A Journey with Lasers and
Physics at High Intensities
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Intertwined Inventions of CPA and Wakefields

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Invention of Laser wakefield accelerator (LWFA) (1979;
Calls for 10^{18} W/cm^2 , 100fs laser)

- ***CPA* invented (1985)**

First LWFA experiment (1994): Nakajima →
collider application (more efficient, more fluence laser)

- ***CAN fiber laser* invented (2009,2013)**

Real-world app; Laser accelerator in body

- ***Thin Film Compression*(2014)**

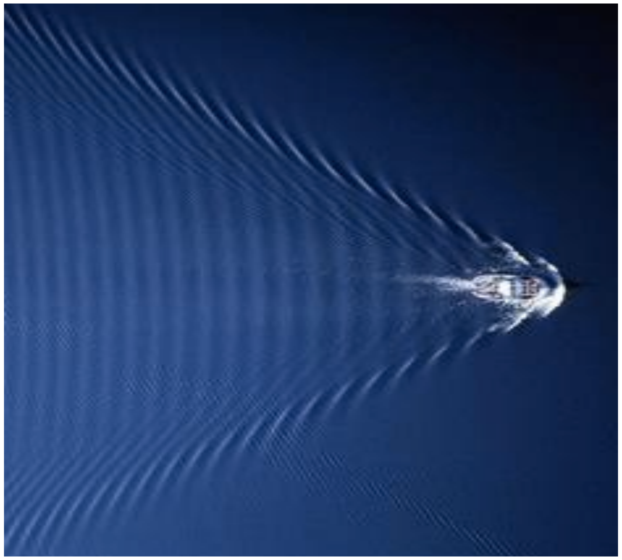
→ *X-ray laser*

" TeV on a chip"

Laser Wakefield (1979):

Wake phase velocity >> water movement speed maintains **coherent** and **smooth** structure

Tsunami phase velocity becomes ~0, causes **wavebreak** and **turbulence**

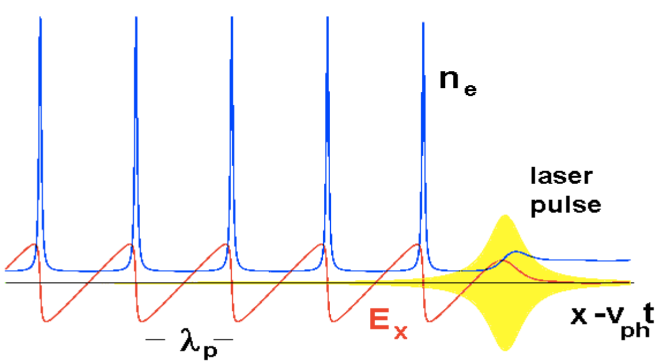


vs

Strong beam (of laser / particles) drives plasma waves to saturation amplitude: $E = m\omega v_{ph} / e$

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

Wave **breaks** at v<c



← relativity regularizes (*relativistic coherence*)

Relativistic coherence enhances beyond the Tajima-Dawson field $E = m\omega_p c / e$ (~ GeV/cm)

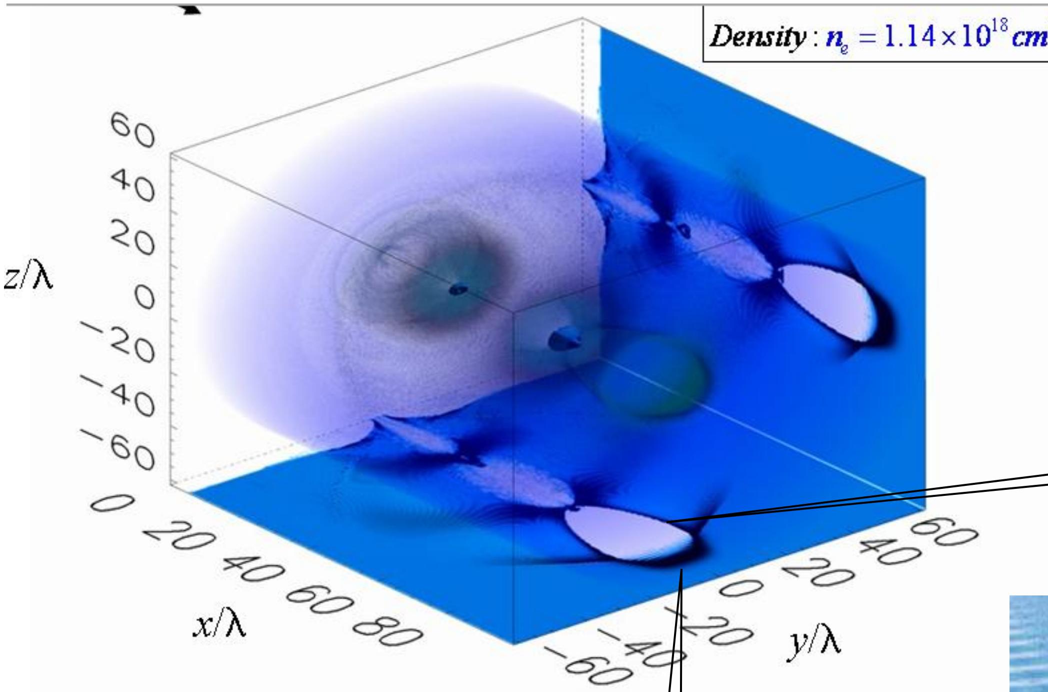
The late Prof. Abdus Salam (1981)

At ICTP Summer School (Trieste,1981),
Prof. Abdus Salam summoned me and
discussed
about laser wakefield acceleration.

Salam: *'Scientists like me began feeling that we had less means to test our theory. However, with your laser acceleration, I am encouraged'*. **(1981)**

He organized the Oxford Workshop
on laser wakefield accelerator in 1982.

