X-ray Wakefield Acceleration in Nanotubes

Toshi Tajima
UC Irvine

IZEST
Ecole Polytechnique
June 8, 2018

abstract

1. New technology thin film compression (TFC) (IZEST = UCI/EP/Laserex/ELI-NP collaboration)

   → relativistic compression →

   Leading to a new innovation X-ray LWFA

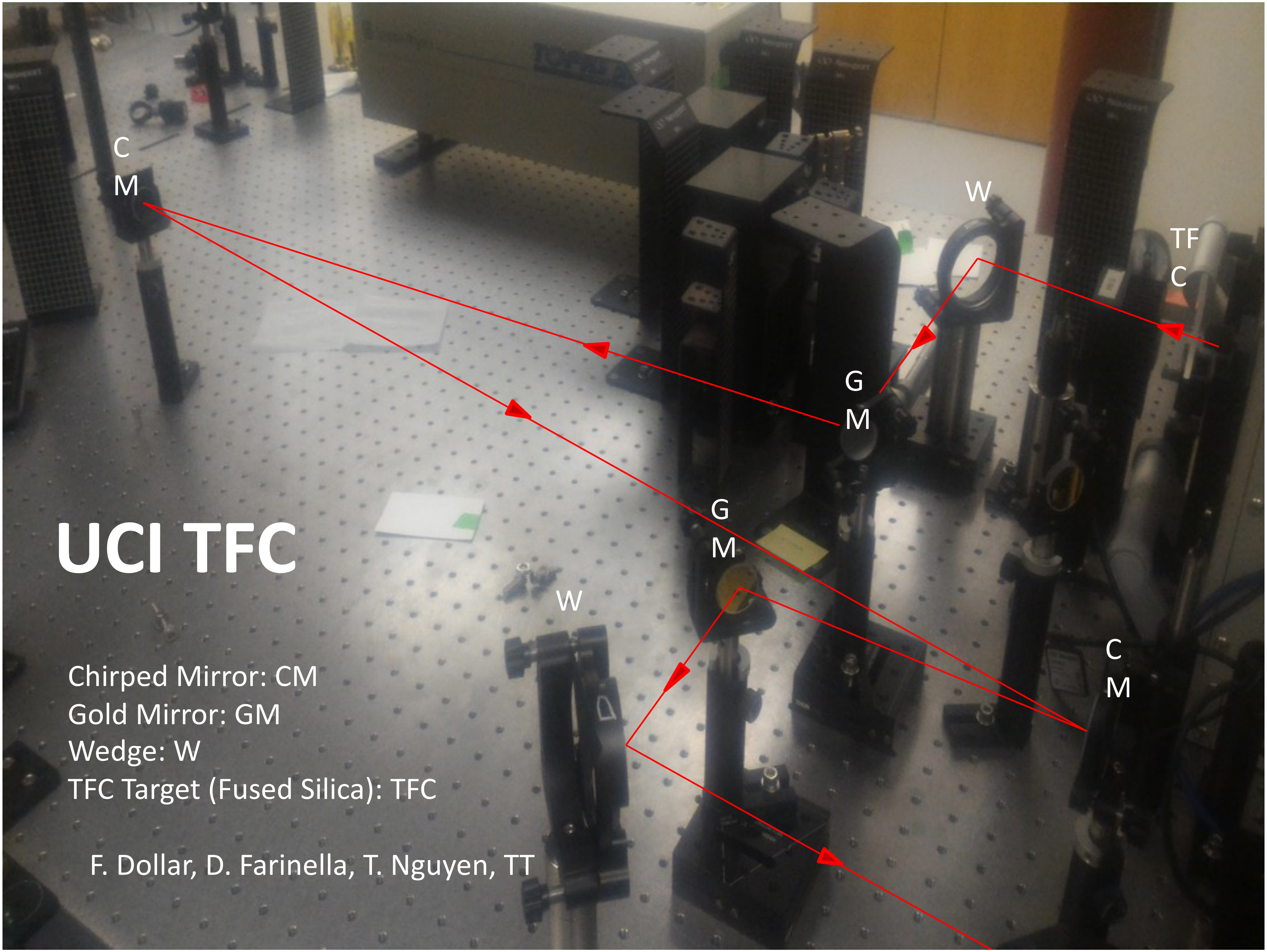
2. X-ray nanostructure acceleration simulation

