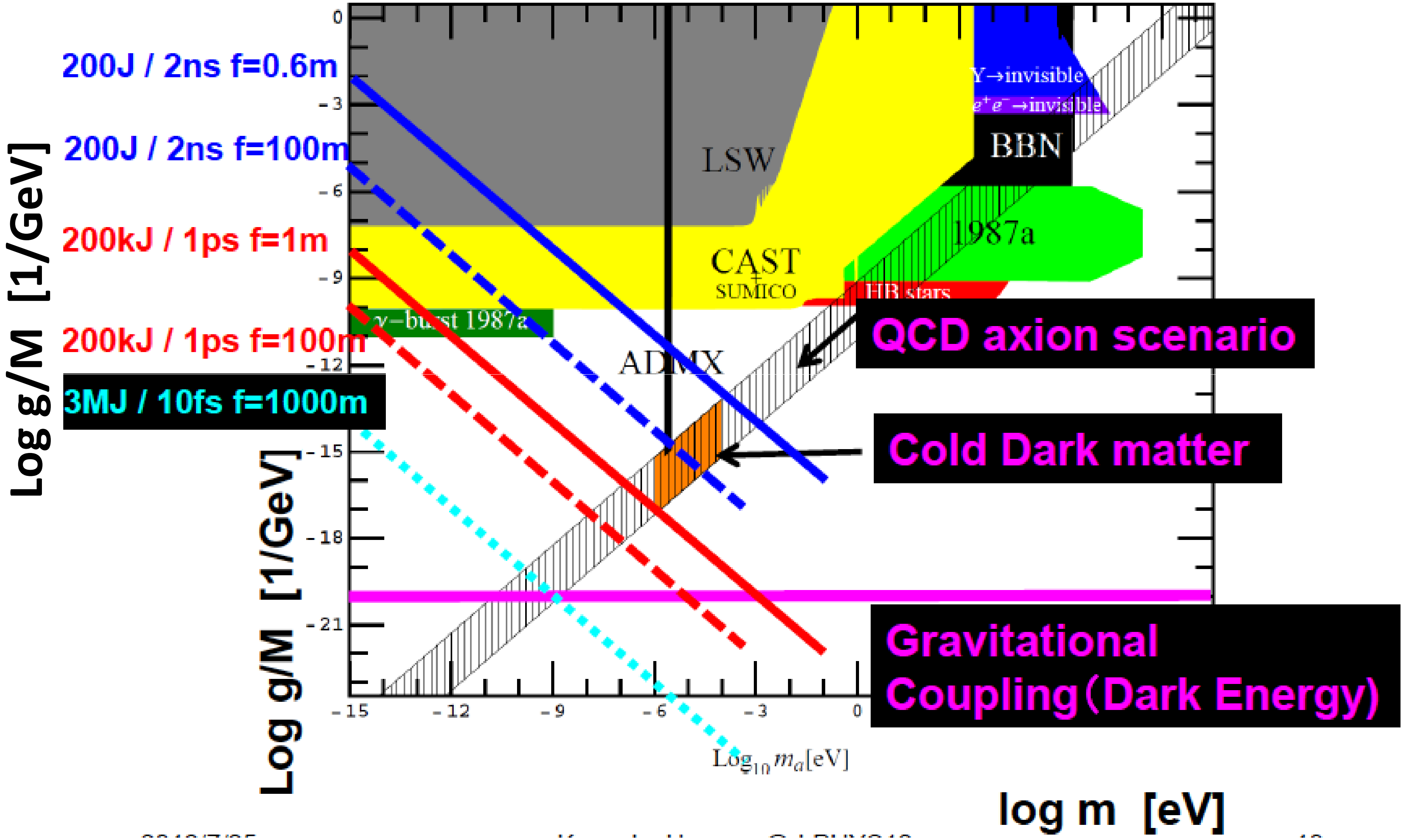
$\sqrt{N_{2\omega}} = << N_{2\omega}|a|N_{2\omega}>>$ $\sqrt{N_{1\omega}} = << N_{1\omega}|a^+|N_{1\omega}>>$

$\propto N^2{}_{2\omega} N_{1\omega}$

Cubic dependence

K.Homma, D.Habs, T.Tajima
Appl. Phys. B (2011)

