The Frontier of High Field Science

Physics and Astronomy Colloquium
UC Irvine
October 17, 2013

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Chair, ICUIL

Acknowledgments for Collaboration: G. Mourou, C. Barty, W. Brocklesby, K. Nakajima, R. Hajima, T. Hayakawa, S. Gales, K. Homma, M. Kando, S. Bulanov, B. Holzer, T. Esirkepov, , F. Krausz, D. Habs, B. LeGarrec, J. Miquel, W. Leemans, D. Payne, P. Martin, R. Assmann, R. Heuer, M. Spiro, W. Chou, M. Velasco, J.P. Koutchouk, M. Yoshida, T. Massard, G. Cohen-Tannoudji, V. Zamfir, T. Ebisuzaki, R.X. Li, X. Q. Yan, K. Abazajian, S. Barwick, G. Yodh, D. Whiteson, T. Tait, M.Kaplingat, Z.H.Lin, S. Murgia, J. Bullock, E. Moses, J. Limpert, D. Payne, K. Koyama, A. Suzuki, Y. Okada, K. Ishikawa, D. Hammer, F. Mako, K. Molvig, C. Roberson, **N. Rostoker***

* I dedicate this lecture to my mentor, **Professor Norman Rostoker**(at 米寿)

content

- High fields that break matter, but keep order

  Guiding principle for order: not atomic cohesion (quantum coherence), but relativistic coherence (and plasma's collective eigenmodes) (Lesson learned in N. Rostoker's lab, 1973-75)

  → laser plasma acceleration, plasma decelerator, plasma optics,…
- High energy accelerators by laser
- Luminosity issue for collider---*ICUIL-ICFA Joint Task*
- Answer to high rep rate and high efficiency → **fiber laser (CAN)**
- Laser (not charged particles) collider for Dark Fields search
- Laser acceleration of ions (since 2000, recurring collective acceleration ~ early 70's)
- CAN lasers : enabling technology also for industrial and societal applications: compact radiation oncology, directed gamma beams (nuclear medicine and pharmacology), homeland security, transmutation of nuclear wastes (ADS, etc.) , ….
- Blazars as astrophysical wakefield accelerators toward ZeV

Incubation period: Collective Accelerators (1973-75)

Professor N. Rostoker

Collective ion acceleration by a reflexing electron beam: Model and scaling

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(Received 21 June 1983; accepted 2 April 1984)

Analytical and numerical calculations are presented for a reflexing electron beam type of collective ion accelerator. These results are then compared to those obtained through experiment. By constraining one free parameter to experimental conditions, the self-similar solution of the ion energy distribution agrees closely with the experimental distribution. Hence the reflexing beam model appears to be a valid model for explaining the experimental data. Simulation shows in addition to the agreement with the experimental ion distribution that synchronization between accelerated ions and electric field is phase unstable. This instability seems to further restrict the maximum ion energy to several times the electron energy.

I. INTRODUCTION

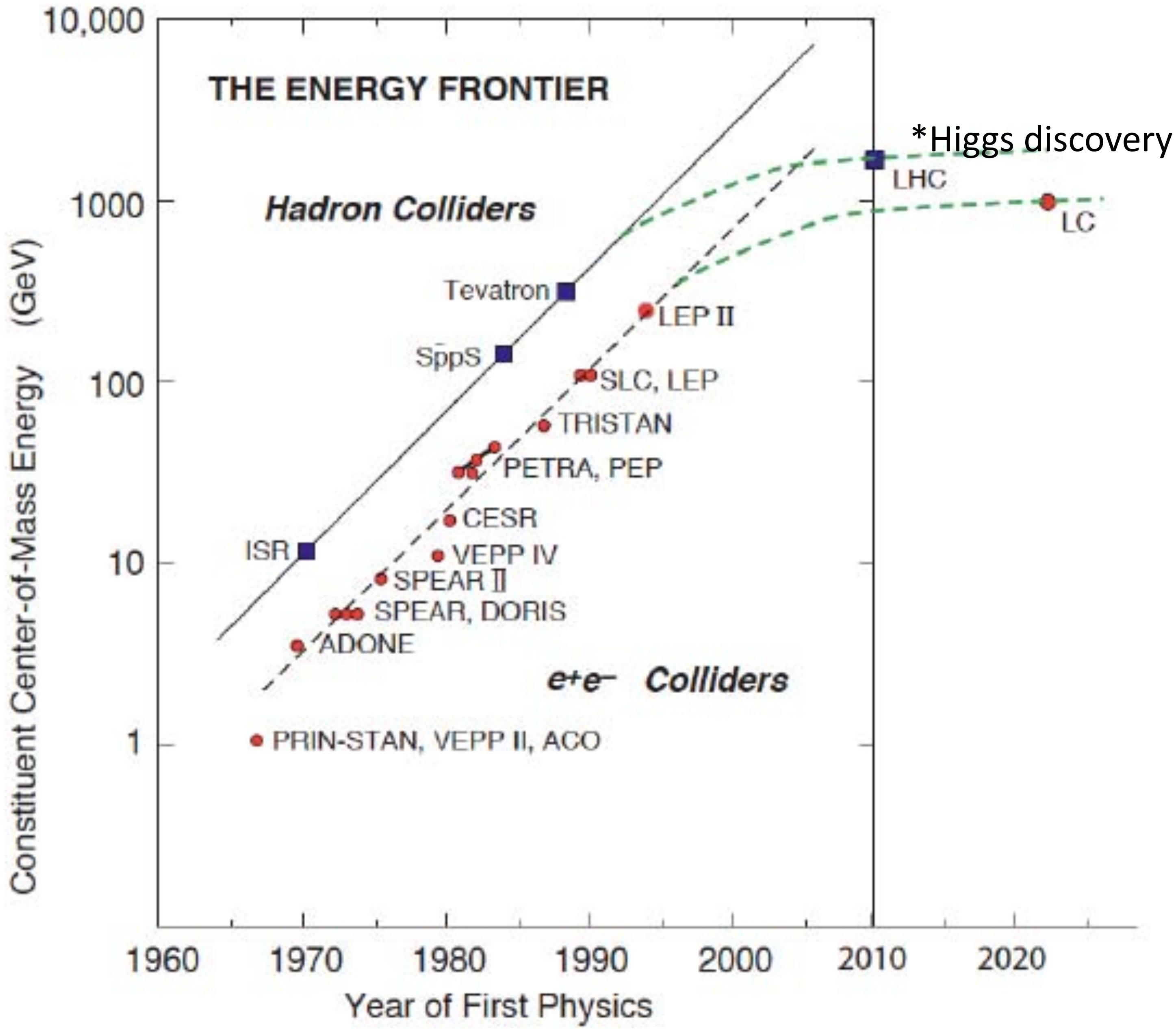
Experiments on collectively accelerating ions utilizing a reflexing intense relativistic electron beam in a plasma have been carried out.[1,2] These experiments began to reveal sever- chronous fashion. Thus, energetic ions would be expected. The ion energy would, of course, be bounded above by the ion to electron mass ratio times the initial electron energy; that is, the energy is bounded when the ions reach the initial

Collective acceleration suggested:
Veksler (1956)
(ion energy)~ (M/m)(electron energy)

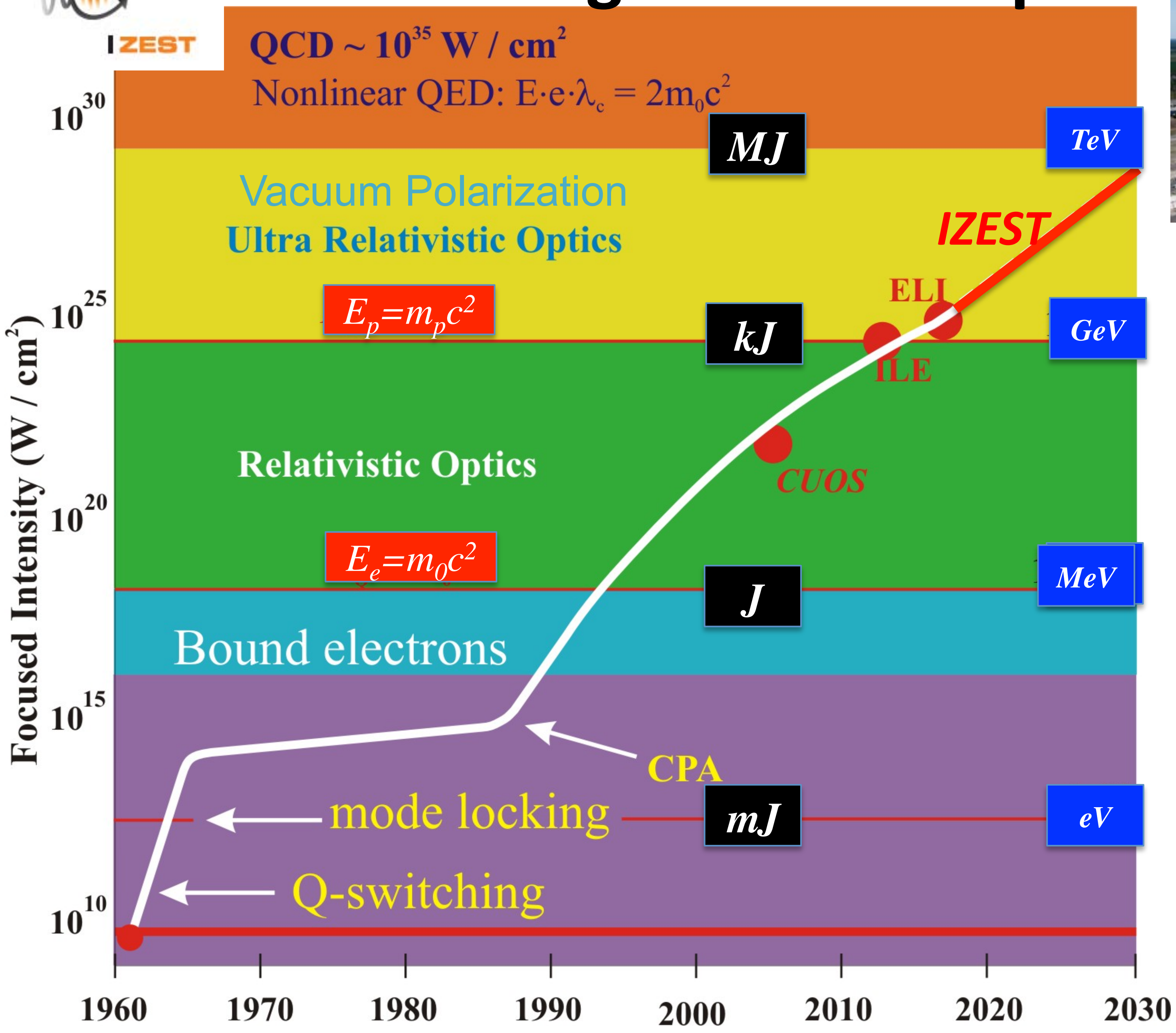
Many experimental attempts (~'70s):
"Collectrive accelerators" (Rostoker/Reiser,1979)
led to no such amplification
(ion energy)~ (several)x(electron)

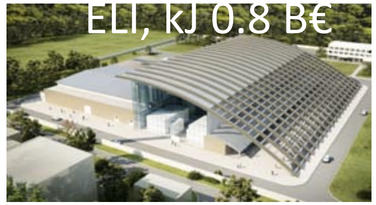
Mako-Tajima analysis (1978;1984)
sudden acceleration, ions untrapped,
electrons return, while some run away
→ #1 **gradual acceleration necessary**
→ #2 **electron acceleration** possible
with **trapping** **(with Tajima-Dawson field)**,
more tolerant for sudden process
→ #3 laser ion acceleration (3 decades later)
similar to Rostoker's experiments

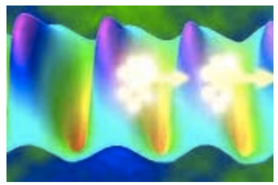
Livingston Chart and Recent Saturation

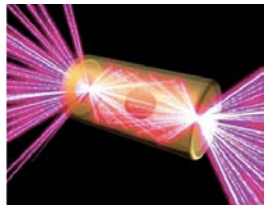


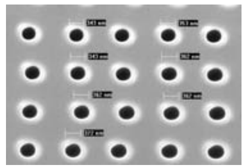
Extreme Light Road Map











ICUIL 2012 Mourou

(G. Mourou, L. Giesen)

Extreme Light Infrastructure (2013-)

(first major science infra east of Elbe other than Russia)

Czech

Hungary

Romania

~600 science/engineering positions are opening up. e.g. ➜

eli attosecond

ÚJ SZÉCHENYI TERV

ELI-HU Research and Development Non-Profit Limited Liability Company is announcing

12 job openings in Young Scientist and Research Fellow positions

Relativistic nonlinearity under intense laser

Plasma free of binding potential , but its electron responses:

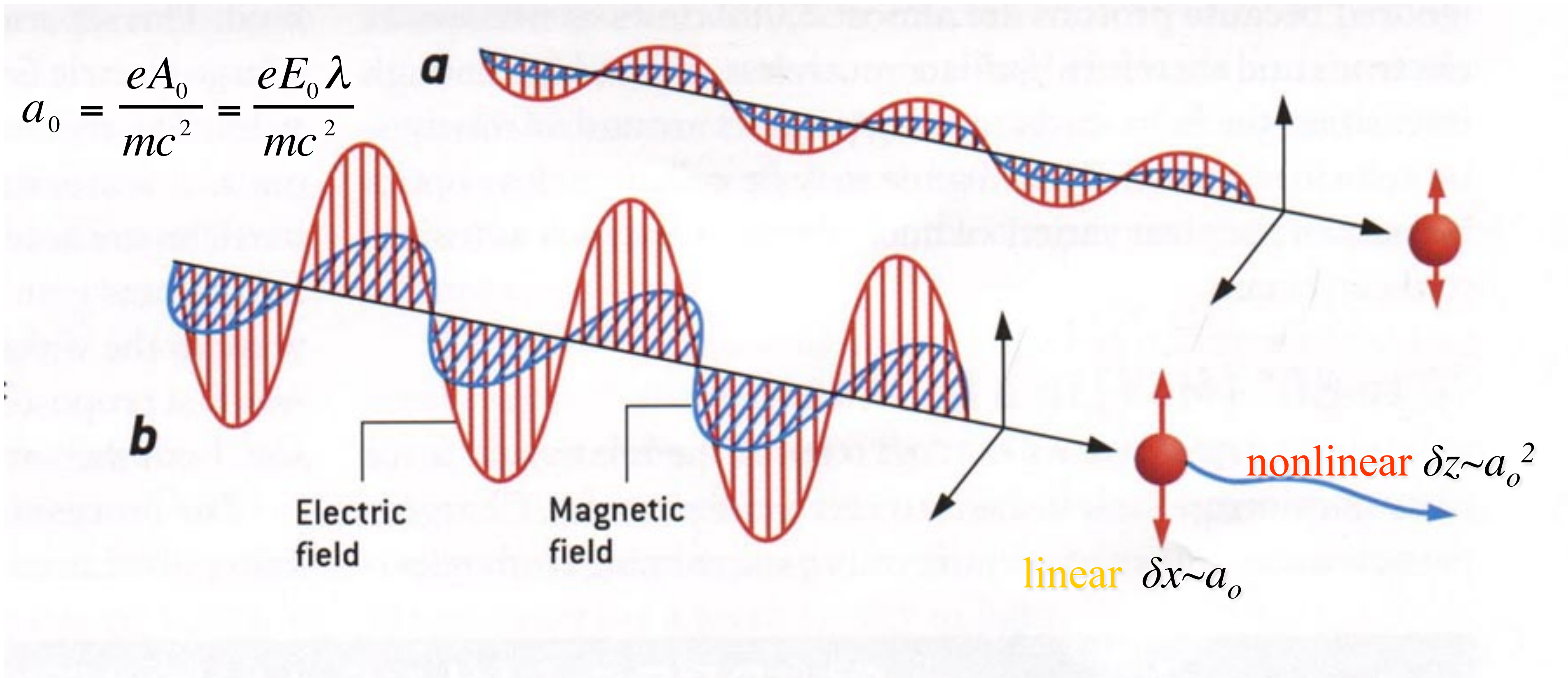
a) Classical optics : $v<<c$,

$a_0<<1$: δx only

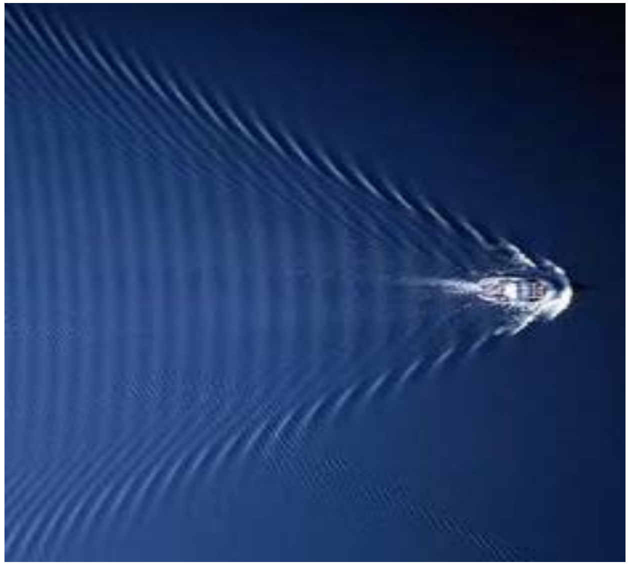
b) Relativistic optics: $v\sim c$

$a_0>>1$: $\delta z >> \delta x$

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



Laser Wakefield (LWFA): nonlinear optics in plasma

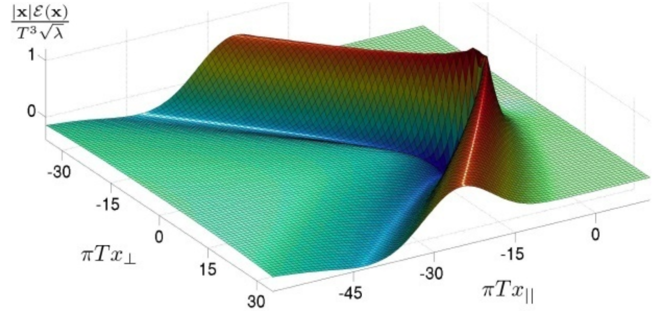


Bow ('ponderomotive')

