Joint Workshop of the France-Japan and France-Korea Particle Physics Laboratories(TYL-FKPPL)

Clermont-Ferrand

May 29, 2012

Plasma Acceleration at IZEST:

Large-Energy Laser and High-Average Power Laser toward High Energy Physics

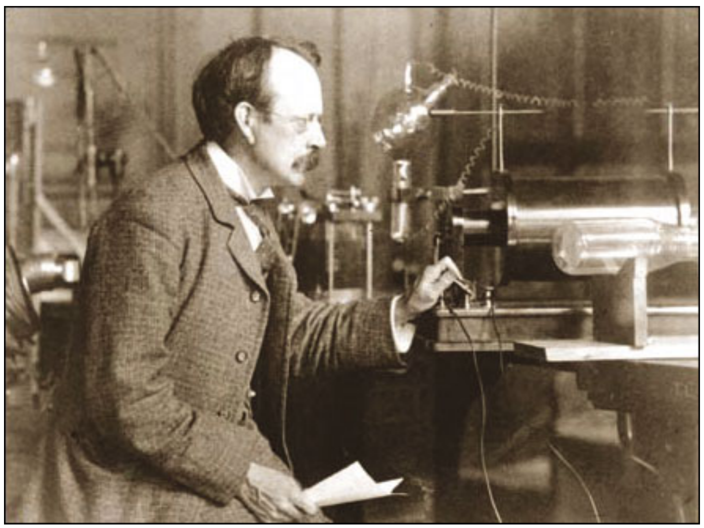
T. Tajima

IZEST

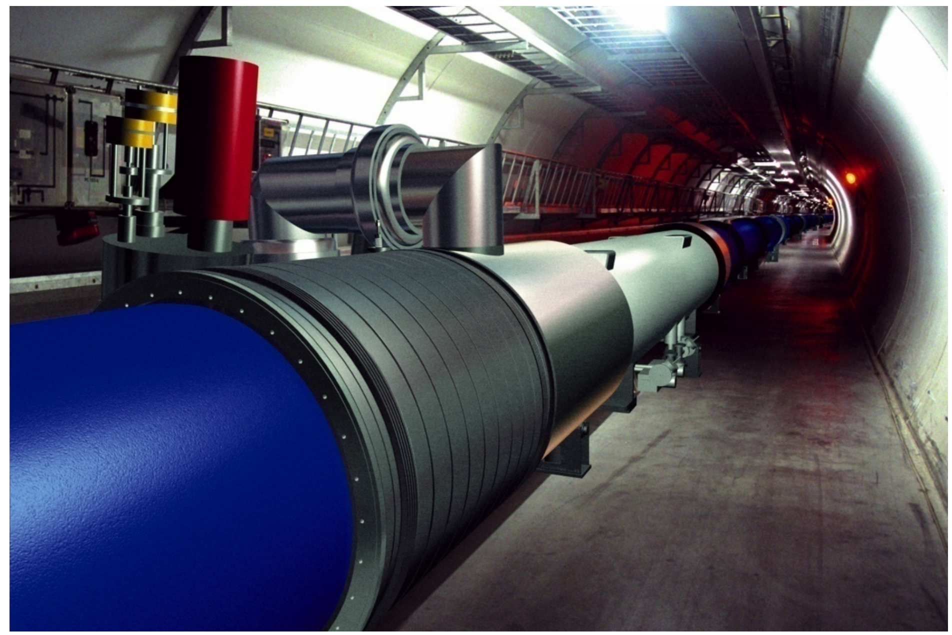
1. Fundamental physics with intense lasers
2. Laser acceleration to high energies (100GeV, TeV and beyond)
   need for large-energy laser (*PETAL @ LMJ*)
3. Collider and Low Luminosity Paradigm
4. High-average power lasers (*ICAN* Project)
5. Low-energy new fields: Frontier of large number of coherent photons:
   Dark Matter and Dark Energy fields
   'Shake the vacuum' by degenerate 4 (laser) wave mixing
6. Mission of *IZEST:*
   kJ [large photon number (=Avogadro number)] laser (*PETAL*)
   + **high-average power** laser (*ICAN*)
   toward fundamental physics
   in the international networking
   (with many willing labs to cover broad parameters)