3. "TeV on a chip" (X-ray LWFA); coherent γ-ray laser

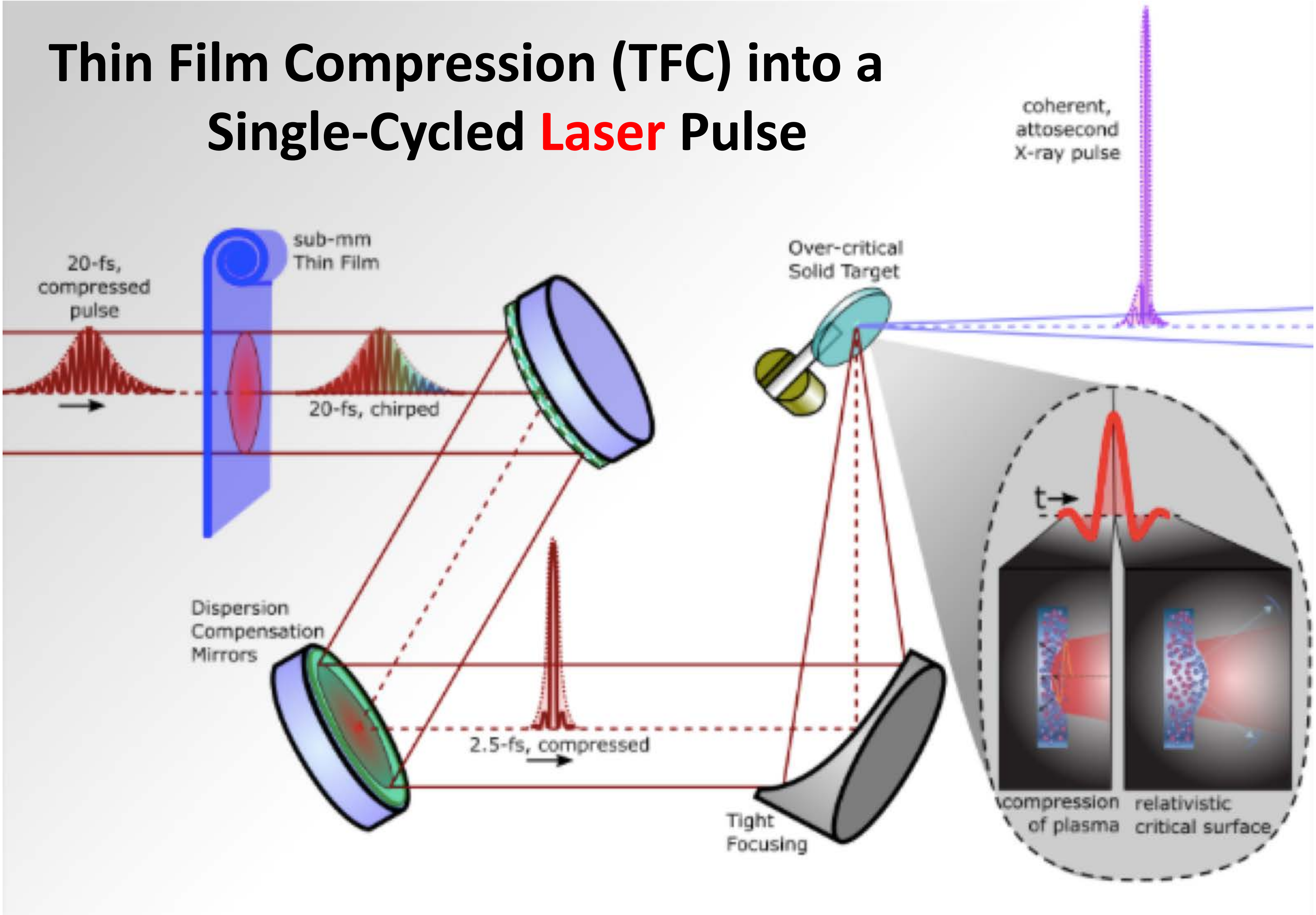
   new zeptosecond Exawatt science; medical (and other compact) accelerators

Thin Film Compression and Relativistic Compression: Path toward X-ray laser at EW and zs

Mourou et al. (2014)


UCI TFC
CM
W
TFC
GM
GM
W
CM
Chirped Mirror: CM
Gold Mirror: GM
Wedge: W
TFC Target (Fused Silica): TFC
F. Dollar, D. Farinella, T. Nguyen, TT

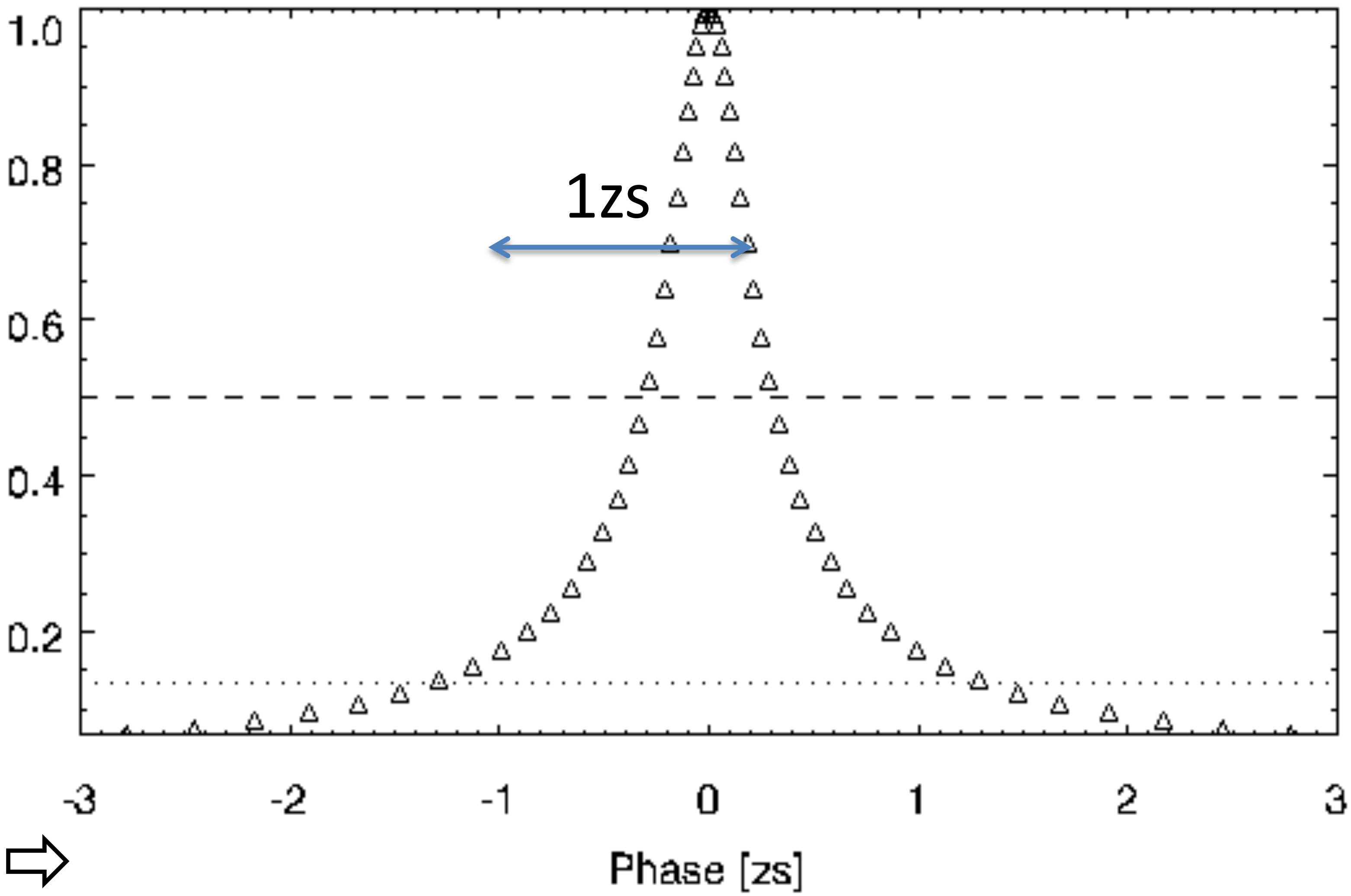
Thin Film Compression (TFC) into a Single-Cycled Laser Pulse



