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Lehrstuhl Tajima
MLL, LMU
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Extreme Lasers and High Field Science

Toshiki Tajima
LMU and MPQ, Garching, Germany

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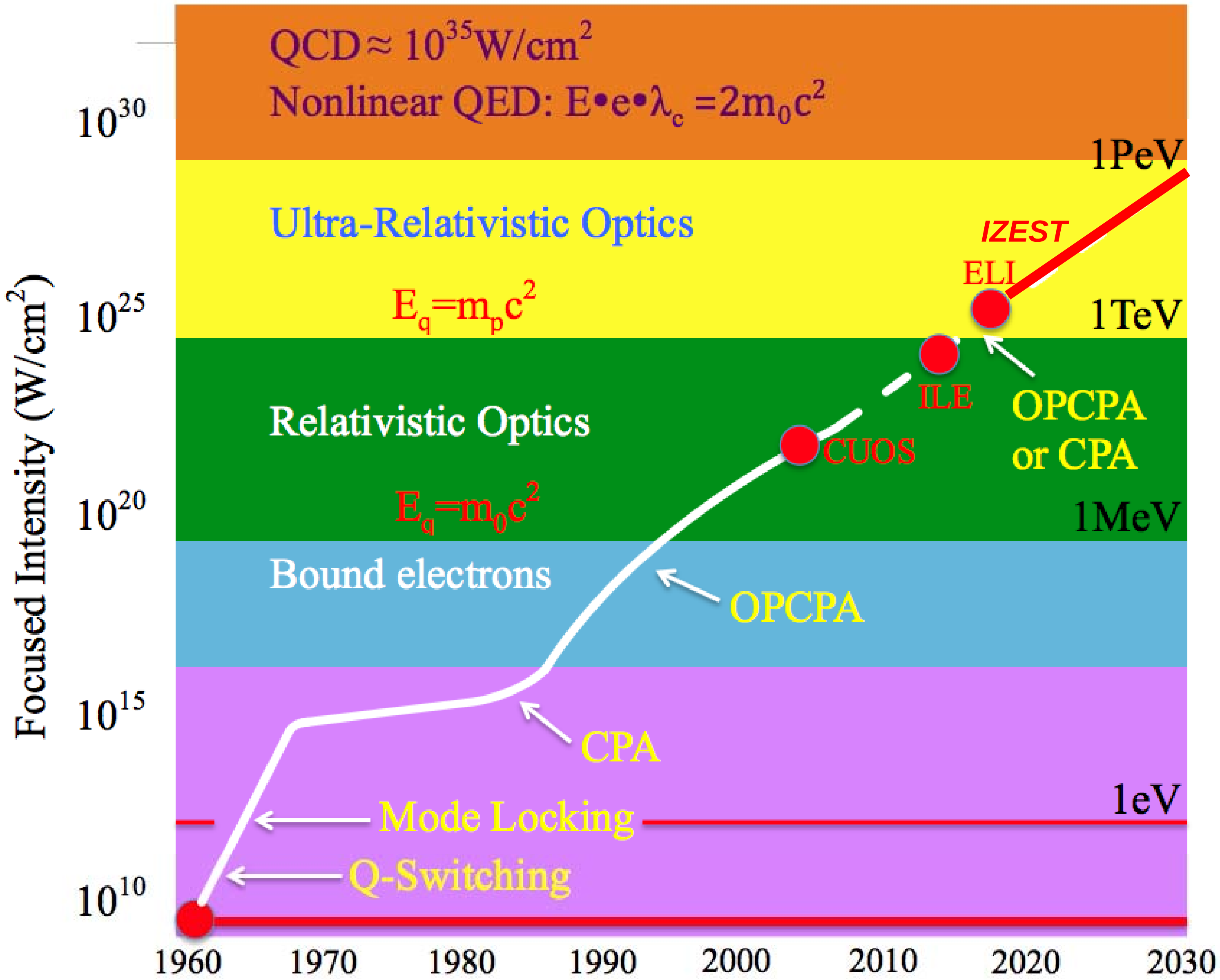
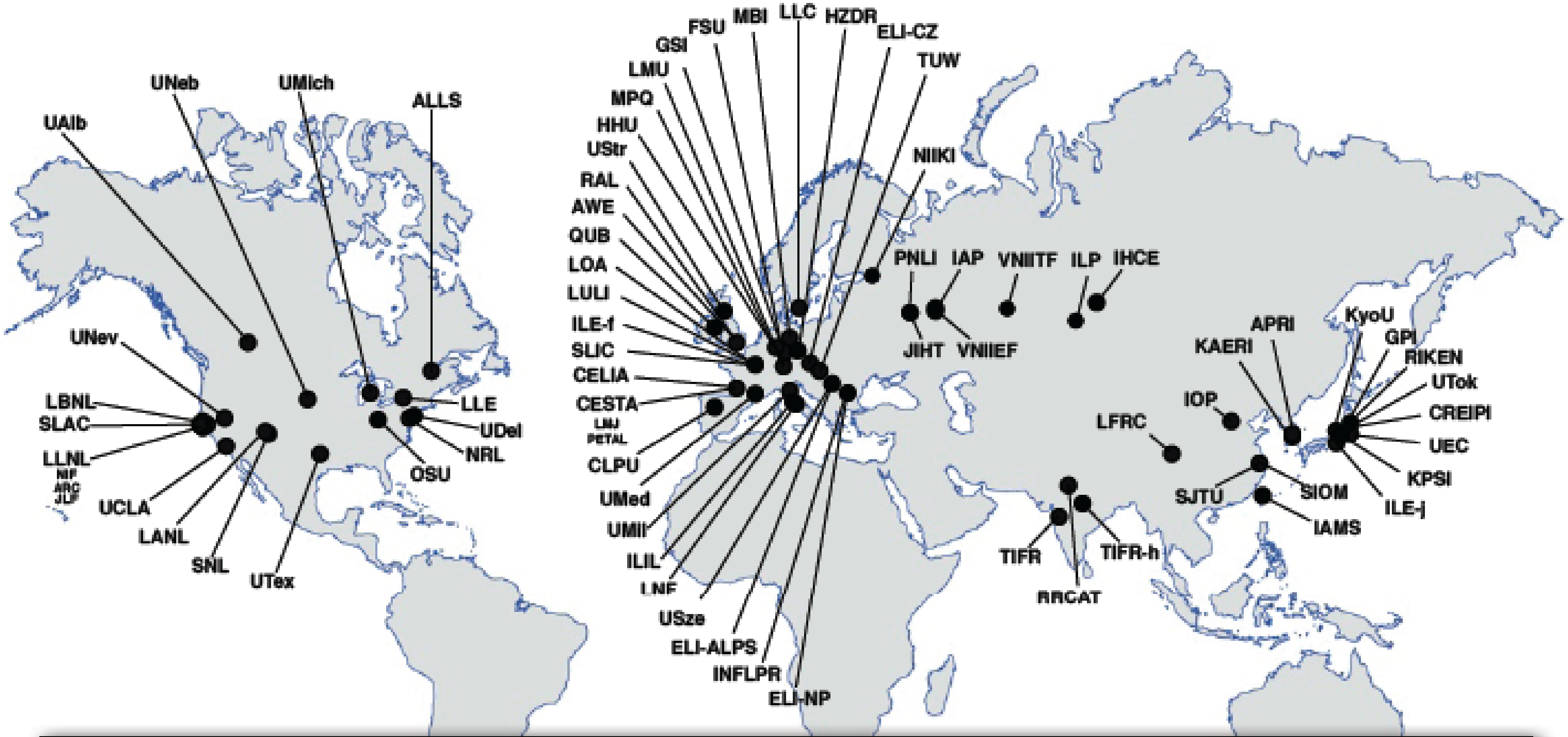
1. **ELI** and beyond: Exawatt-Zettawatt laser
2. Suzuki's challenge in high energy physics
   - High energy frontier: TeV and beyond (EuroNNAc proposal)
   - A collider? -----ICAN (EU proposal); low density operation
3. Non-collider paradigm
   - Vacuum texture and synchrotron radiation in high energy
     - Lorentz invariance check
   - Energy frontier at PeV with attosecond metrology
     - without luminosity
4. High Field explores low energy new fields:
   - high field of laser (cf. high momentum)
   - Dark matter and dark energy fields in vacuum (Homma's initiative)
     - degenerate 4 wave mixing, role of ultrawide band laser
5. zs streaking of vacuum by laser and γ photon
   - ELI: ELI-NP/γ-photonics, ELI-ALPS
6. New initiative : **IZEST** = LIL compression, XCELS in Russia,
   - ELI 4th Pillar, EW-class science

Laser Intensity vs. Years



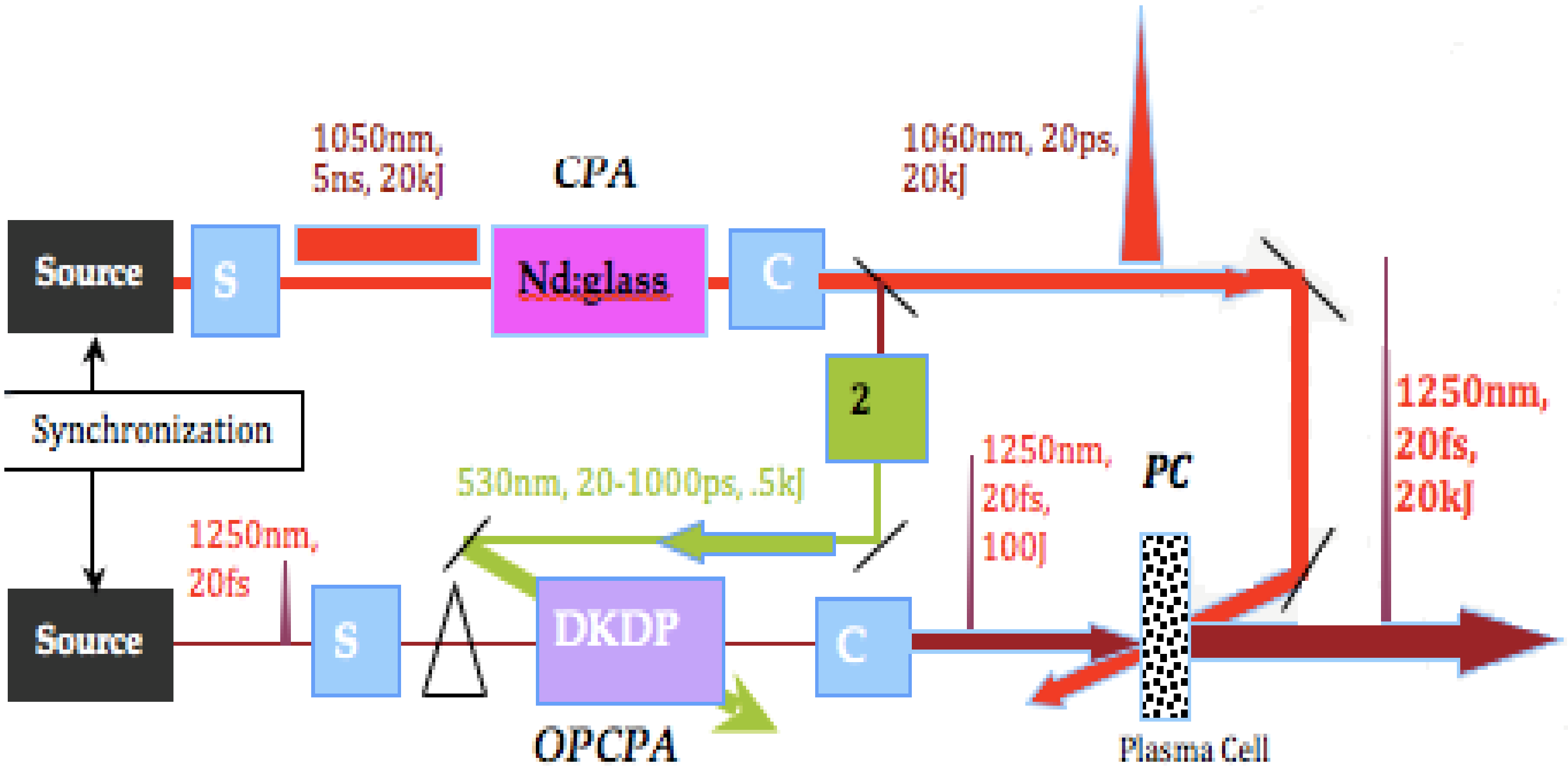
2010 ICUIL World Map of Ultrahigh Intensity Laser Capabilities

IZEST constituency resides in UHIL community



- 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

New Laser Concept : C³
(Cascaded Compression Conversion)



Mourou et al. Opt. Comm. (2011)

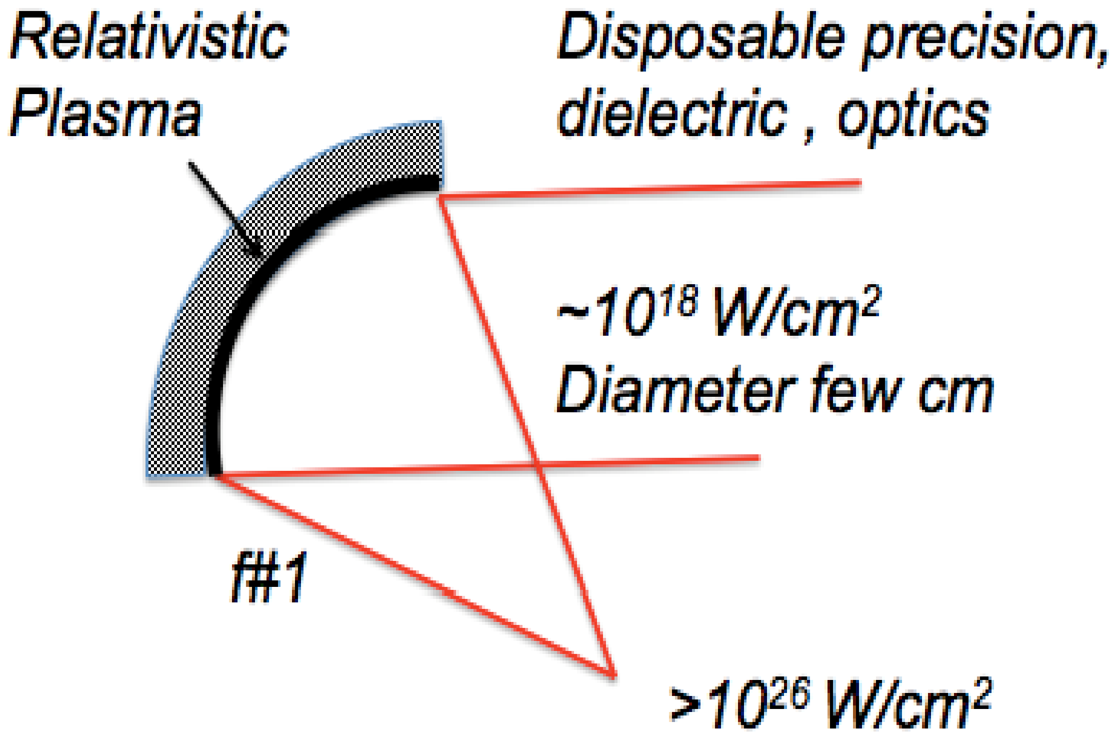
Plasma Optics

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

Optics can handle several **kJ/cm^2**.