IZEST

20^{th} 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

IZEST's Missions

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

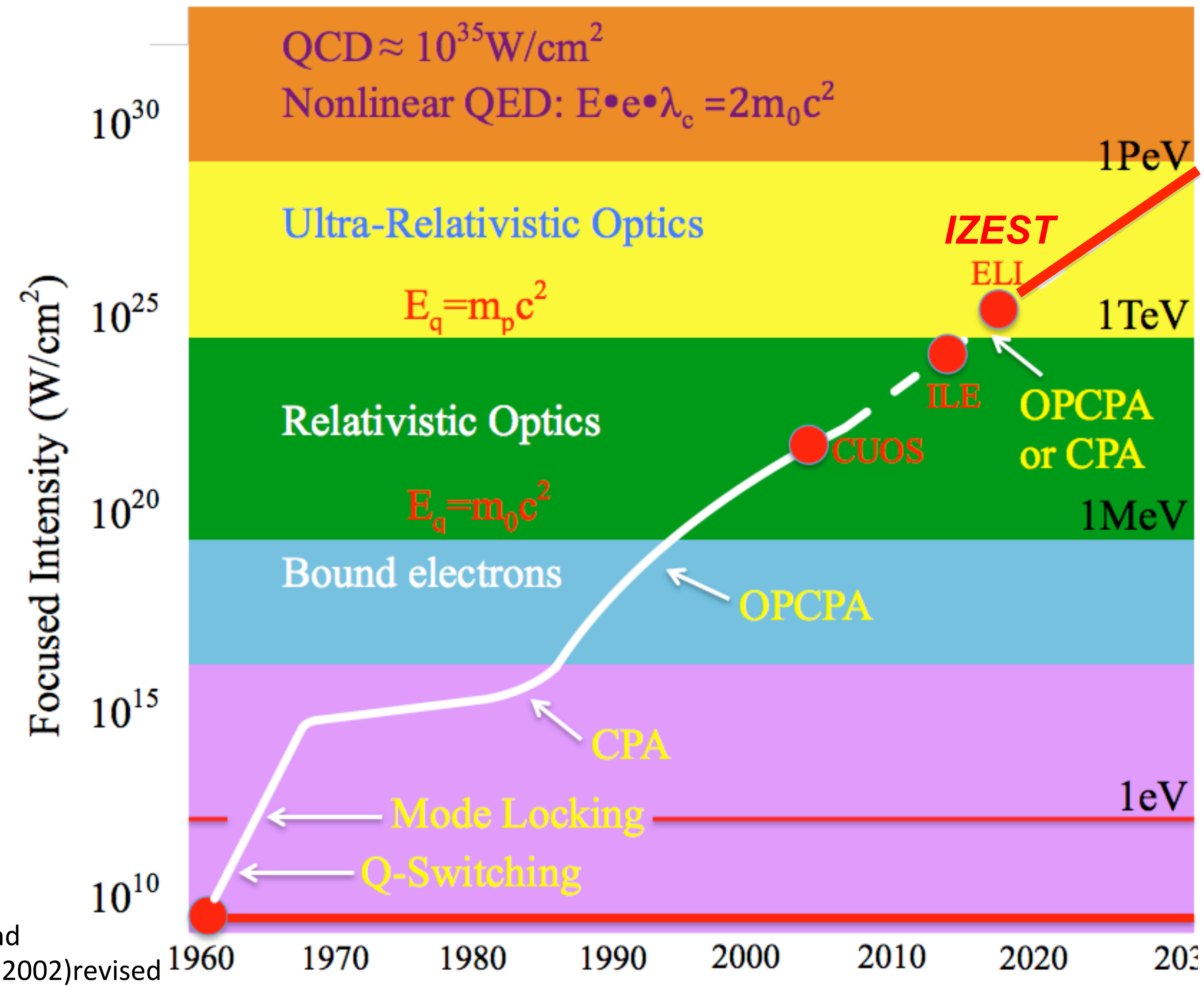
"The Roadmap of Ultra High Intensity Laser"
and apply it to
"Laser-Based Fundamental Physics"

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

See more:
www.int-zest.com/

Also: Tajima and Mourou PR STAB(2002)

Laser intensity exponentiates over years

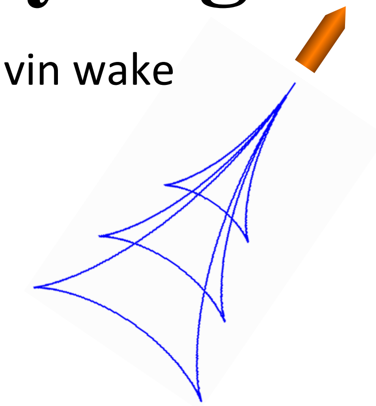


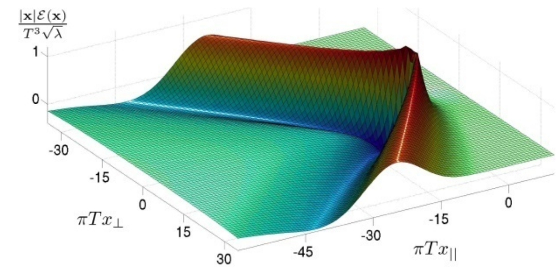
Tajima and Mourou (2002)revised

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

Laser Wakefield (LWFA): relativity regulates

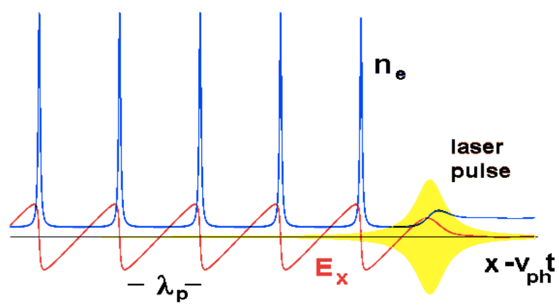
Kelvin wake





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

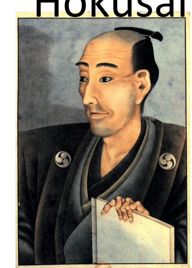
No wave breaks and wake **peaks** at v≈c