Mourou et al. (2014)

Even,isolated zeptosecond X-ray laser pulse possible

(simulation by N. Naumova, et al., 2014)



1PW optical laser → 10PW single osc. Optical laser

→ EW single osc. X-ray laser

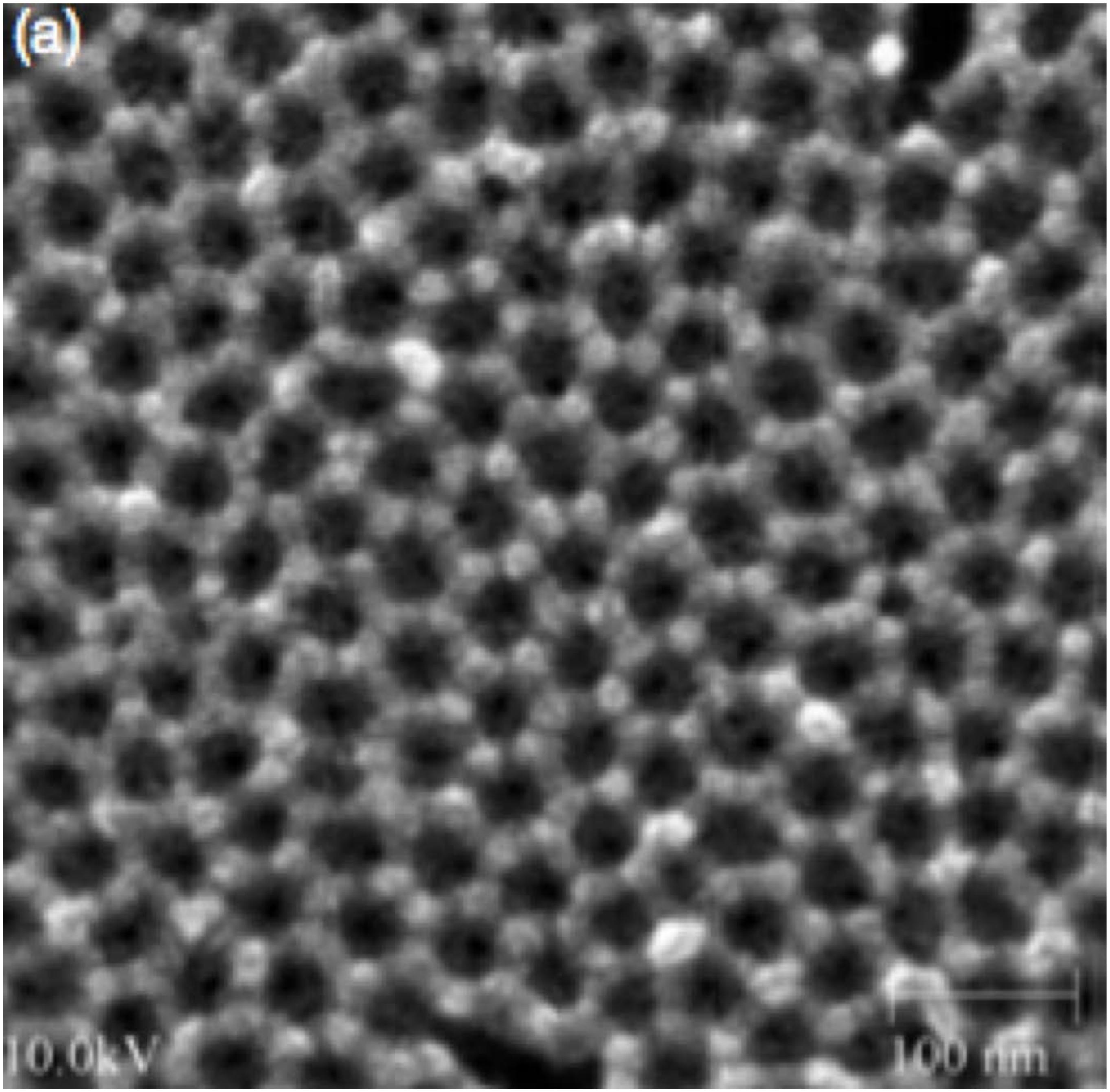
Consistent with "Intensity-pulse-width Conjecture" (Mourou-Tajima, Science **331** (2011))