Size reduction by1000 in area.

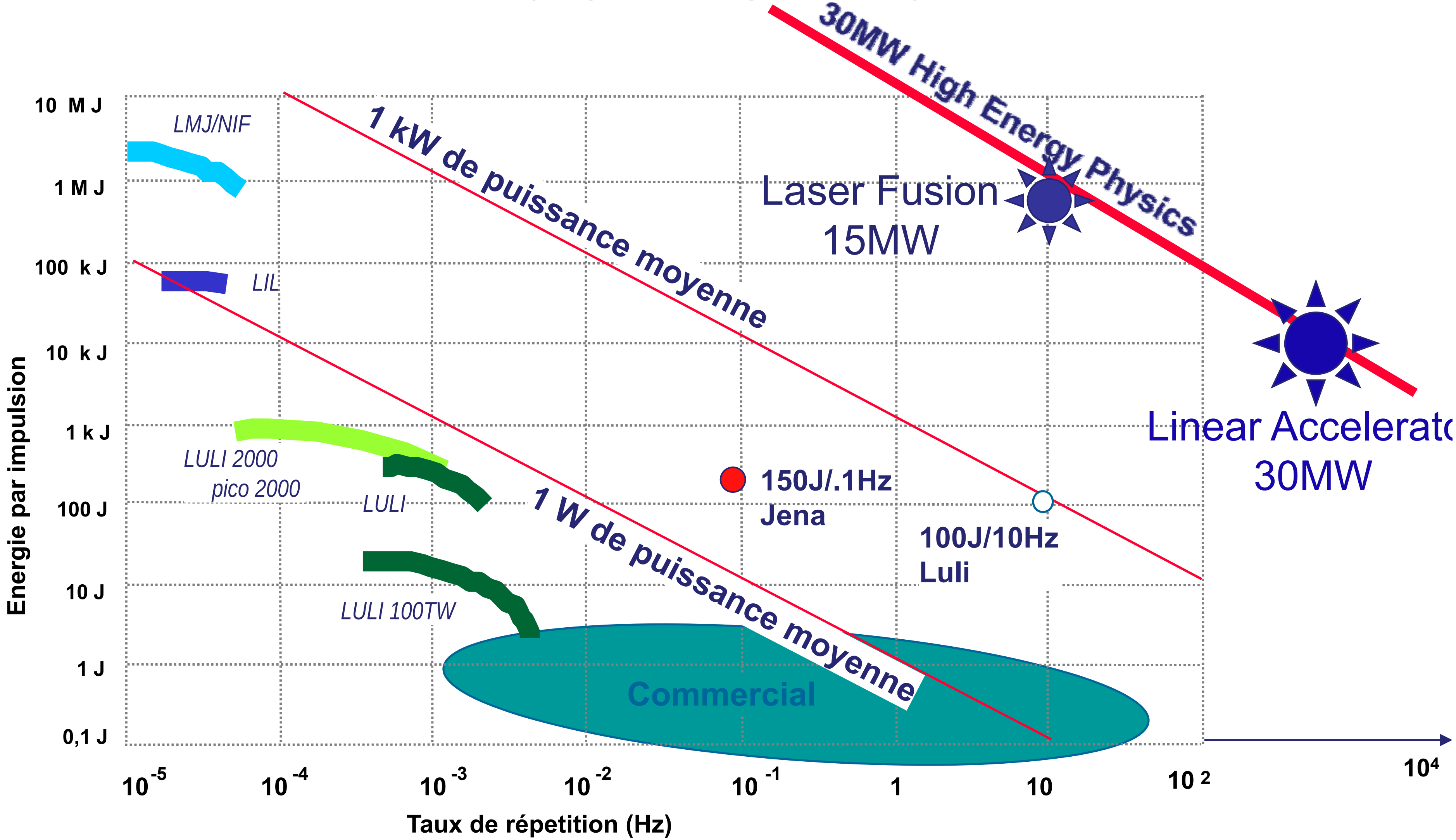
Disposed after each shot.



Mourou et al. Opt. Comm (2011)

New Scientific Regime Calls for New Technologies: *ICAN*

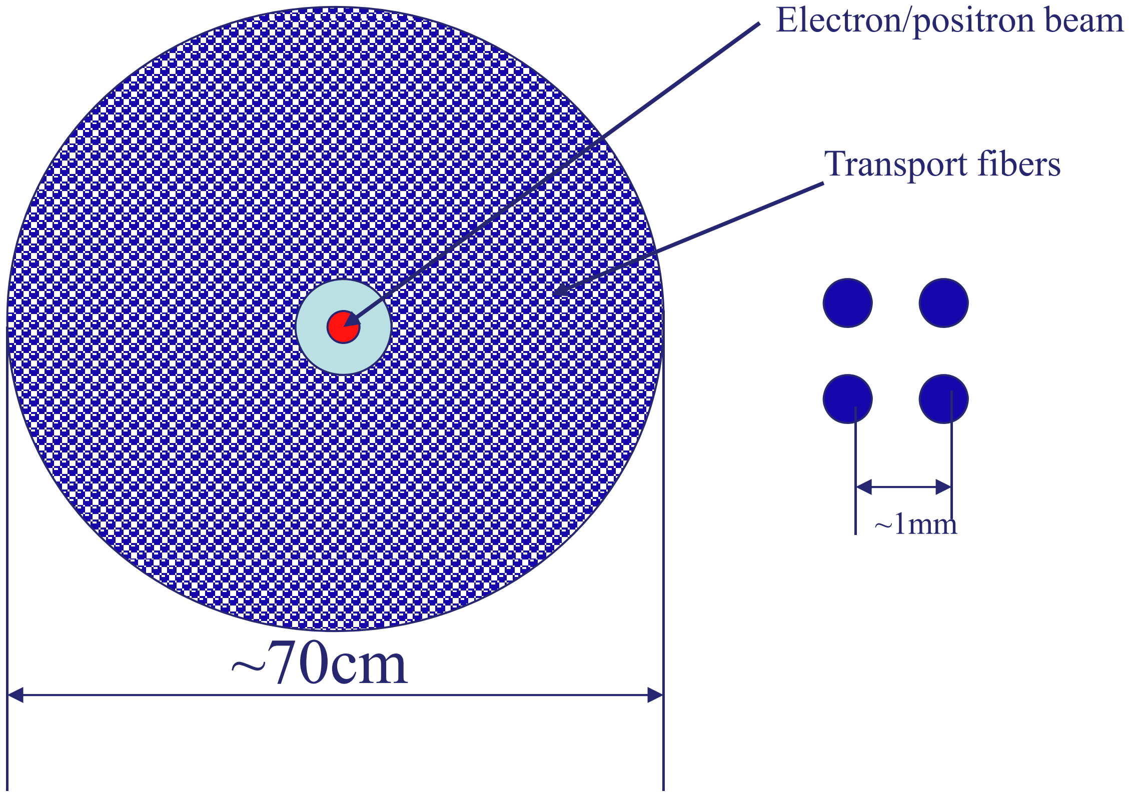
(high average power)



G. Mourou (2005)

The CAN Concept

10^4 fibers all coherently phased.

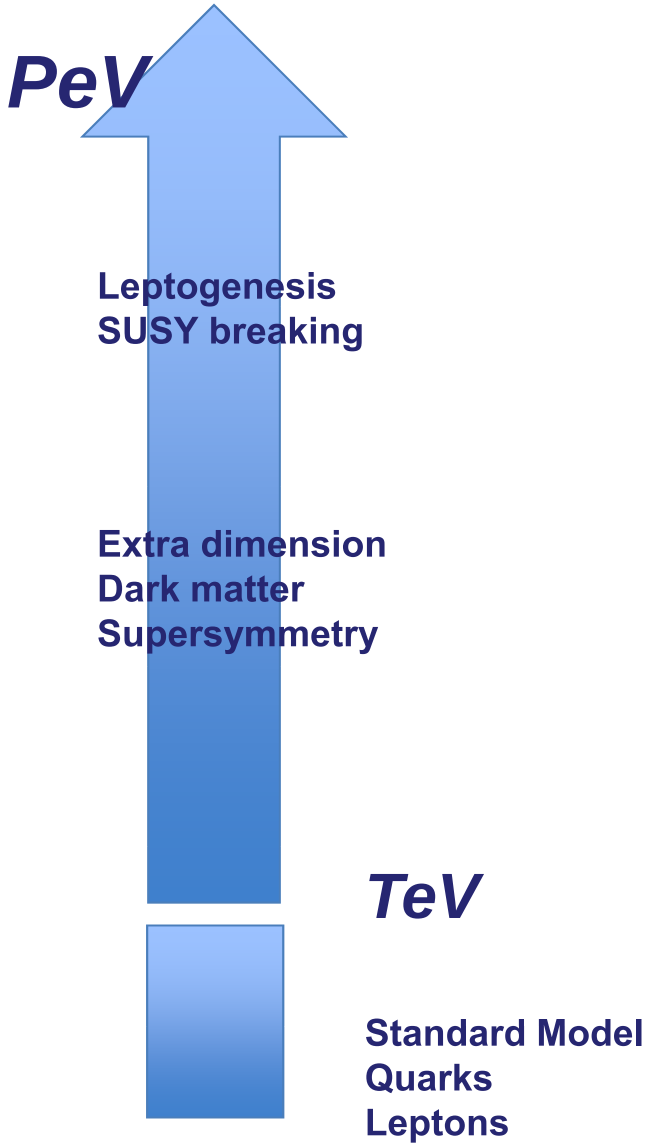


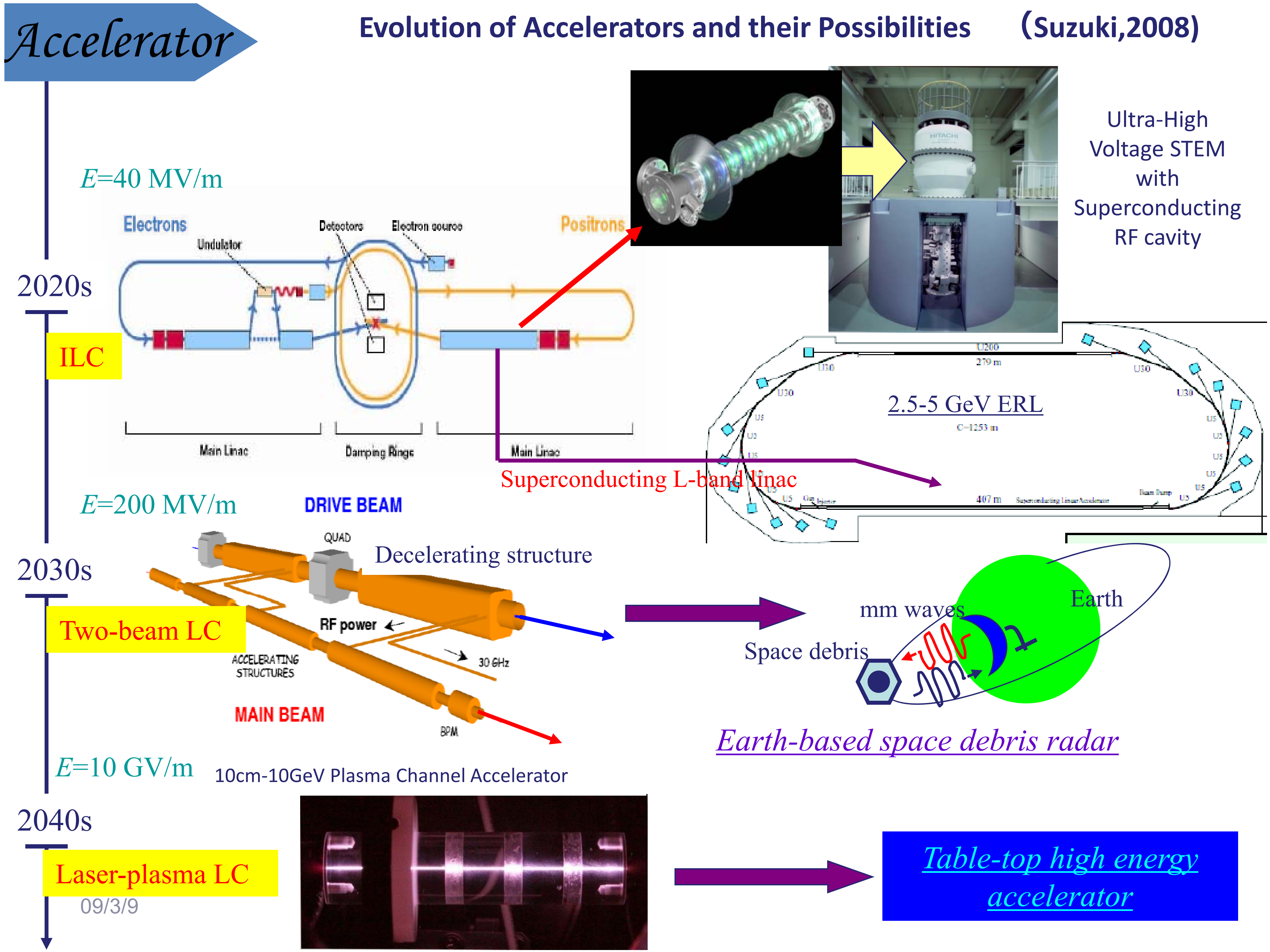
Length of a fiber ~2m   Total fiber length~ 5 10^4km

