High energy ion beam generation by intense-ultrashort laser irradiation

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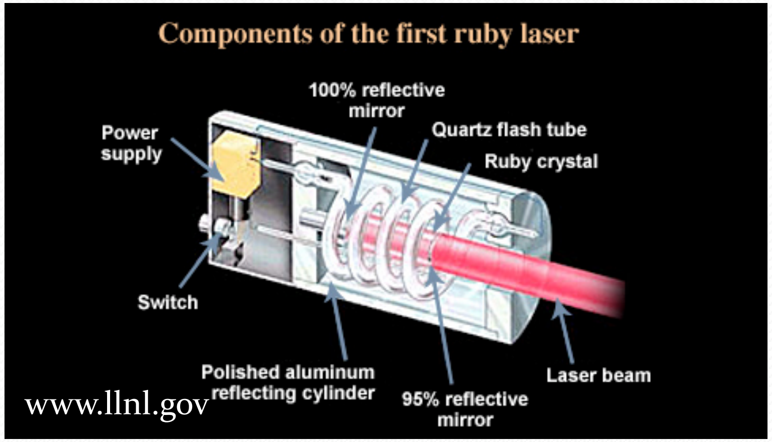
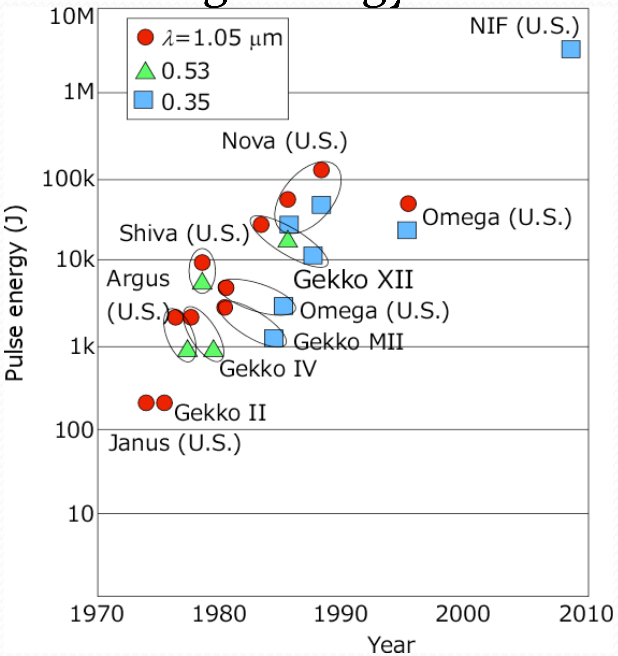
50th anniversary from laser innovation