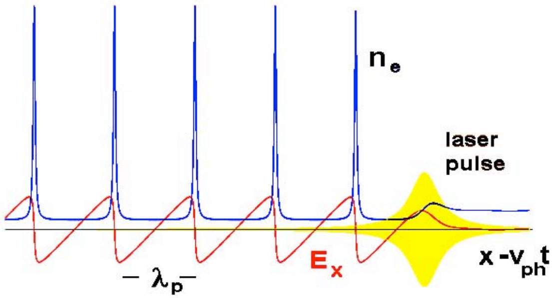
and Kelvin **wake** waves

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

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



Wave **breaks** at v<c



← relativity regularizes (*relativistic coherence*)

(The density cusps.
Cusp singularity)

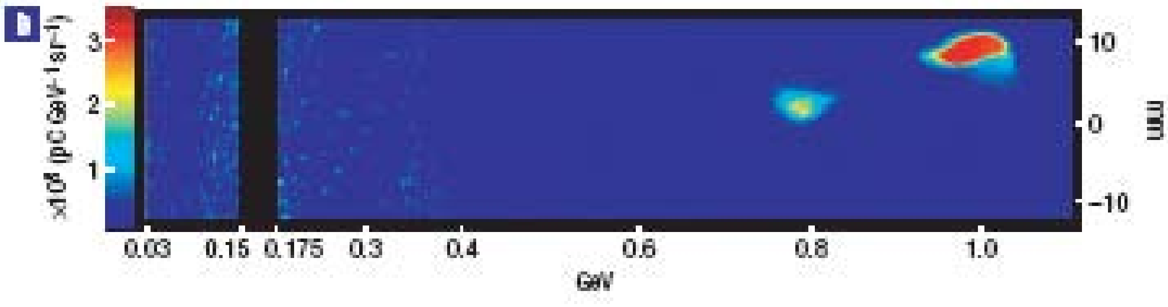
Hokusai

Maldacena

(Plasma physics vs.
Superstring theory)

GeV electrons from a centimeter LWFA

(a slide given to me by S. Karsch)



Leemans et al., Nature Physics, september 2006

310-μm-diameter channel capillary

P = 40 TW

density 4.3×10^{18} cm^{-3}.

laser intensity 10^{18} W/cm^2

VOLUME 43, NUMBER 4 PHYSICAL REVIEW LETTERS 23 JULY 1979

Laser Electron Accelerator

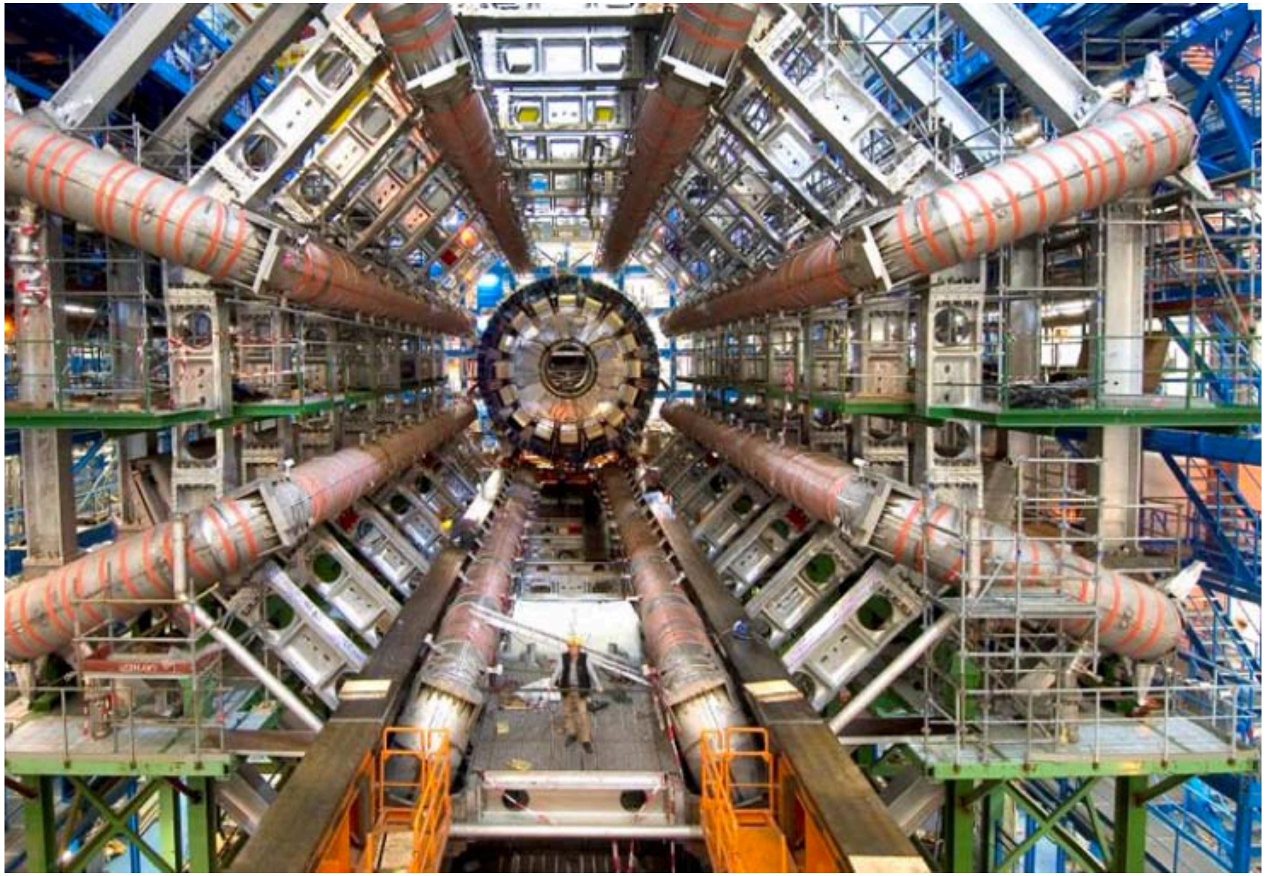
T. Tajima and J. M. Dawson
Department of Physics, University of California, Los Angeles, California 90024

(Received 9 March 1979)

An intense electromagnetic pulse can create a weak of plasma oscillations through the action of the nonlinear ponderomotive force. Electrons trapped in the wake can be accelerated to high energy. Existing glass lasers of power density 10^{18}W/cm^2 shone on plasmas of densities 10^{18} cm^{-3} can yield gigaelectronvolts of electron energy per centimeter of acceleration distance. This acceleration mechanism is demonstrated through computer simulation. Applications to accelerators and pulsers are examined.

(emphasis by S. Karsch)

High Field Science (IZEST) Supporters: CERN

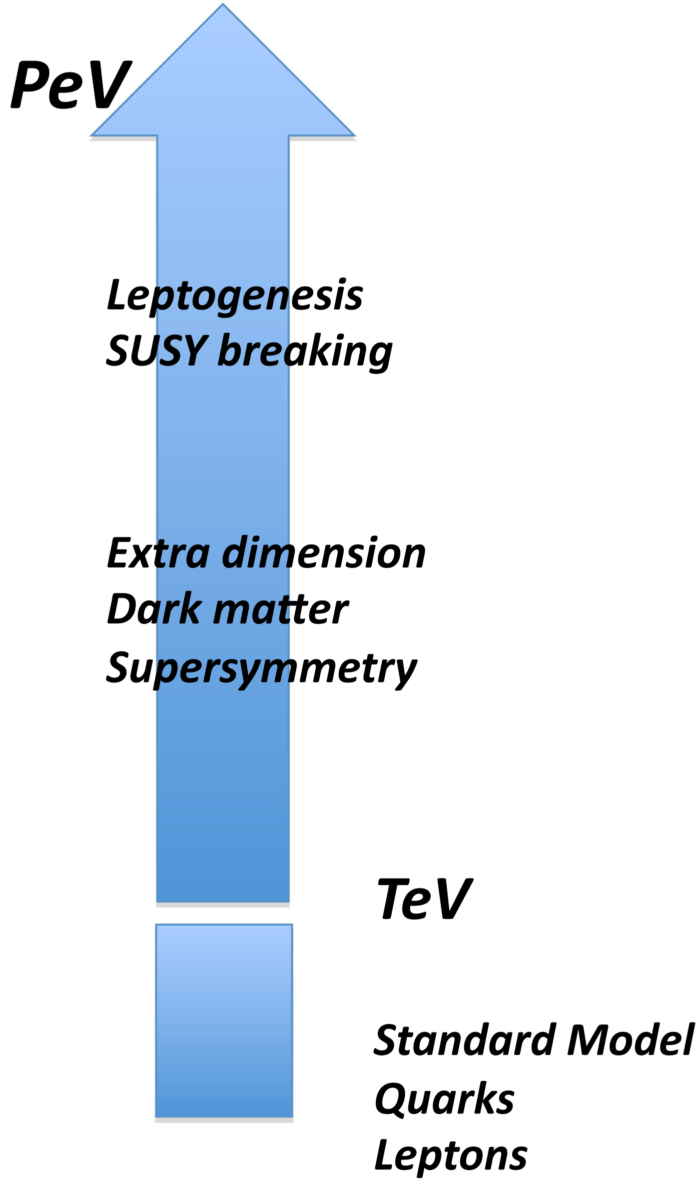


Rolf Heuer
CERN Director General

IZEST's Mission: Responding to <u>Suzuki's Challenge</u>

Atsuto Suzuki:
KEK Director General,
Former ICFA Chair

New Paradigm



Greetings from Michel Spiro

(Former) President of CERN Council

As President of the CERN Council, I would like to express our interest and warm support in developing new ultra high gradient techniques of particle acceleration.
Plasma acceleration seems a very promising avenue.
The IZEST project is a bold and fierce adventure. It will open the way to a new generation of ultra high energy and compact accelerator and give access to totally new physics like probing quantum vacuum and testing the basic laws of physics.
I wish great success to the IZEST conference and to the IZEST project.

Best wishes,
Michel

[Court. A. Oeftinger(CERN)]

IZEST Associate Laboratories

1. **Ecole Polytechnique -** Palaiseau, France
2. **CEA -** Commissariat à l'Energie Atomique et aux énergies alternatives, Bordeaux, France
3. **PPPL -** Princeton Plasma Physics Laboratory, Princeton, New Jersey, USA
4. **FERMILAB -** Fermi National Accelerator Laboratory, Chicago, Illinois, USA
5. **LLNL -** Lawrence Livermore National Laboratory, Livermore, California, USA
6. **CUOS -** Center for Ultrafast Optical Science, Ann Arbor, Michigan, USA
7. **ALLS -** Advanced Laser Light Source, Montreal, Canada
8. **JAI -** John Adams Institute for accelerator science, Oxford, UK
9. **TOPS -** TeraHertz to Optical Pulse Source, Strathclyde, UK
10. **HHU -** Heinrich Heine Universität, Düsseldorf, Germany
11. **MEPhI -** Moscow Engineering Physics Institute, Moscow, Russia
12. **IAP -** Institute of Advanced Physics, Nizhy Novgorod, Russia
13. **GIST -** Gwangju Institute of Science and Technology, Gwangju, Republic of Korea
14. **KEK -** High Energy Accelerator Research Organization, Tsukuba, Japan
15. **KPSI -** Kansai Photon Science Institute, Kansai, Japan
16. **LeCosPa -** Leung Center for Cosmology and Particle Astrophyics, Taipei, Taiwan
17. **CLPU -** Centro de Láseres Pulsados Ultracortos Ultraintensos, Salamanca, Spain
18. **CERN -** Organisation Européenne pour la Recherche Nucléaire, Genève, Switzerland
19. **SIOM -** Shanghai Institute of Optics and Fine Mechanics, Shanghai, China
20. **Kyoto University -** Kyoto, Japan
21. **ELI-NP -** Extreme Light Infrastructure - Nuclear Physics, Magurele, Romania
22. **Beijing University** - Beijing, China
23. **TCHILS** - Texas Center for High Intensity Laser Science, Austin, USA

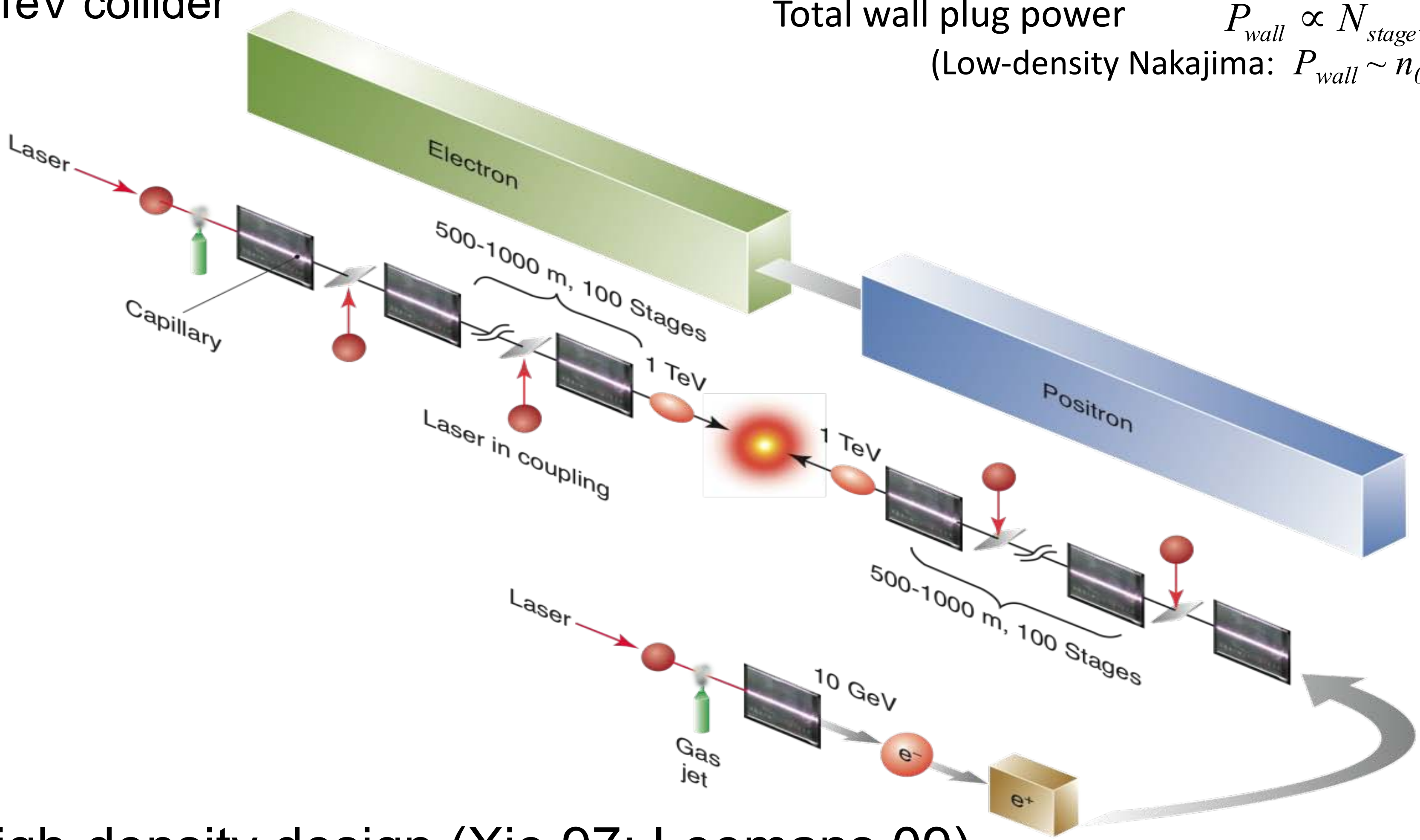
Laser driven collider concept

Laser energy: $U_L \sim n_0^{-3/2}$

a TeV collider

Total wall plug power $P_{wall} \propto N_{stage} P_{avg} \propto n_0^{1/2}$

(Low-density Nakajima: $P_{wall} \sim n_0^{3/2}$)