IZEST's Mission: Responding to Suzuki's Challenge

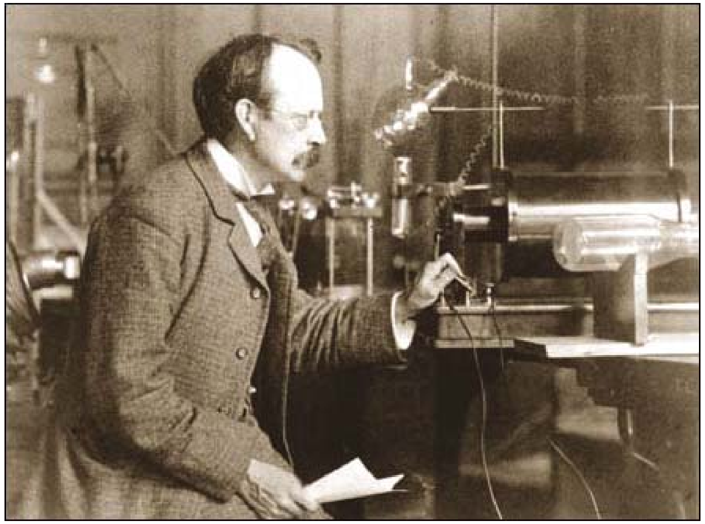
Atsuto Suzuki:
KEK Director General,
ICFA Chair

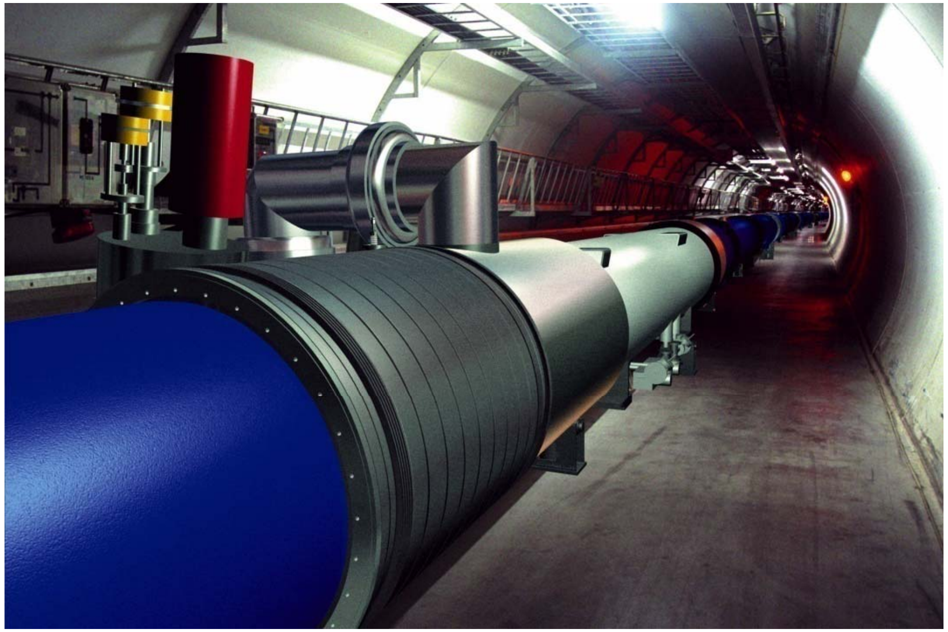
New Paradigm




Accelerator
Evolution of Accelerators and their Possibilities (Suzuki,2008)
Ultra-High Voltage STEM with Superconducting RF cavity
E=40 MV/m
Electrons
Undulator
Detectors
Electron source
Positrons
2020s
ILC
Main Linac
Damping Rings
Main Linac
Superconducting L-band linac
2.5-5 GeV ERL
E=200 MV/m
DRIVE BEAM
QUAD
Decelerating structure
2030s
Two-beam LC
RF power
ACCELERATING STRUCTURES
30 GHz
MAIN BEAM
BPM
mm waves
Earth
Space debris
Earth-based space debris radar
E=10 GV/m
10cm-10GeV Plasma Channel Accelerator
2040s
Laser-plasma LC
09/3/9
Table-top high energy accelerator

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





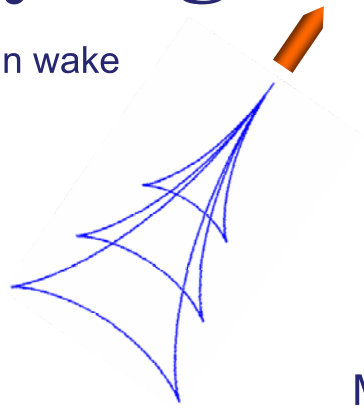
J. J. Thomson

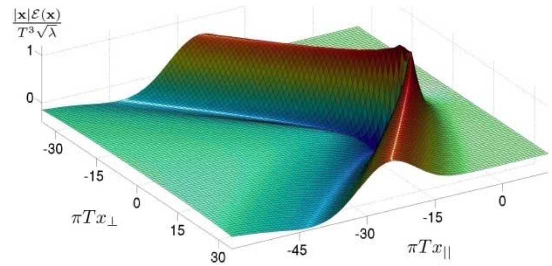
21st Century; the Photon Century
Could basic research be driven
by the massless and chargeless particles;
Photons?

C. Townes

Laser Wakefield (LWFA): relativity regulates

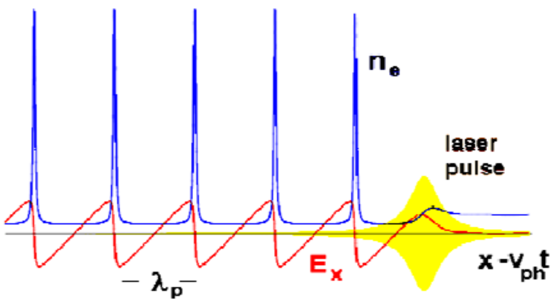
Kelvin wake





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

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



← relativity regularizes

(The density cusps.
Cusp singularity)

Wave **breaks** at v<c

Hokusai

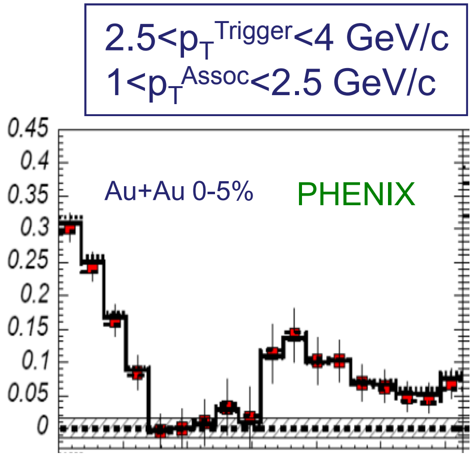
Maldacena

(Plasma physics vs.
superstring theory)

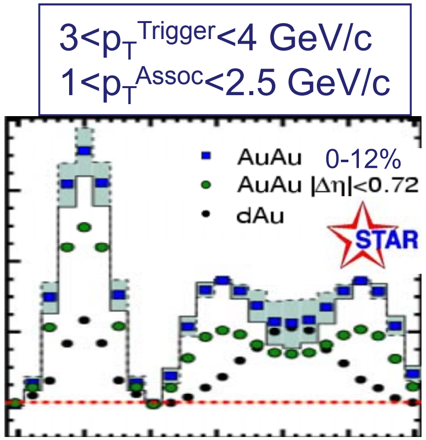
Nuclear Wake?

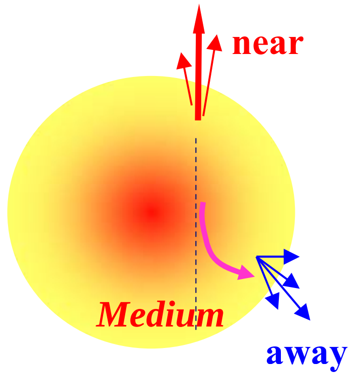
- BNL (and CERN) heavy ion collider: **"monojet"**
- Could be caused by:
  - Large angle gluon radiation (Vitev and Polsa and Salgado).
  - Deflected jets, due to flow (Armesto, Salgado and Wiedemann) and/or path length dependent energy loss (Chiu and Hwa).
  - Hydrodynamic conical flow from mach cone shock-waves (Stoecker, Casalderrey-Solanda, Shuryak and Teaney, Renk, Ruppert and Muller).
  - Cerenkov gluon radiation (Dremin, Koch).
- Jet quenching: collective deceleration by wakefield?
  - LWFA method (Wu et al. 2010) or ~Maldacena's superstring method

PHENIX PRL 97, 052301 (2006)

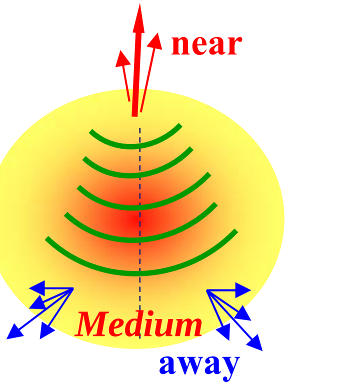


Horner (STAR) QM2006





Deflected Jets



Conical Emission

↓

Collective Interaction in subatomic scales

Density scalings for collider **LWFA**

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}	$\propto n_e^{1/2}$

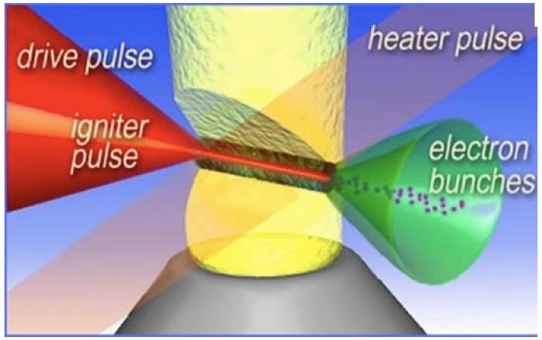
(Nakajima, 2011)

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

PeV Accelerator

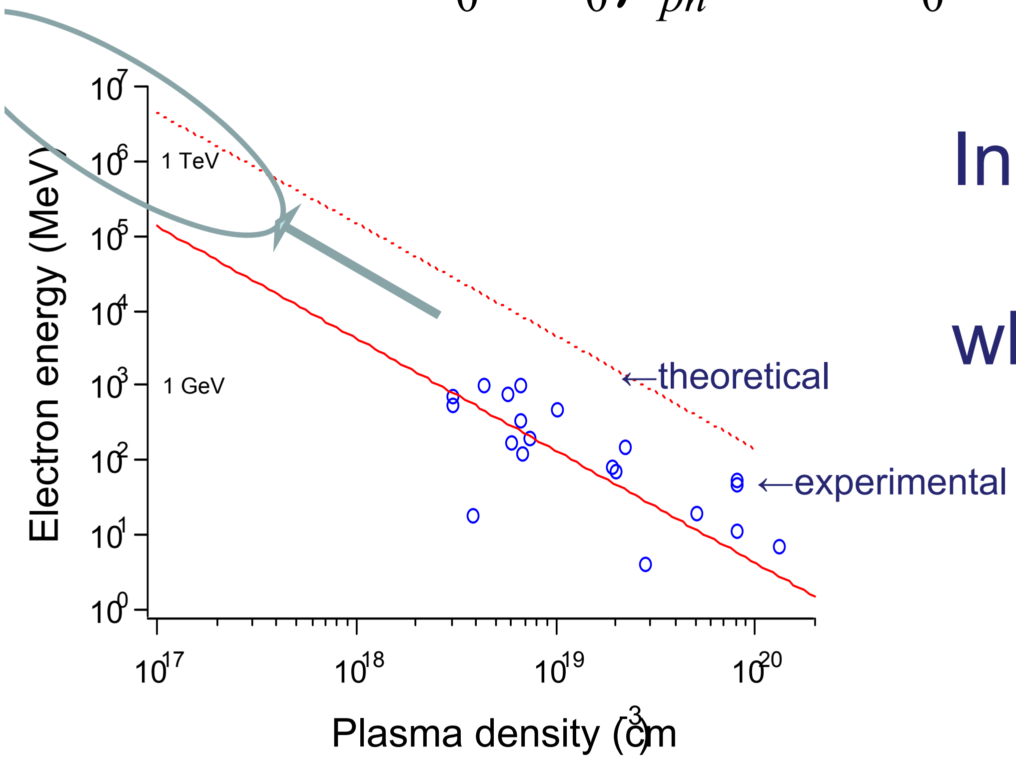
With conventional Technology
The accelerator would Girdle the Earth:
Fermi's vision (1954)

1km laser plasma accelerator
with LIL or LMJ
(Vision 2011)



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)

$\rightarrow$ 0.7PeV

(with Kando, Teshima)

γ-ray signal from primordial GRB

LETTERS NATURE

(Abdo, et al, 2009)