← relativity regularizes

Wave **breaks** at v<c

Hokusai



Maldacen

(The density cusps.
Cusp singularity)

(Plasma physics vs.
superstring theory)

Density scalings of **LWFA** for collider

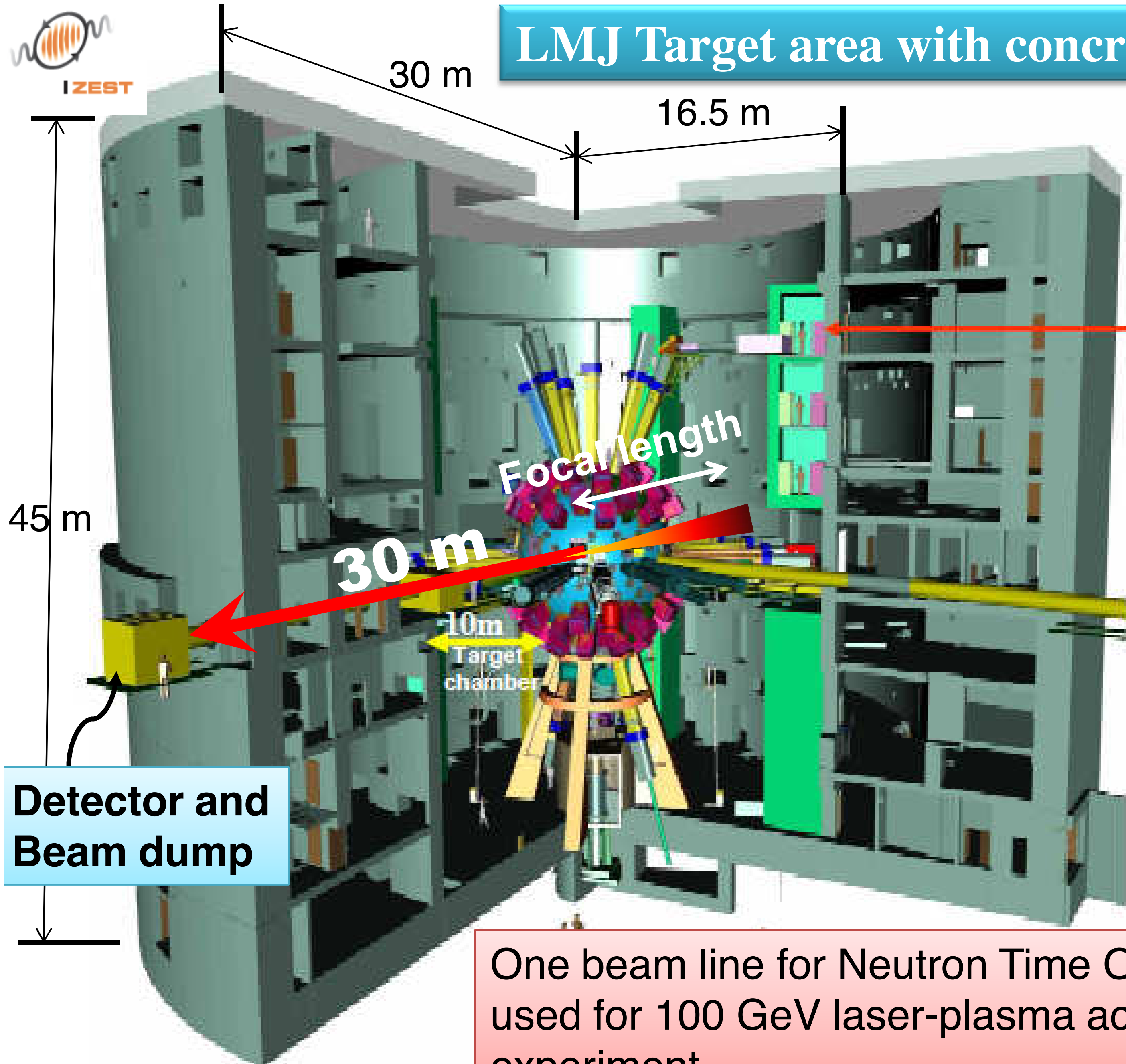
Accelerating field E_z	$\propto n_e^{1/2}$
Focusing constant K	$\propto n_e^{1/2}$
Stage length L_{stage}	$\propto n_e^{-3/2}$
Energy gain per stage W_{stage}	$\propto n_e^{-1}$
Number of stages N_{stage}	$\propto n_e$
Total linac length L_{total}	$\propto n_e^{-1/2}$
Number of particles per bunch N_b	$\propto n_e^{-1/2}$
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