X-ray LWFA in Nanostructure

Tajima, EPJ 223 (2014)
Hakimi, et al, Zhang, Posters

Porous Nanomaterial:

rastering possible



Nano holes:

reduce the stopping power

keep strong wakefields

➔ Marriage of *nanotech* and *high field* science

Spatia (nm), time(as-zs), density 10^{24} /cc), photon (keV) scales:

Transverse and longitudinal **structure of nanotubes**: act as e.g., accelerator structure (the structure intact in time of ionization, material breakdown times fs > x-ray pulse time zs-as)

Porous alimina on Si substrate Nanotech. **15**, 833 (2004);

P. Taborek (UCI): porous alumina (2007)

X-ray wakefield acceleration in nanomaterials tubes

T. Tajima, EPJ (2014)

X-ray laser with short length and small spot:

NB: electrons in outers-shell bound states, too, interact with X-rays

Simulation:

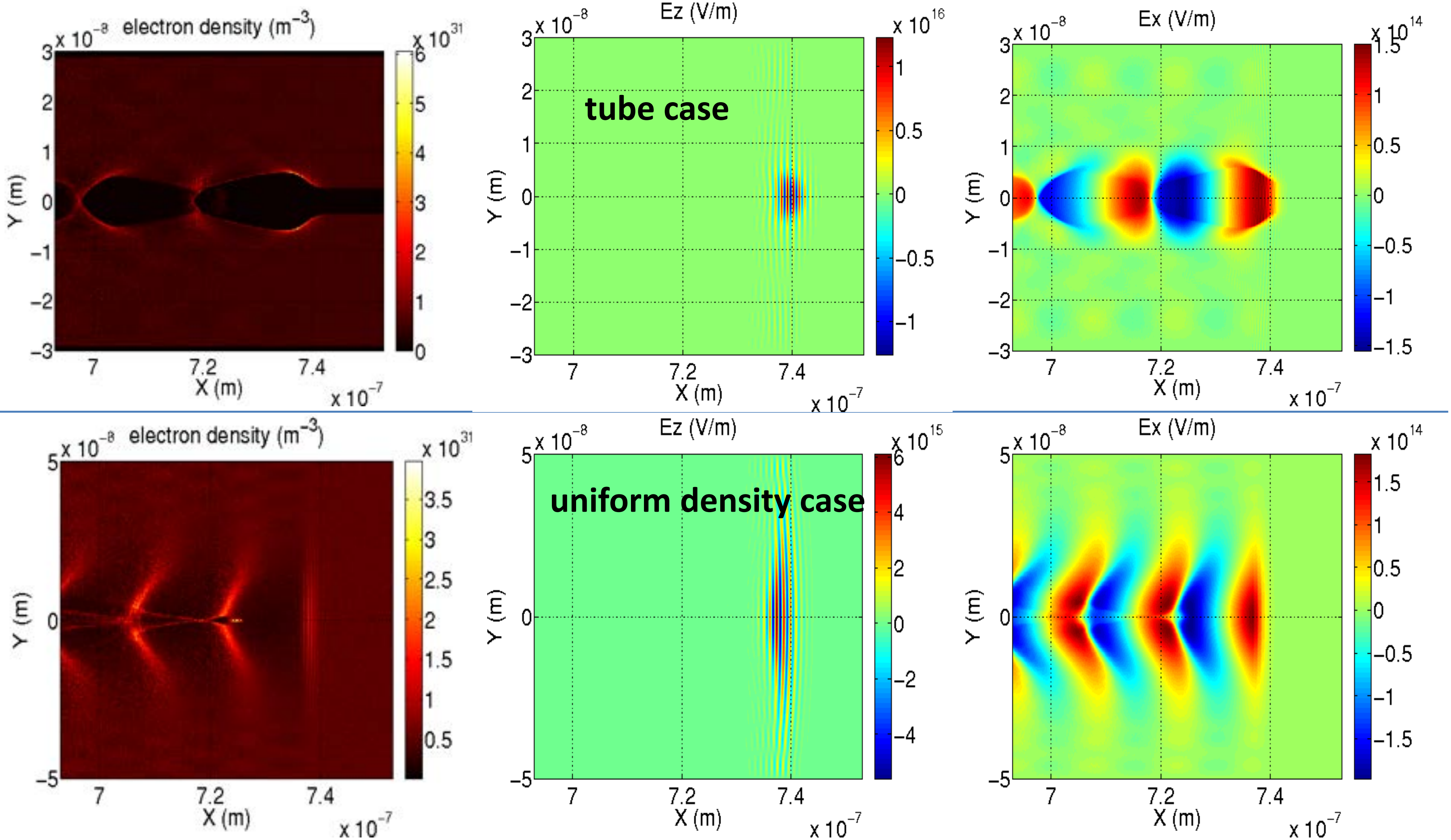
X.M. Zhang, et al.PR AB (2016)