←lower energy

higher→

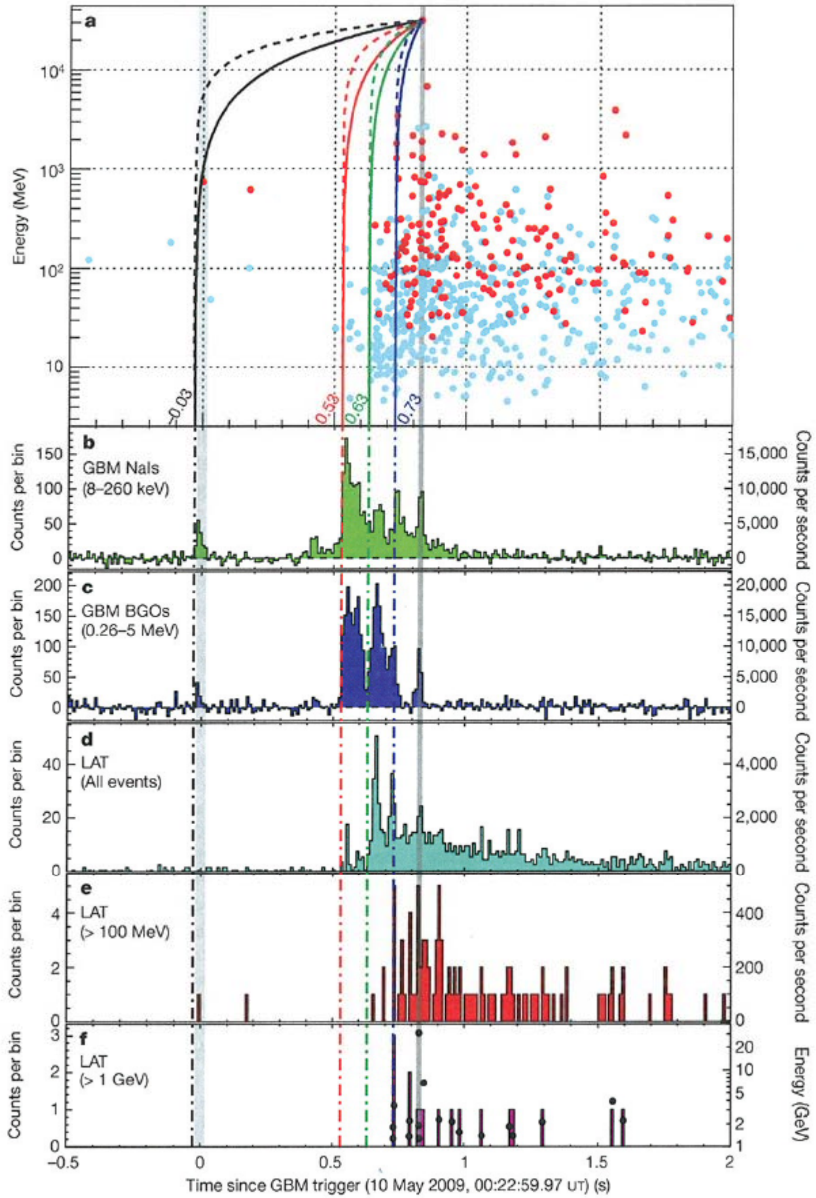


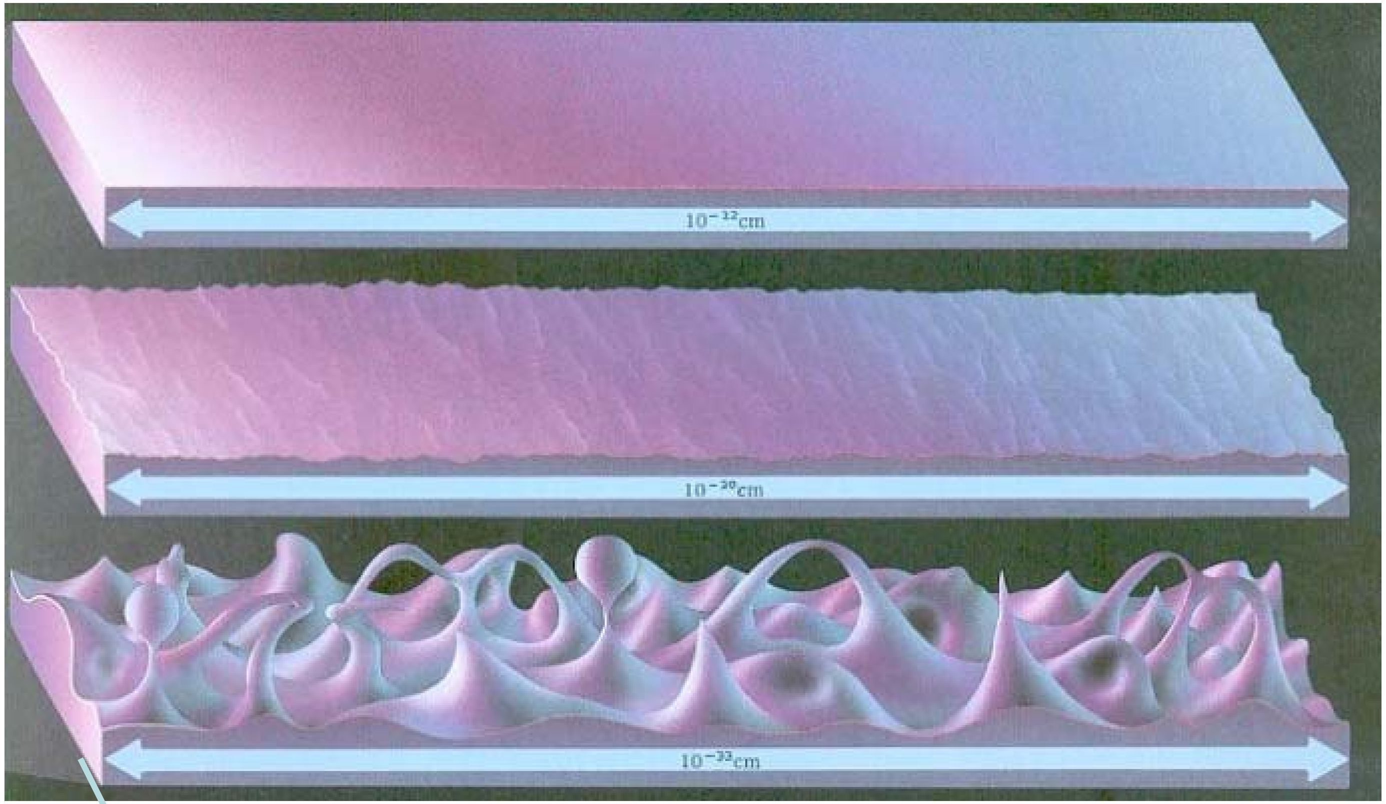
Figure 1 | Light curves of GRB 090510 at different energies. a, Energy ... lowest to highest energies. **f** also overlays energy versus arrival time for each

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)

1km ←(1PeV : fs behind)

PeV γ (converted from e^-)

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

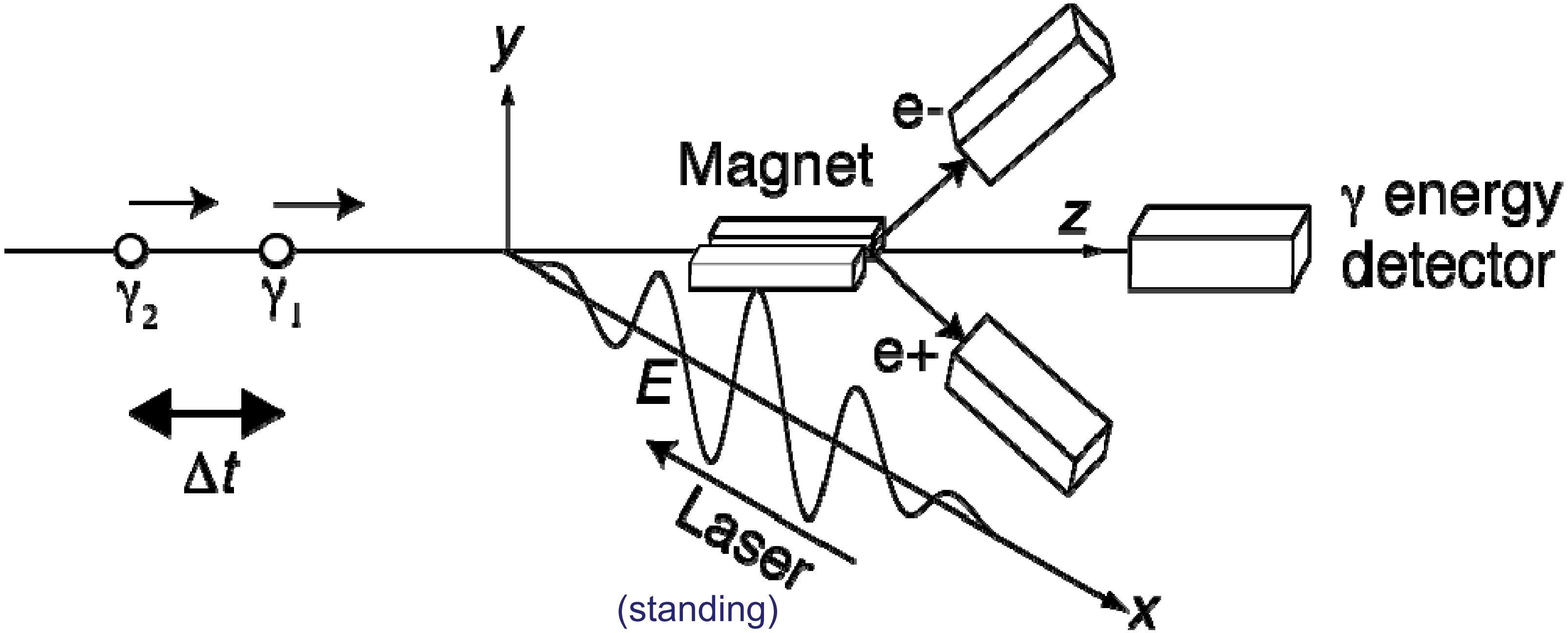
$$P(\vec{p}) = P_0(\vec{p})\{1 + 4\gamma^2[\delta(\hat{p}) - \delta_\gamma(\hat{p})]\}, \qquad (14)$$

Synchrotron radiation
radiation

↑ Lorentz violating term (>30TeV)

Attosecond Metrology of PeV γ Arrivals

(Tajima, Kando, Teshima PTP, 2011)



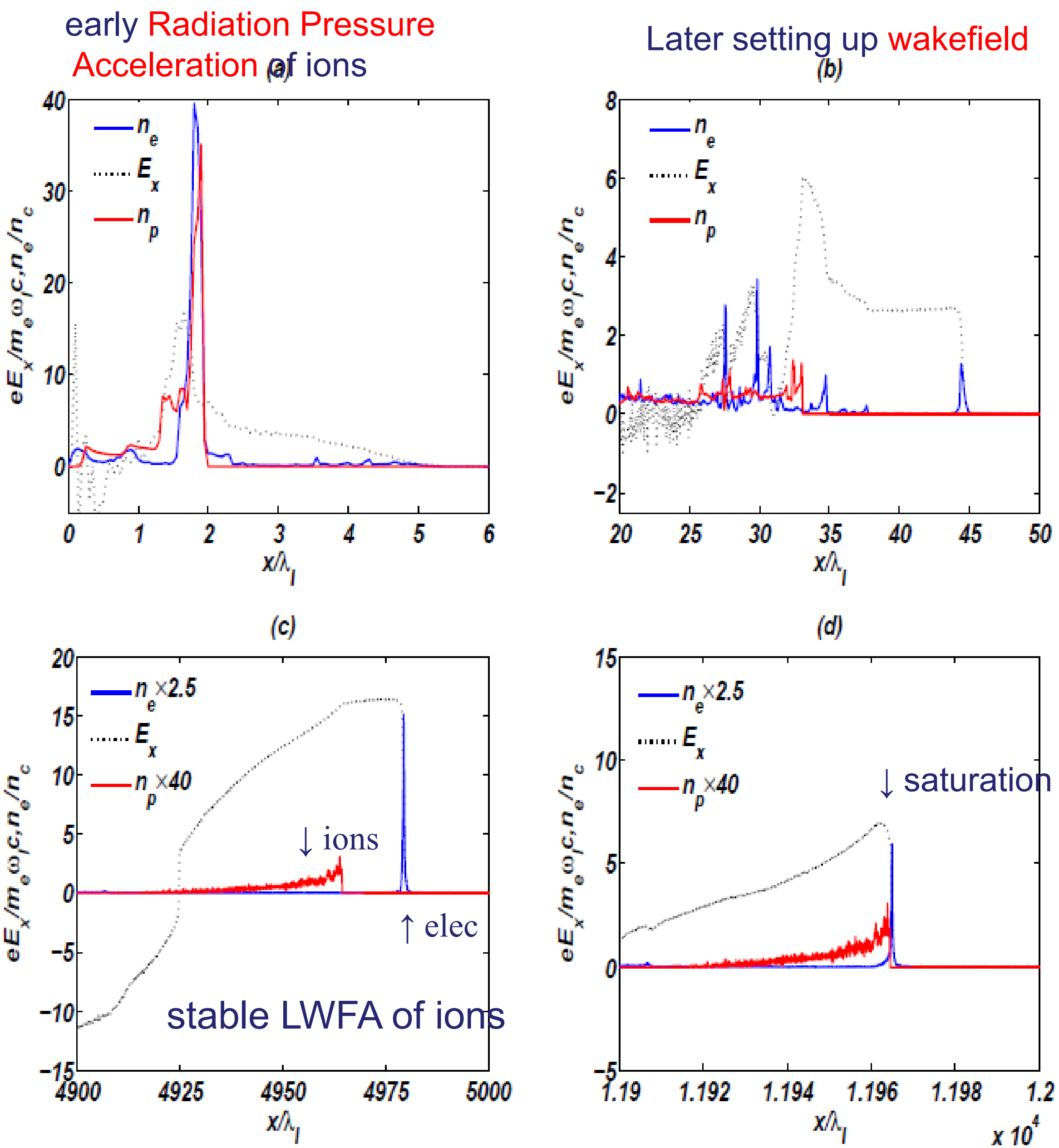
High energy γ- induced Schwinger breakdown
(Narozhny; Nikishov, Ritus)