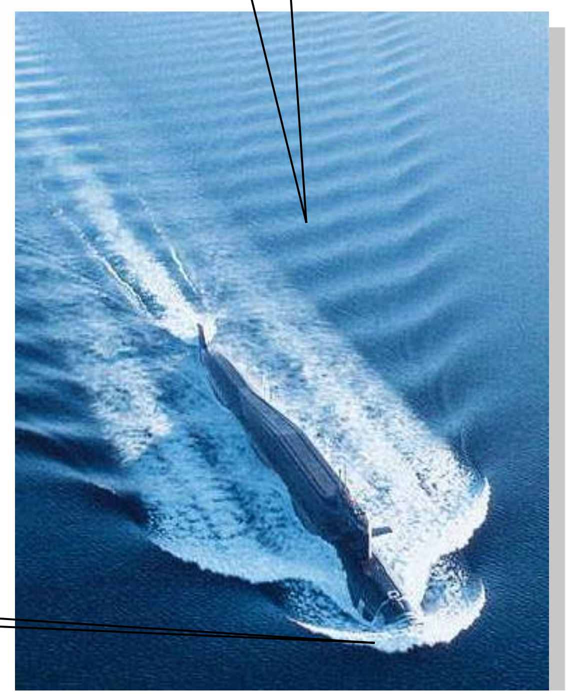
Laser-driven Bow and Wake



(Bulanov, Esirkepov)