LMJ Target area with concrete shielding

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

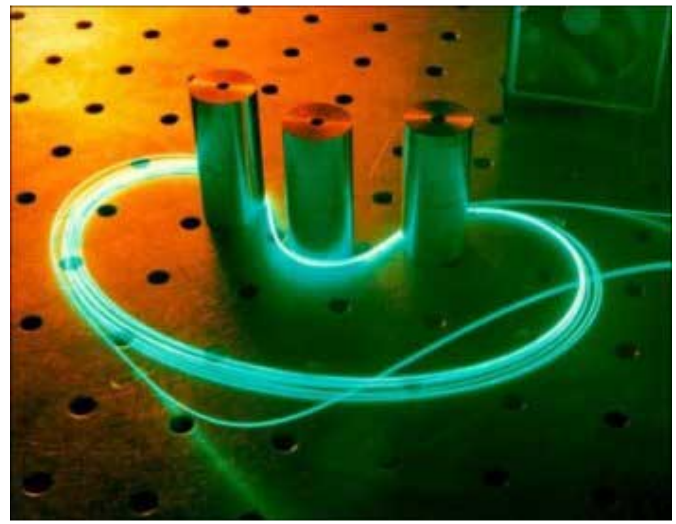


One beam line for Neutron Time Of Flight is used for 100 GeV laser-plasma accelerator experiment.

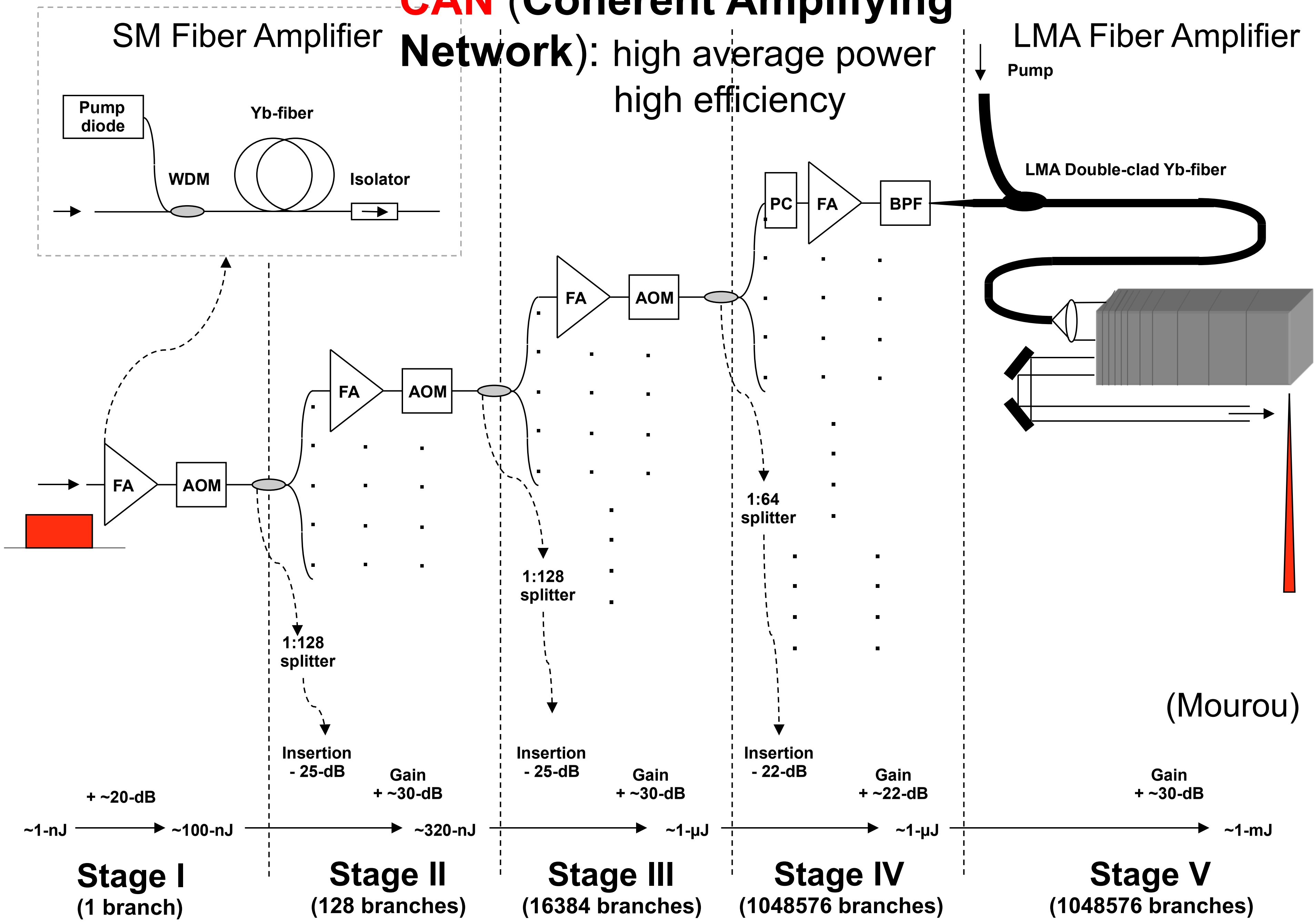
Nakajima, LeGarrec

Fiber vs. Bulk lasers

- High Gain fiber amplifiers allow ~ 50% total plug-to-optical output efficiency (reachable).
- 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
- They can be mass-produced at low cost. 10€/W today and *10C/W* in15 years