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

Attosecond electron streaking

γ- energy tagging possible

TeV proton acceleration by LWFA



High Intensity regime

I = 10^{23} W/cm^2

(using ELI type laser)

$$E_i = (1/6)\, a_0^2\, (n_c/n_e)\, mc^2$$

Snowplow LWFA
of ions injected by RPA
as injector at multi-GeV

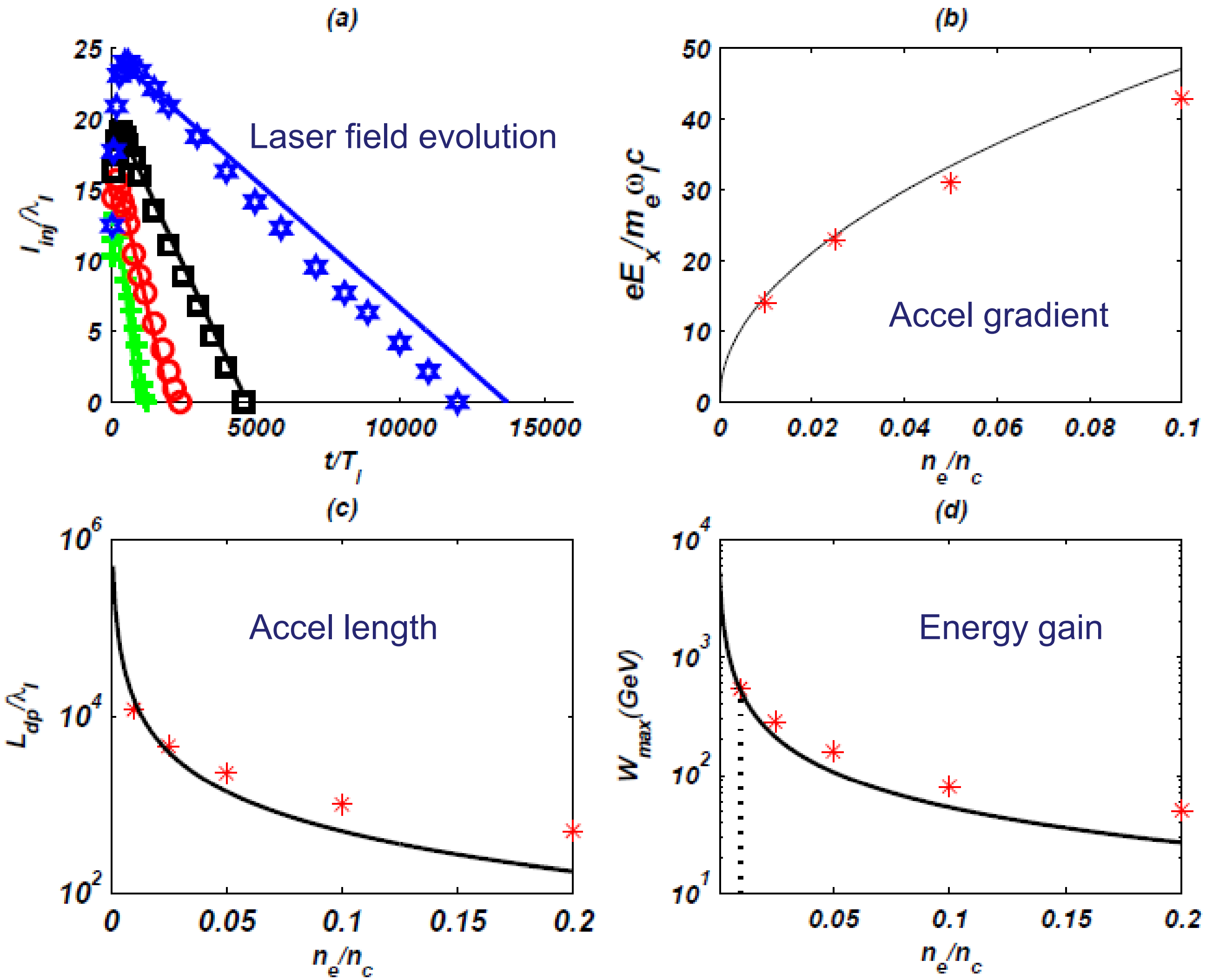
0.5TeV over

dephasing length of 1cm

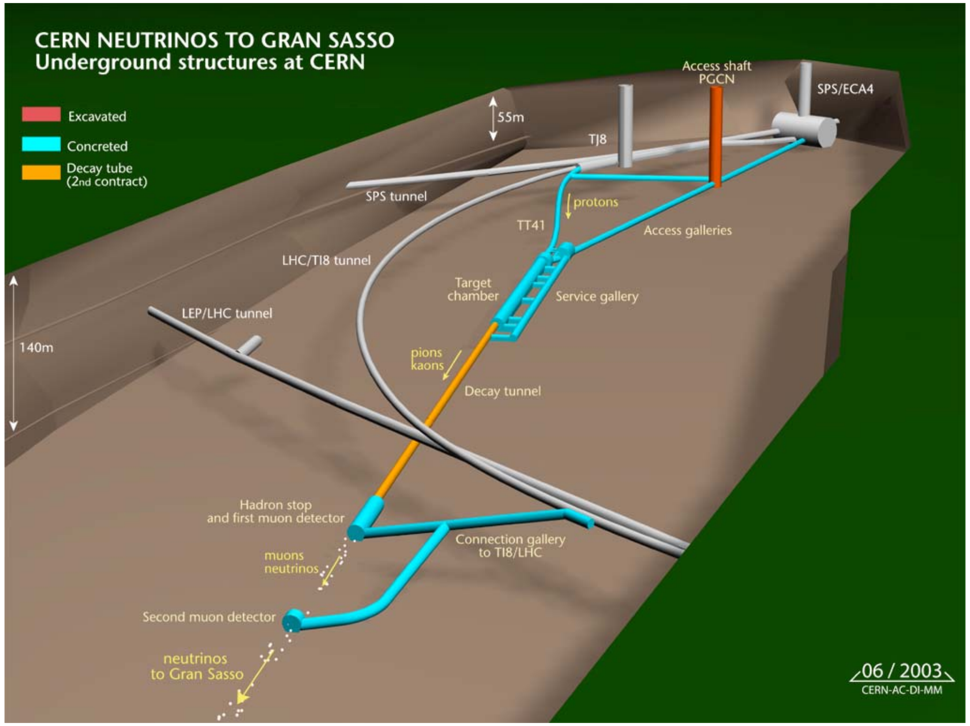
Zheng et al., 2011

TeV proton Energy Scalings(RPA x LWFA)

TeV over cm @ 10^{23}W/cm^2



(Zheng et al. 2011)



Neutrino speeding faster than *c* ?

(OPERA collaboration)

microsec rise time vs.
ns advance time:
<u>room for a large error</u>

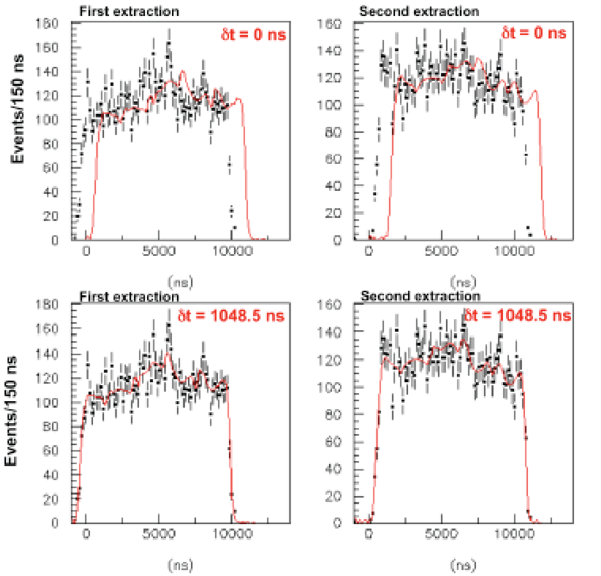


Fig. 11: Comparison of the measured neutrino interaction time distributions (data points) and the proton PDF (r line) for the two SPS extractions before (top) and after (bottom) correcting for δt (blind) resulting from the maxim likelihood analysis.

The 17.4 ns correction in Table 1 takes into account all the effects related to DAQ and T delays, as well as the difference between the value of Δt_{clock} determined in 2006 from a test-ben

IZEST:

LWFA with RPA (X. Yan's group)
TeV proton over cm
fs pulse, far narrower rise time

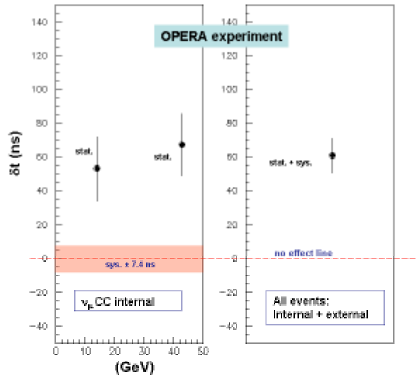


Fig. 13: Summary of the results for the measurement of δt. The left plot shows δt as a function of the energy for ν_μ CC internal events. The errors attributed to the two points are just statistical in order to make their relative

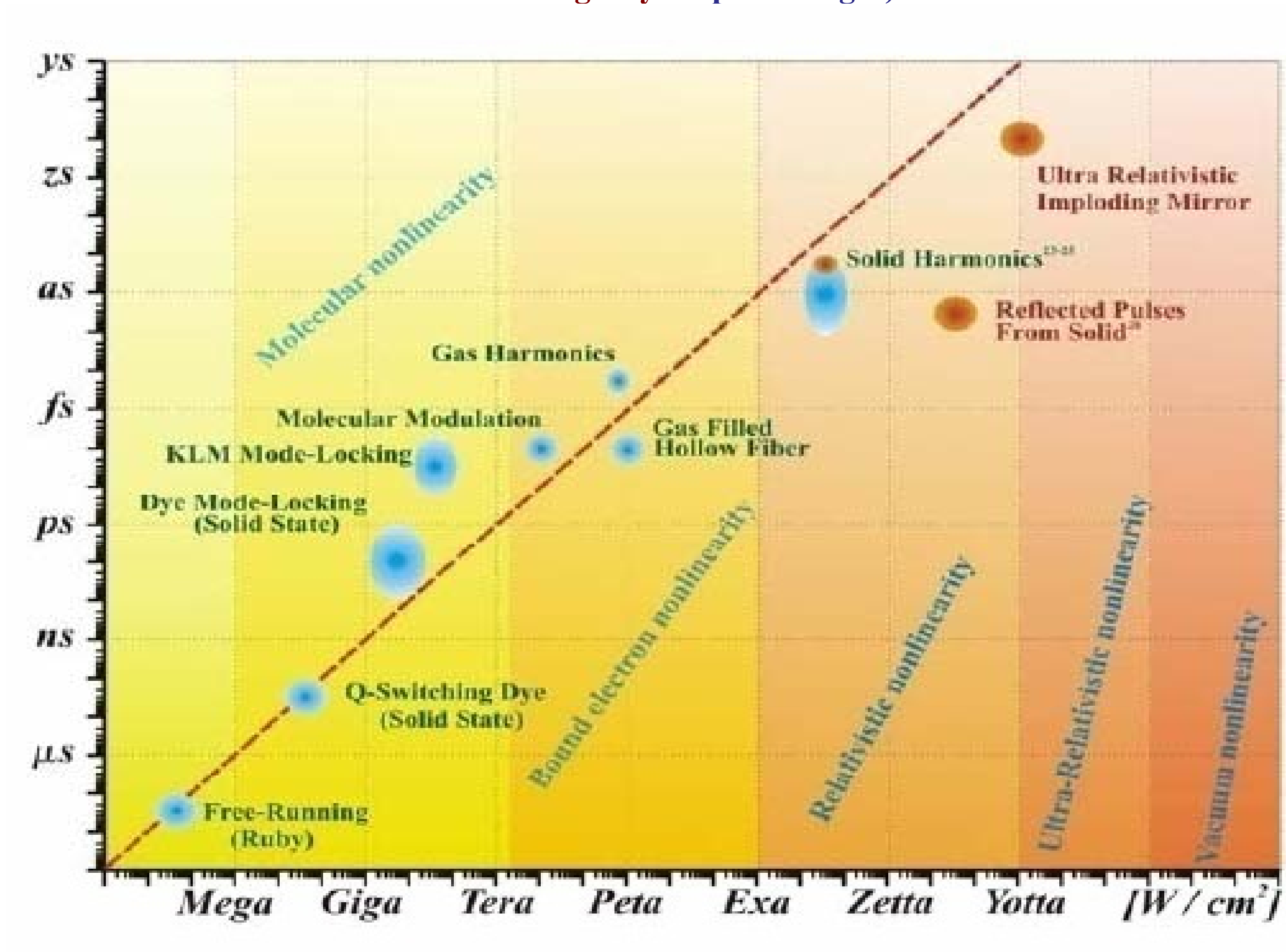
T. Adam et al. (OPERA)
(2011)

The Conjecture

(← physics: "Matter is nonlinear"

"The more rigid nonlinearity, the more intense to manipulate it";
rigidity vs. pulse length)

Pulse duration



Pulse intensity →

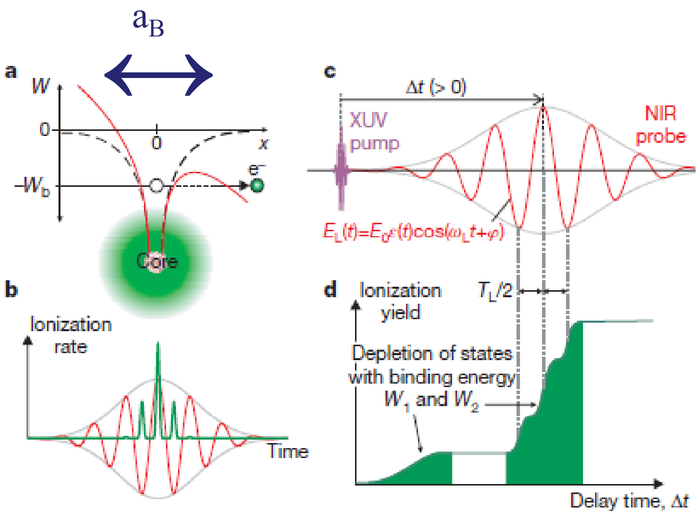
(Mourou / Tajima, science, 2011)
(Seggebrock et al, 2011---proof of the above)

Streaking Vacuum

(from atomic physics to QED vacuum physics)

atom

XUV photon ionization
Laser streaking
→ attosecond dynamics



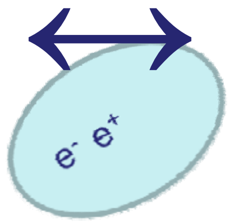
Uiberacker et al. (2007)

vacuum

Gamma photon ‘ionization’
XUV streaking
→zeptosecond dynamics

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

size
$\lambda_C = \alpha\, a_B$



depth of potential
$\Phi = \alpha^{-2} W_B$

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

[illegible] (36')

Nikishov(1964)
Nonperturbative:

For large values of x we essentially have $u \gg 1$ in the integrals (36). Using this fact, we obtain

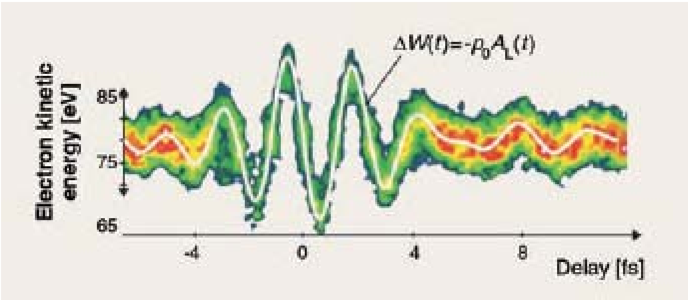
Multiphoton:

[illegible] (36'')