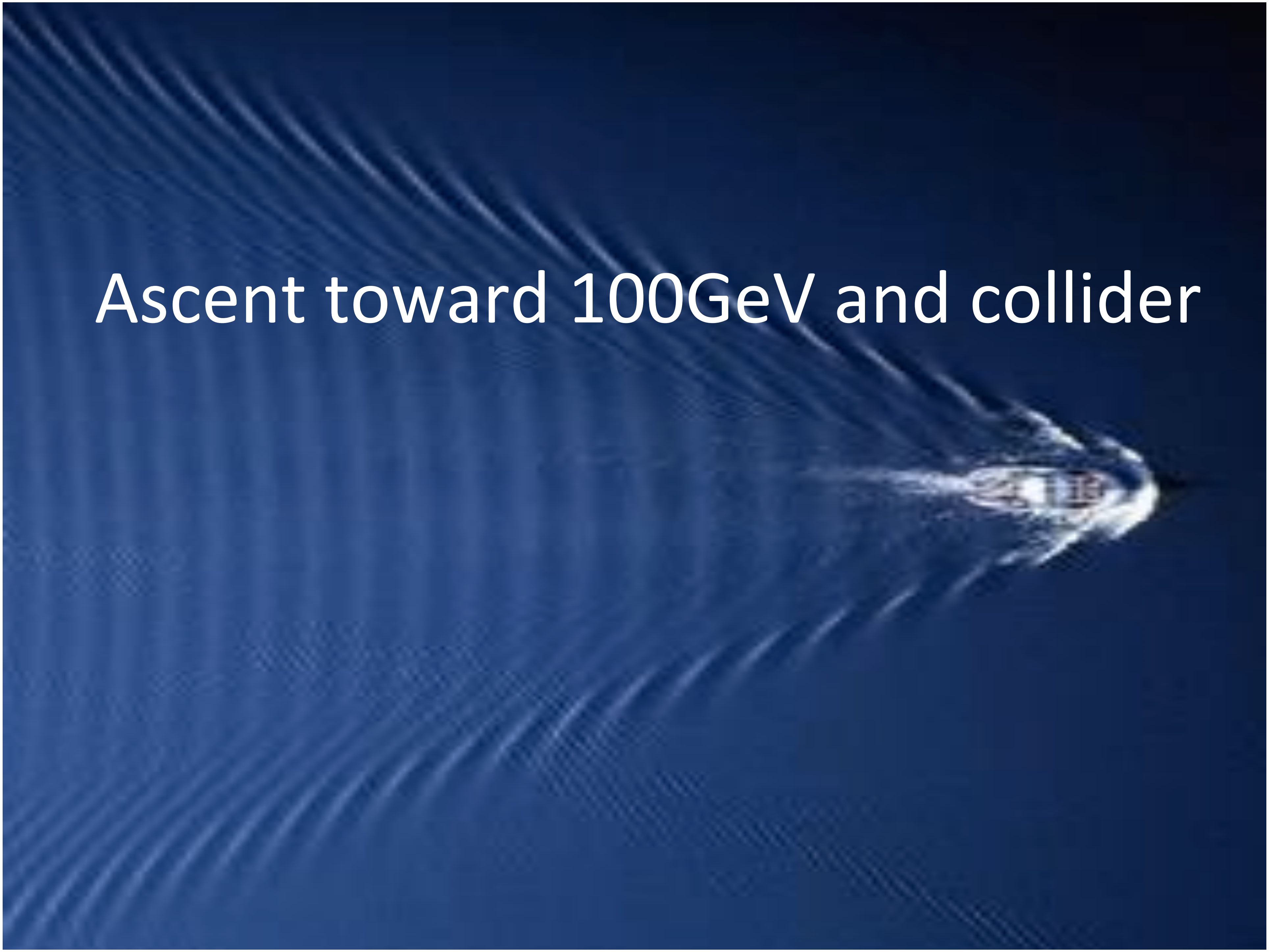
Wakefield acceleration

Wake Wave

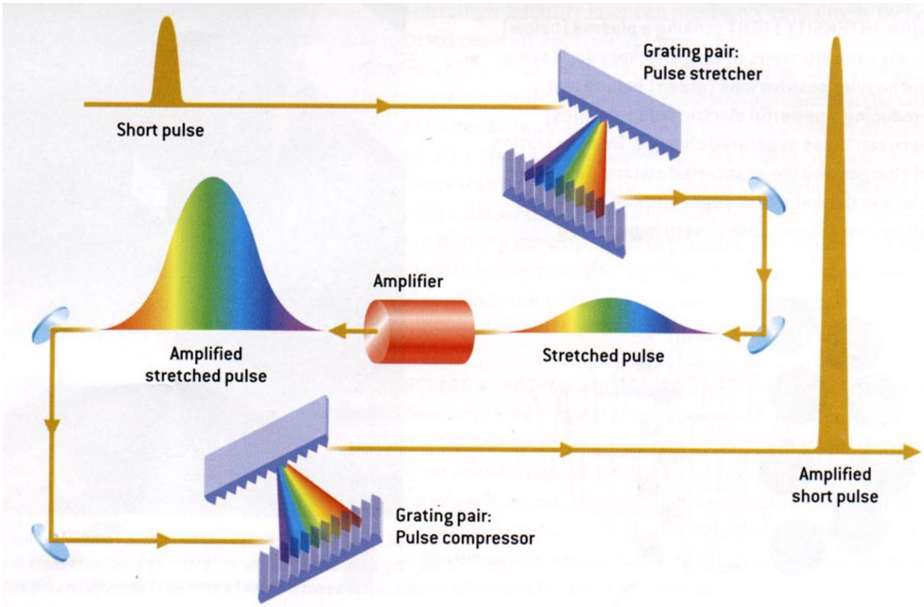


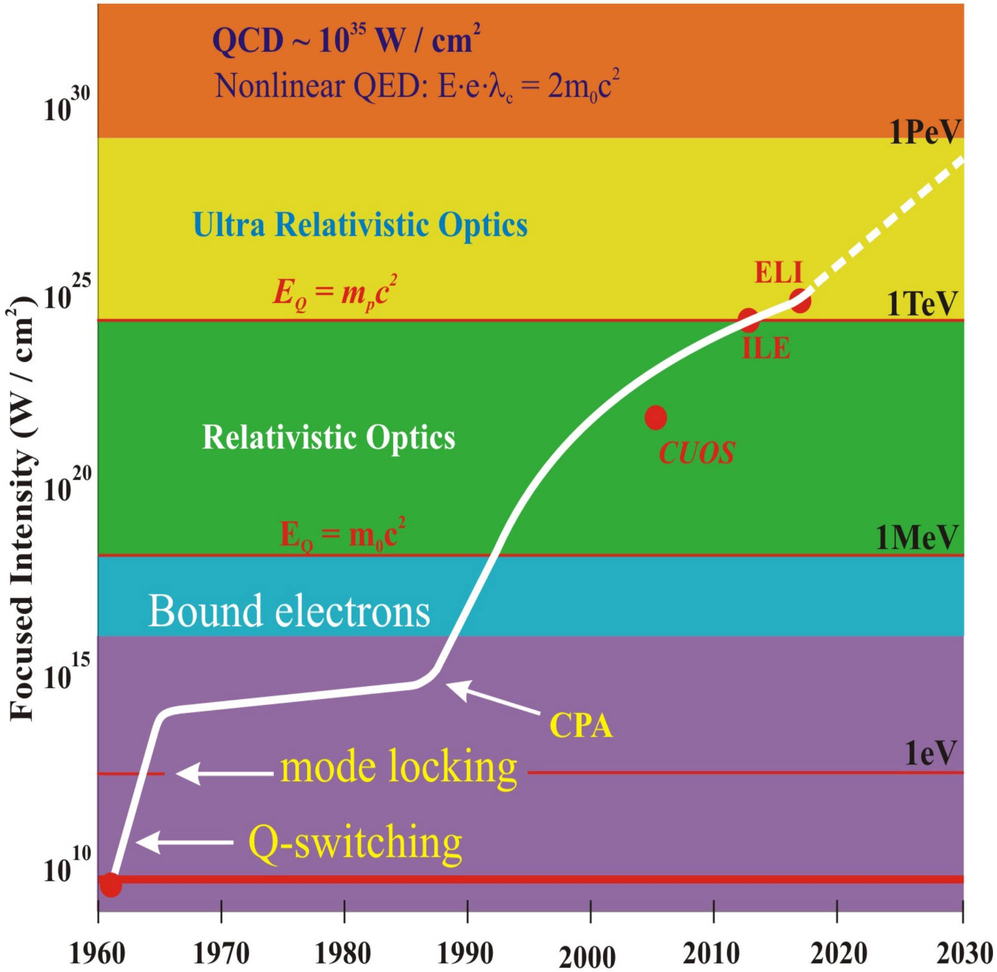
Bow Wave

Ponderomotive acceleration


Ascent toward 100GeV and collider

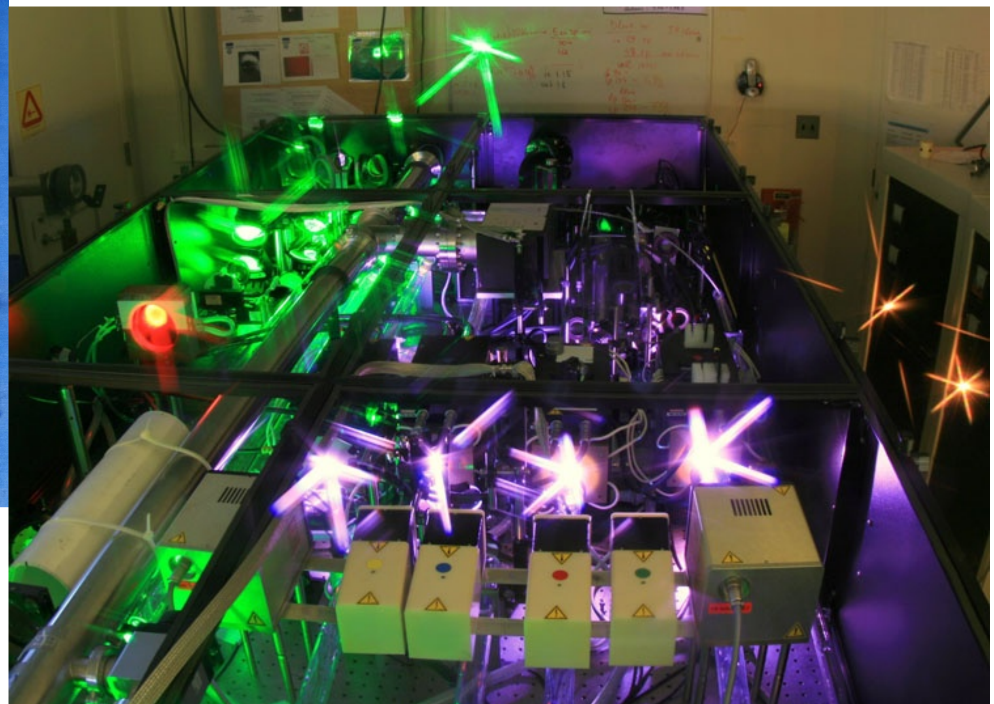
Enabling technology: laser revolution



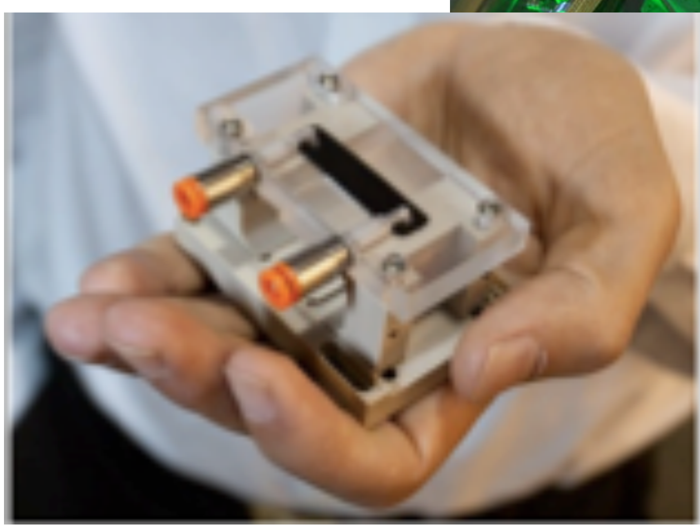


G. Mourou-D. Strickland invented **Chirped Pulse Amplification** (1985)
Laser intensity exponentiated since,
to match the required intensity for Tajima-Dawson's **LWFA** (1979)