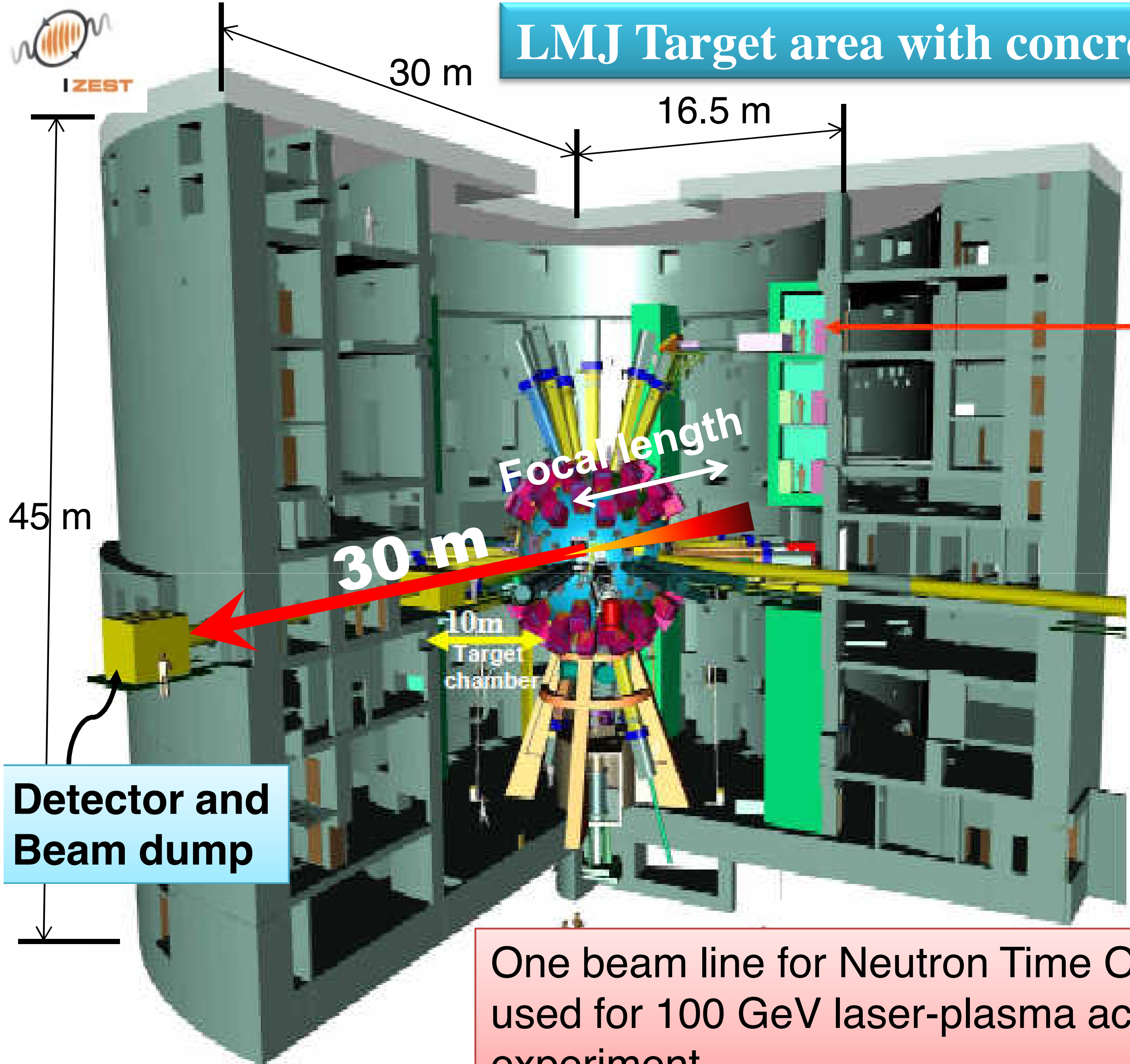


High-density design (Xie,97; Leemans,09)

ICFA-ICUIL Joint Task Force on Laser Acceleration(Darmstadt,10)

LMJ Target area with concrete shielding

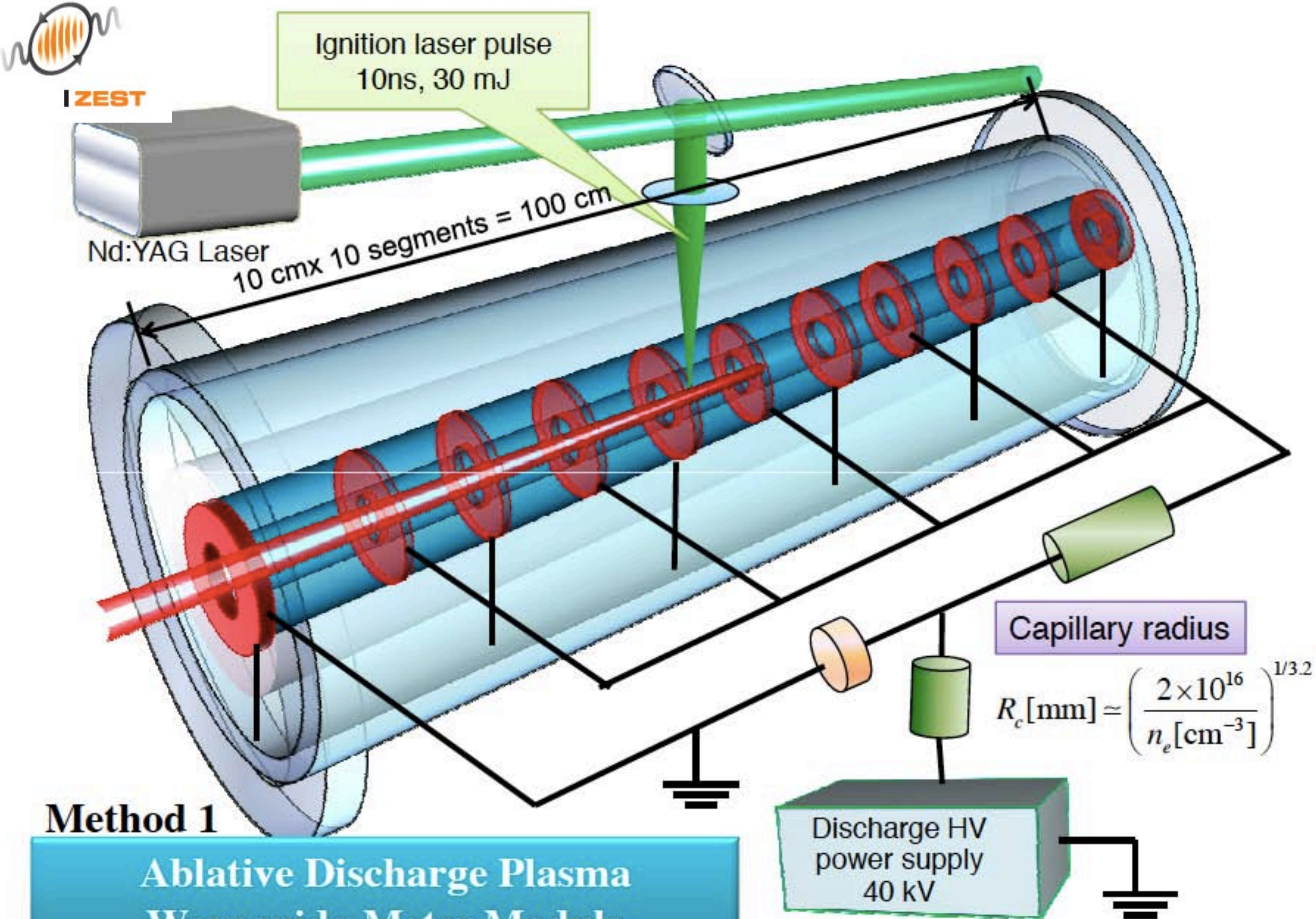
First Workshop on
100GeV IZEST Project:
May 31-June 1, ’12
@ Bordeaux



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

Nakajima, LeGarrec

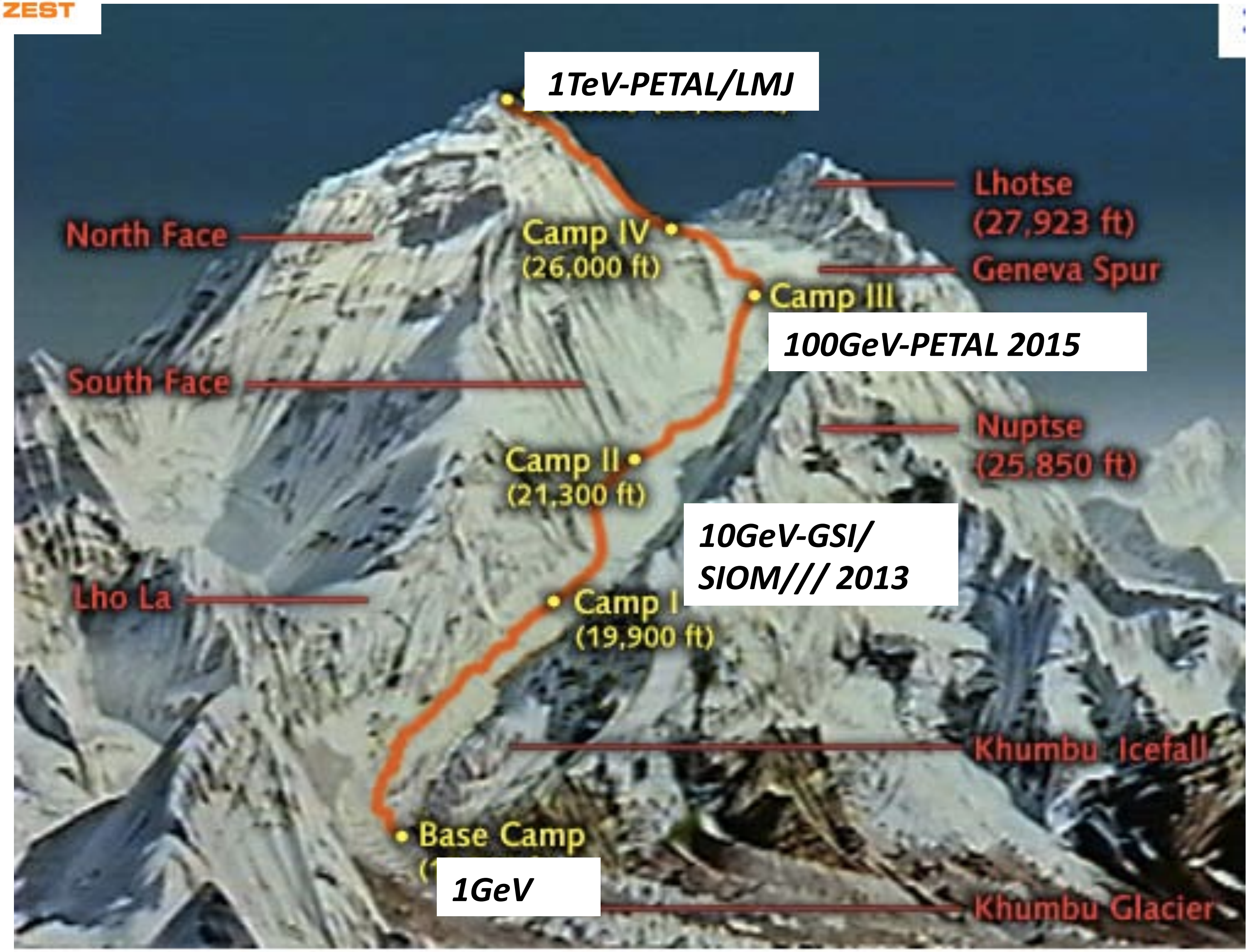
Courtesy of PETAL



Method 1

Ablative Discharge Plasma Waveguide-Meter Module

IZEST 100GeV Ascent



Density scalings of **LWFA** for collider

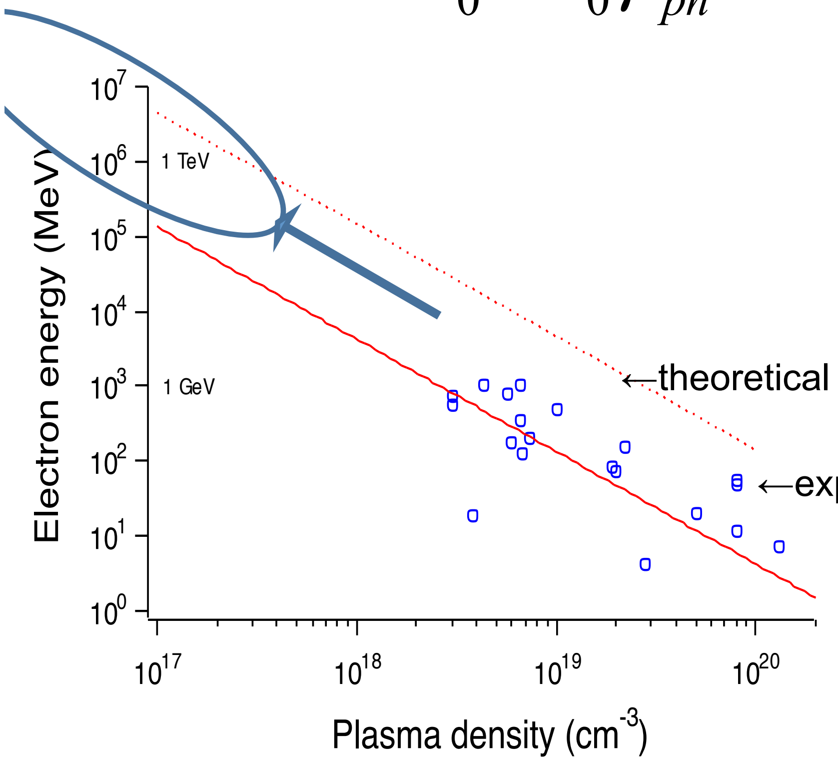
Accelerating field E_z	$\propto n_e^{1/2}$
Focusing constant K	$\propto n_e^{1/2}$
Stage length L_{stage}	$\propto n_e^{-3/2}$
Energy gain per stage W_{stage}	$\propto n_e^{-1}$
Number of stages N_{stage}	$\propto n_e$
Total linac length L_{total}	$\propto n_e^{-1/2}$
Number of particles per bunch N_b	$\propto n_e^{-1/2}$
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^{18} /cc (conventional) → 10^{16} /cc

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

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

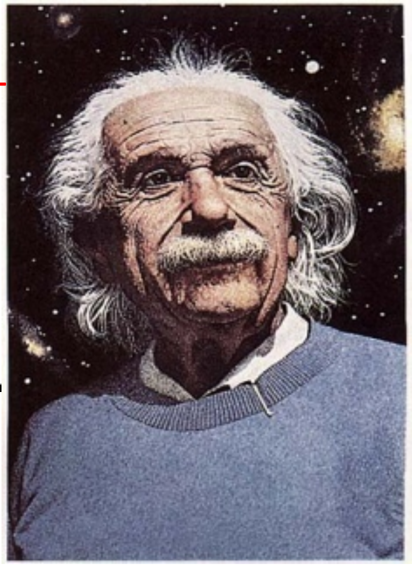
pump depletion length

Adopt:
NIF laser (3MJ)
→ 0.7PeV
(with Kando, Teshima)

Einstein and Ether

What is fundamentally new in the ether of the general theory of relativity as opposed to the ether of Lorentz consists in this, that the state of the former is at every place determined by connections with the matter and the state of the ether in neighbouring places, which are amenable to law in the form of differential equations; whereas the state of the Lorentzian ether in the absence of electromagnetic fields is conditioned by nothing outside itself, and is everywhere the same. The ether of the general theory of relativity is transmuted conceptually into the ether of Lorentz if we substitute constants for the functions of space which describe the former, disregarding the causes which condition its state. Thus we may also say, I think, that the ether of the general theory of relativity is the outcome of the Lorentzian ether, through relativation.