γ-photon induced vacuum streaking by lasers

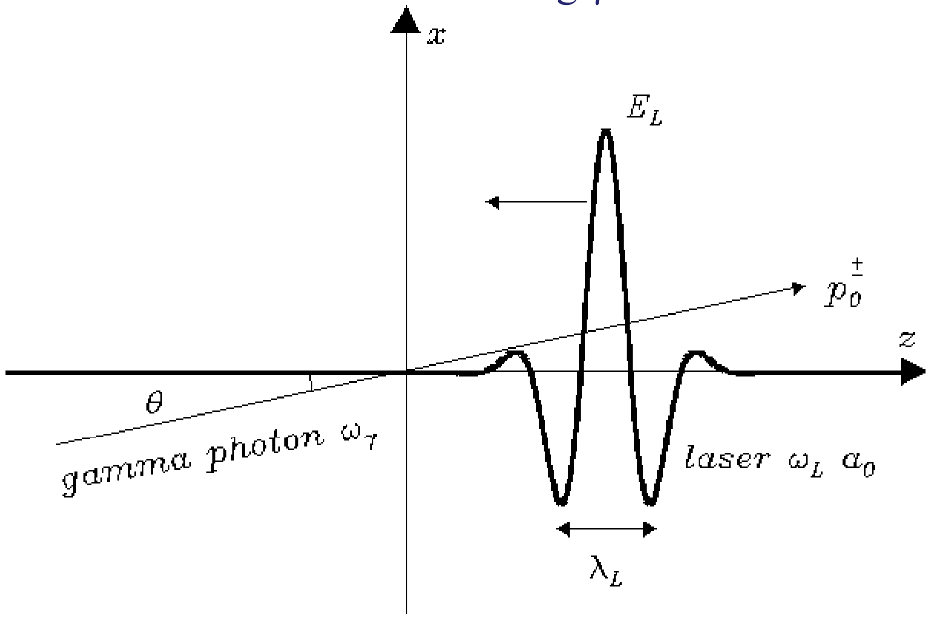
Tajima, Goulielmakis, Krausz, et al (2011)

Atomic as streaking



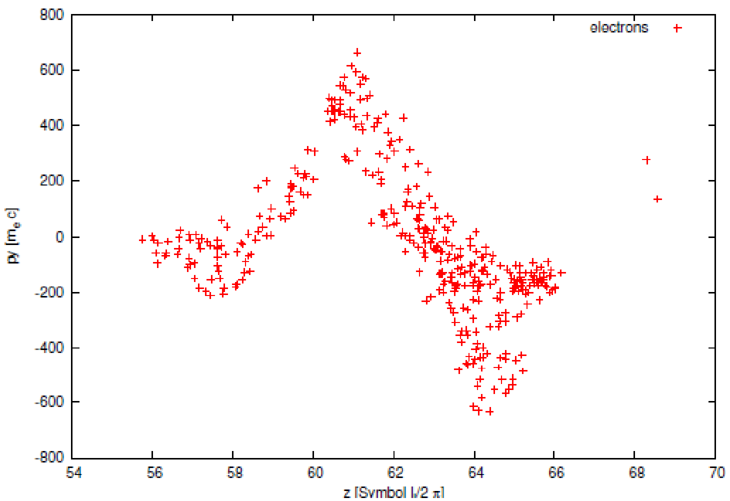
Goulielmakis(2008)

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



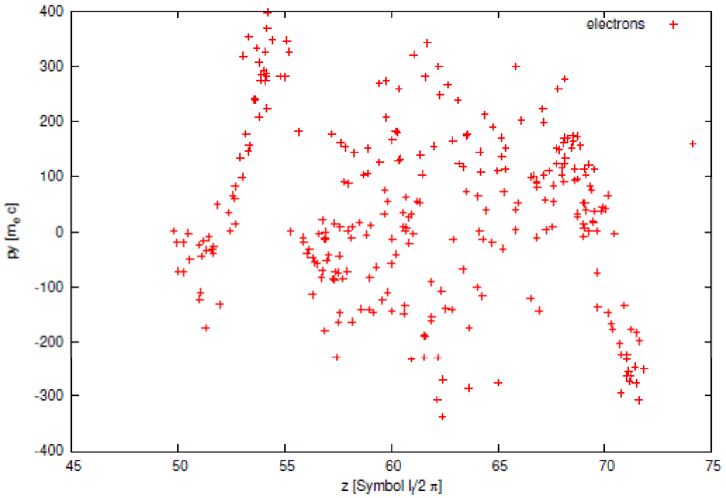
QED vacuum streaking

earlier



→

later; cascade effects

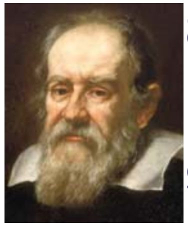


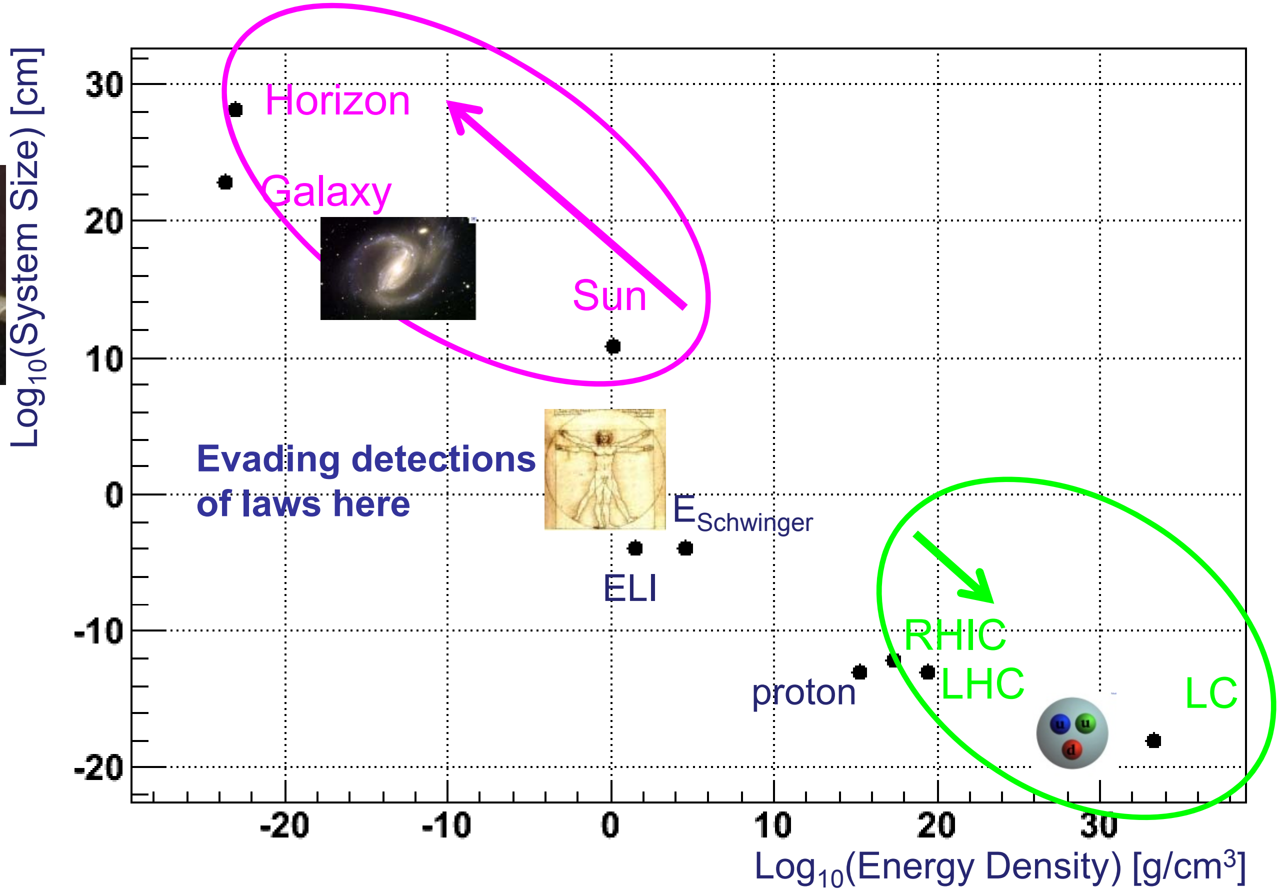
C. Klier et al (2011)

Laser fits the gaping hole

in search of unknown fields:
dark matter/dark energy

Cosmological observation





High energy collider

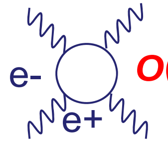
Domains of physical laws

Homma, Habs, Tajima (2011)

Birefringence by QED in eV range

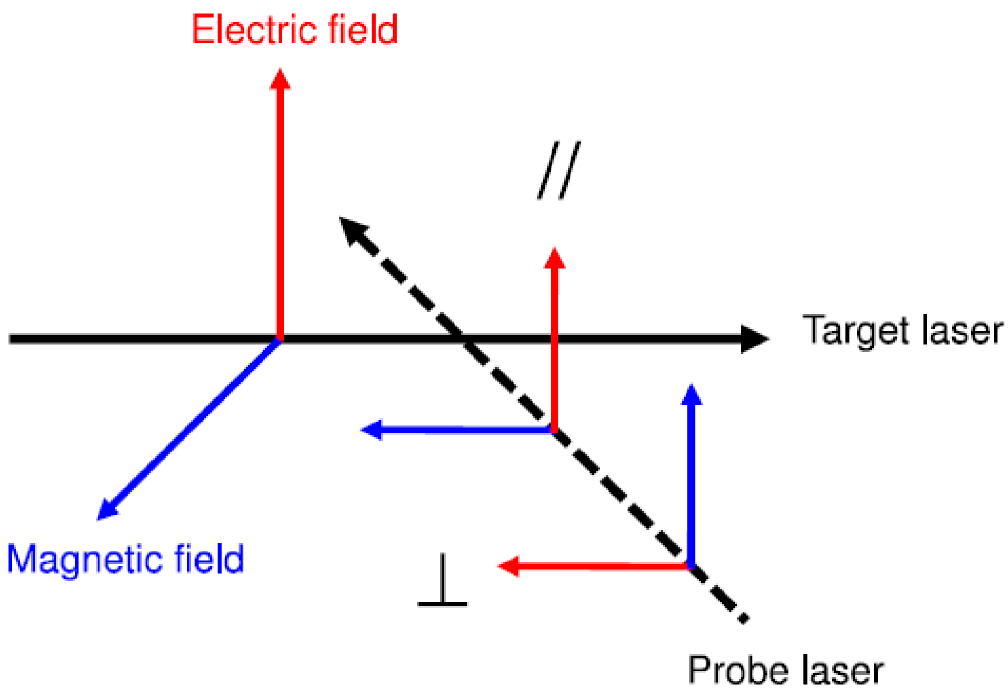
Euler-Heisenberg one-loop Lagrangian

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



$O(10^{-42}b)$

Refractive index depends on polarizations



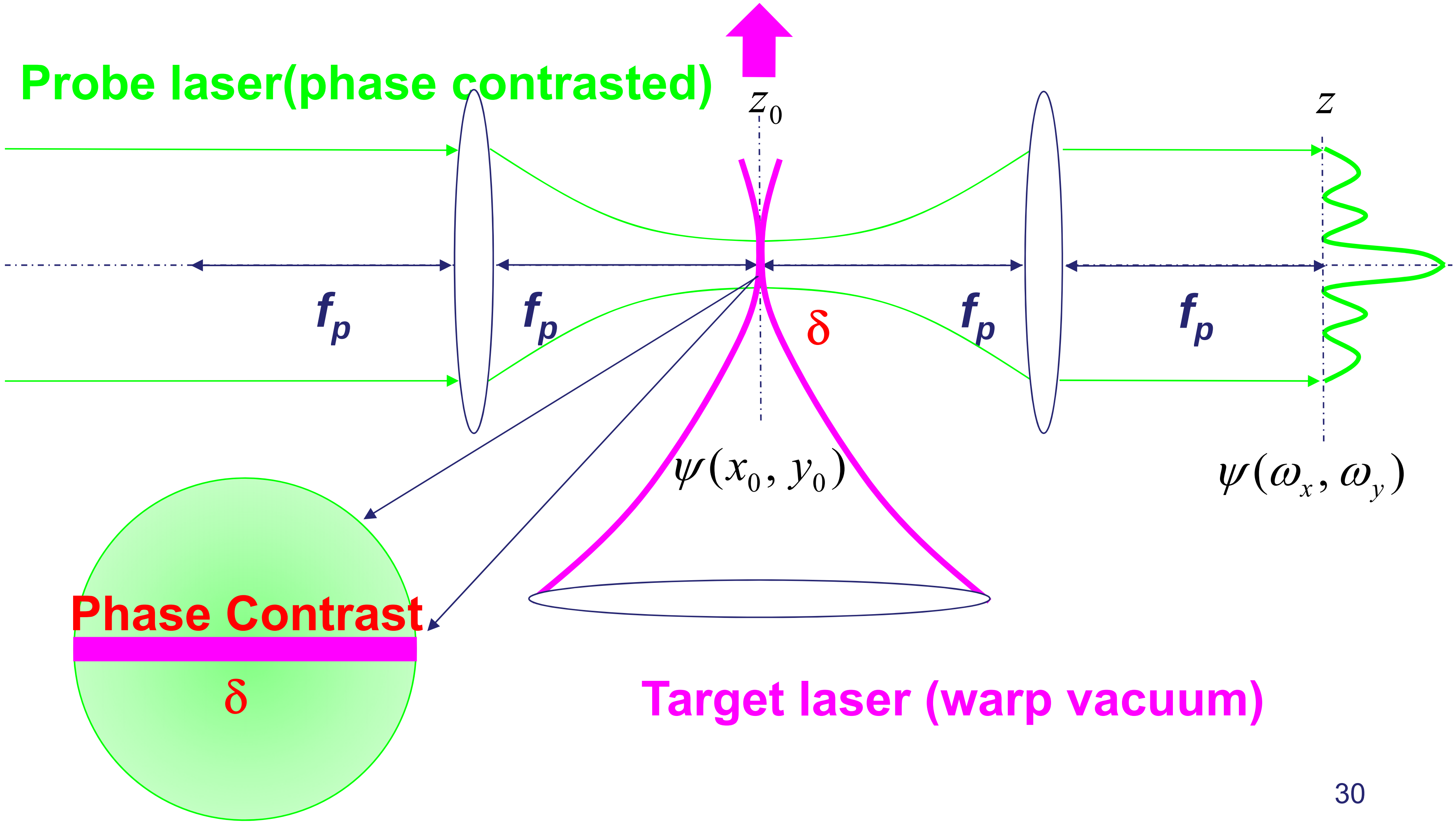
$$n_{\parallel} = 1 + \frac{16}{45}\frac{\alpha^2 U}{U_e}, \quad n_{\perp} = 1 + \frac{28}{45}\frac{\alpha^2 U}{U_e}$$