Demonstration, realization, and applications of **laser wakefield** accelerators



(Michigan)

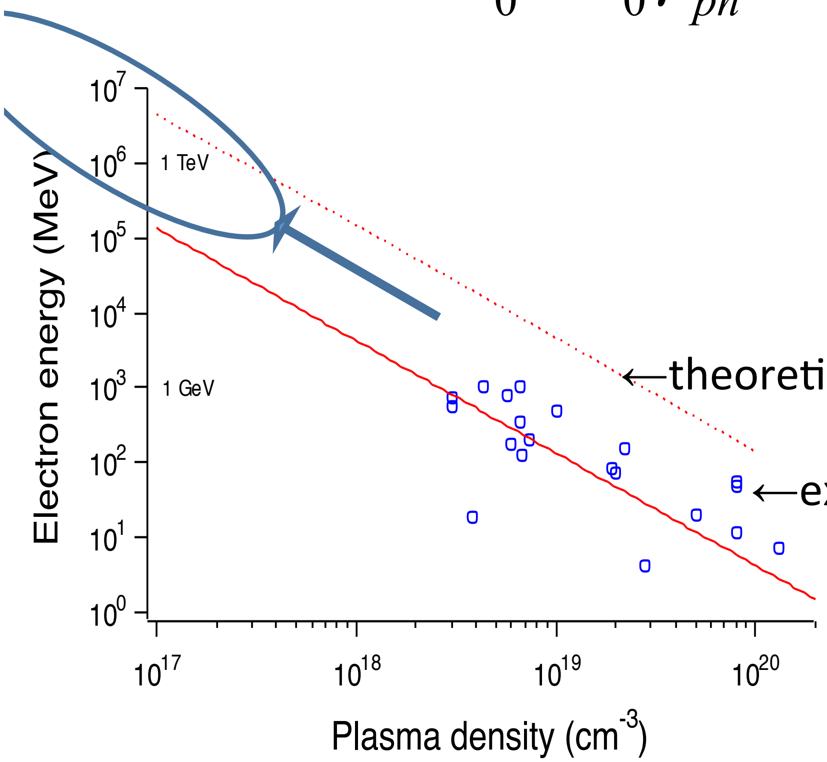


4 GeV **laser accelerator** LBL

3GeV Synchrotron SOLEIL

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

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

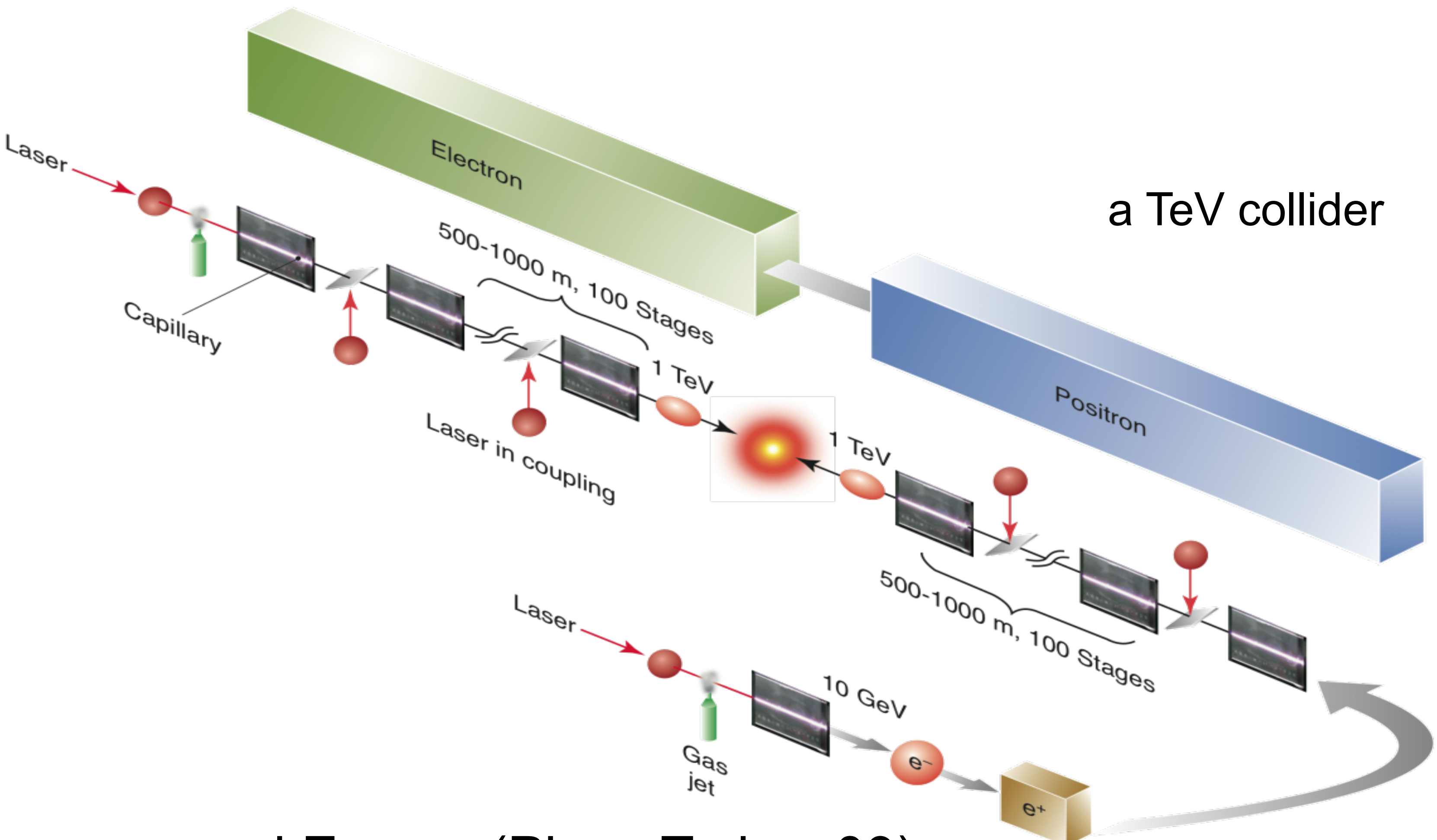
n_{cr} $=10^{21}$ (1eV photon)
→ 10^{29} (10keV photon)