CAN (Coherent Amplifying Network): high average power high efficiency



(Mourou)

Dark Matter / Dark Energy (Quantum Gravity Vacuum)

- Weakly interacting particles like axion or axion-like, U(1) gauge bosons with low mass in the sub-electron volt?
- Nonlinear effect in large electromagnetic fields: light shinning through a wall → much more sensitive new technique.
- Ultralight ultraweak coupling fields of quantum gravity origin (Dark Energy candidate) in ~ nano-electron volts?

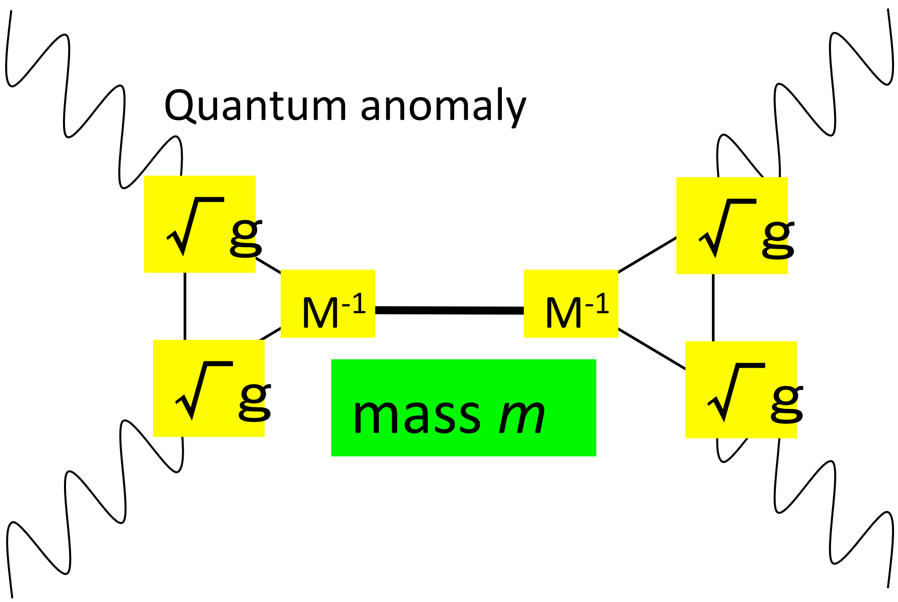
Beyond QED photon-photon interaction

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

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

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

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

QCD-instanton, Dark Matter

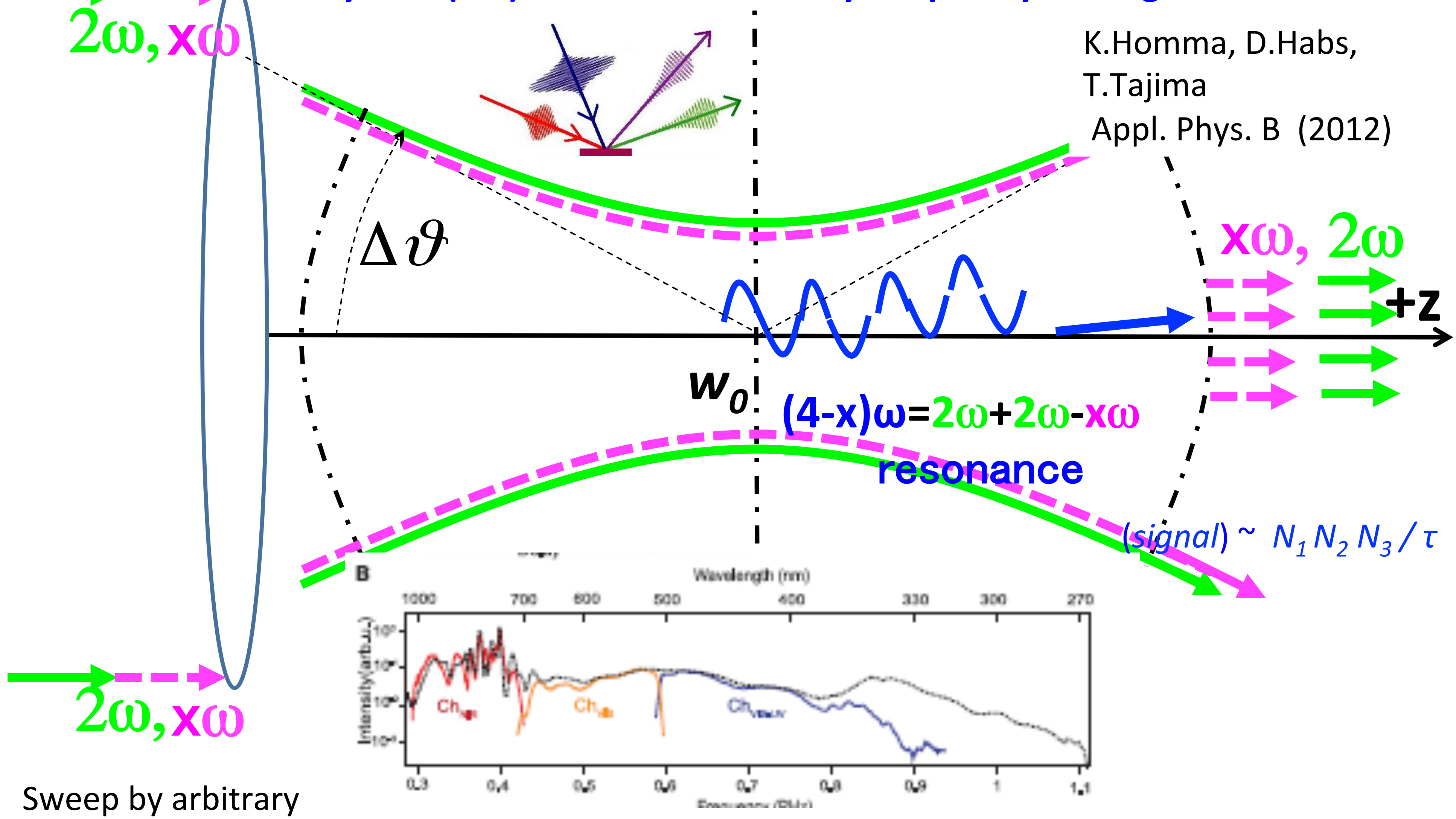
$$gM^{-1}F^{\mu\nu}\tilde{F}_{\mu\nu}\sigma$$