Photon mixer road to unknown fields: dark matter and dark energy

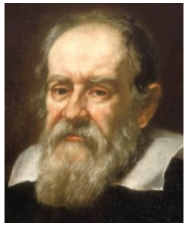


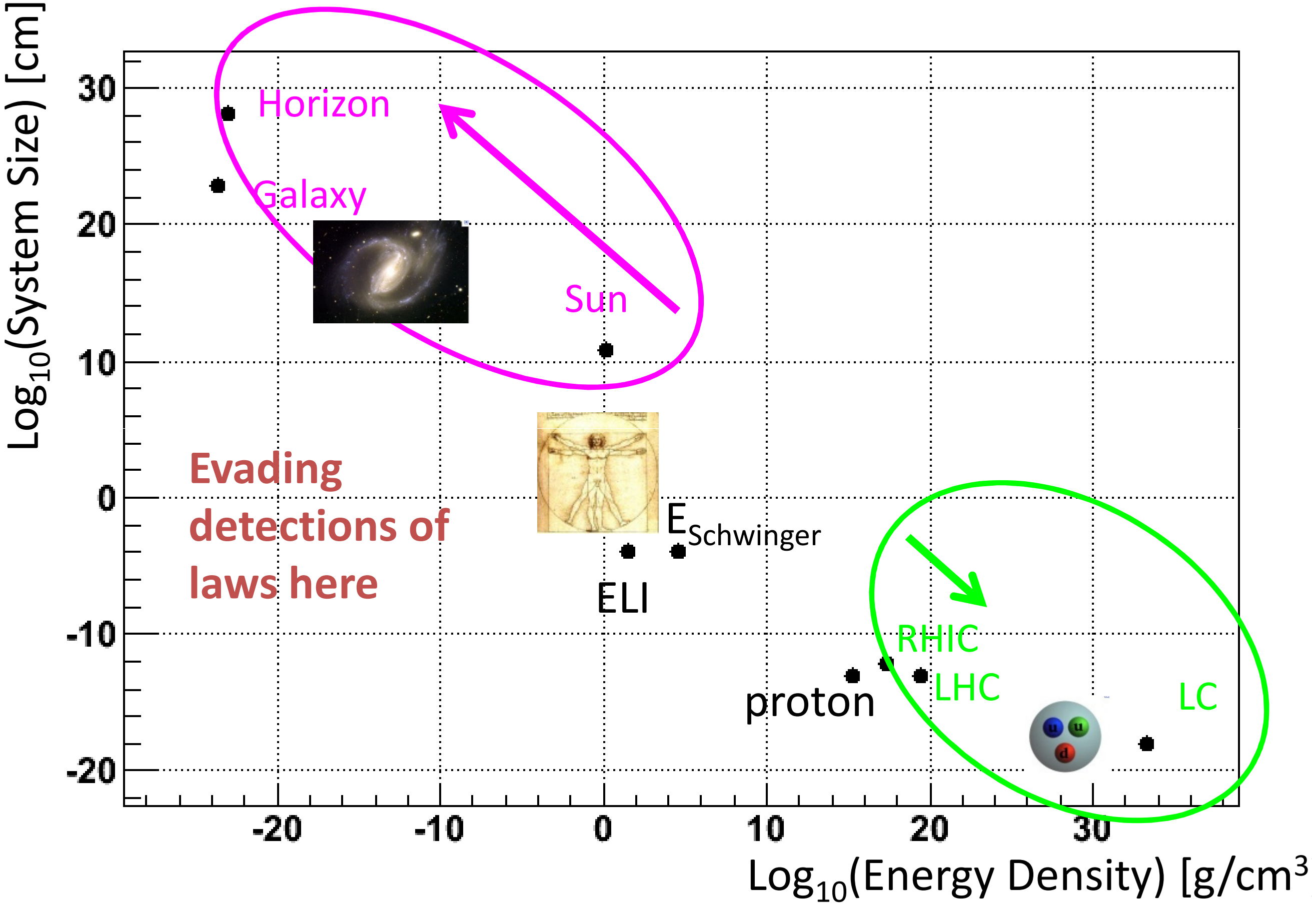
K.Homma, D.Habs, T.Tajima (2011)

Laser fits multiple of new searches

in search of unknown fields:
dark matter/dark energy

Cosmological observation





High energy collider

Domains of physical laws

Homma, Habs, Tajima (2011)