1960 Ruby laser (Maiman)

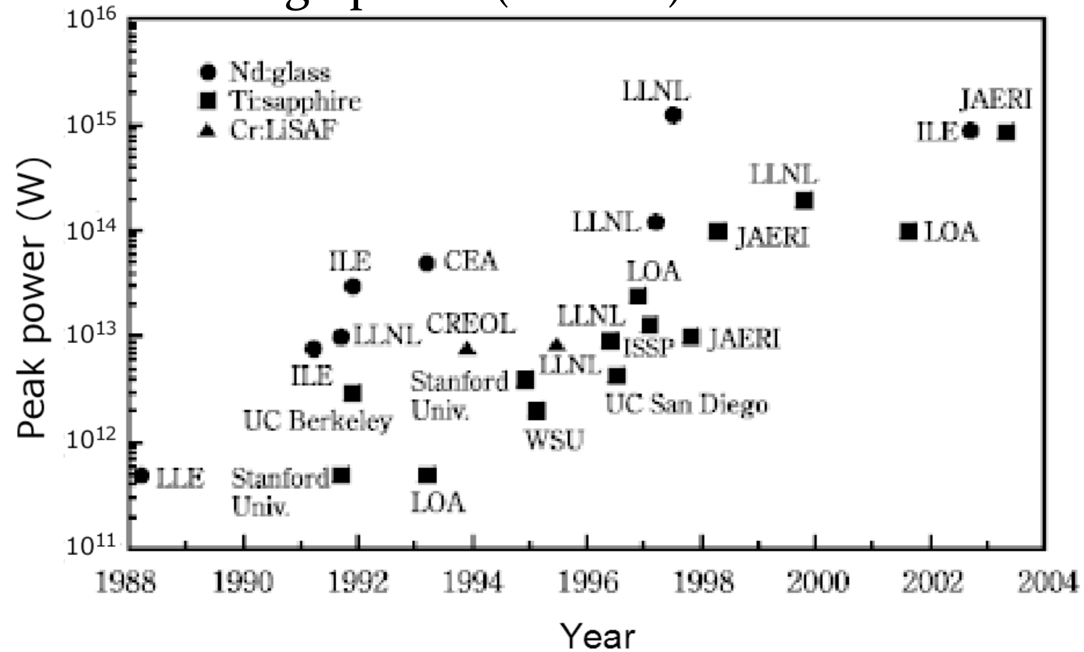
5 kW, 1 J, 0.5 ms pulse laser



High energy lasers



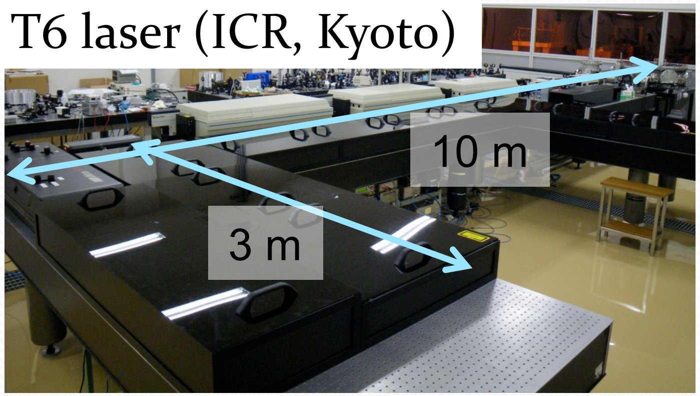
High power (intense) lasers

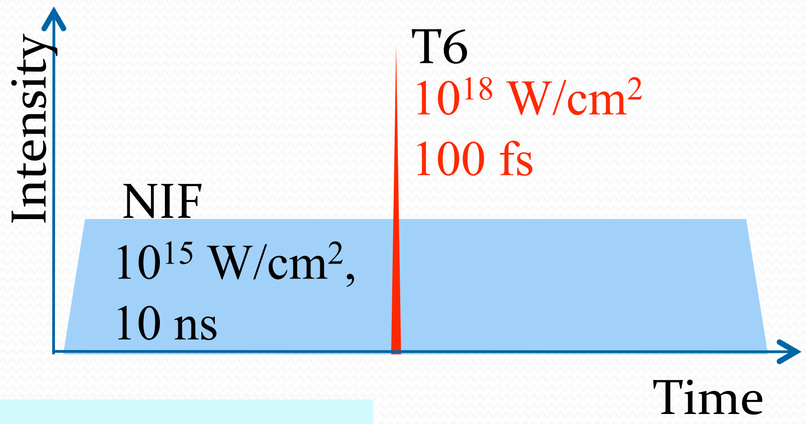


Short pulse laser systems can realize higher peak power than large facilities

National Ignition Facility (U. S.)

T6 laser (ICR, Kyoto)