Laser pulse with small spot can be well controlled and guided with a tube. Such structure available e.g. with **carbon nanotube,** or **alumina nanotubes** (typical simulation parameters)

$$\lambda = 1nm, a_0 = 4, \sigma_L = 5nm, \tau_L = 3nm / c$$

$$n_{tube} = 5 \times 10^{24} / cm^3, \sigma_{tube} = 2.5nm$$

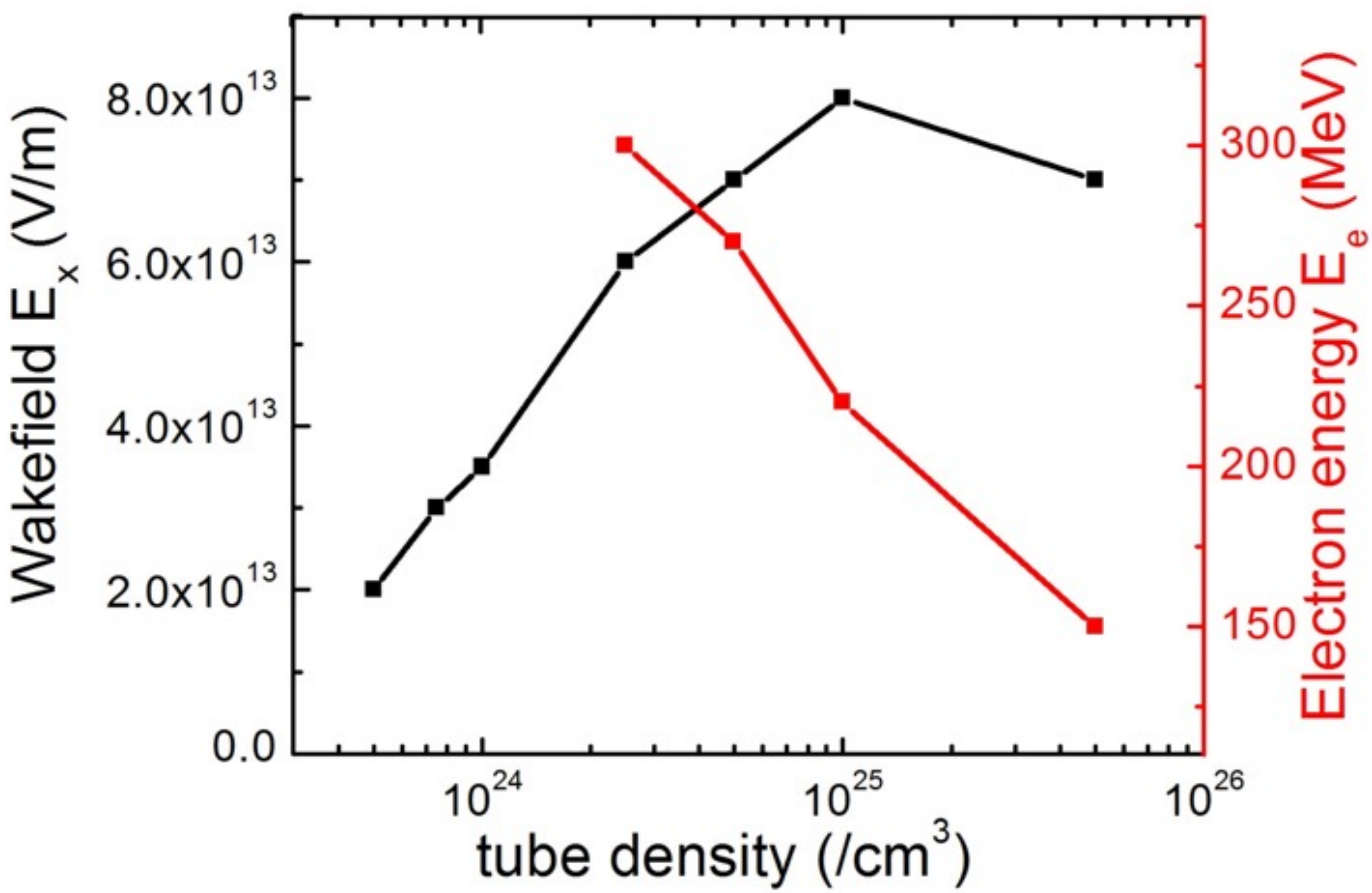
Wakefield comparison between the cases of a tube and a uniform density



X. M. Zhang

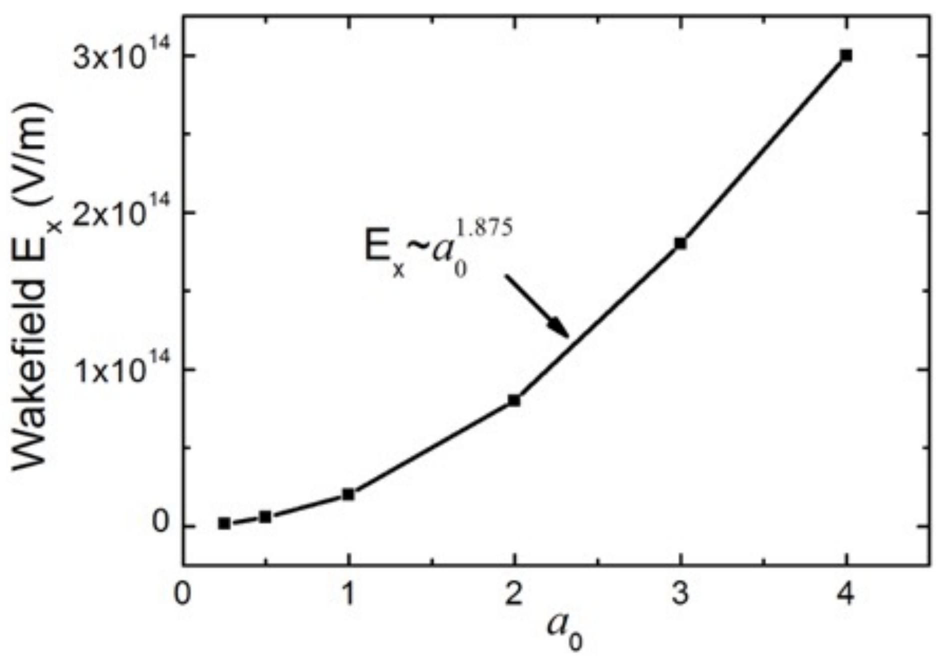
PIC simulation of X-ray wakefields in a nanomaterial tube: Density scaling