n_e $= 10^{16}$ (gas) → 10^{23} (solid)

$$L_d = \frac{2}{\pi}\lambda_p a_0^2\left(\frac{n_{cr}}{n_e}\right), \quad L_p = \frac{1}{3\pi}\lambda_p a_0\left(\frac{n_{cr}}{n_e}\right),$$

dephasing length — pump depletion length

Laser driven collider concept



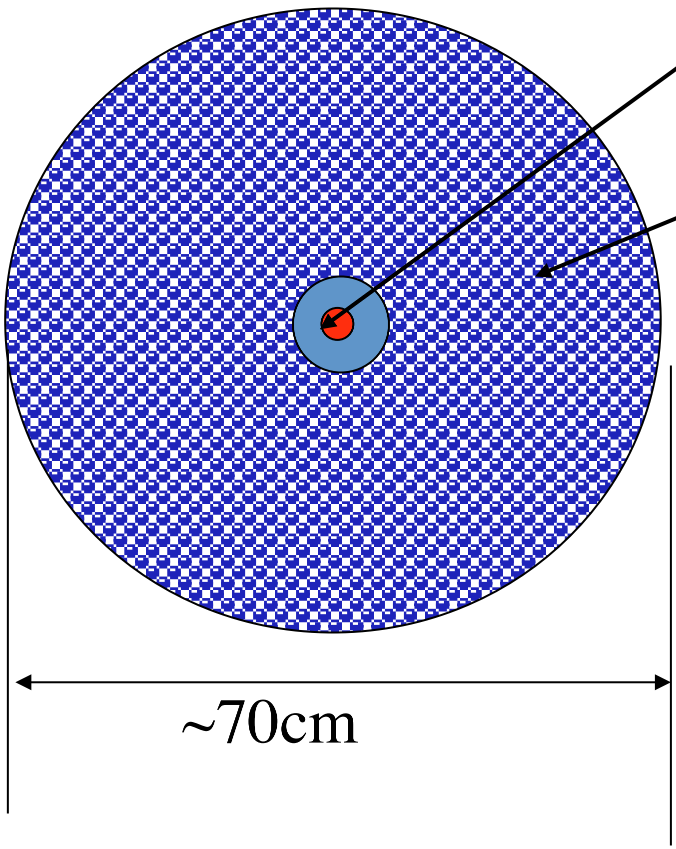
a TeV collider

Leemans and Esarey (Phys. Today, 09)

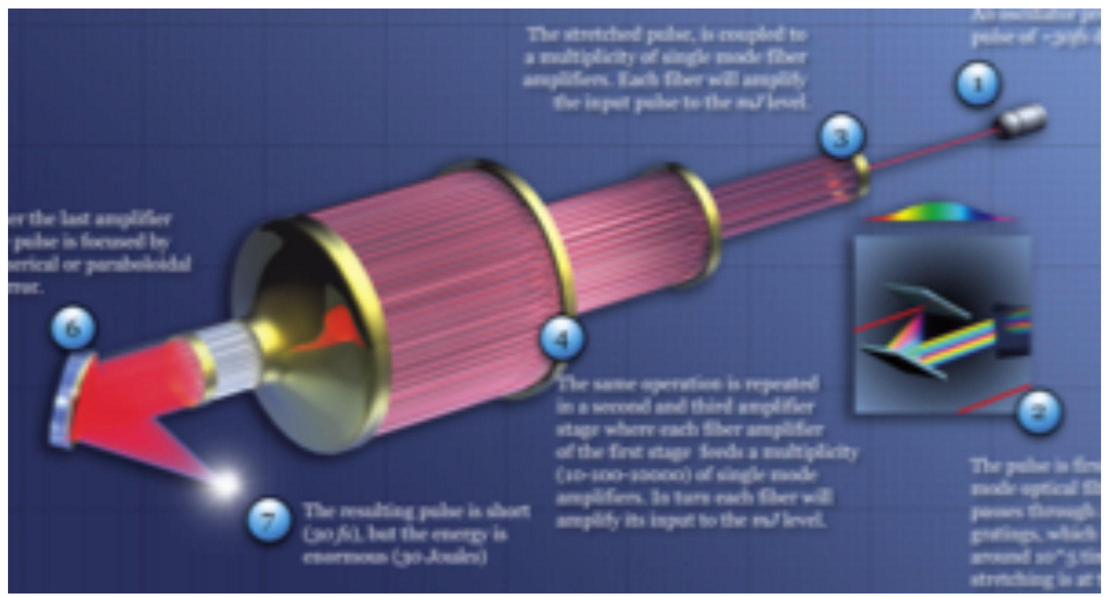
ICFA-ICUIL Joint Task Force on Laser Acceleration(Darmstadt,10)

CAN Laser:

Need to Phase
32 J/1mJ/fiber~ $3x10^4$ Phased Fibers!