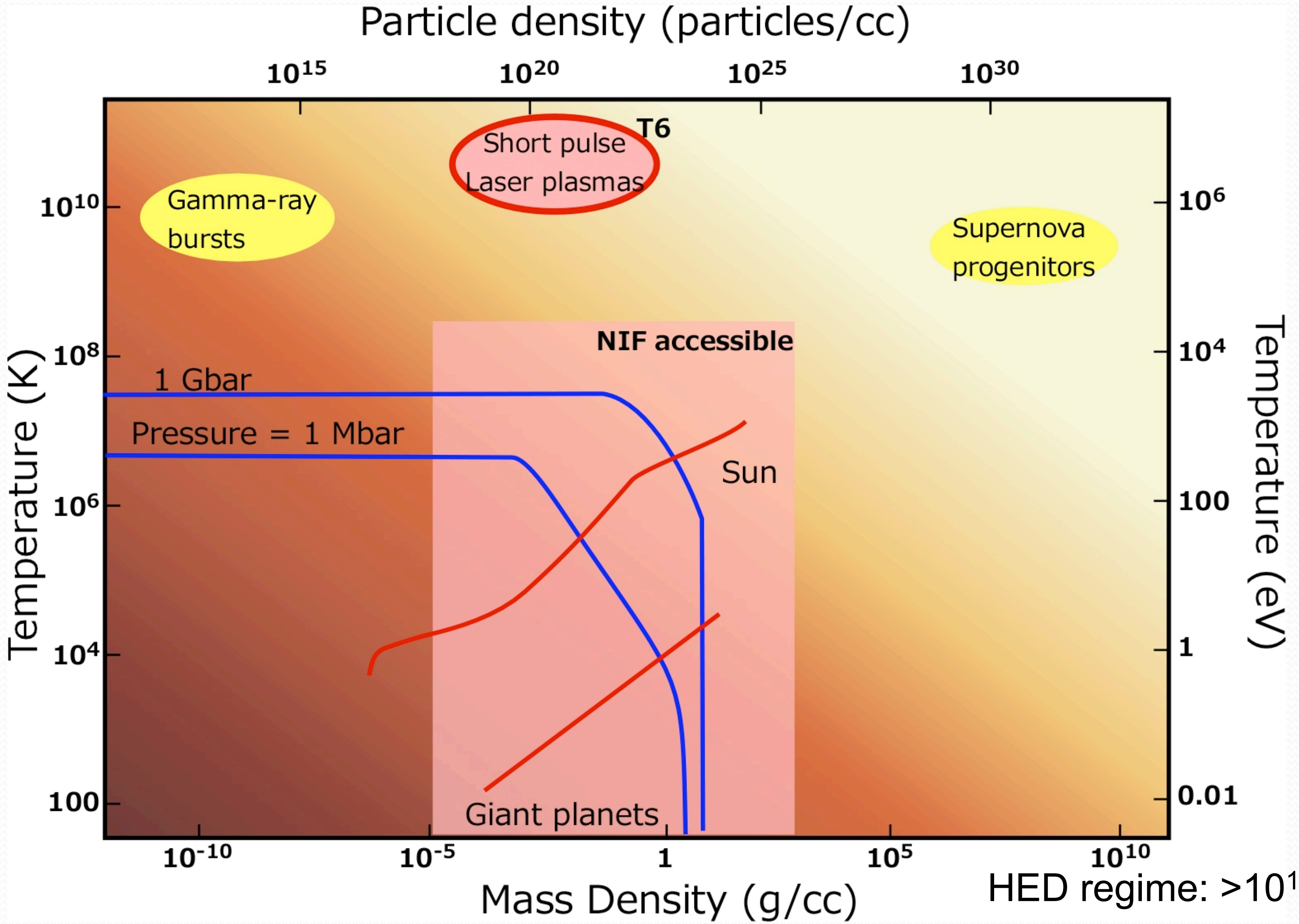




$$10^{15} < 10^{18}\ \mathrm{W/cm^2}$$

(3 MJ >> 100 mJ)

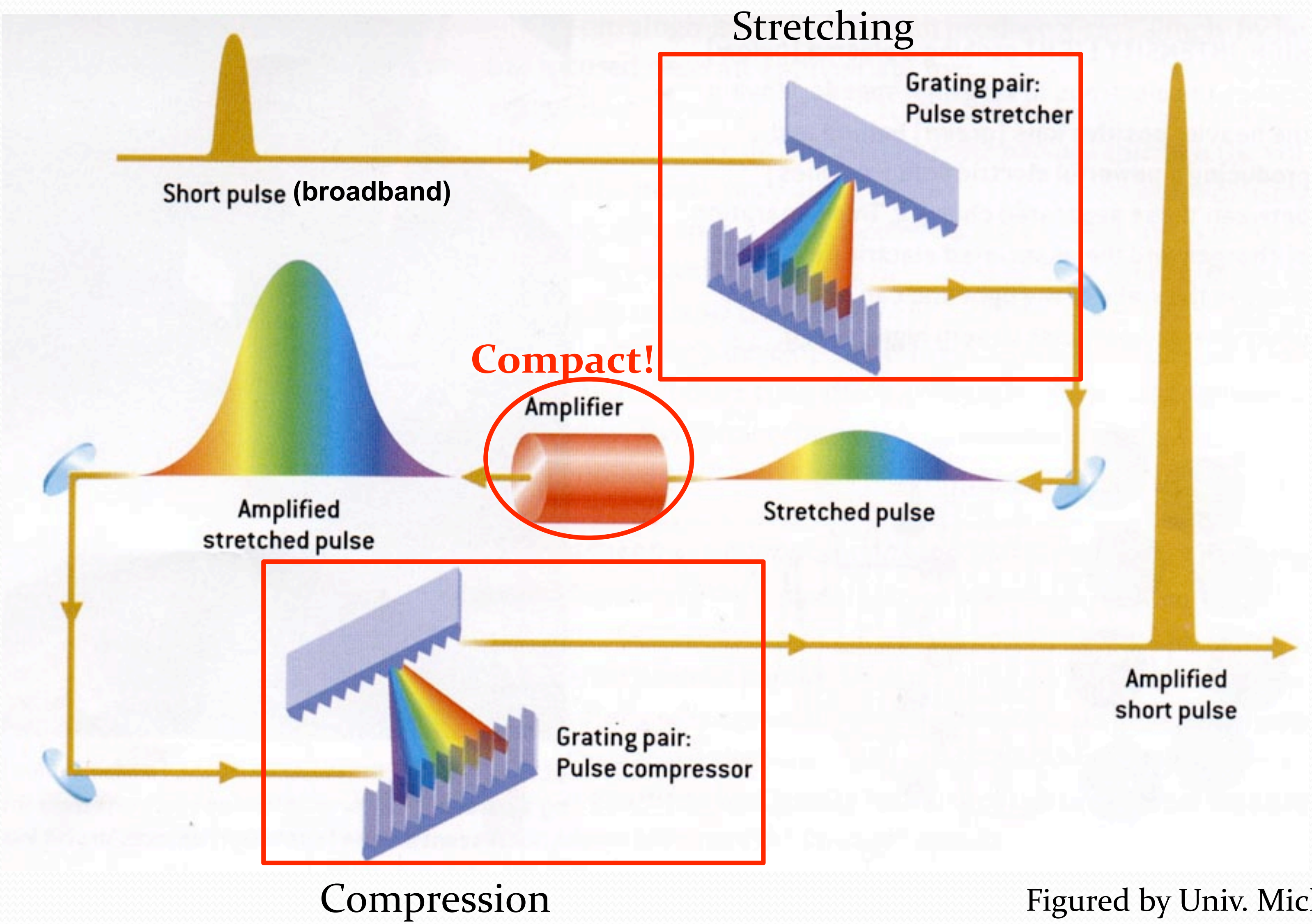
Frontiers in High energy density physics (HEDP)