K.Homma, D.Habs,
T.Tajima (20121, 2012)

Degenerate Four-Wave Mixing (DFWM)

Laser-induced nonlinear optics in <u>vacuum</u> (cf. Nonlinear optics in crystal)

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



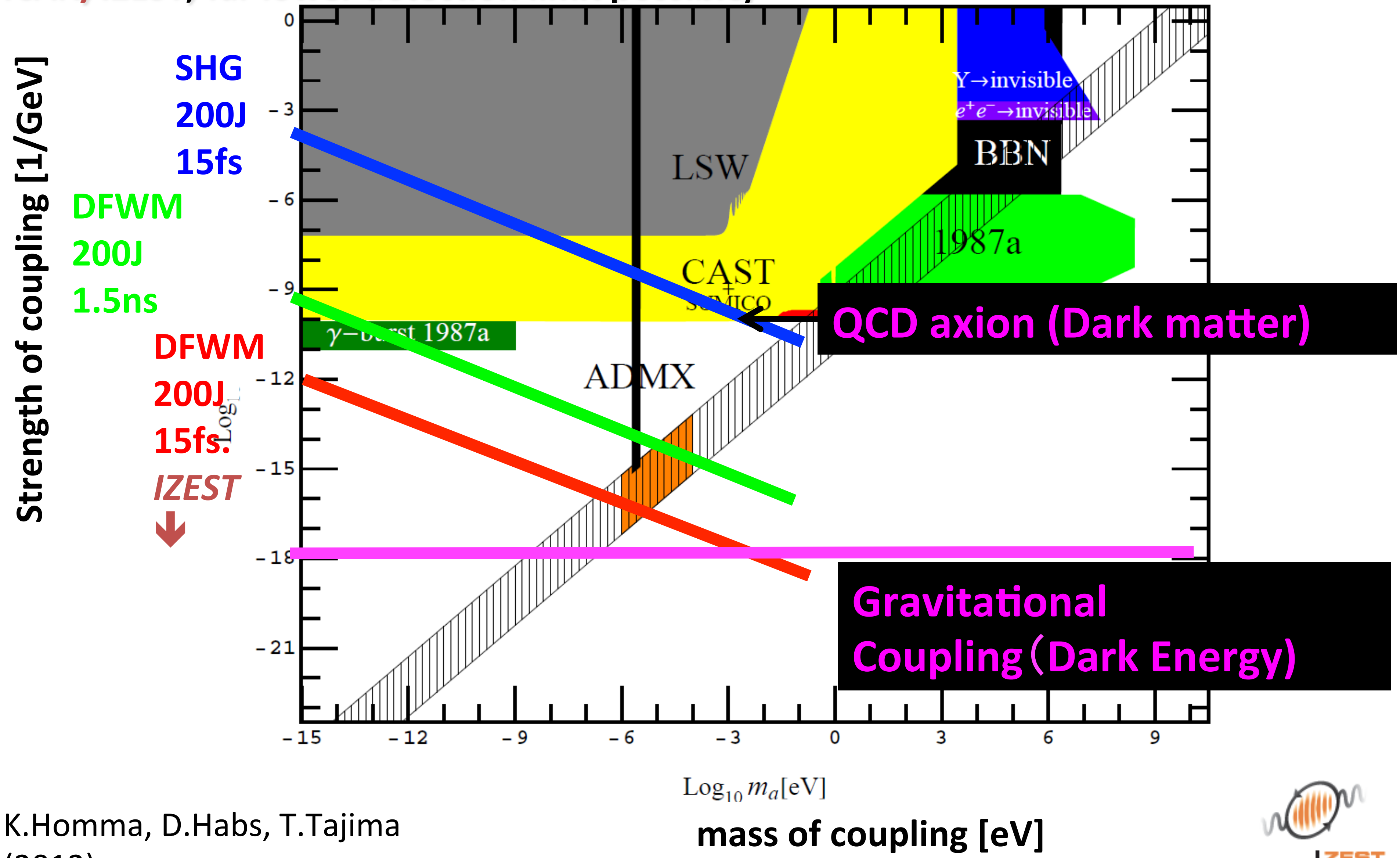
K.Homma, D.Habs, T.Tajima Appl. Phys. B (2012)