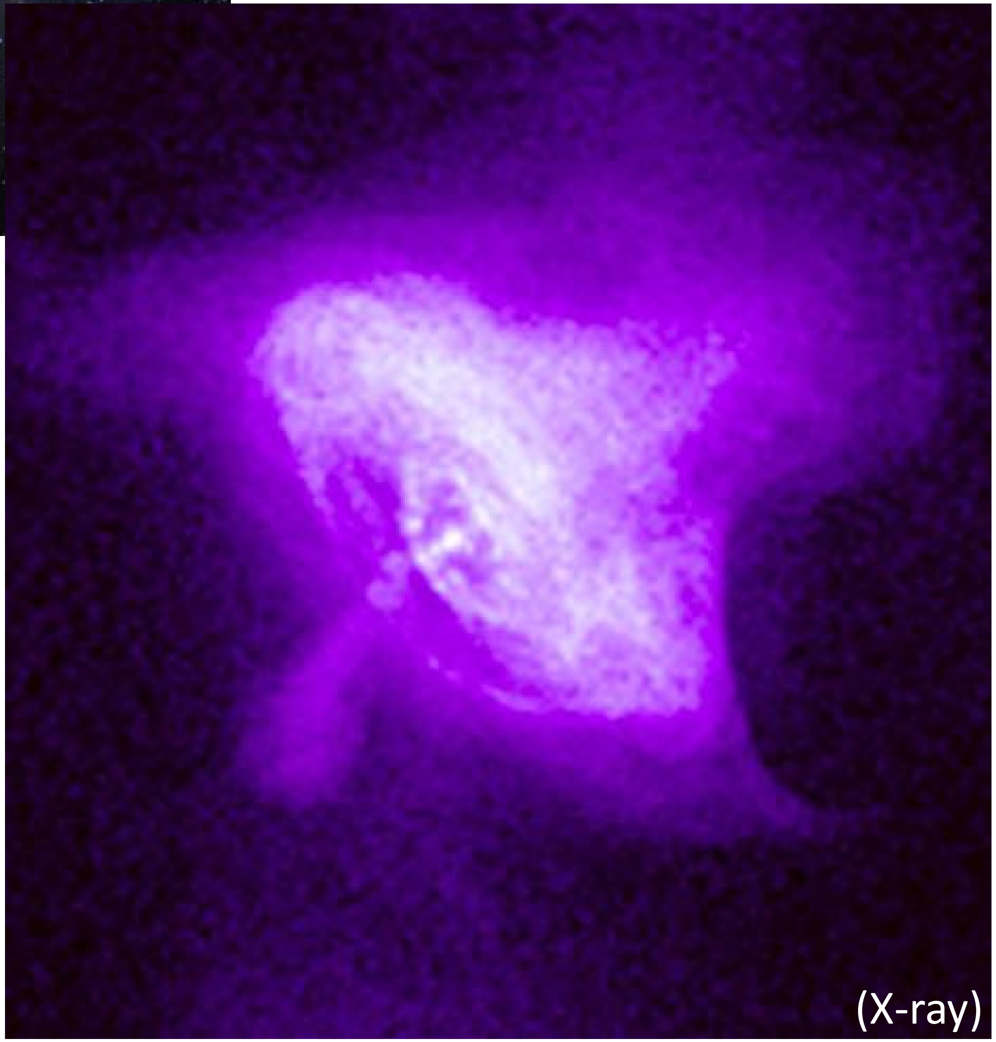
Conclusions

- March toward EW lasers is made immediate by **CEA**
- kJ-MJ energy lasers by CEA: for high energy /fundamental physics research. *ICAN* project launched for high-average power laser technology
- Order of magnitude leaps enabled toward laser acceleration
- Paradigm of non-collider as well as collider approaches
- Laser search of new fields by devised high-amplitude approach (photon-photon mixer with luminosity ~ N^3, N Bose-Einstein condensated large number)
- zs metrology of vacuum (CALA), Lorentz invariance check, ….
- New vigorous way of doing fundamental physics emerging

➔Following Bordeaux meeting, "IZEST Conf: Ascent to HEP"

Nov. 12-13, 2012, Strathclyde, including Peter Higgs

Crab nebula:
Cosmic PeV accelerating machine



Danke schoen!