HED regime: $>10^{12}$ erg/cc

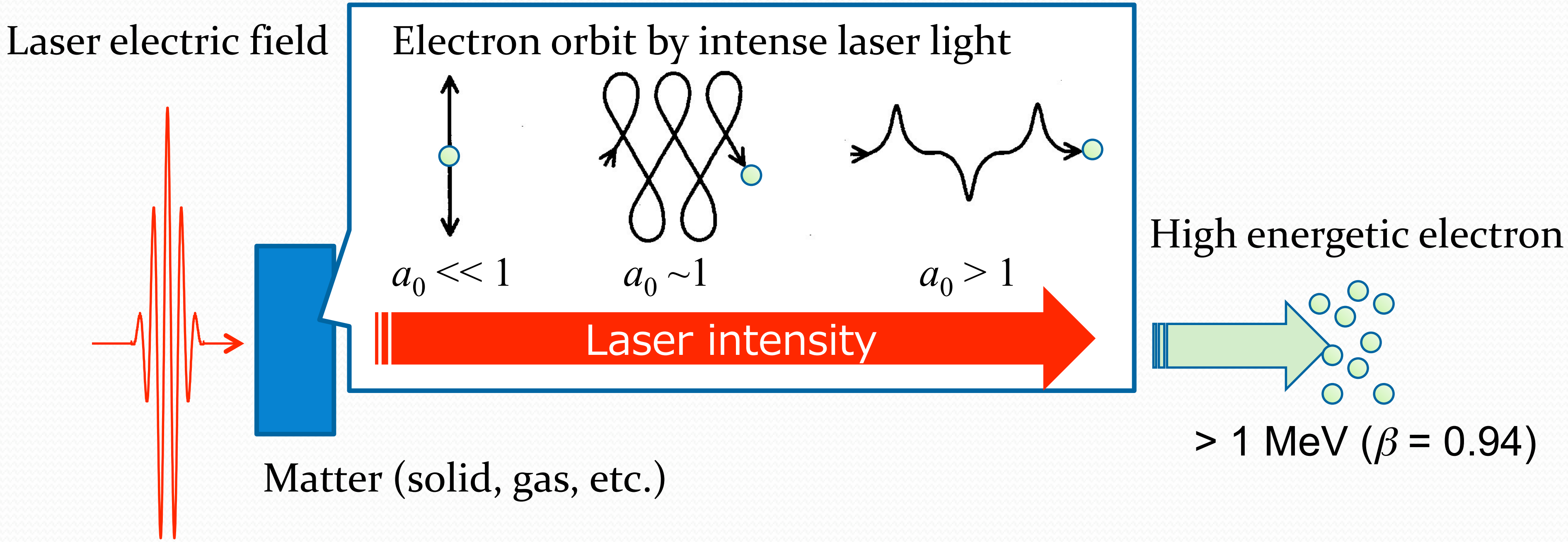
the NRC Report:
"High Energy Density Physics: The X-Games of Contemporary Science"

An intense laser pulse in small laboratories is achieved with Chirped Pulse Amplification