Sweep by arbitrary frequency xω

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

Photon mixer to new fields:

Dark Matter and Dark Energy in a single shot (with rep-rate such as *ICAN/IZEST*, far lower detection limit possible)

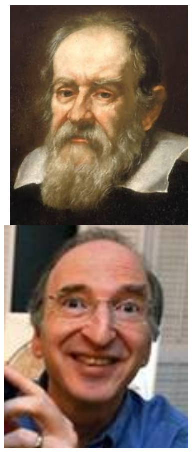


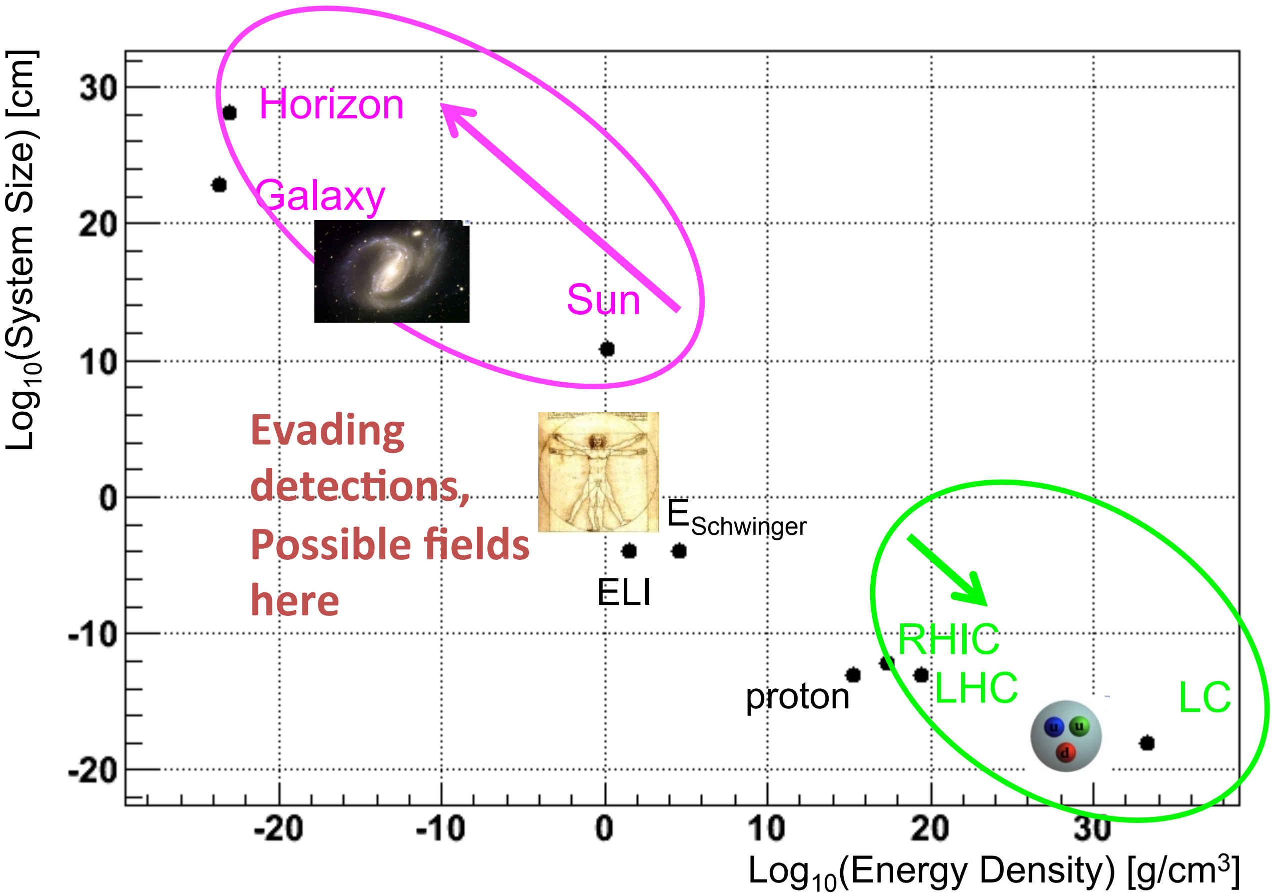
K.Homma, D.Habs, T.Tajima (2012)