As to the part which the new ether is to play in the physics of the future we are not yet clear. We know that it determines the metrical relations in the space-time continuum, e.g. the configurative



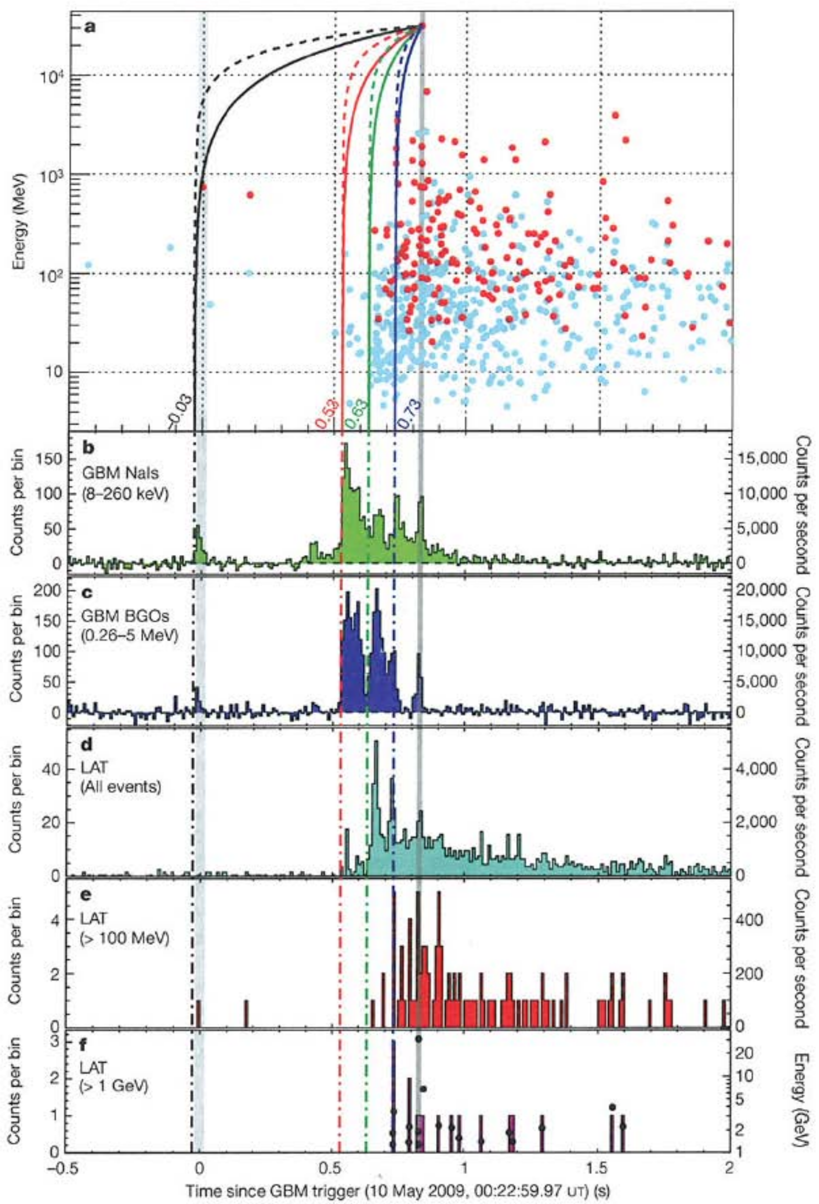
(A. Einstein, 1922)

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

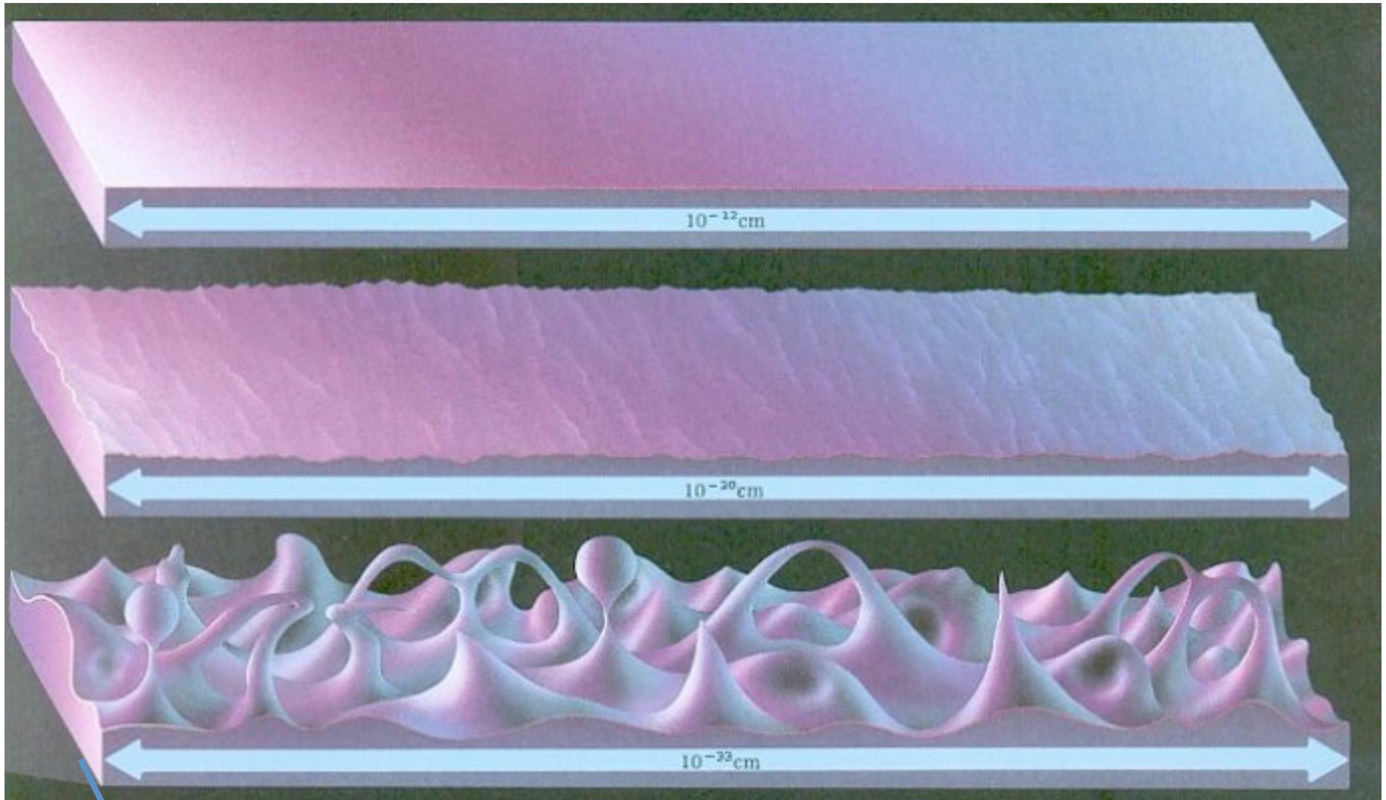
Energy-dependent
photon speed ?
Observation of primordial Gamma Ray Bursts (GRB)
(limit is pushed up close to Planck mass)

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)

$c < c_0$



Coarser, lower energy texture

Finer, higher energy texture

← (0.1PeV)

1km

←(1PeV : fs behind)

PeV γ (converted from e^-)

Brief History of *ICUIL* – *ICFA* Joint Effort

– *ICUIL* Chair (Tajima) sounded on A. Wagner (Chair *ICFA*) and Suzuki (incoming Chair) of a common interest in laser driven acceleration, Nov. 2008

– *ICFA* GA invited Tajima for presentation by *ICUIL* and endorsed initiation of joint efforts on Feb. 13, 2009

– *Joint Task Force* formed of *ICFA* and *ICUIL* members, W. Leemans, Chair, Sept, 2009

– First Workshop by *Joint Task Force* held @ GSI, Darmstadt, April, 2010

– Report to *ICFA* GA (July,2010) and *ICUIL* GA (Sept, 2010) on the findings

– *EuroNNAc* Workshop on Novel Accelerators (CERN, May, '11)

– Publication of *Joint Task Force* Report (Dec. 2011)

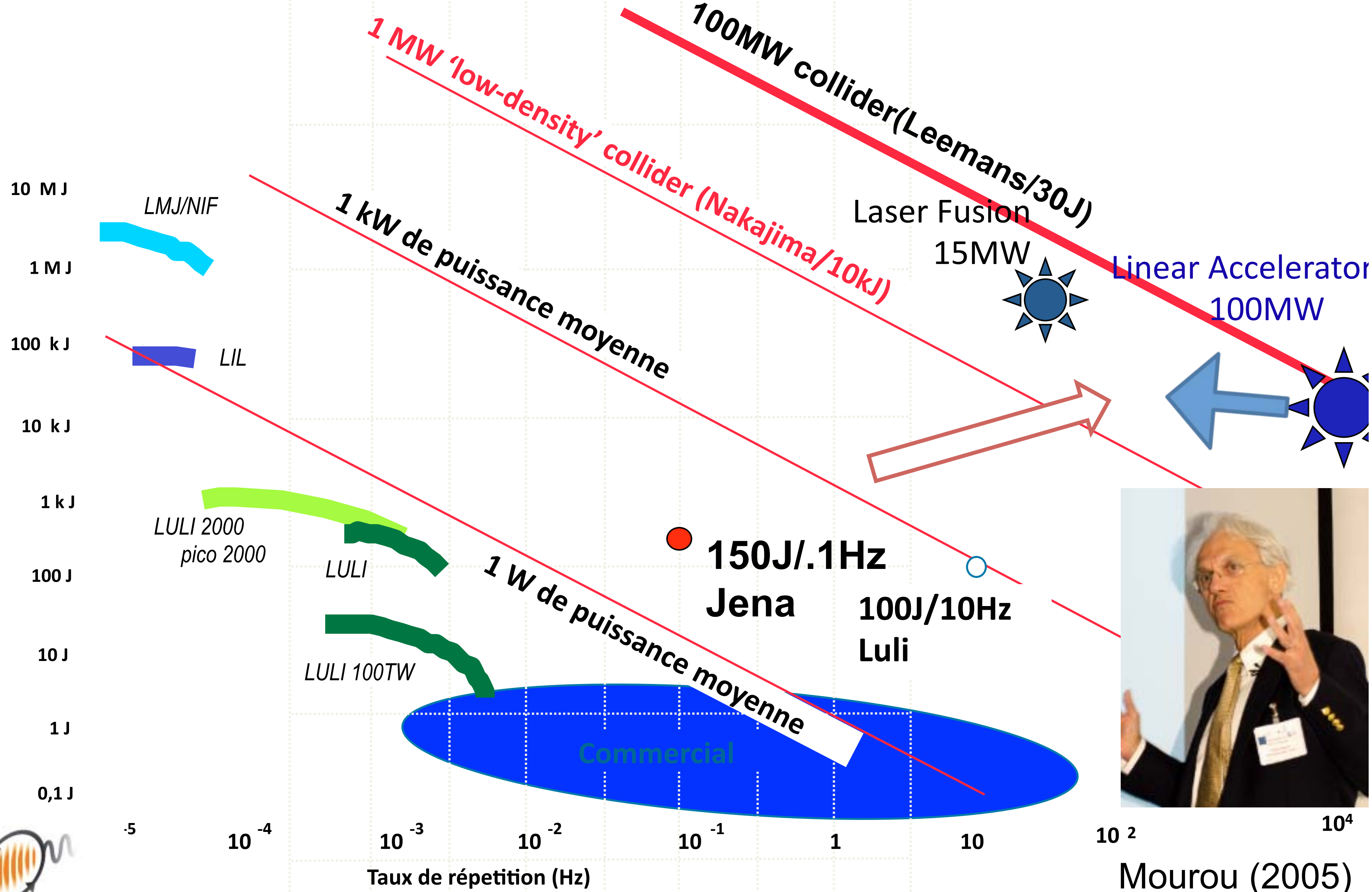
– Initiative of *ICAN* under *IZEST* (Nov., 2011~) started @ CERN (Feb., 2012)

– CAN laser paper published (April, 2013)

– Final *ICAN* Conference @ CERN (June, 2013) → next phase *WE-CAN (?)*

ican
International Coherent Amplification Network

Etat de l'Art *(HEEAUP 2005): collider consideration*



Mourou (2005)

Mourou/ICAN (2013); Nakajima (2011)

IZEST

(International Center for Zetta- Exawatt Science and Technology)

aspires to push the average power of ultraintense laser from **Watt** to **MW**

(ICAN-International Coherent Amplification Network)

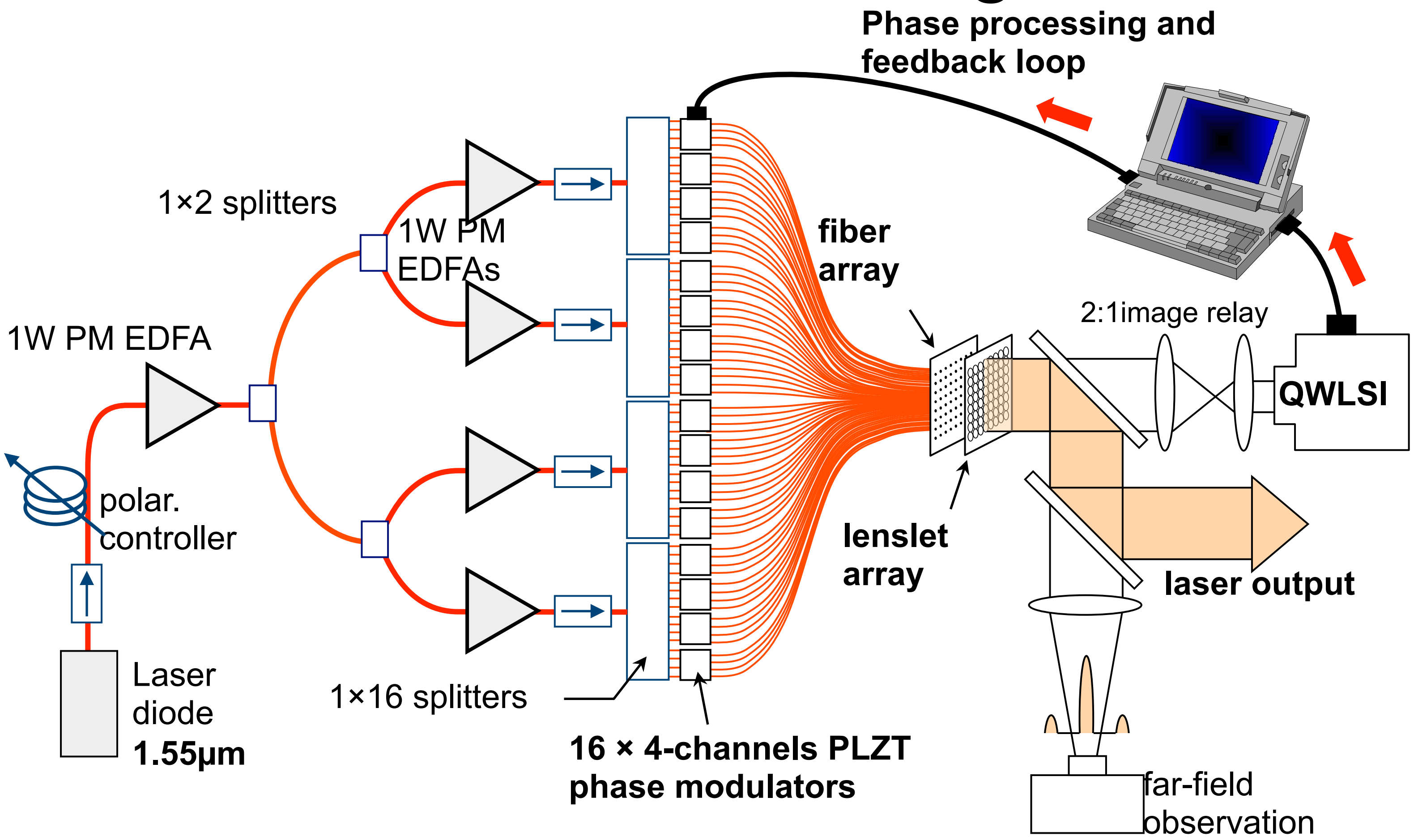
Communities of Laser and High-energy Physics are bridging the gap

an *IZEST*'s mission

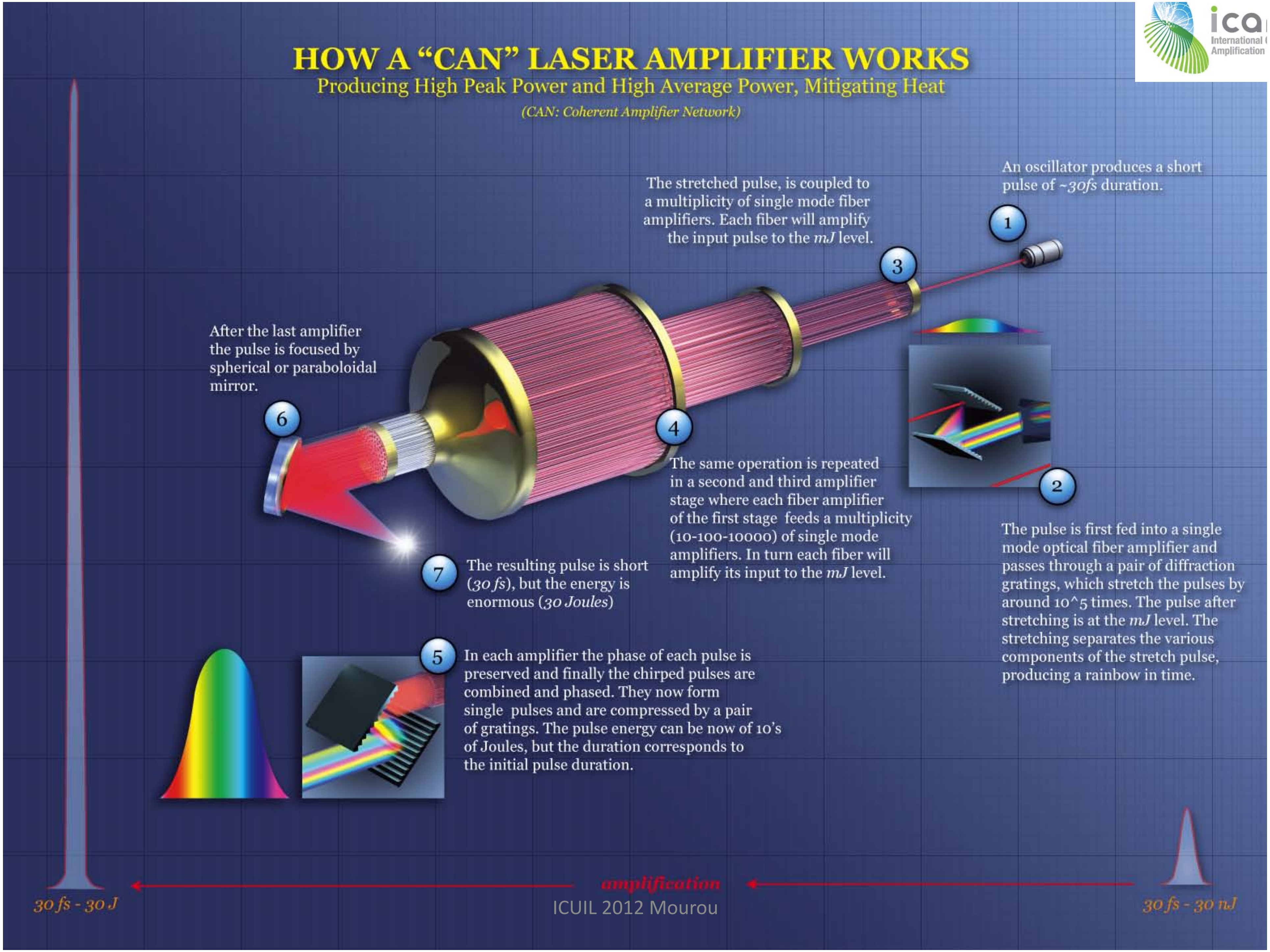
(IZEST Conference @ Strathclyde, 2012)