Figured by Univ. Michigan

Electrons are accelerated to relativistic velocity in intense light field

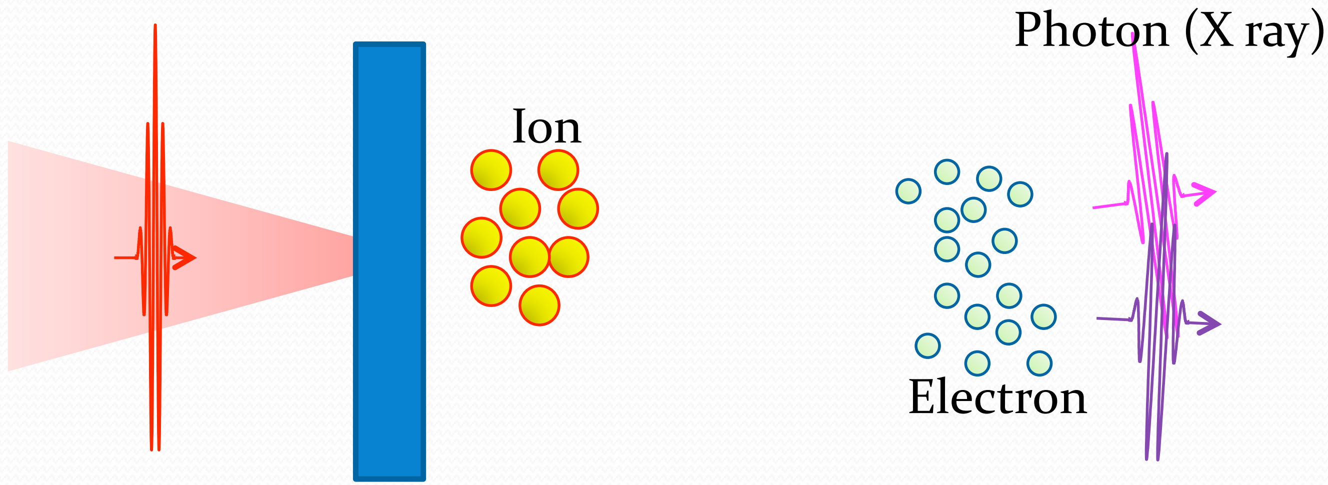


$$a_0 = \frac{v_{max}}{c} = \frac{eE}{m_0 \omega \cdot c}$$

$$= \left(\frac{I\,(\mathrm{W/cm^2})\,\lambda\,(\mu\mathrm{m})^{2}}{1.38 \times 10^{18}} \right)^{1/2}$$

v_{max}: Maximum electron velocity
I: laser intensity
λ: wavelength of laser

Many species of radioactive particles are emitted from the laser irradiated matter

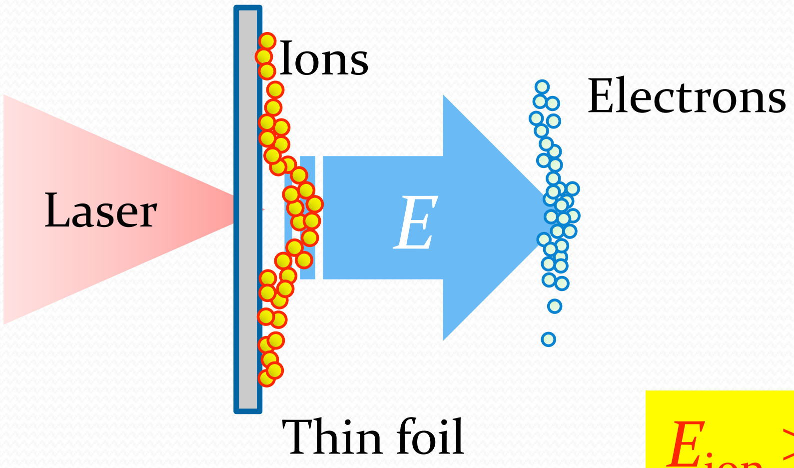


Laser induced radiations and emissions
(Electrons, Protons, Light ions, X rays, Terahertz rad., etc.)
•Short pulse (~ps)
•Point source
•Simultaneous emissions