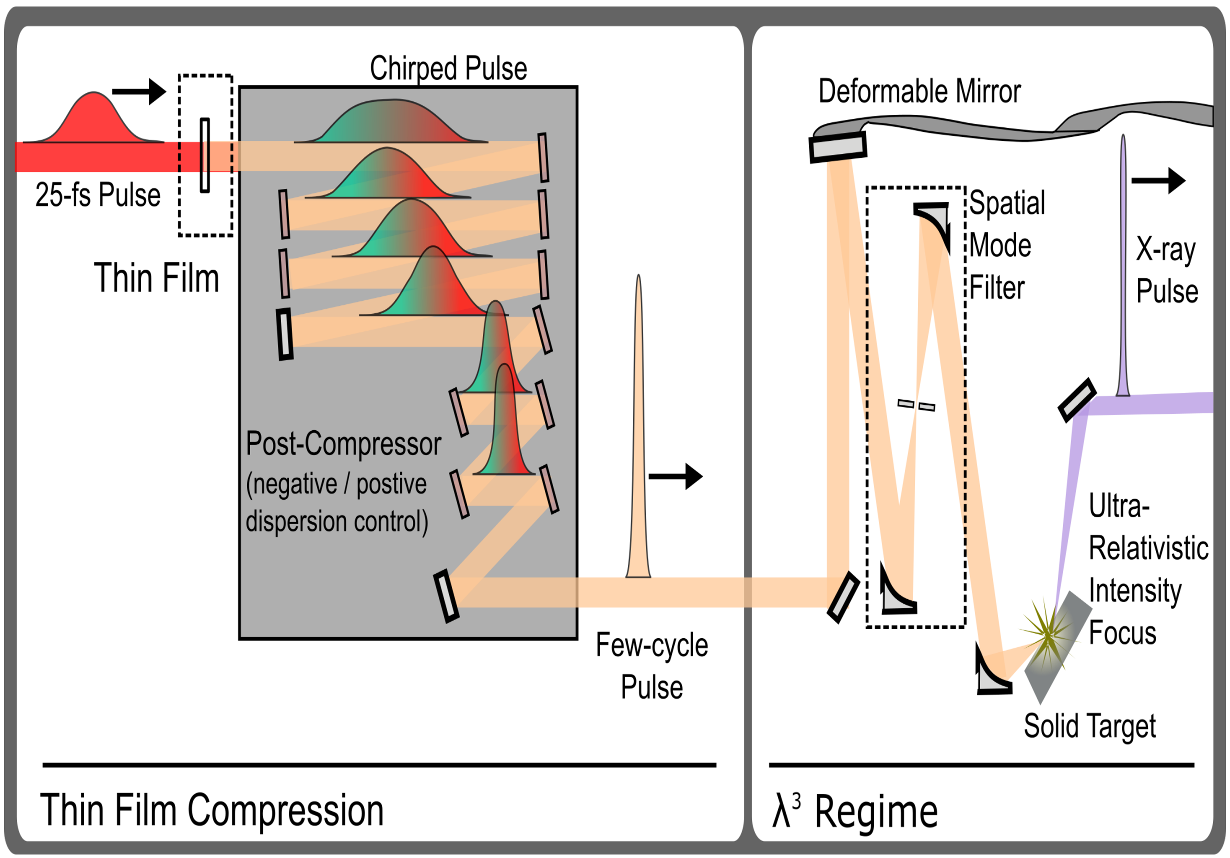
G. Mourou: patent (2009)
Mourou, Brockesby, Tajima, Limpert (2013)

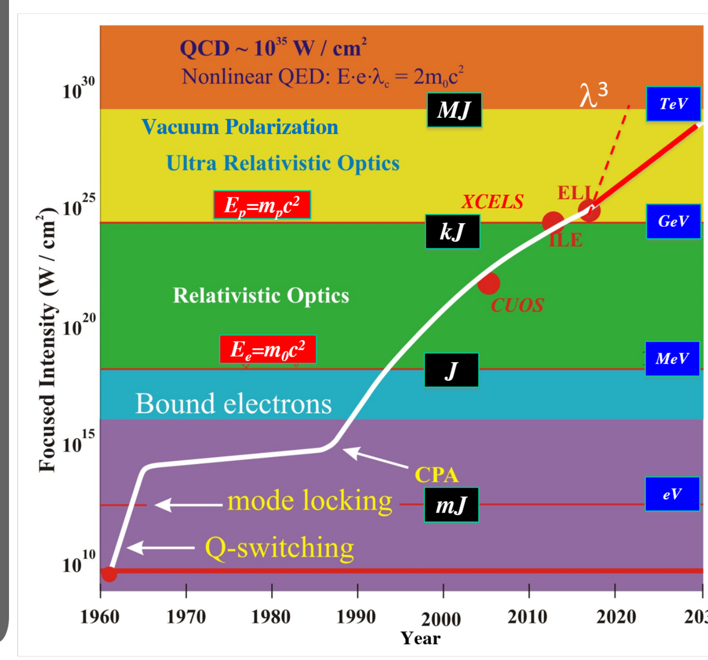


Length of a fiber ~2m Total fiber length~ 5 10^4km


Single-cycled laser and “TeV on a chip”