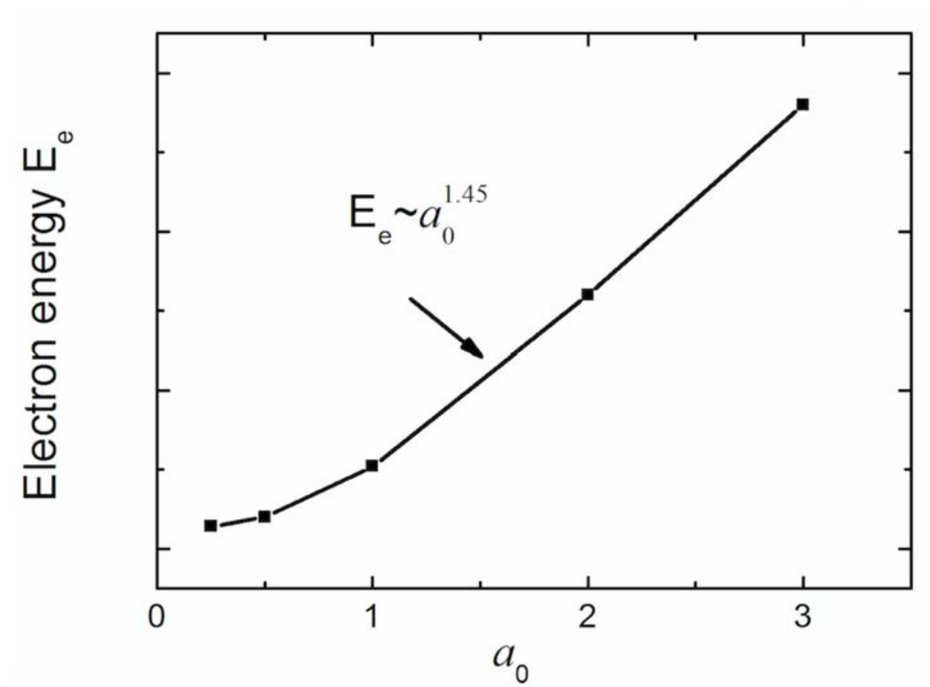
Photon energy = 1keV,tube radius = 5nm, a_0=4, a few-cycled laser (around n_{cr} / n = 200)



X. M. Zhnag (2016)

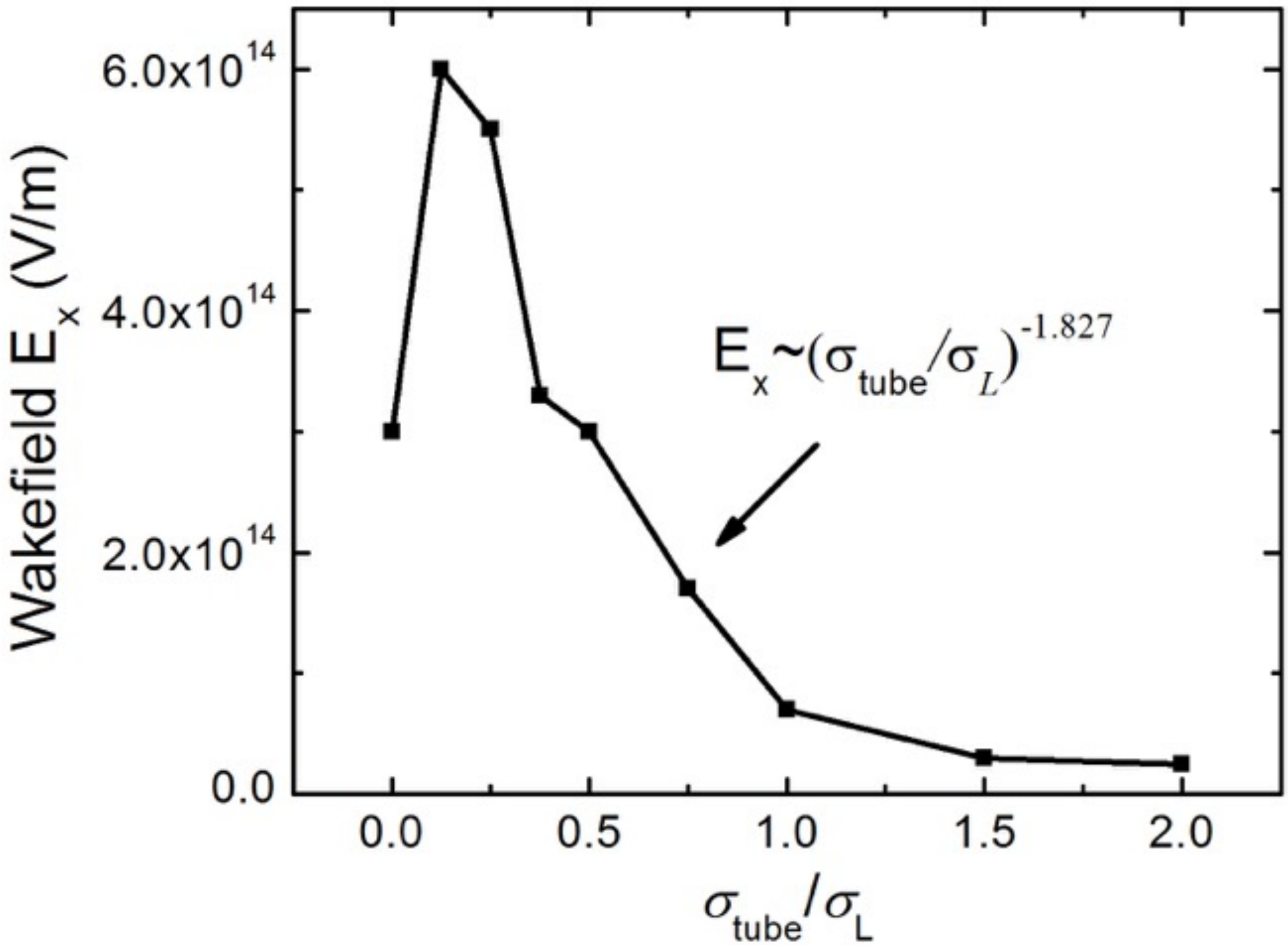
Wakefield scaling to the X-ray laser amplitude