J. Bourderionnet, A. Brignon (Thales), C. Bellanger, J. Primot (ONERA)

Coherent Fiber Combining

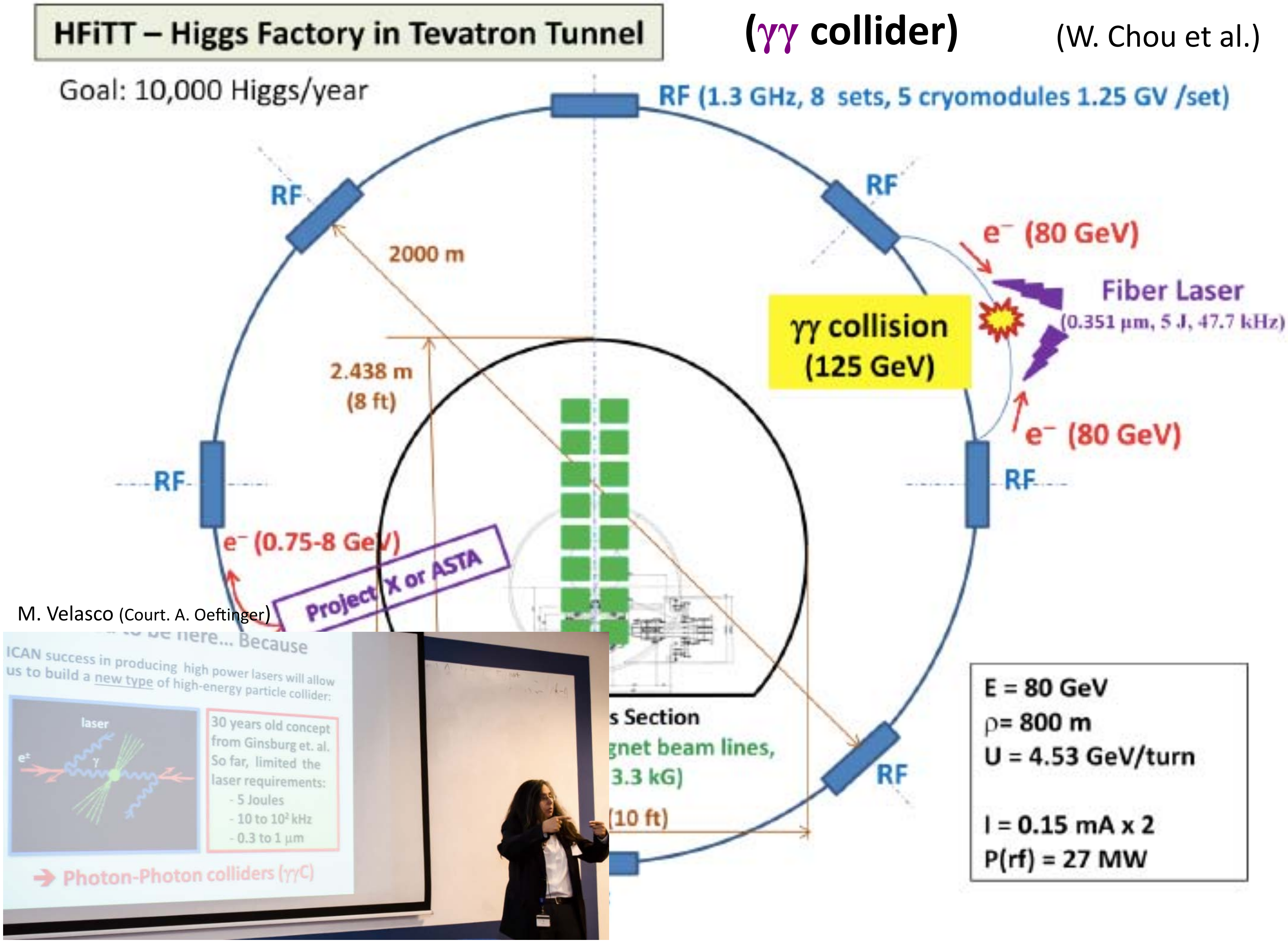


Achievement 2011
→ 64 phase-locked fibers



HOW A "CAN" LASER AMPLIFIER WORKS
Producing High Peak Power and High Average Power, Mitigating Heat
(CAN: Coherent Amplifier Network)
An oscillator produces a short pulse of ~30fs duration.
1
The stretched pulse, is coupled to a multiplicity of single mode fiber amplifiers. Each fiber will amplify the input pulse to the mJ level.
3
After the last amplifier the pulse is focused by spherical or paraboloidal mirror.
6
4
The same operation is repeated in a second and third amplifier stage where each fiber amplifier of the first stage feeds a multiplicity (10-100-10000) of single mode amplifiers. In turn each fiber will amplify its input to the mJ level.
2
The pulse is first fed into a single mode optical fiber amplifier and passes through a pair of diffraction gratings, which stretch the pulses by around 10^5 times. The pulse after stretching is at the mJ level. The stretching separates the various components of the stretch pulse, producing a rainbow in time.
7
The resulting pulse is short (30 fs), but the energy is enormous (30 Joules)
5
In each amplifier the phase of each pulse is preserved and finally the chirped pulses are combined and phased. They now form single pulses and are compressed by a pair of gratings. The pulse energy can be now of 10's of Joules, but the duration corresponds to the initial pulse duration.
30 fs - 30 J
amplification
30 fs - 30 nJ
ICUIL 2012 Mourou

($\gamma\gamma$ collider) (W. Chou et al.)



M. Velasco (Court. A. Oeftinger)

Smart control of laser

Emittance (and thus luminosity) of the particle beam

rapidly increases with the jitters of laser [in multi-stage acceleration]

smart control of laser →contains jitters

We see:

CAN laser property of **smartness**

higher rep rate, easier to operate CAN laser

higher rep rate, easier to feed-forward control

feedforward control → quality of beams

CAN laser : coherently connected (both in *parallel*, but also in *tandem*)

each fiber (digital unit): coherently and digitally controllable

→ digitally controlled **smart laser :** a new paradigm

ICAN Applications

Scientific :

- **Laser acceleration toward TeV**
- **Higgs factory with γ-γ collider**
- **Physics beyond the Standard Model: Dark Matter search with laser**
- **ZeV astrophysics (astrophysical manifestation of wakefields)**

Societal:

- **Laser proton acceleration and applications:**
  - Neutron sources
  - Accelerator Driven System(ADS) for transmutation of nuclear waste
  - Accelerator Driven Reactor(ADR) for safer energy production
- **Laser-driven γ beam applications:**
  - Fukushima
  - Homeland security
  - Nuclear pharmacology, nuclear medicine

Opportunities Enabled by CAN

CAN Fiber Laser → Collider requirements

- Average power (rep rate x peak power) → luminosity
- Efficiency → cost
- Smartness (digital control) → emittance
- Intensity → gradient

R. Aleksan (Court. A. Oeftinger(CERN))

γ-γ collider requirements

1-50kHz rep rate (other reqs are easier)

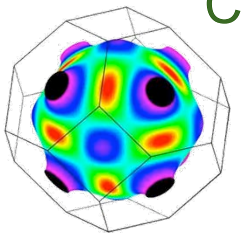
Dark matter search

average power → luminosity

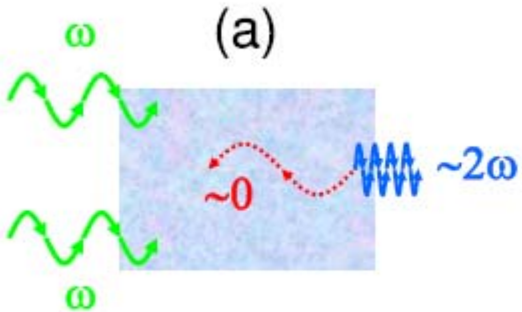
Proton acceleration

intensity (energy of beam), smartness (beam quality), average power (fluence)

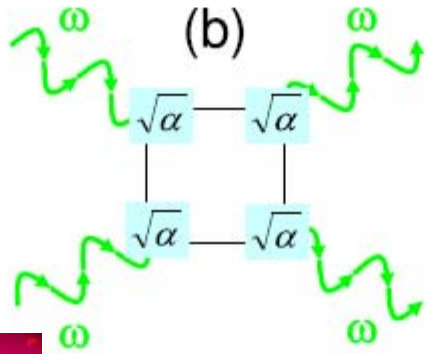
Intense laser probes matter /vacuum nonlinearity

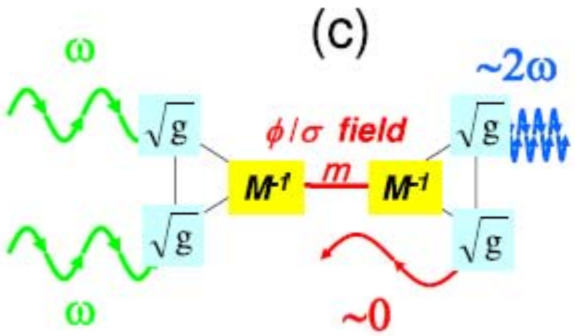


Crystal nonlinearity →
second harmonic generation (Franken et al)



Learn from **Nonlinear Optics** of matter for vacuum:





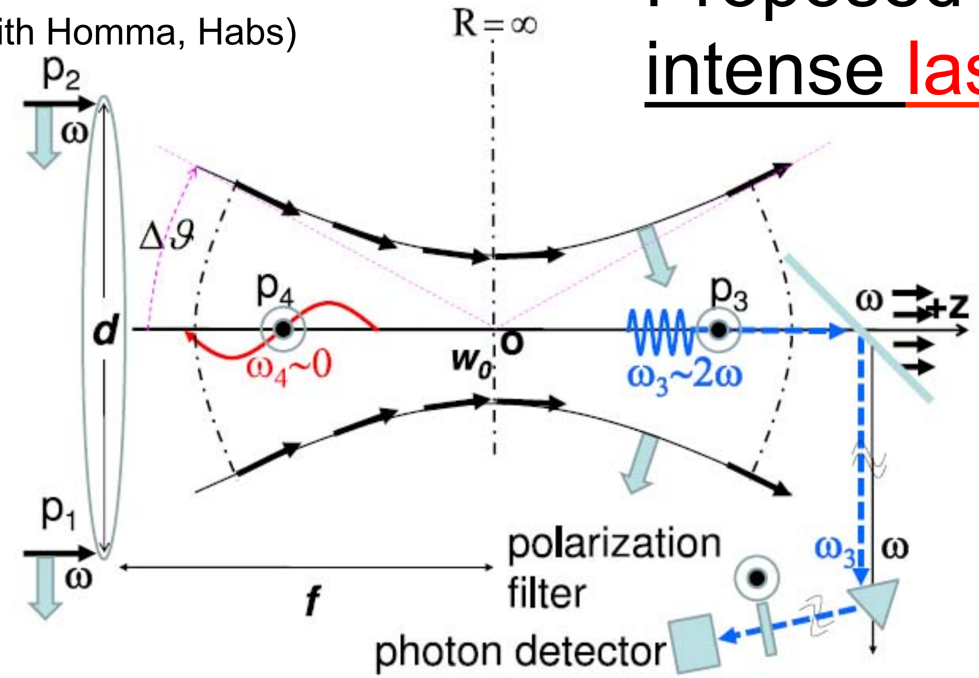
QED nonlinearity

Vacuum nonlinearity by light- mass field (dark energy, axion,..)
→ second harmonic

Learning from laser parametric scattering: low energy (meV - neV) fields (vacua)

Proposed scheme of co-parallel intense laser probe of vacuum

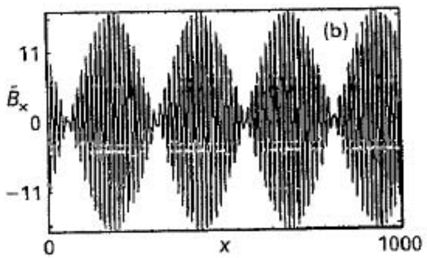
(with Homma, Habs)



Many orders of magnitude gain in resonant coupling and sensitivity over long interaction:

Nonlinearity of vacuum

$\omega + \omega \rightarrow 2\omega$ (SHG a la Franken)



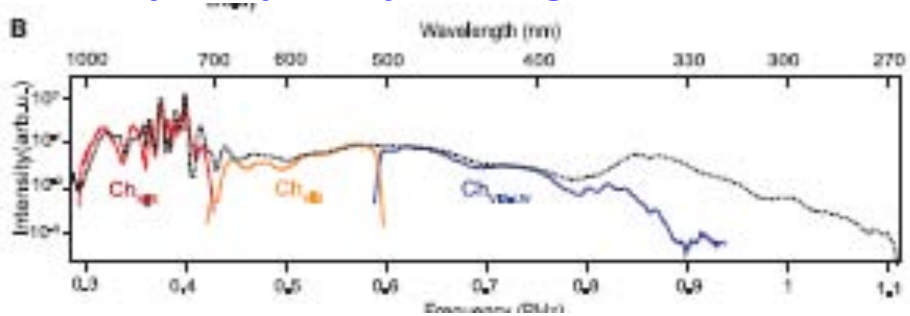
cf. Brillouin forward scattering beat / optical parametric excitation = phonon mediating (Nambu-Goldston boson)

Mass of light fields(dark energy fields, axion-like fields) resonates with specific crossing angle of co-propagating lasers

Degenerate Four-Wave Mixing (DFWM)

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

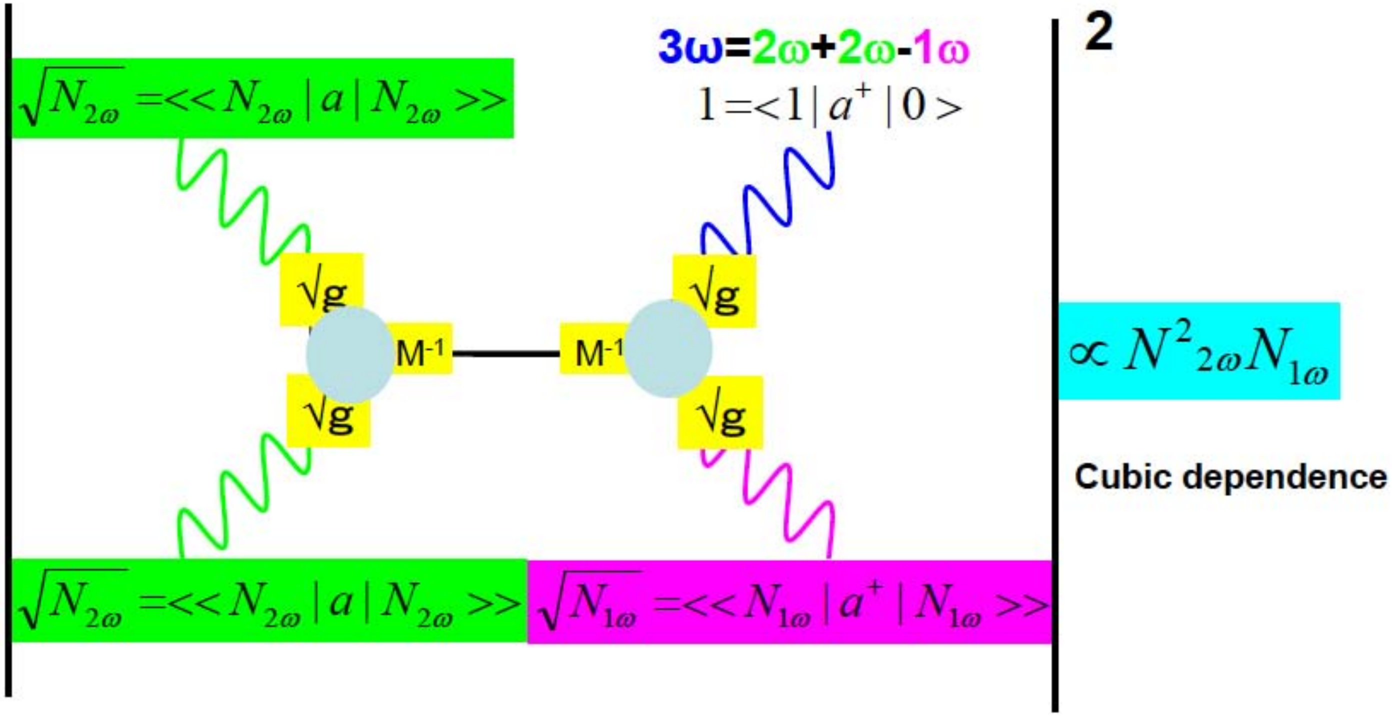
Decay into (4-x)ω can be induced by frequency-mixing