Thin film compression and single-cycle optical and X-ray lasers

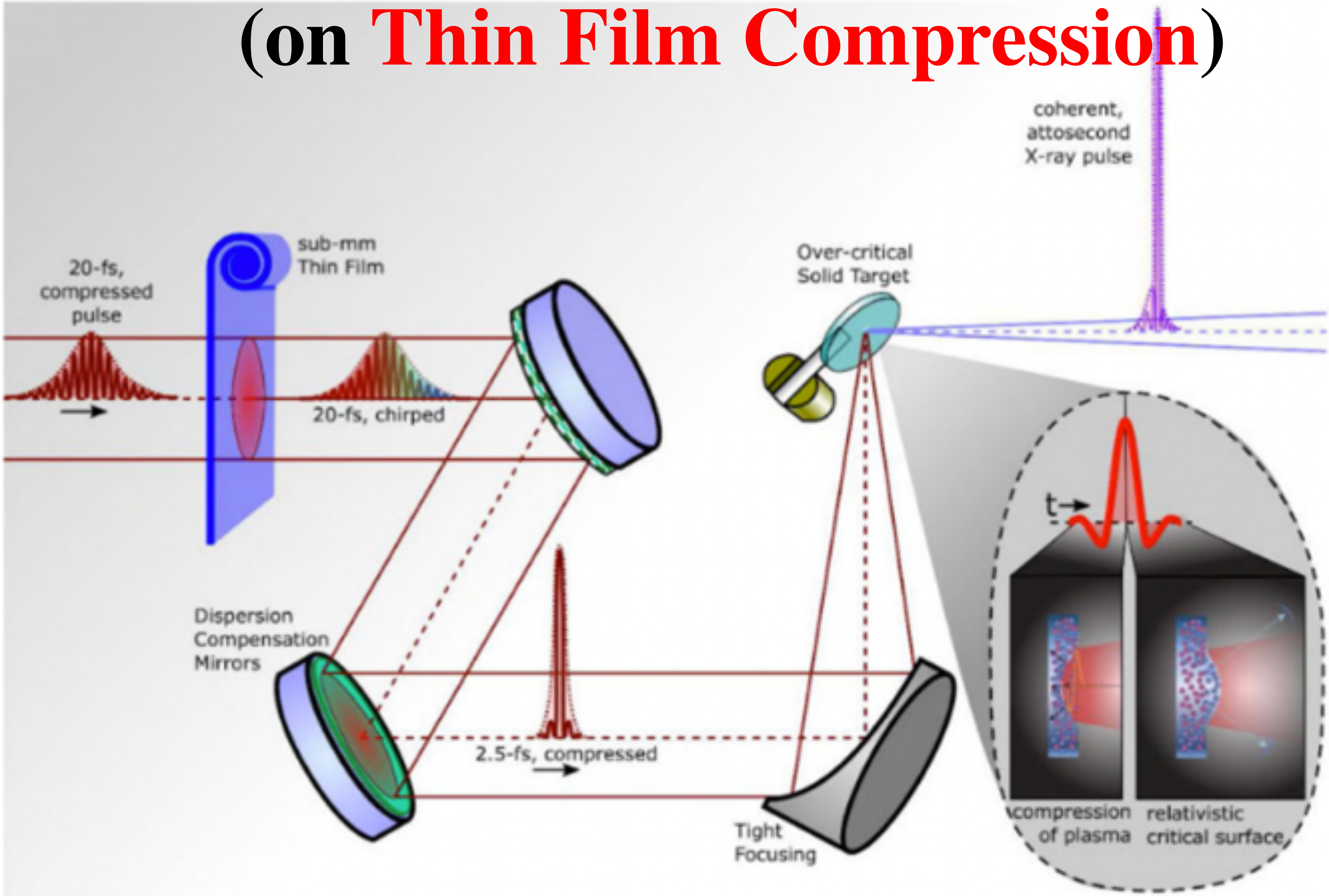




G. Mourou et al. (2014)

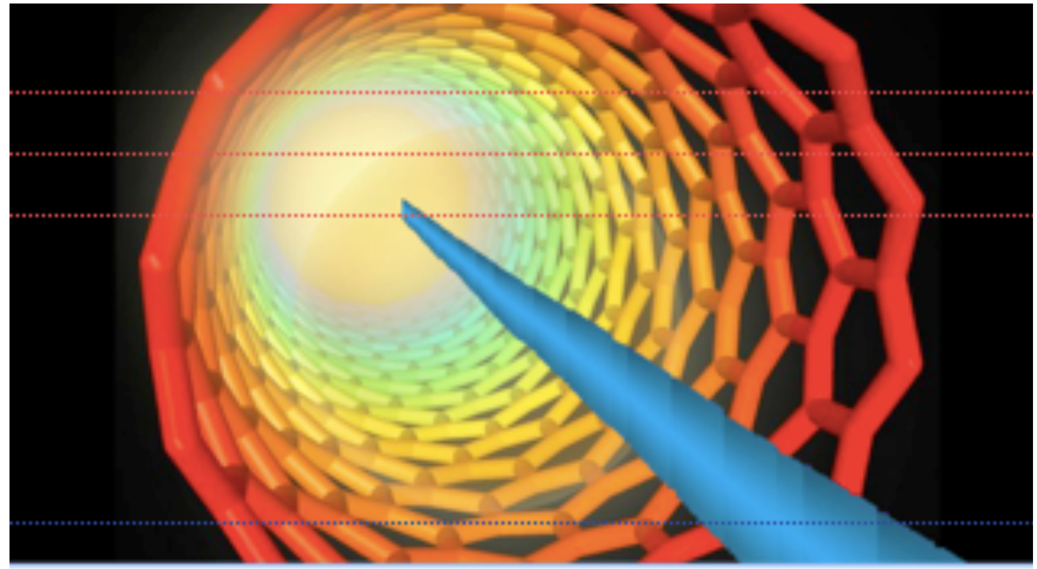
→High Field Science

Next Generation X-ray Lasers (on Thin Film Compression)



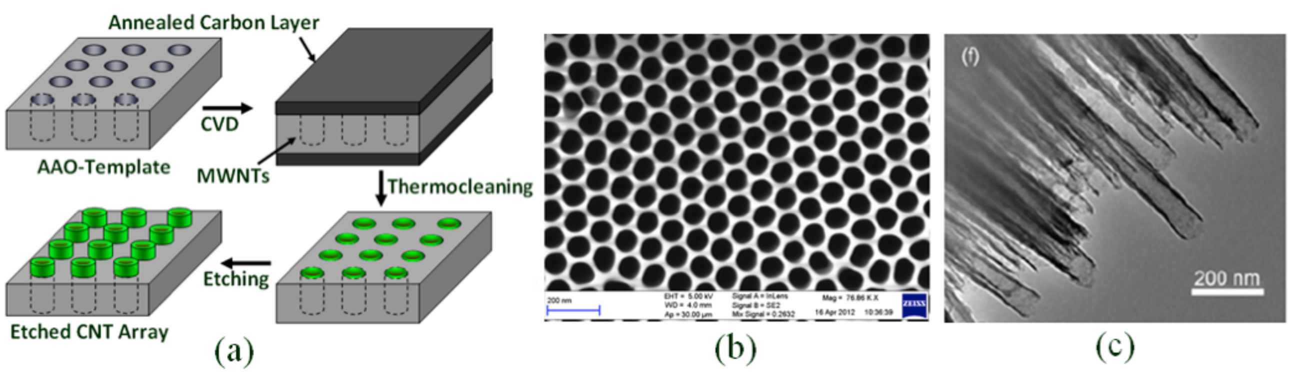
Wheeler J, Mourou G, Tajima T. Technology and Applications of Advanced Accelerator Concepts 2016