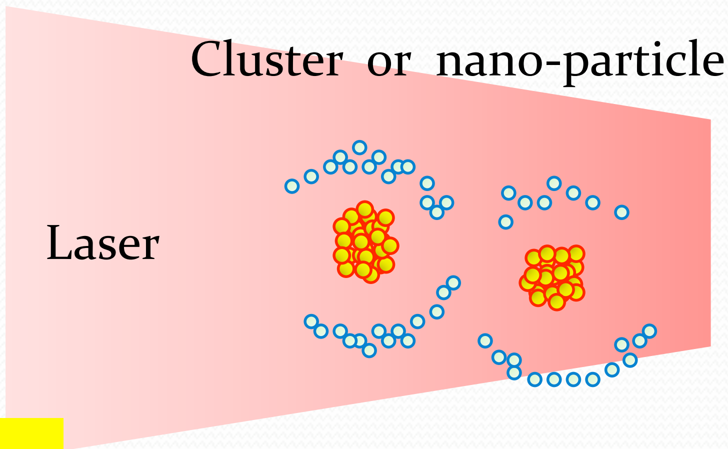
Ion acceleration mechanisms by sheath or spherical electro-magnetic field

<u>Target Normal Sheath Acceleration</u>

S. C. Wilks, *et al*., Phys. Plasmas 8, 542 (2001)



<u>Coulomb Explosion</u>



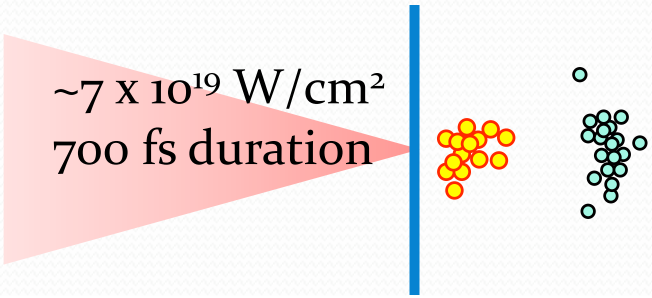
$E_{ion} > 1\text{MeV}$

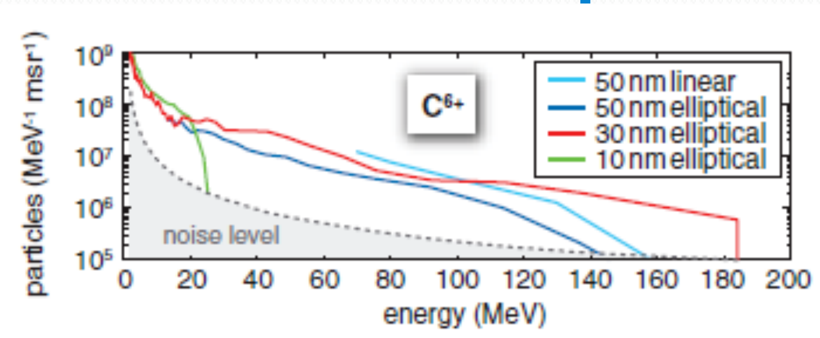
Possibilities of next generated small accelerator for research, medical, and industrial applications

Issues for applications:
- High energy
- High luminosity
- Spectral shaping (mono energy)

High energy and quasi-mono-energetic ion beam are demonstrated

Thin diamond like carbon foil
(thickness: 10-50 nm)

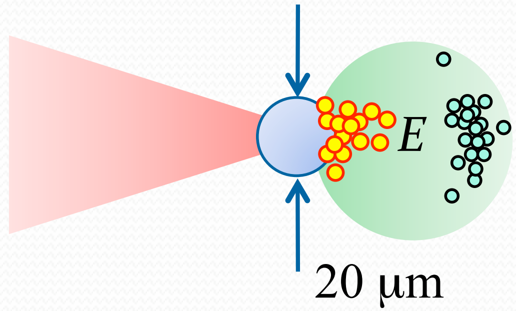


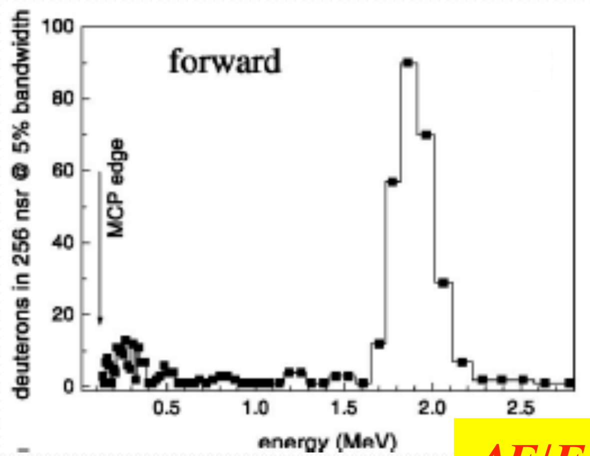


E_{max} = 185 MeV

Henig, *et al.*, PRL **103** 045002 (2009)