Sweep by arbitrary frequency xω

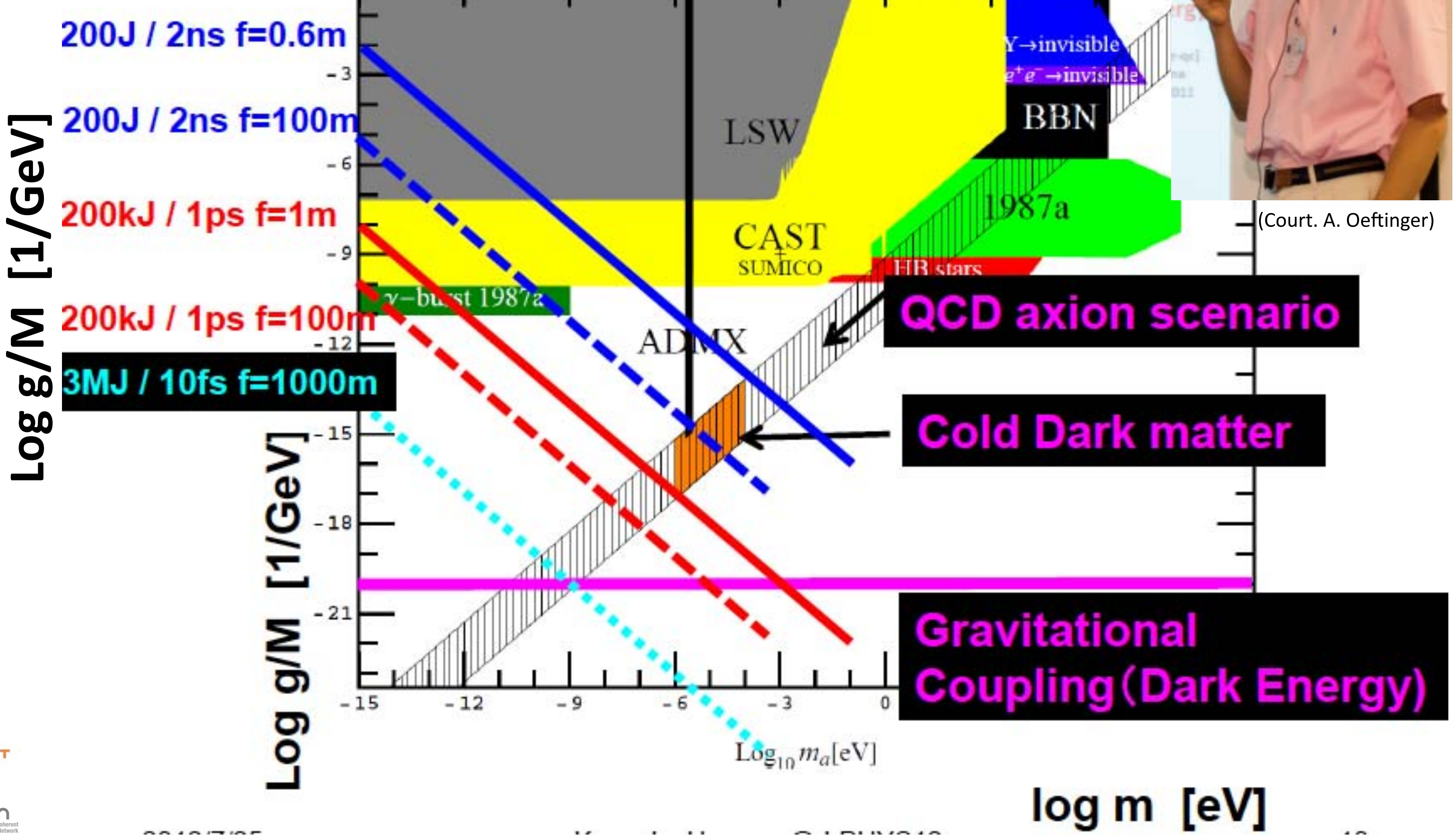
e.g. $x\omega = 1\omega$

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



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

Photon mixer's road to unknown fields: Dark Matter and Dark Energy



(Court. A. Oeftinger)

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

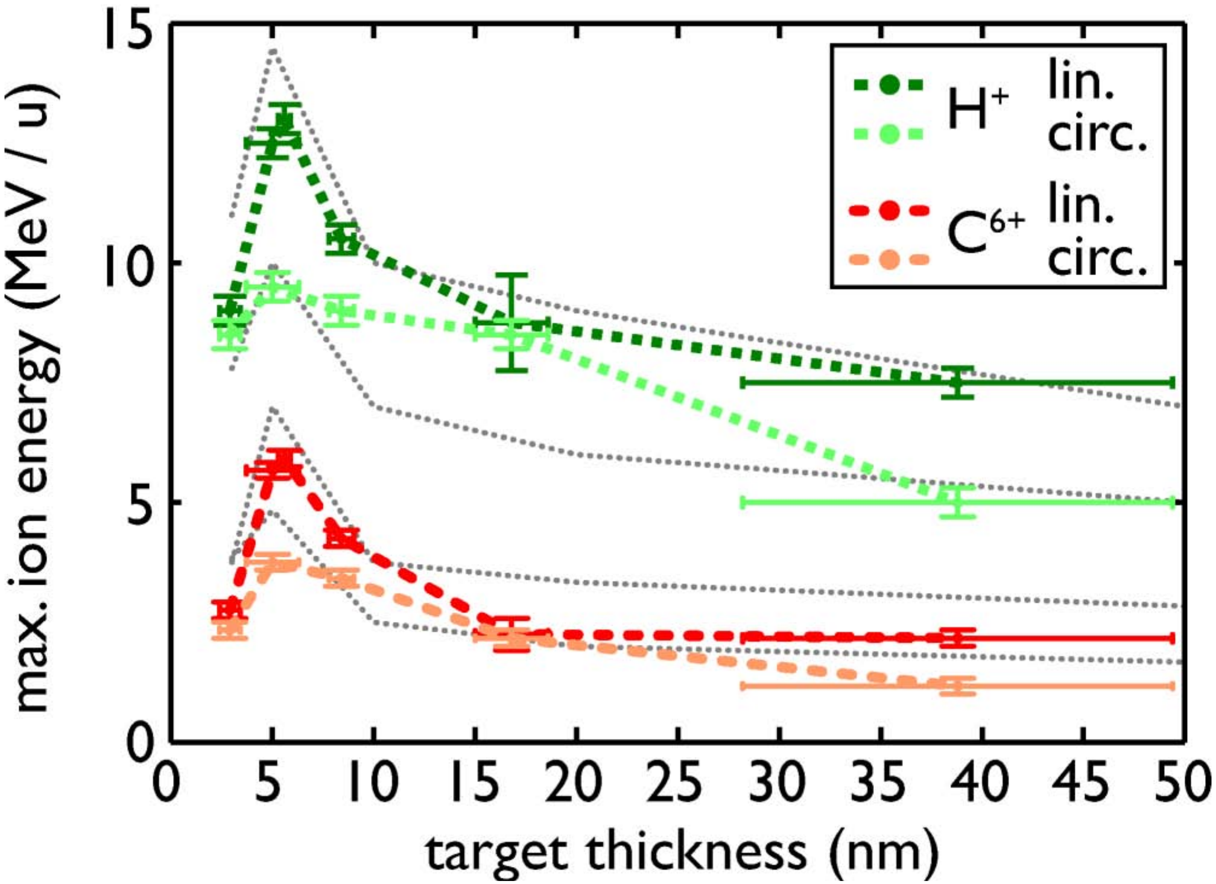
Recent laser acceleration of ions (2009)

recurrence of N. Rostoker lab's collective acceleration experiments

High laser contrast at 10^{19} W/cm^2: not to destroy ultrathin target;

Ultrathin film :$\sigma = a_0$, where $\sigma = d\, n / \lambda n_c$ ($\xi = \sigma / a_0$)

ξ=1 ↓



Black dots:

Mako-Tajima theory extended

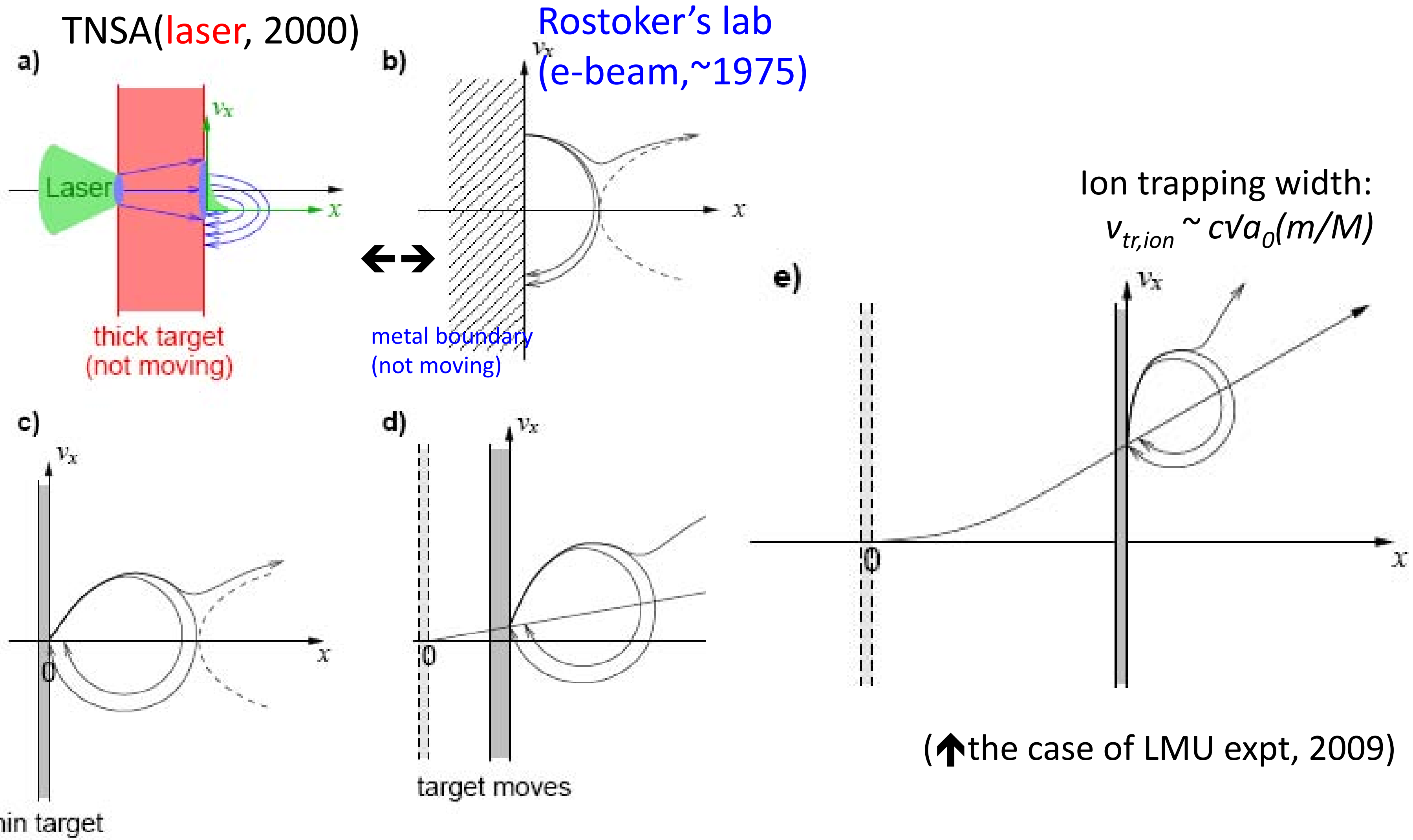
Colored dots:

laser expt of ion acceleration

LMU + MBI

(Henig et al, PRL 2009)

Comparison of the phase space dynamics: toward more Adiabatic Acceleration

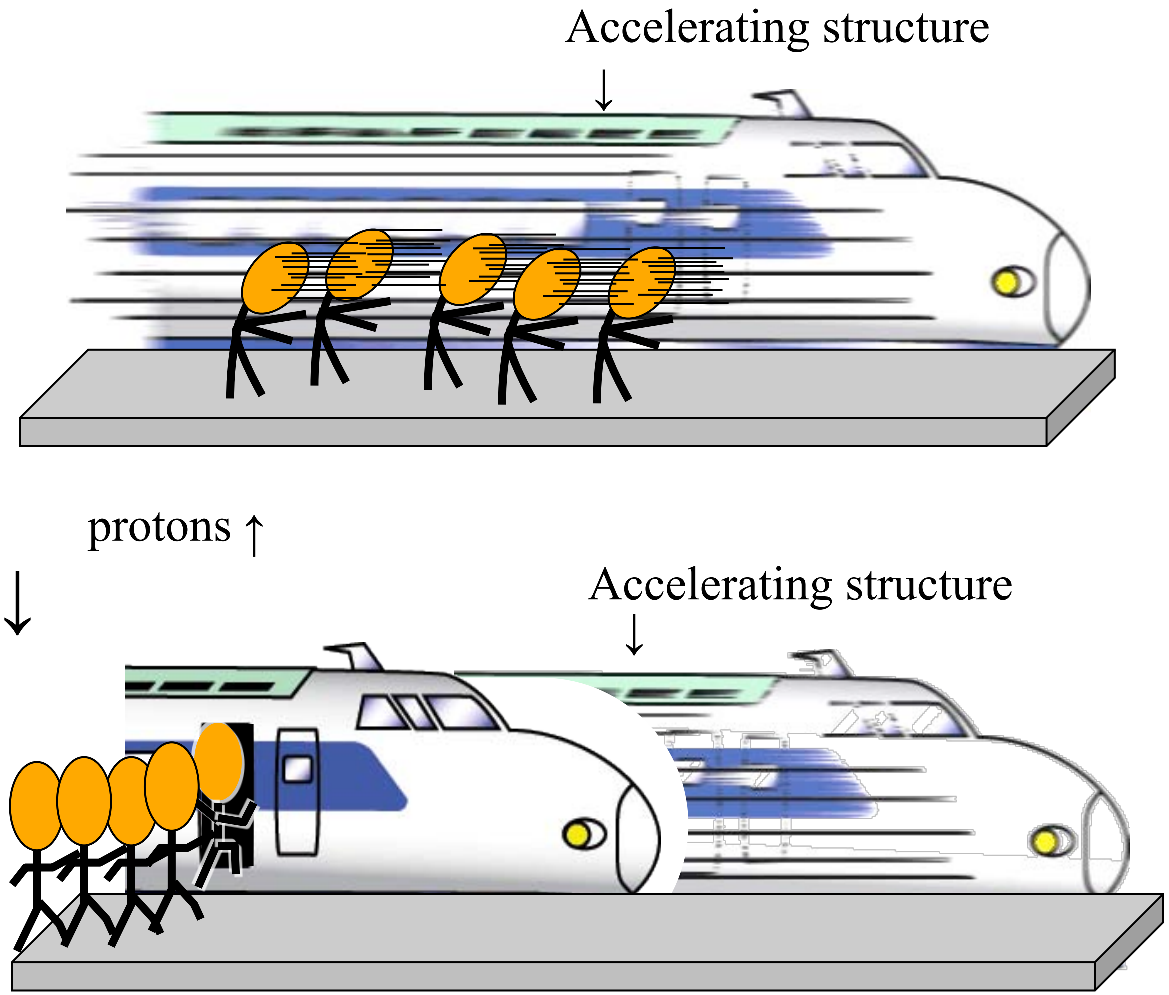


The more relativistic, the more adiabatic

Rev. Accel. Sci. Tech.
(Tajima, Habs, Yan, 2009)

Adiabatic (Gradual) Acceleration

from #1 lesson of Mako-Tajima problem



Inefficient if <u>suddenly</u> accelerated

(cf.human trapping width: $v_{tr,human}$ ~ 1m/s << c_s)

Efficient when <u>gradually</u> accelerated

Lesson #1: gradual acceleration → Relevant for ions

GeV-TeV proton Energy Scalings(RPA x LWFA)

TeV over cm @ 10^{23}W/cm^2 (Zheng et al, 2012)
10GeV over mm @ 10^{22}W/cm^2 (Zheng et al, 2013)
200MeV @10^{21}W/cm^2 (Wang et al, 2013)

PHYSICS OF PLASMAS 20, 013107 (2013)

CrossMark

Laser-driven collimated tens-GeV monoenergetic protons from mass-limited target plus preformed channel