Wakefield acceleration in nano tube



Carbon nanotube with
Particle beam / X-ray pulse

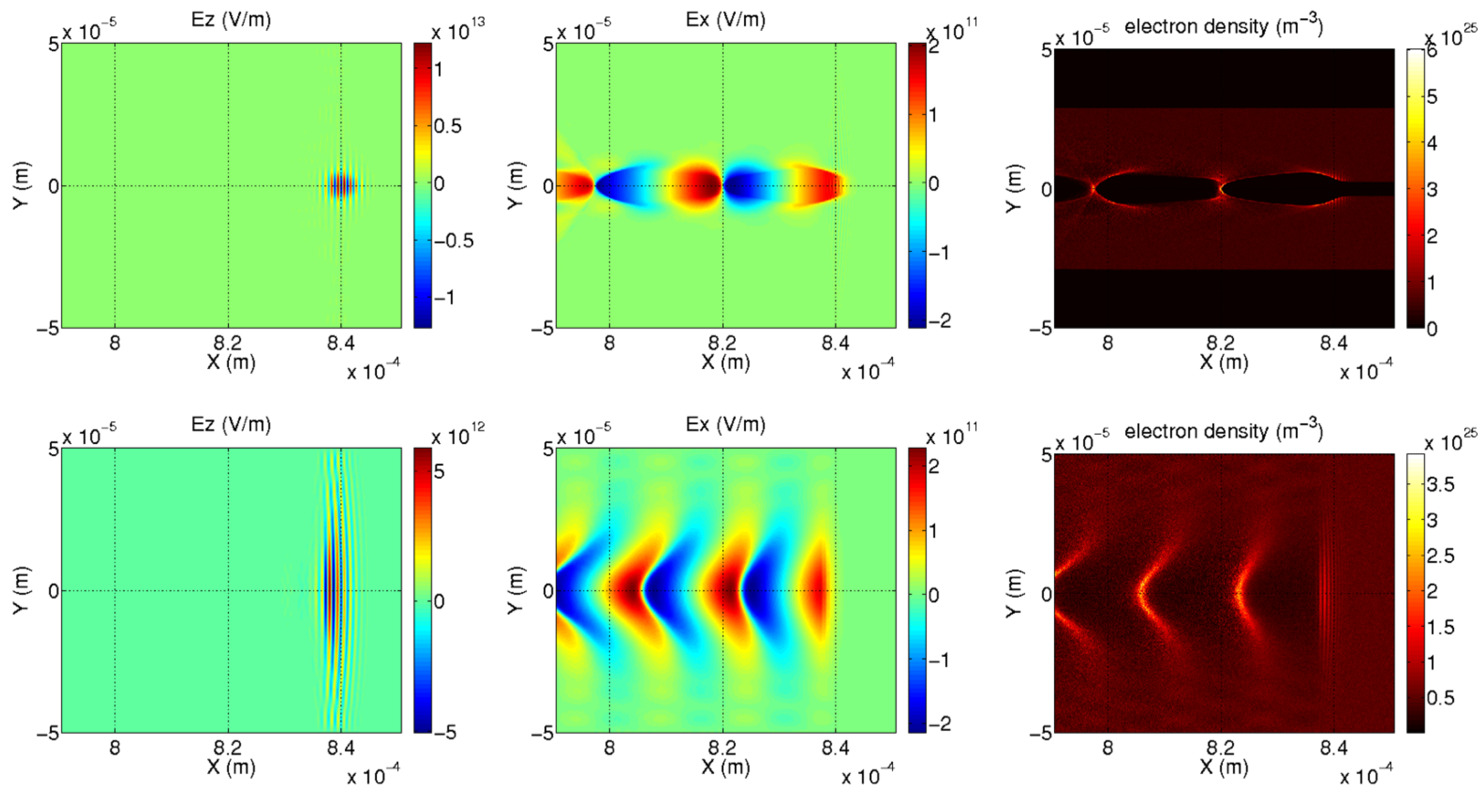
Porous nanomaterial



→ **TeV on a Chip** (*E* ~ TeV / cm)

→ **PeV over 10m**

X-ray LWFA in a tube vs. uniform solid



in nanotube

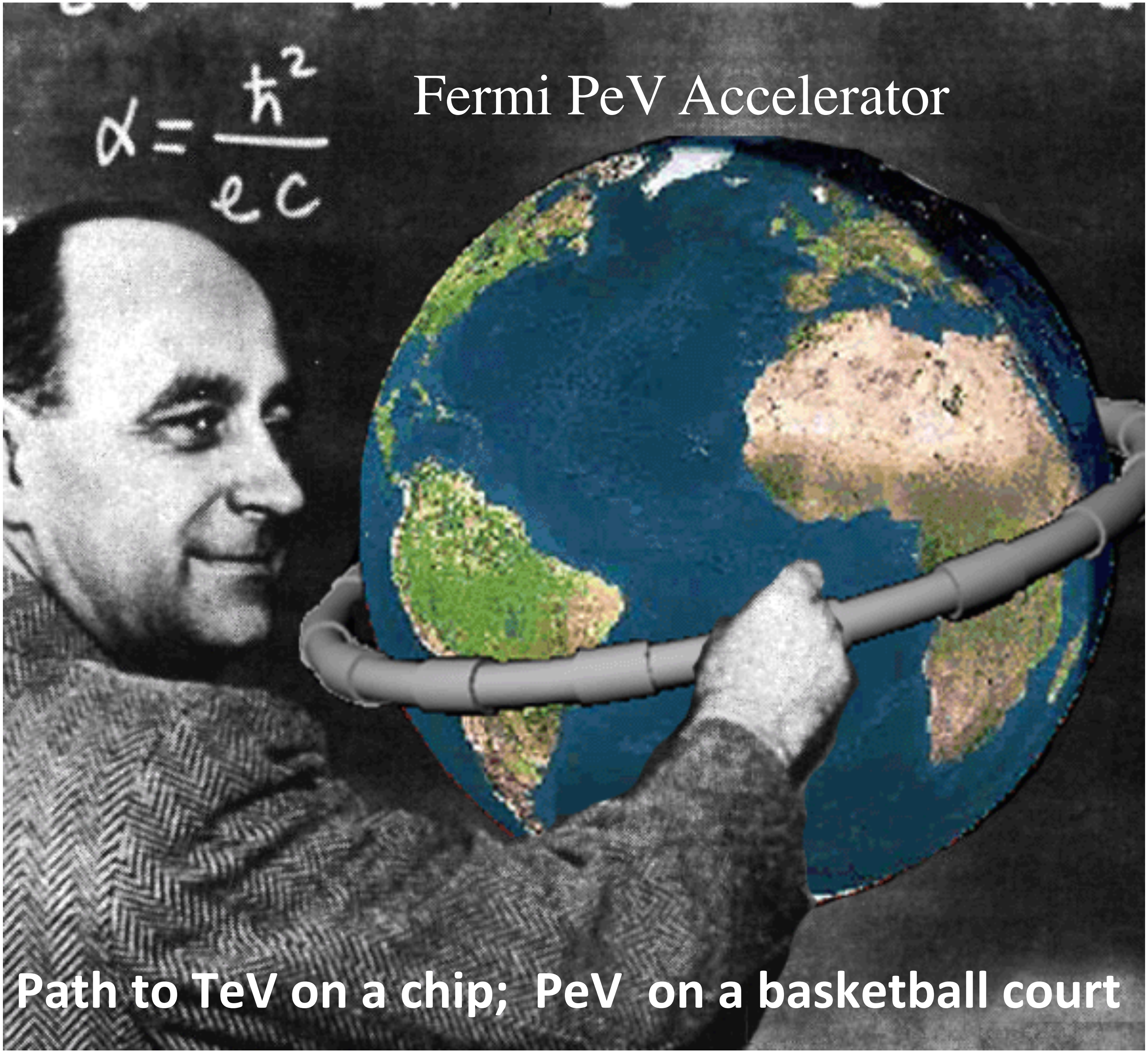
in uniform solid

A few-cycled 1keV X-ray pulse (a_0 ~ O(1)), causing 10TeV/m wakefield in the tube

more strongly confined in the tube

cf: uniform solid

X. Zhang (2016)


Fermi PeV Accelerator
$\alpha = \frac{\hbar^2}{ec}$
Path to TeV on a chip; PeV on a basketball court