$U_e = m_e^4 c^5 / \hbar^3 \approx 1.42 \times 10^6\ J/\mu m^3$

ELI(~200J per ~20fs)
can reach $\Delta n \sim 10^{-9} \sim 10^{-10}$

(Homma, Habs, Tajima)

Phase contrast imaging of vacuum



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

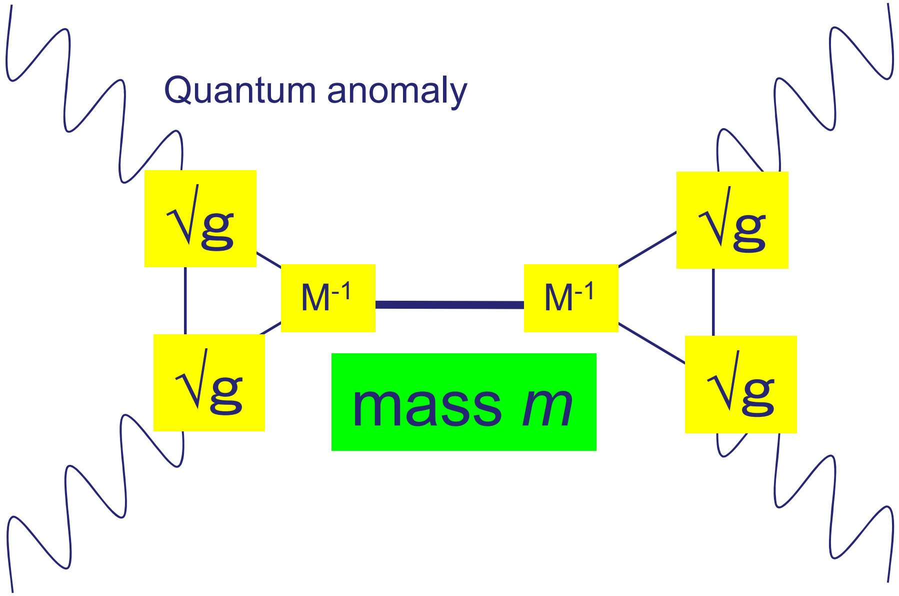
Beyond QED photon-photon interaction

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

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

Away from 4 : 7 = QCD , low-mass scalar ϕ, or pseudoscalar σ

Resonance in quasi-parallel collisions in low cms energy



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

$$gM^{-1}F^{\mu\nu}F_{\mu\nu}\phi$$

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

QCD-instanton, Dark Matter

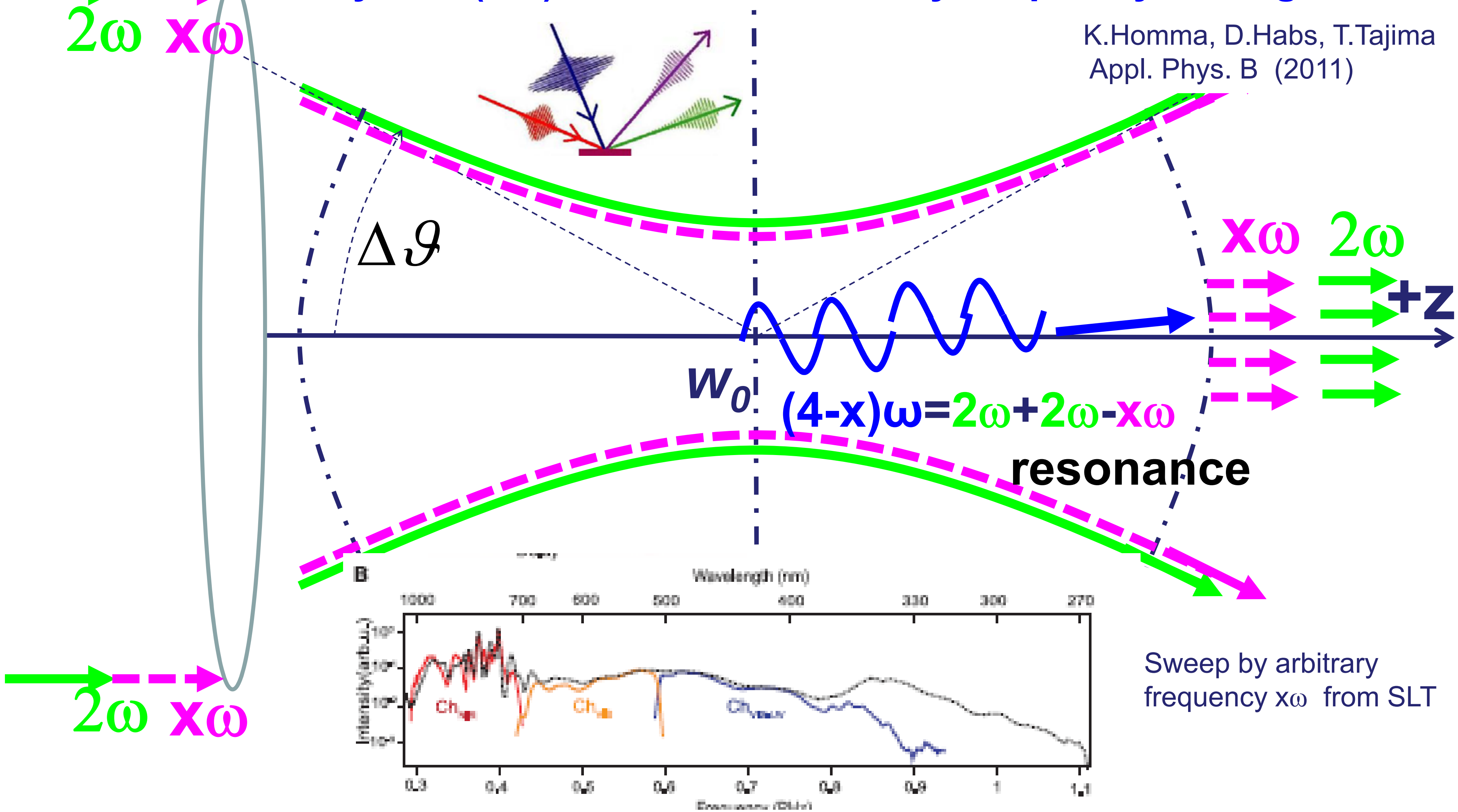
$$gM^{-1}F^{\mu\nu}\tilde{F}_{\mu\nu}\sigma$$

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

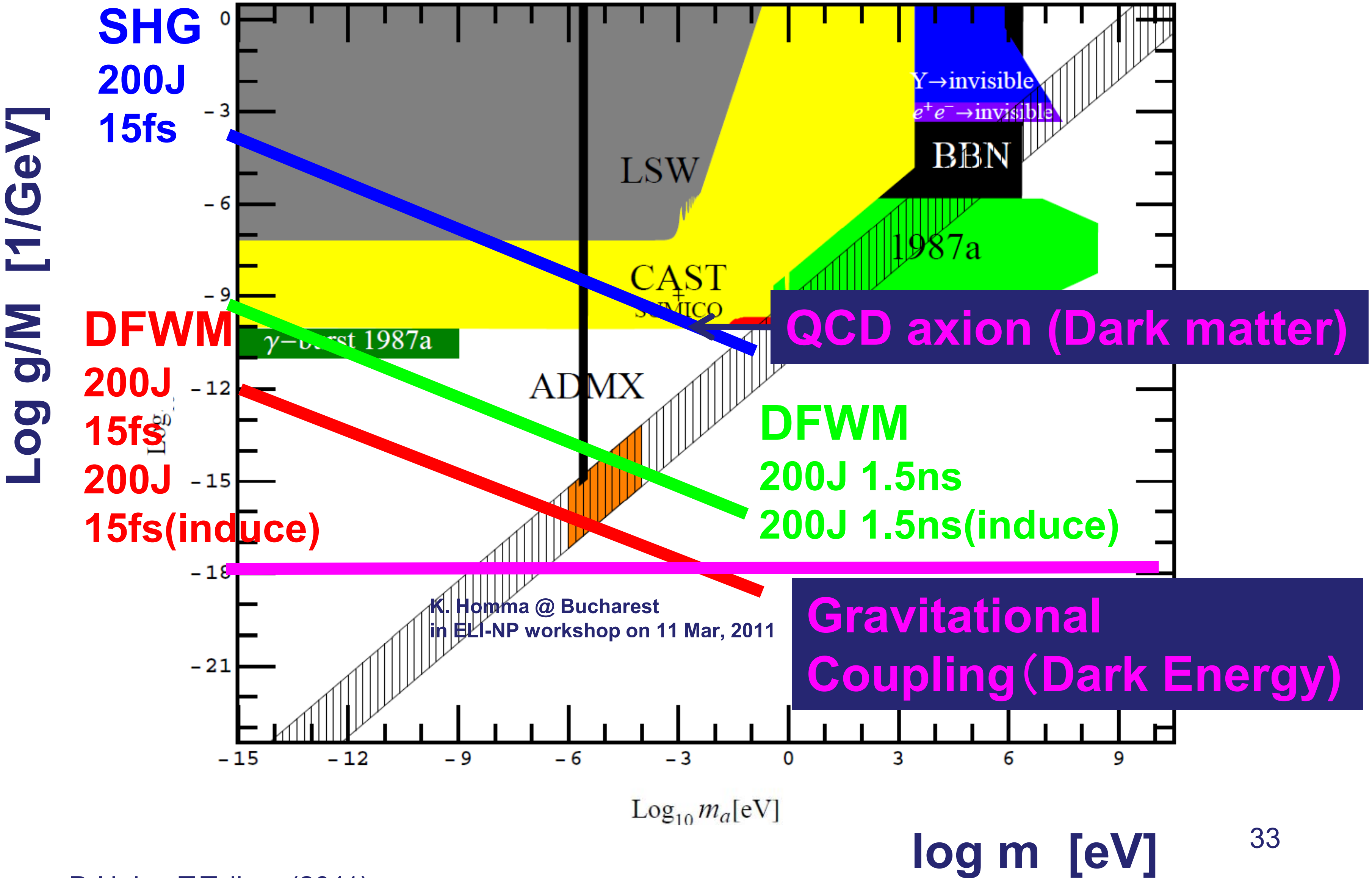


K.Homma, D.Habs, T.Tajima
Appl. Phys. B (2011)

Sweep by arbitrary frequency xω from SLT

Wirth et al. (2011: synthesized light transients)

HFS road to unknown fields: dark matter and dark energy



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

Latest Development: CERN getting into the game

EuroNNAc Workshop on novel accelerators (May 3-6, 2011)

Tuesday 03 May 2011

Introductory Presentations - Kjell Johnsen Auditorium (08:30-10:30)

- Conveners: Dr. Collier, Paul (CERN)

time	title	presenter
08:30	Goals of Network and Workshop (00h15')	ASSMANN, Ralph (CERN)
08:45	Accelerator R & D as Driver of Innovation (00h45')	HEUER, Rolf (CERN)
09:30	History and Outlook for Plasma Acceleration (00h30')	TOSHI, Tajima (LMU Munich)
10:00	Modern Lasers for Novel Acceleration Methods (00h30')	MOUROU, Gerard (ILE)

Coffee Break - 30-7-012 (10:30-11:00)

Introductory Presentations - Kjell Johnsen Auditorium (11:00-12:30)

- Conveners: Dr. Collier, Paul (CERN)

time	title	presenter
11:00	Accelerator R & D for Particle Physics (00h30')	MYERS, Steve (CERN)
11:30	Status Report Asia (00h30')	SHENG, Zhengming (Shanghai Jiao Tong University)
12:00	Status and Plans US (beam driven) (00h15')	HOGAN, Mark (SLAC)
12:15	Status and Plans US (Laser driven) (00h15')	ESAREY, Eric (LBNL)

IZEST

International Center for Zetta-Exawatt Science and Technology

* Highest intensity using existing / near future lasers with the world brainpower
* TeV (and PeV) energy frontier, with non-collider paradigm (such as Lorentz invariance check)
* High field approach (as opposed to high momentum) of fundamental physics
* Works with ICUIL and ICFA, in a shorter timeline than a generation

Under the Aegis of
CEA, Ecole Polytechnique and
Ministry of Research and Education
of France