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[4]*Institut für Theoretische Physik I, Ruhr-Universität Bochum, D-44780 Bochum, Germany*
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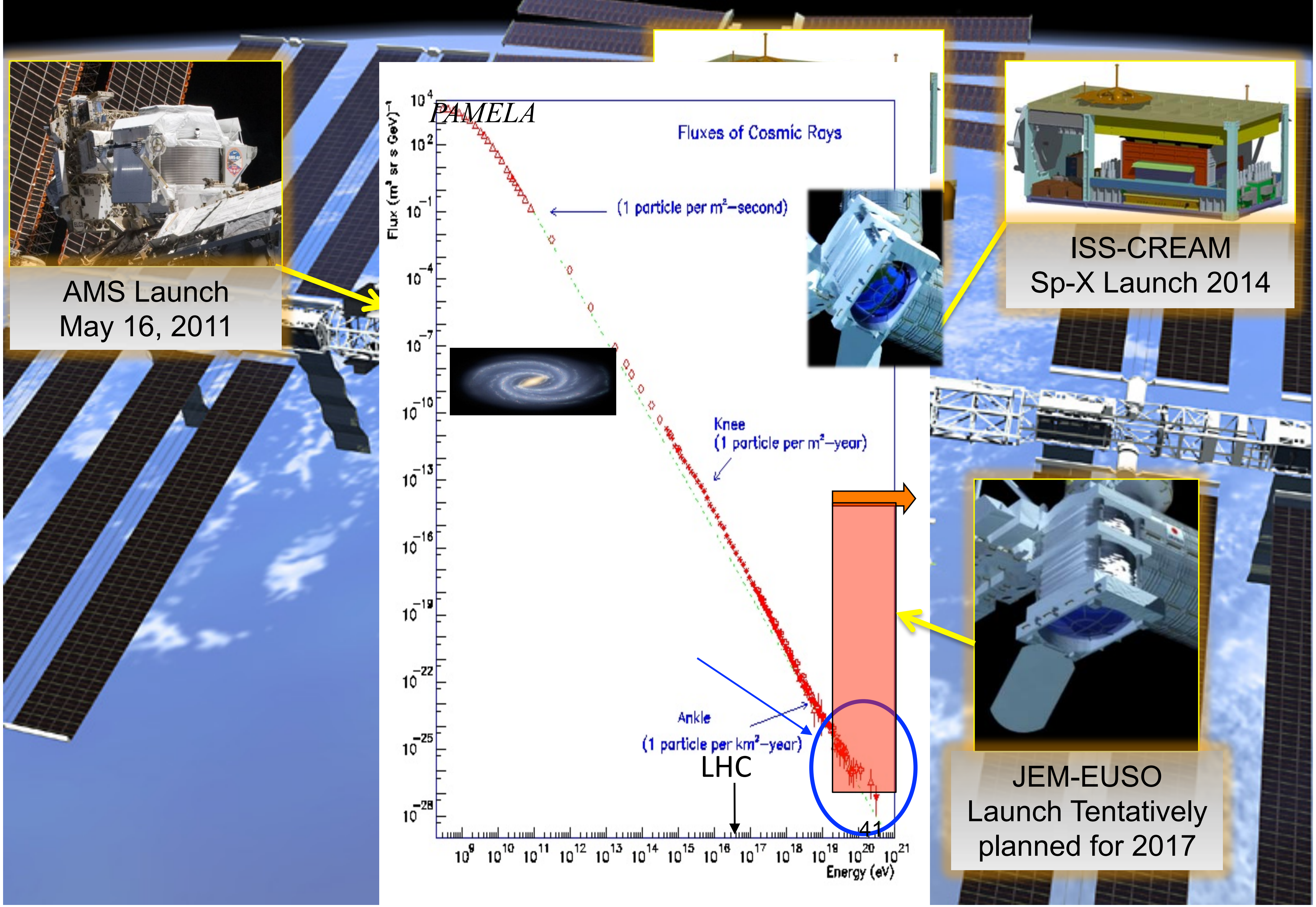
(Received 10 September 2012; accepted 27 December 2012; published online 11 January 2013)

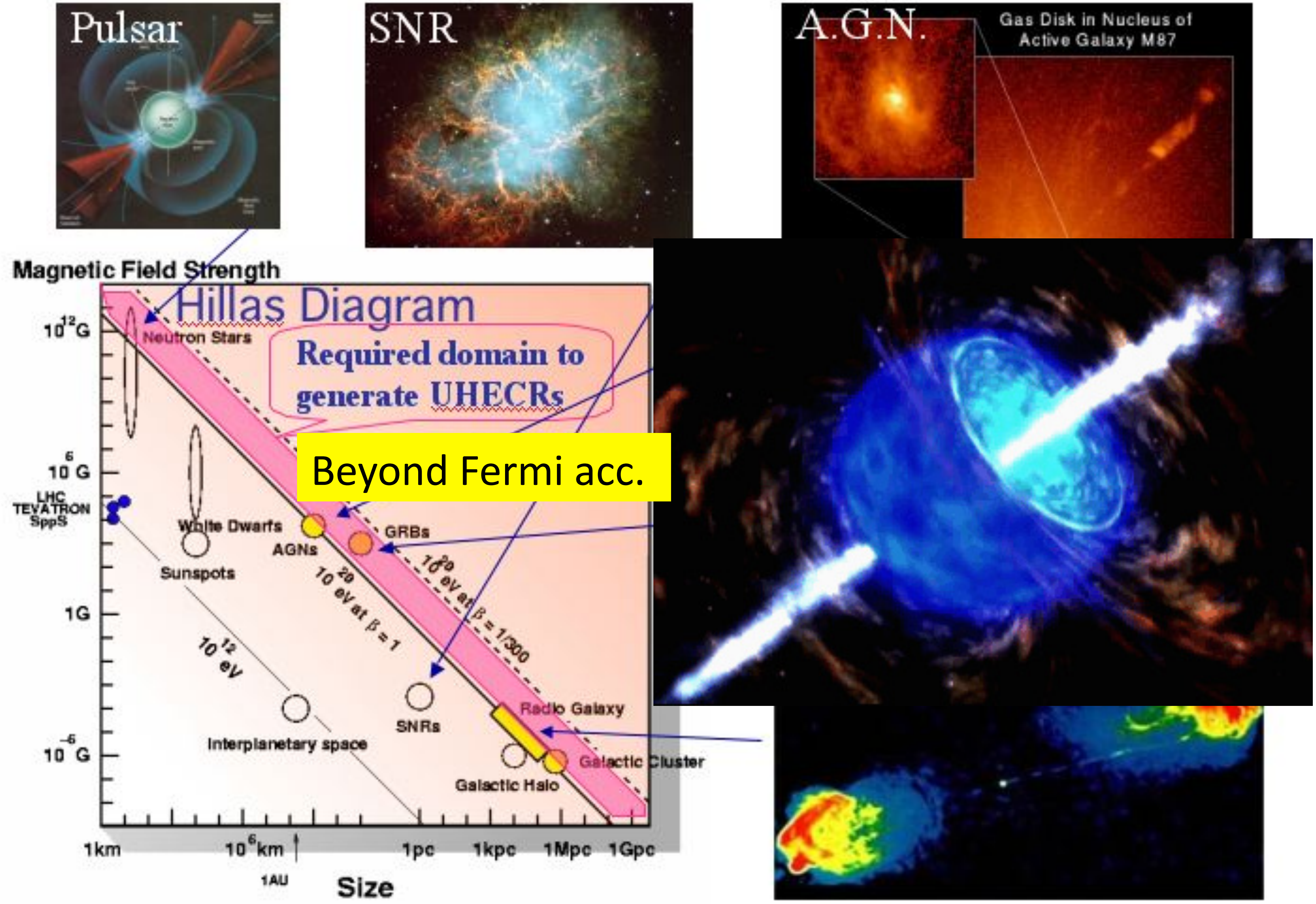
Proton acceleration by ultra-intense laser pulse irradiating a target with cross-section smaller than the laser spot size and connected to a parabolic density channel is investigated. The target splits the laser into two parallel propagating parts, which snowplow the back-side plasma electrons along their paths, creating two adjacent parallel wakes and an intense return current in the gap between them. The radiation-pressure pre-accelerated target protons trapped in the wake fields now undergo acceleration as well as collimation by the quasistatic wake electrostatic and magnetic fields. Particle-in-cell simulations show that stable long-distance acceleration can be realized, and a 30 fs monoenergetic ion beam of >10 GeV peak energy and <2° divergence can be produced by a circularly polarized laser pulse at an intensity of about 10^{22} W/cm^2. © *2013 American Institute of Physics*. [http://dx.doi.org/10.1063/1.4775728]

ican
International Coherent Amplification Network

Extreme High Energy Cosmic Rays (EHECR)

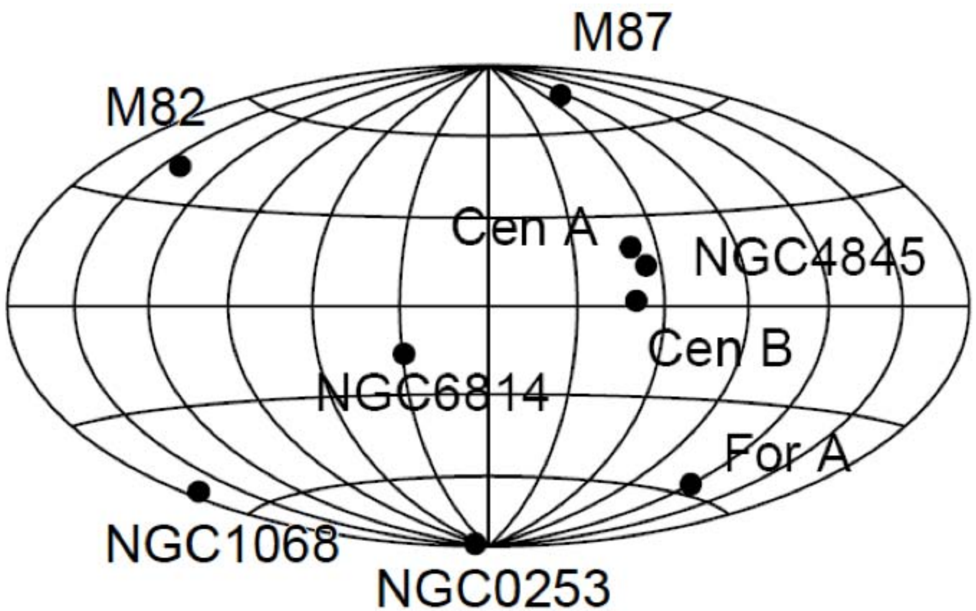


Hillas: Theoretical limit by *Fermi Acc.* < 10^{20} eV

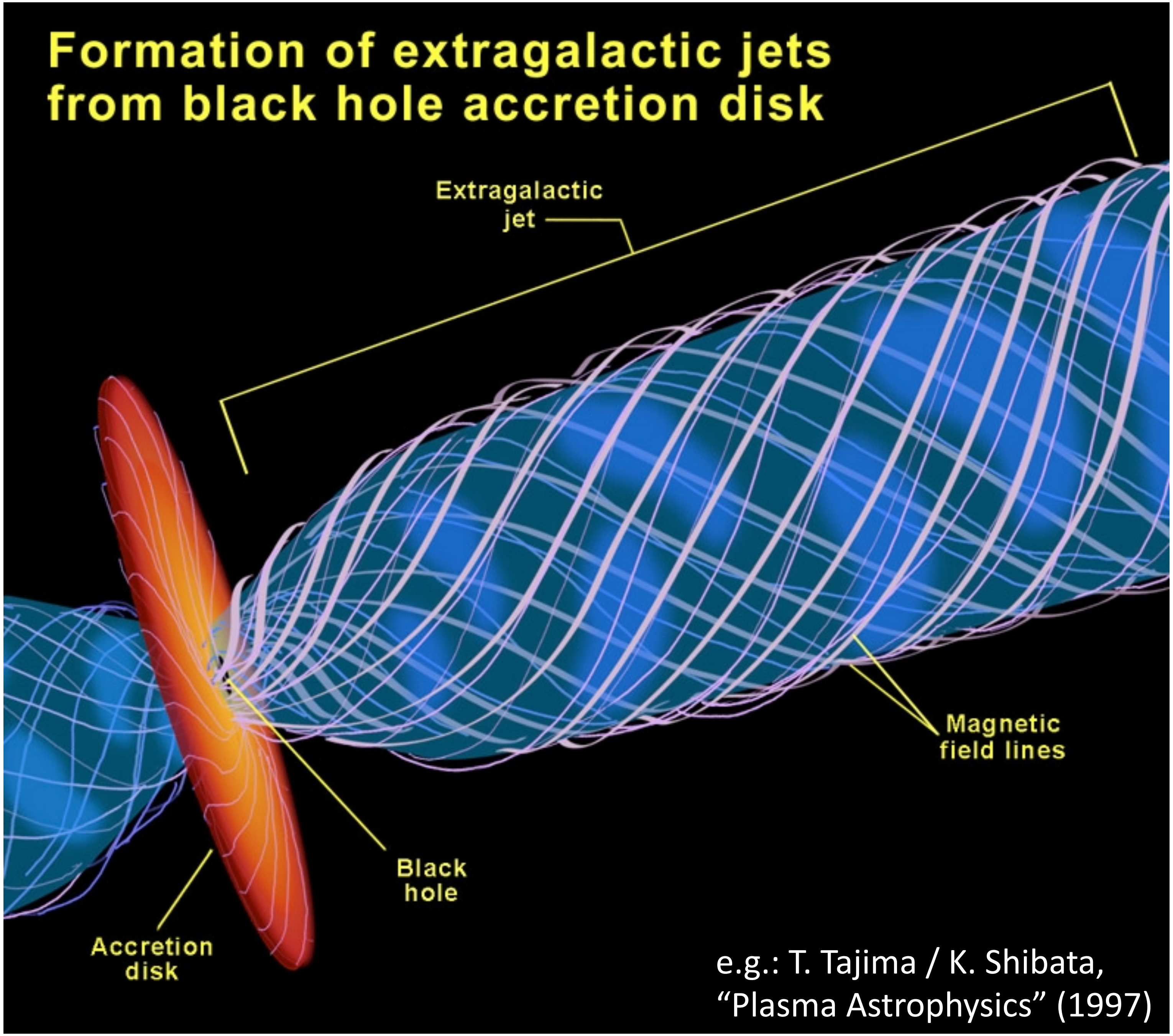


Cen A: an example of AGN

- Distance：3.4Mpc
- Radio Galaxy
  - Nearest
  - Brightest radio source (collective oscillations!)
- Elliptical Galaxy
- Disk, AGN jets, halos: visible
- Other AGN: similar

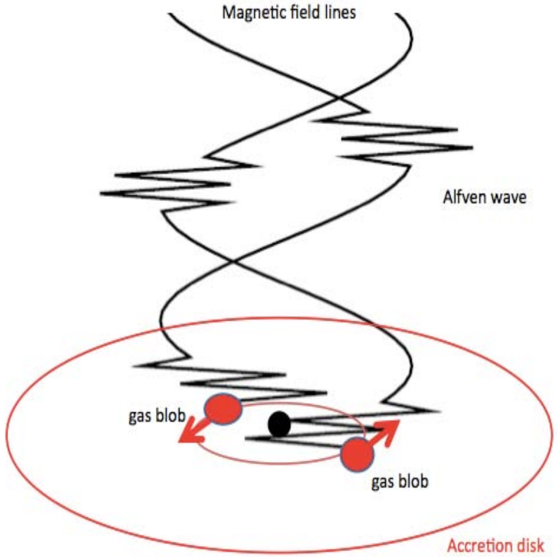


Brightest AGNs

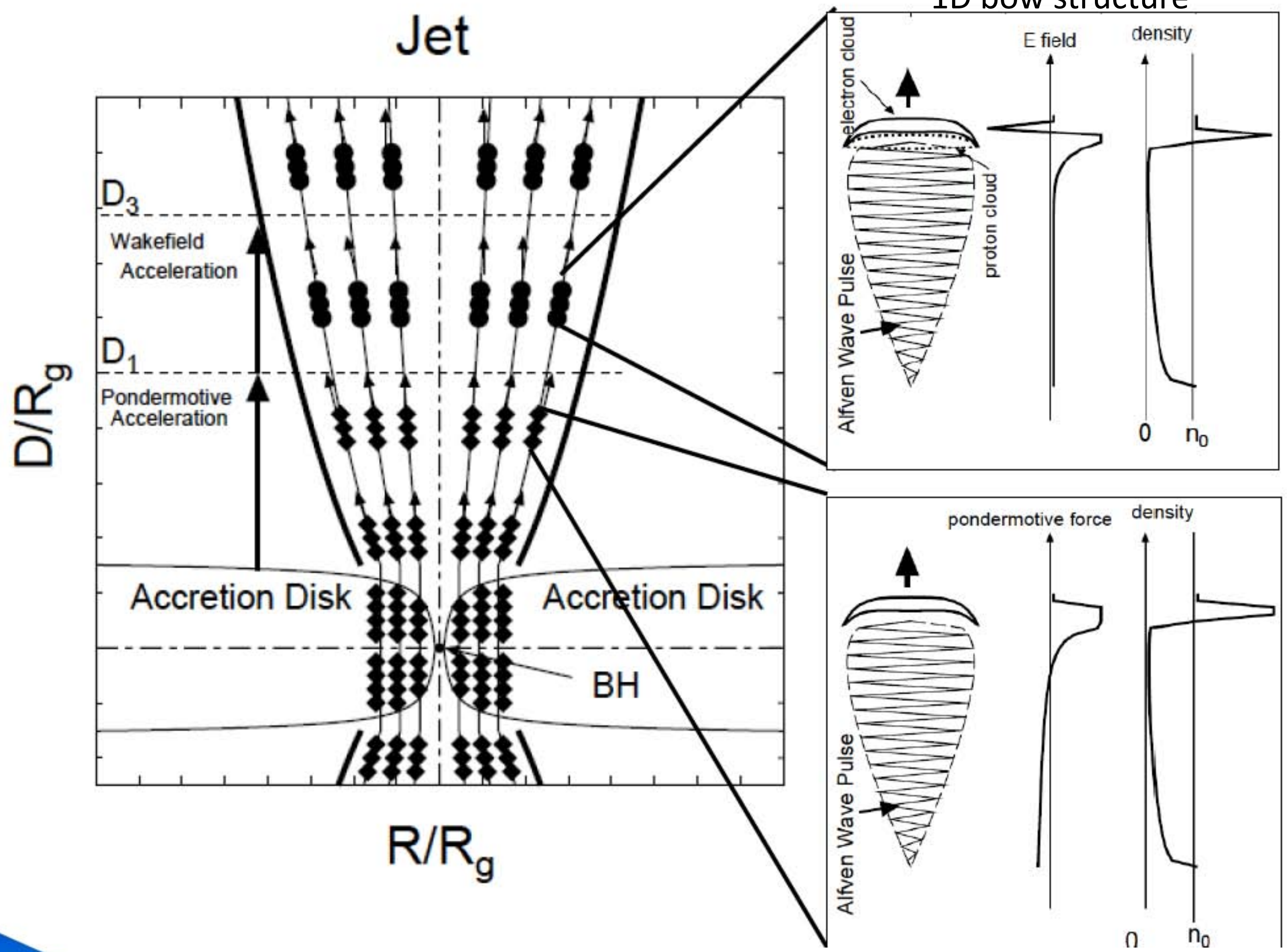


e.g.: T. Tajima / K. Shibata,
"Plasma Astrophysics" (1997)