X. M. Zhnag (2016)

Wakefields and the tube geometry



X. M. Zhang (2016)

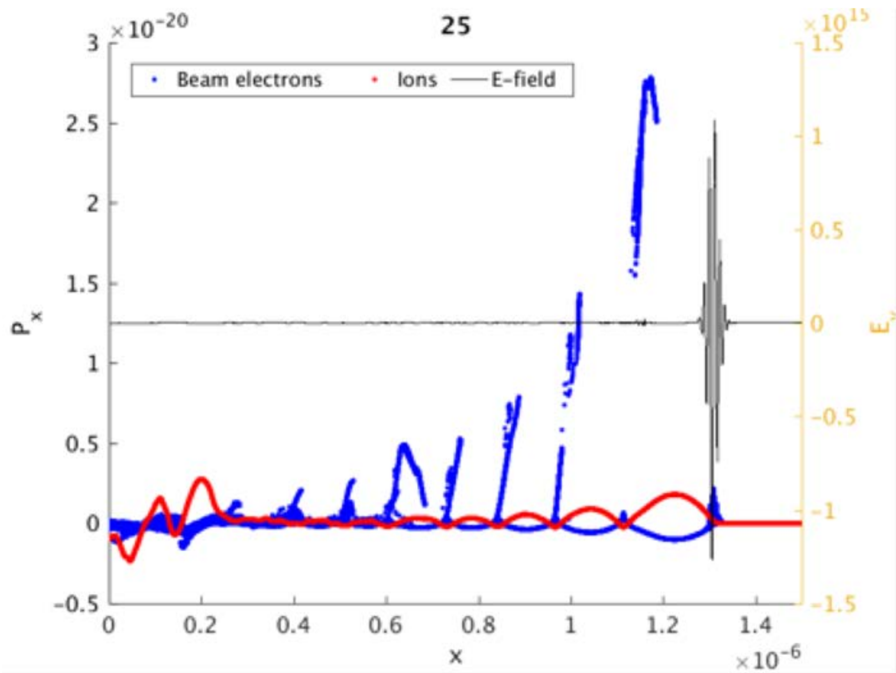
With and without **optical phonon branch**

Model of optical phonon branch: *T. Tajima and S. Ushioda, PR B (1978)*

→ nanoplasmonics in X-ray regime

Without lattice force (i.e. plasma)

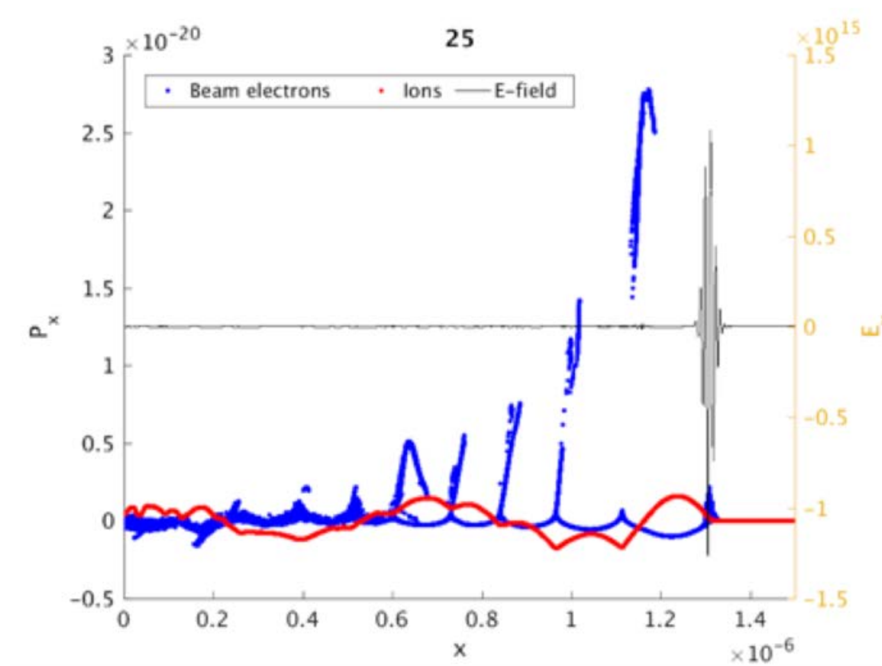
(when ω_{TO} is much smaller than ω_{pe}, there is no noticeable difference from the below where $\omega_{TO} = 0$)