IZEST Associate Laboratories

CUOS
Michigan
USA

ALLS
Montreal
Ca

GSI
Darmstadt

GSI(?)Willi
Dusseldorf

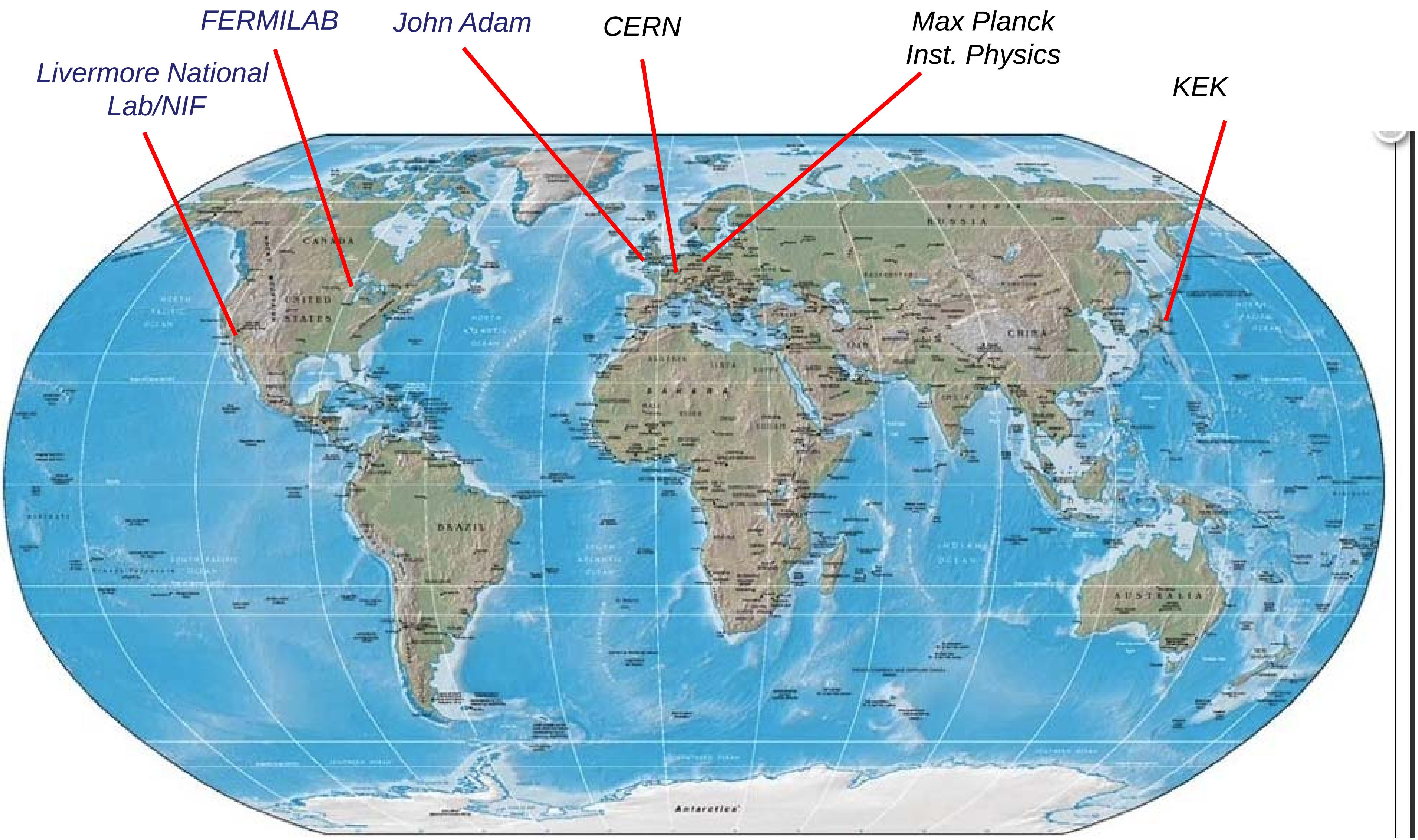
Nishny Novgorod
IAP Russia

NT-LeCos
Taiwan

APRC
Kansai Japan

.Kyoto U.
Japan

IZEST Support Laboratories



IZEST
Launching Workshop:
Laser-based High Field Fundamental Physics
Preparing for the future
28-29 November, 2011
Ecole Polytechnique,Palaiseau,Paris

Fundamental High Energy Physics has been mainly driven by the high energy fermionic colliding beam paradigm. Today the possibility to amplify laser to extreme energy and peak power offers, in addition of possibly more compact and cheaper way to help HEP, a complementary new alternative underpinned by single shot, large field laser pulse, that together we could call High Field Fundamental Physics. The main mission of the International center on Zetta-Exawatt Science and Technology (IZEST) is to muster the scientific community behind this new concept. As an example, we project to use the laser field to probe the nonlinearity of vacuum due to nonlineairities and light-mass weak coupling fields such as Heisenberg-Euler QED, dark matter and dark energy. The advancement of intense short-pulsed laser energy by 2-3 orders of magnitude empowers us a tremendous potential of unprecedented discoveries. These include: TeV physics, new light-mass weak-coupling field discovery potential, nonlinear QED and QCD fields, radiation physics in the vicinity of the Schwinger field, and zeptosecond dynamical spectroscopy of vacuum.

Today, a number of exawatt class facilities in Europe and in the world are already in the planning stage, like the ELI-Fourth Pillar, French LIL, and the Russian Mega Science Laser as well as Japanese Exawatt Laser. IZEST should serve as a common platform opened to the international scientific community with a passion for this emerging opportunies and the desire to be engaged. Ist headquarter will be located at the Ecole Polytechnique, the center of ist theoretical facility. The experimental programs will be performed on the most powerful european laser, the LIL laser at the CEA-CESTA in Bordeaux. It is expected that a large part of the work will also be carried out in the IZEST-associated laboratories around the world.

November 28-29, 2011 at the Ministery of Research, Paris V, we intend to hold a three-day workshop with the participation of the main players to first review the role of high field in fundamental physics and to examine the new technology that needs to be brought to bear to accomplish the above mission. Second as one of the main objectives, we will establish a joint strategy, put together coordination groups, and provide recommendation for the facilities in the planning stage.

Among the main topics that will be discussed include:

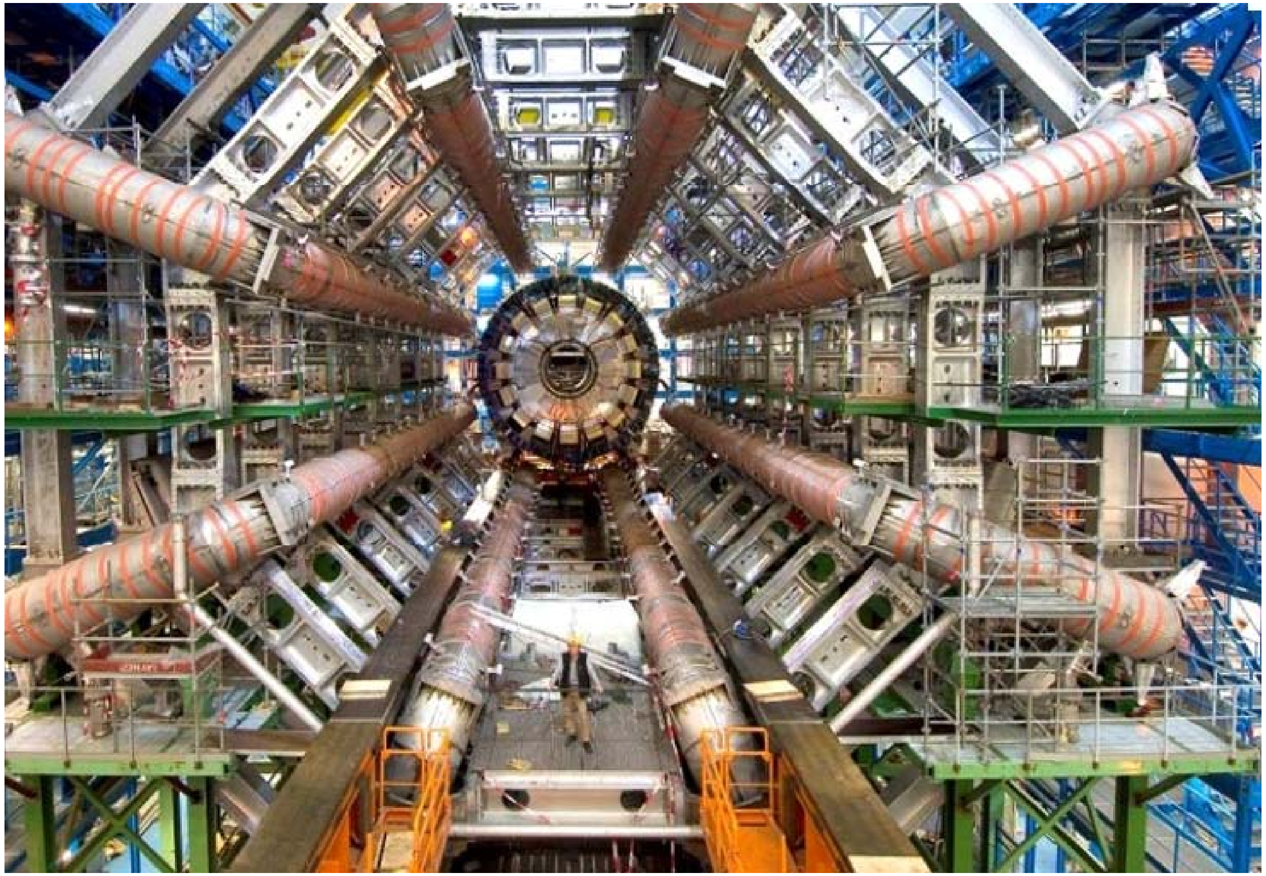
Exawatt and Zettawatt laser technology
TeV physics
Nonlinear effects in Vacuum
Dark energy and dark matter
Radiation near the Schwinger field
Other fundamental physics issued addressable by extreme high fields

Supporter of *IZEST*:

Atsuto Suzuki:
KEK Director General,
ICFA Chair

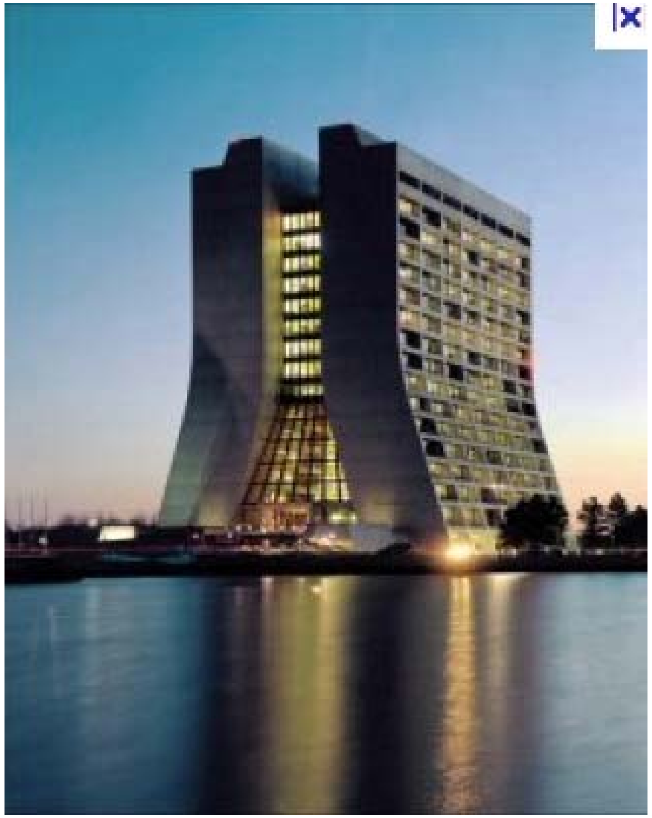
CERN

Rolph Heuer
CERN Director General



IZEST High Energy Physic (and intense laser) Supporters:

Young-Kee Kim
Fermilab Deputy Director



Fermilab

John Adam Institute for Accelerator Science

Director
Andrei Seryi

Max Planck Institute of Physics (The Heisenberg Institute)

Mashahiro Teshima
MPP Director

Japan Atomic Energy Agency
Quantum Beam Science

Paul Bolton
Quantum Beam Directorate
Deputy Director General

National Ignition Facility LLNL

Edward Mose
Director NIF Program

ELI (2010), now **Mega Project** on Extreme **Laser** (2011)

Extreme Light Infrastructure: EU decided (2010) at Czech, Hungary, and Romania
Now, Russia announced July 5, 2011: 6 Mega Projects (3-4B Euro) include **Extreme Laser**

Beyond Exawatt
Beyond 10kJ

ELI: serving Chair, Scientific Advisory Committee
Extreme Laser Mega Project (in budget negotiation):
Chief Scientific Advisor/
Mega Grant Honorary Director (suggested)
International team being formed:
IZEST (International Center for Zetawatt / Exawatt Science and Technology)

S&TRF НАУКА И ТЕХНОЛОГИИ РФ

Евразийский открытый институт, используя обучение через интернет, реализует 18 программ ба..

По диаметру отверст можно определить и веществ у ..

05.07.11
Σ Стерлигов Иван
Правительственная комиссия по высоким технологиям и инновациям: Обсуждение

Обсуждение
Версия для печати
добавить ссылку

Сверхмощный лазер как интегратор науки

В числе меганаучных проектов, которые будут реализованы на территории России, – Международный центр исследований экстремальных световых полей на основе сверхмощного лазерного комплекса в Нижнем Новгороде. Руководит центром всемирно известный физик Жерар Муру при поддержке Минобрнауки России. STRF.ru подробно рассказывал об этой работе в статье «Российские учёные строят сверхмощный лазер». Насколько значим этот проект для мировой науки, мы выяснили у Тосики Тадзимы, заведующего кафедрой физического факультета Университета Людвига Максимилиана в Мюнхене, председателя Международного комитета по сверхмощным лазерам (International Committee on Ultra-High Intensity Lasers, ICUIL).

Тосики Тадзиме не терпится поучаствовать в российском мегапроекте по созданию сверхмощного лазера

Справка STRF.ru:
Международный комитет по сверхмощным лазерам – подразделение Международного союза фундаментальной и прикладной физики, основанное в 2003 году. Задача ICUIL – продвижение науки и технологии сверхмощных лазеров и координация исследований и разработок в этой области. Под сверхмощными лазерами в комитете понимают лазеры с интенсивностью 10^{19} ватт на $см^2$ и мощностью около 10 тераватт

На Ваш взгляд, что примечательного произошло в области сверхмощных лазеров в последнее время?

– Прошлый год стал эпохальным для нас благодаря решению Евросоюза о запуске проекта Extreme Light Infrastructure [ELI, включает целый ряд сверхмощных лазеров в нескольких регионах Европы], а также началу реальной работы National Ignition Facility в США – альтернативный токамакам проект термоядерной энергетики, основанный на лазерном нагреве и инерционном удержании плазмы. Мы предполагаем, что развитие сверхмощных лазеров и сопутствующих областей науки значительно ускорится, и стараемся способствовать

http://strf.ru/

XCELS (Russian ‘Mega Science’ laser: 2011-)

Conclusions

- Optical approach: does it overtake the accelerator in high energy and fundamental physics?
- Collider physics requirements: ==➔ low density operation, laser with large energy per stage
- Energy frontier (beyond TeV) with precision w/ a few shots possible = non-collider paradigm of fundamental science

  e.g. Lorentz invariance test , quantum gravity
- High field science approach: capability to explore

  new fields (dark matter; dark energy): DFWM,

  learning from NLO (in matter) / SLT; zs metrology
- Join us at ***IZEST ------intense laser applications to fundamental physics***

Centaurus A:

cosmic wakefield linac?

Danke schoen!

Tajima's HP: http://www.munich-photonics.de/1/menschen/members/member/?personid=136&cHash=c8b0c3ef3