Laser fits the gaping hole

in search of unknown fields:
dark matter/dark energy

Cosmological observation





High energy collider

Domains of physical laws

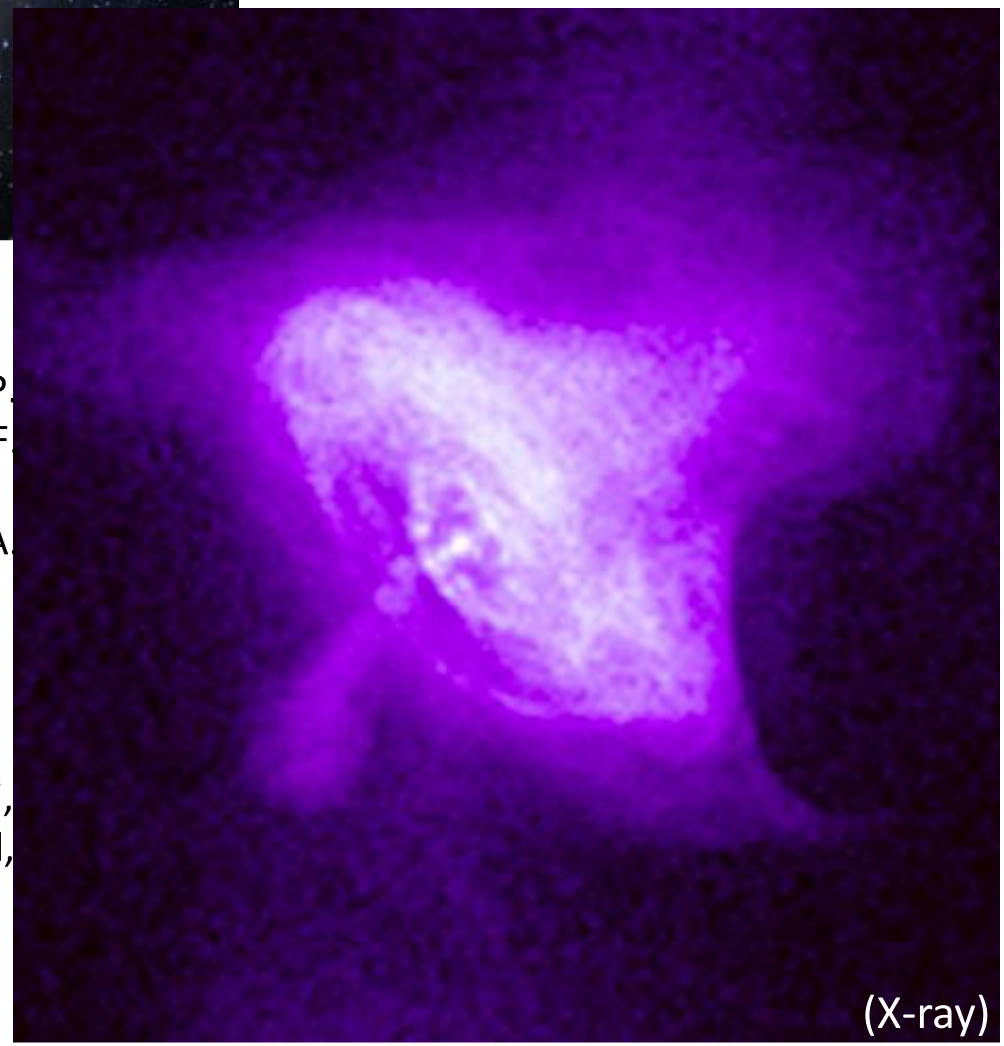
Homma, Habs, Tajima (2012)

Conclusions

- Frontier of fundamental high-energy physics
  ← high-intensity lasers
- 100GeV proof-of-principle experiment at *PETAL*(10kJ laser):
  ‘*IZEST’s 100GeV Ascent Workshop*’ (Bordeaux, May 31-June 1)
- For future colliders: High Average-power lasers (fiber lasers) = Coherent Amplification Network (*ICAN:* funded by EU---CERN, KEK participants)
- Search of Dark Matter(axion-like particles) and Dark Energy
  Degenerate 4 wave mixing method: started IZEST collaboration
- High sensitivity of the coherent large photon number:
  Luminosity (per shot) N^3/τ [N the number of laser photons (~Avogadro number), τ the pulse length]: $N^3/\tau \sim 10^{70}$ ($N^3 f/\tau$ when rep-rate f is applied, could be greater than 10^{80} per year)

Merci Beaucoup!

Cosmic PeV accelerating machine
Crab nebula:
← optics ↓ X-rays



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