Micro droplet target

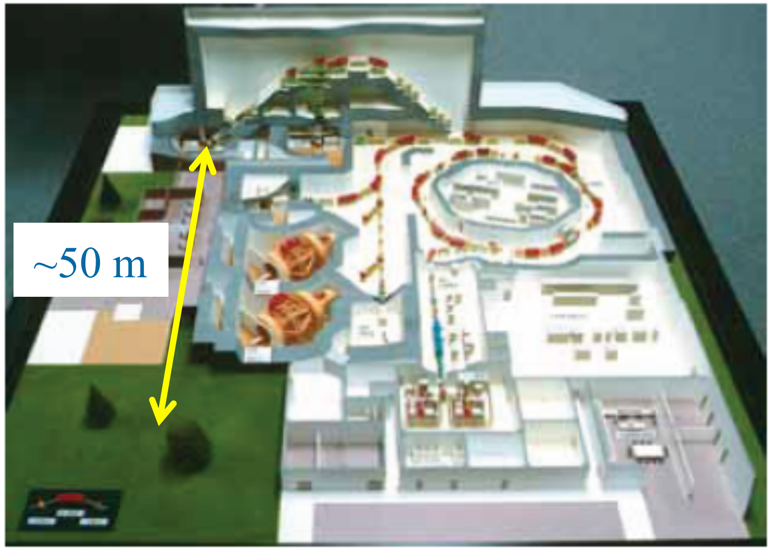




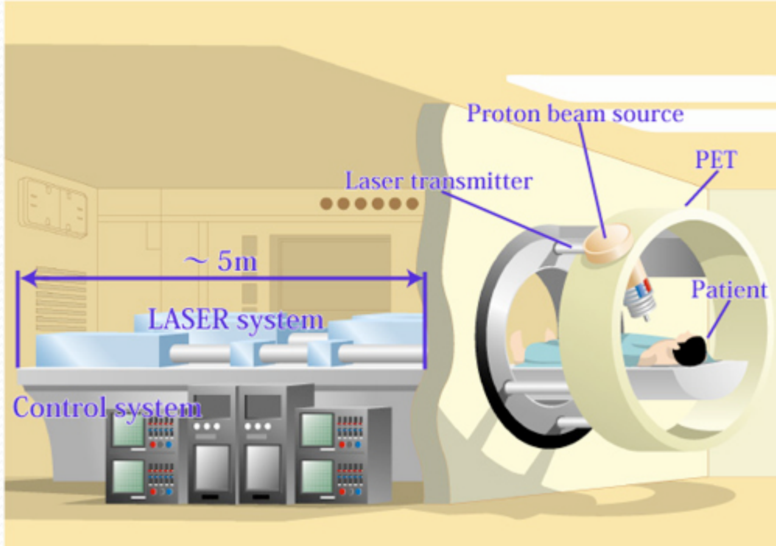
***ΔE/E* =20%**

Ter-Avetisyan, *et al.*, PRL 96, 145006 (2006)

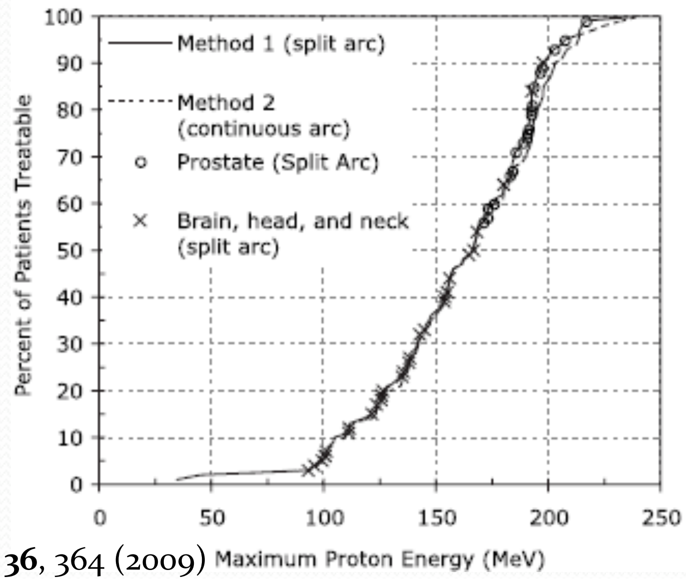
Proton therapy by using compact laser system



(Hyogo Ion Beam Medical Center)