With lattice force (optical phonon branch present)

$$\epsilon = 1 - \frac{\omega_{pe}^2}{\omega^2} - \frac{\Omega_p^2}{\omega^2 - \omega_{TO}^2}$$

$$\frac{\omega_{TO}}{\omega_{pe}} \simeq 0.75 \qquad \frac{\Omega_p}{\omega_{pe}} \simeq \frac{1}{43}$$



S. Hakimi, et al. (2017)

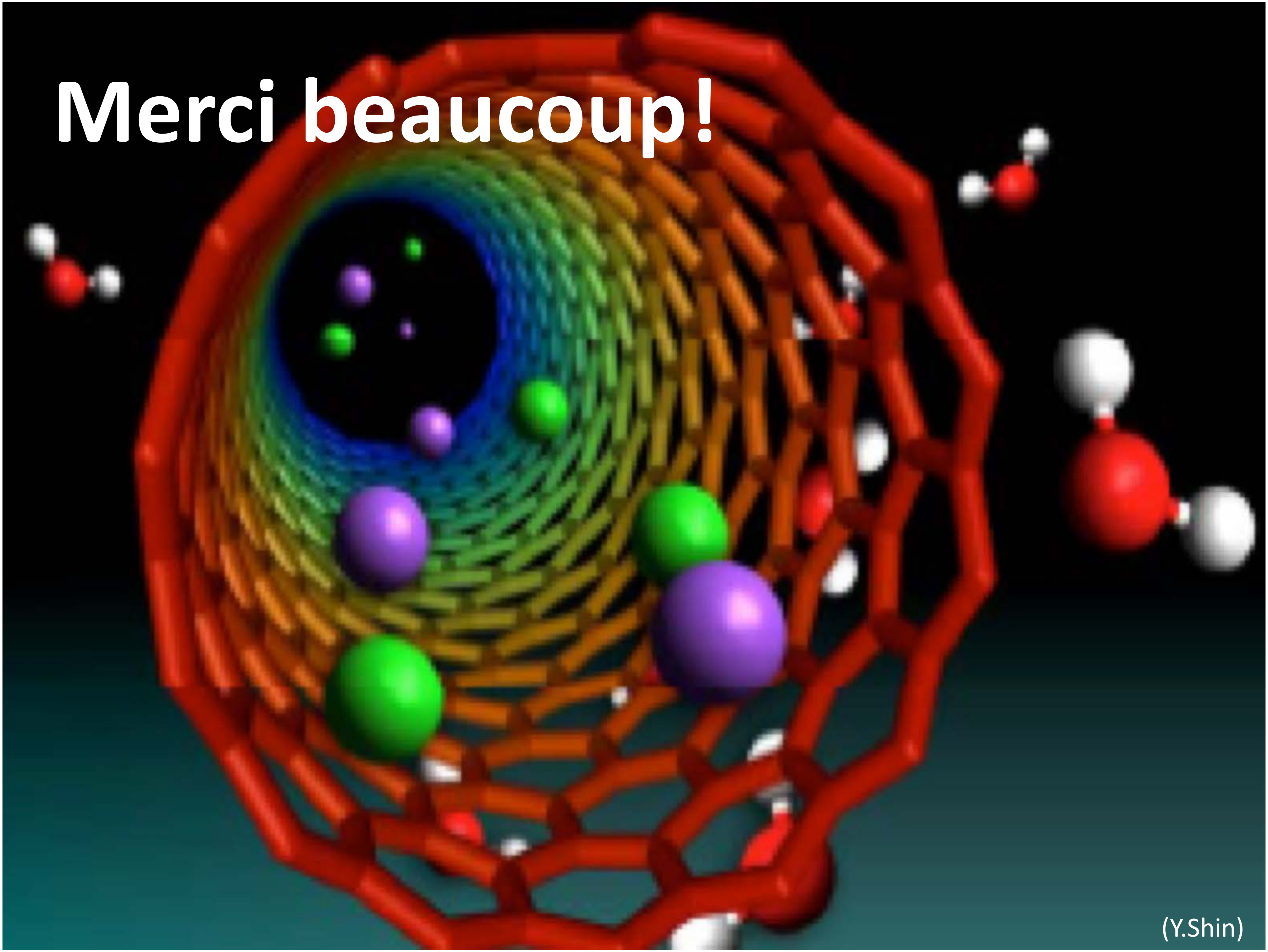
Conclusions

- **IZEST collaboration → TFC experimental demonstration**
- **Possible: EW 10keV X-rays laser** from 1PW optical laser
- Single-cycled X-ray laser pulse (relativistic compression)
- **X-ray LWFA in crystal**: accelerating gradient (from GeV/cm) →TeV/cm
- **Crystal nanoengineering**: s.a. nanoholes, arrays, focus nano-optics for nano-accelerator
- Start of **zeptoscience**: ELI-NP zeptoproject (collaboration)---

laser tools fit for nuclear phys. (←→attoseconds for atoms)

- **Scale revolution**: eV→keV; PW→EW; as→zs; μm→nm; GeV/cm→TeV/cm; 100m→cm; μ-beam→nanobeam; 10^{18} /cc → 10^{24}/cc

→**societal impact**


Merci beaucoup!
(Y.Shin)