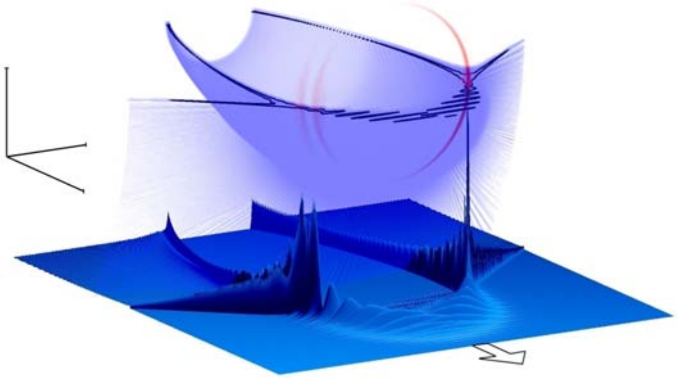
Superintense Alfven Shock in the Blackhole Accretion Disk Bow/Wakefield Acceleration toward ZeV Cosmic Rays



1D bow structure



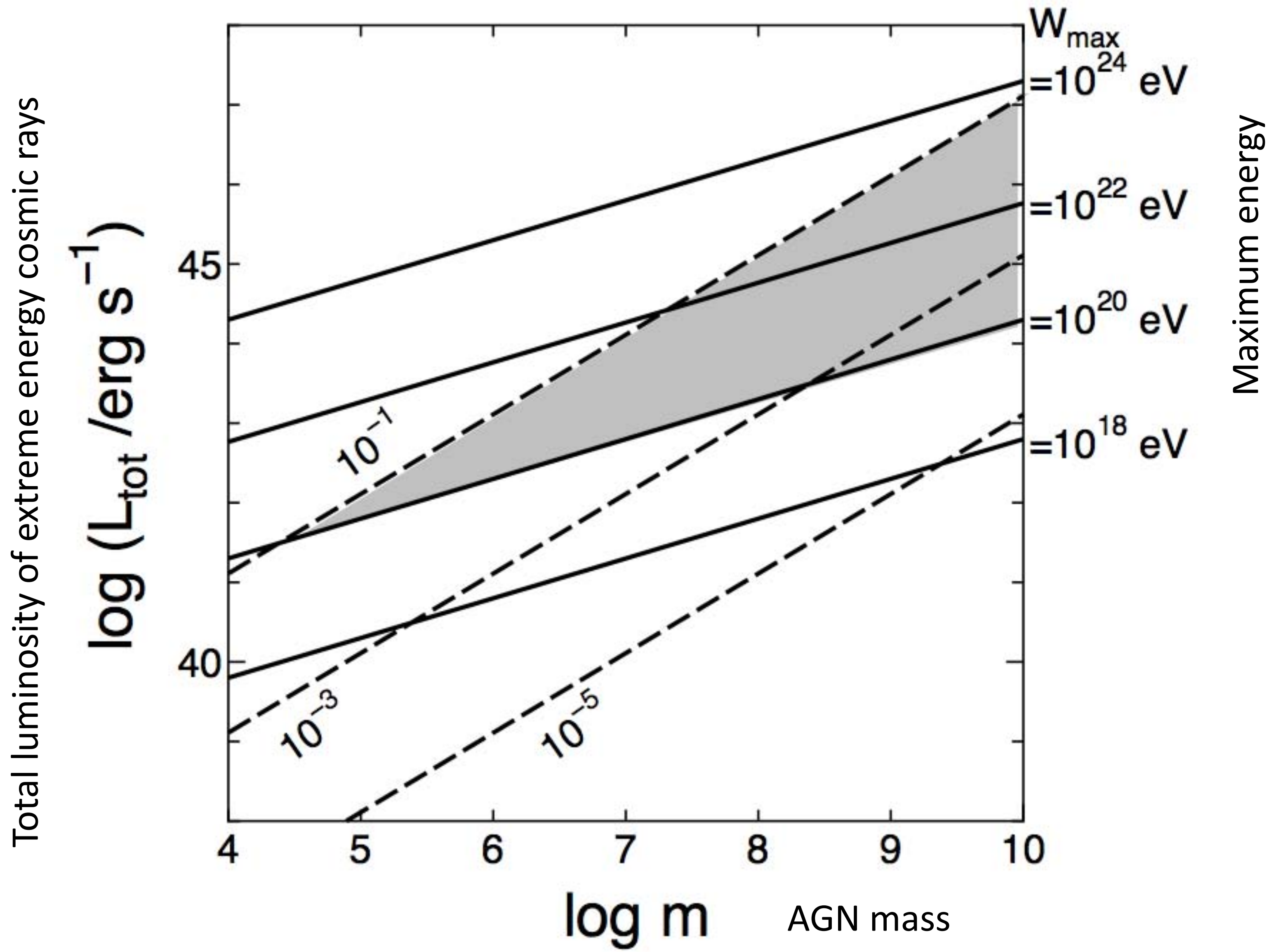
3D bow structure



Ebisuzaki and Tajima (2013)

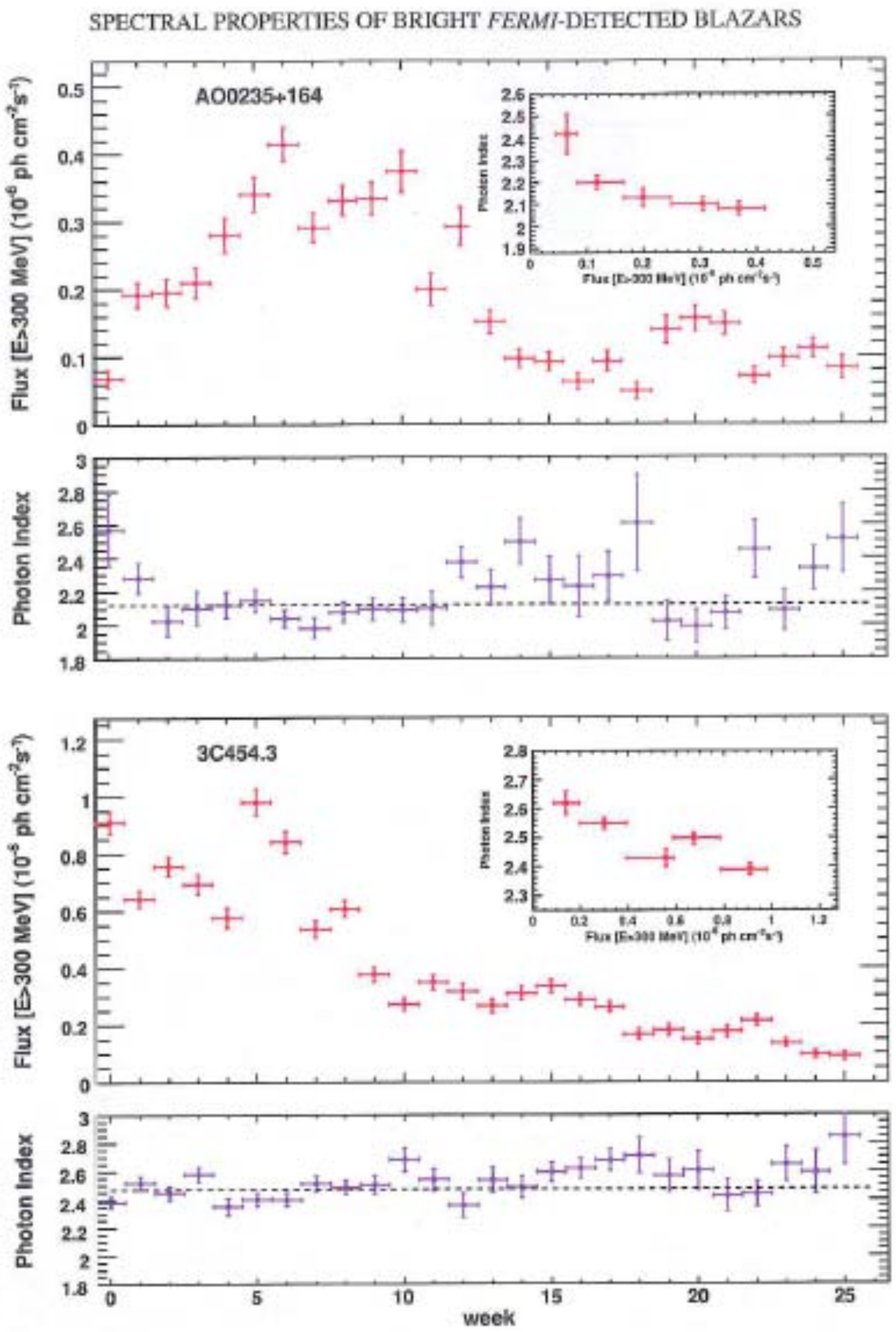
Max Energy W_{max} and Luminosity L_{tot} of Extreme Energy Cosmic Rays as a Function of AGN Masses *m*

Wakefield theory



Brightest γ rays from Blazars: Flux and spectral power index

(Abdo et al, 2010)



➔**Blazar luminosity**

anti-correlates with

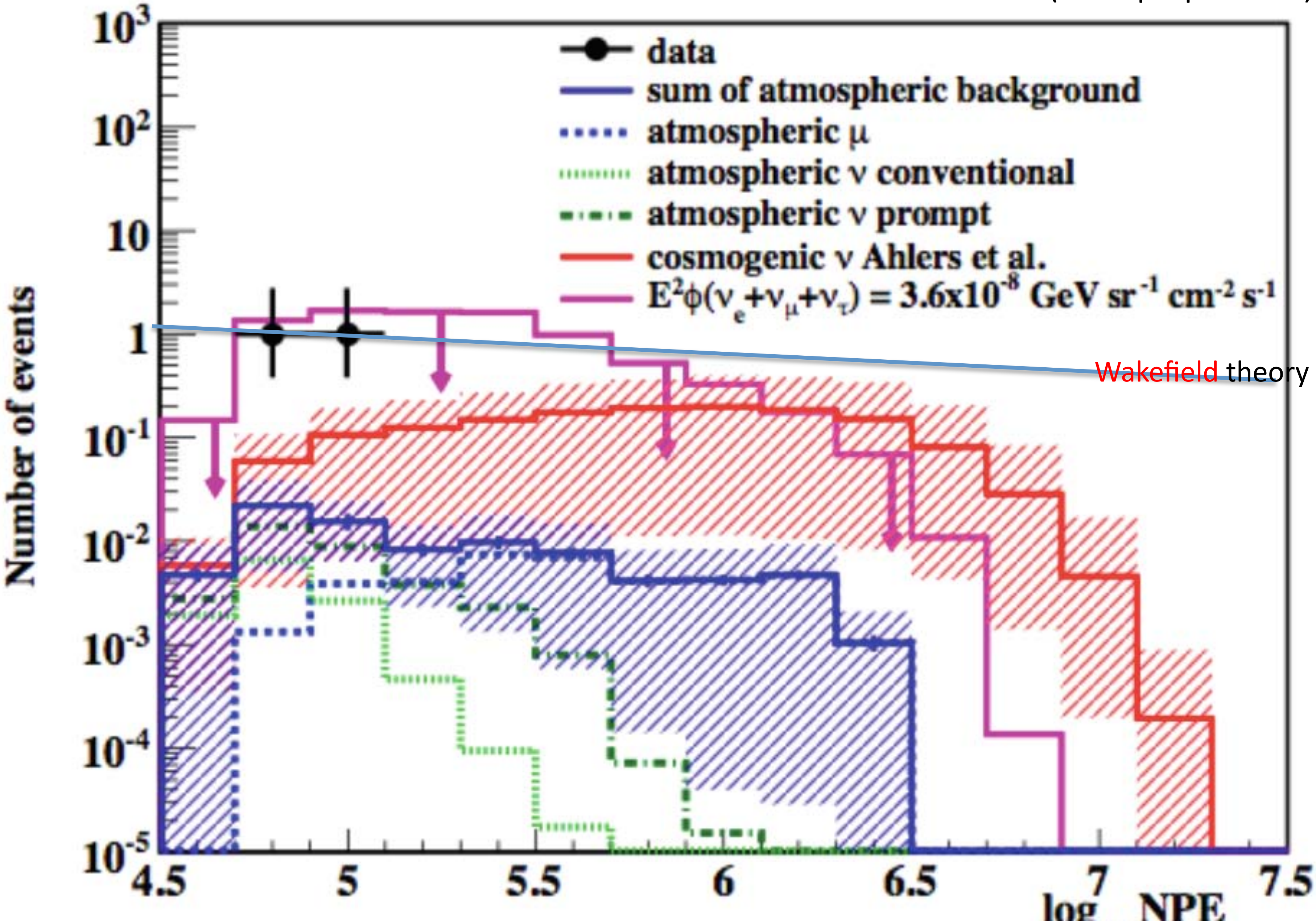
➔**γ ray spectral index**

Anticipated from wakefield theory

(Abazajian et al, 2013)

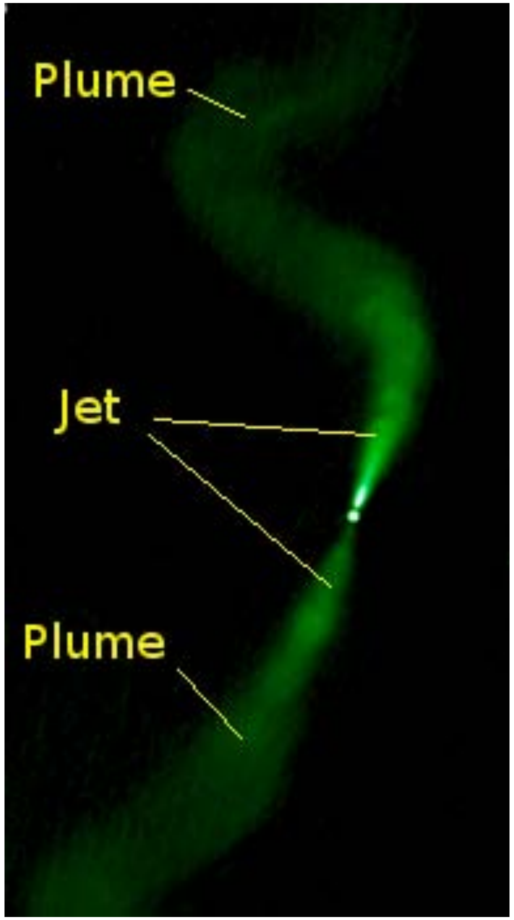
High Energy Neutrino Flux (IceCube): wakefield theory

Barwick et al. (2013 preparation)



Conclusions

- **High field science** frontier expanding
- Laser-driven accelerators for high energy physics collider in particular------learned lesson from Norman's lab
- Large fluence, high efficiency of CAN lasers important for many new scientific and societal applications
- CAN laser = smart laser : highly controllable
- Higgs factory by γ-γ collider emerging
- New weak-coupling field search of vacuum by laser
- Nuclear transmutation by laser-driven neutron sources, ADS, ADR; compact neutrino source, relic neutrino search
- Other industrial applications (auto-industry, chemical industry, mechanical industry, medical, etc.) with large fluence and high efficiency lasers
- EHECR <--> terrestrial laser acceleration
- IZEST Tokyo Conference (Nov. 18-20): UCI x IZEST



Blazar: Cosmic laser wakefield linac?

Thank you!