Illustrated by Photo Medical Research Center



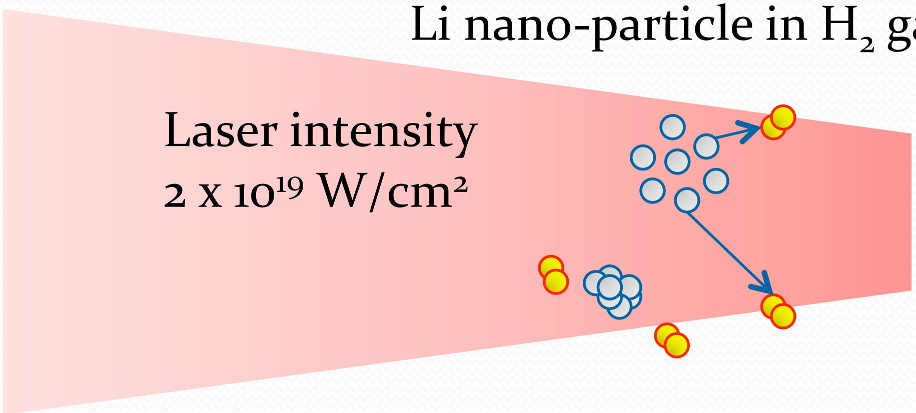
Sengbusch, Med. Phys. **36**, 364 (2009)

Features:
- Point source of proton
- Compact system

Issues:
- >200 MeV proton
- High repetition

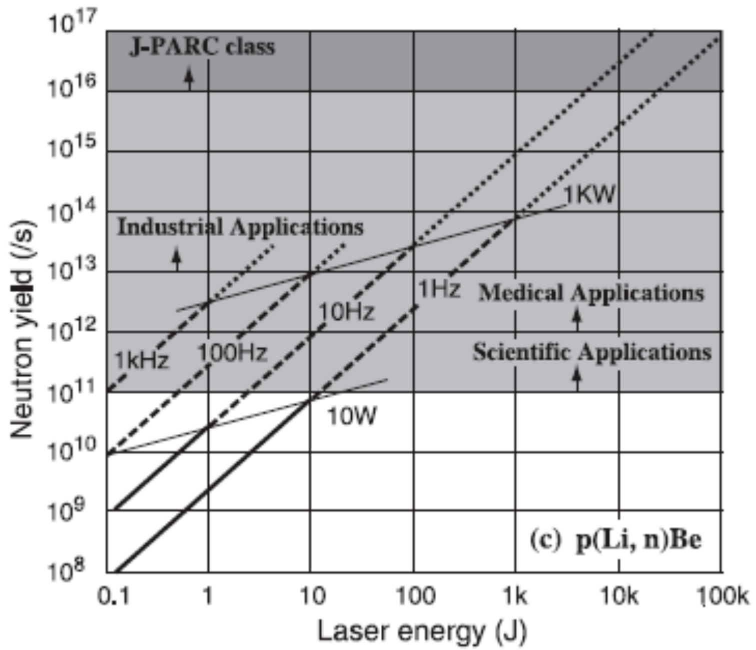
Neutron production for a compact facility

Li nano-particle in H_2 gas

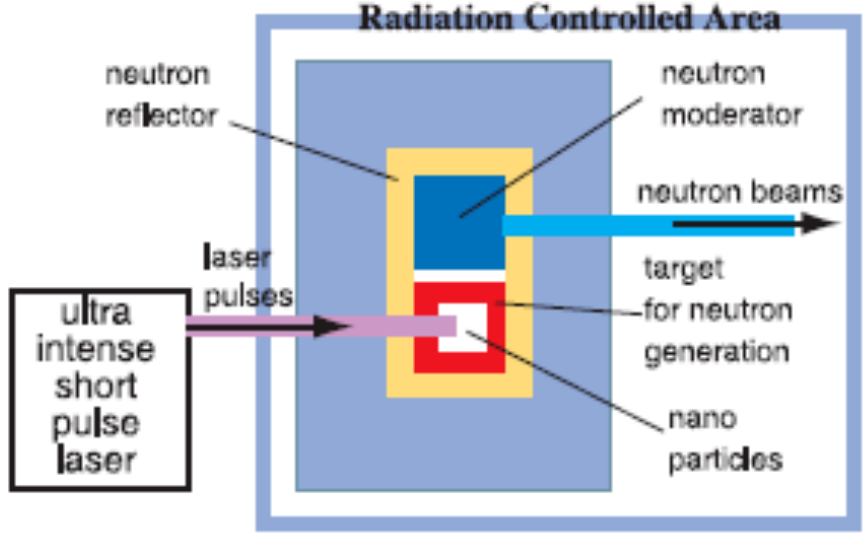


Li(p, n)Be

E_{Li} = 16 MeV, E_n = 1.6 MeV

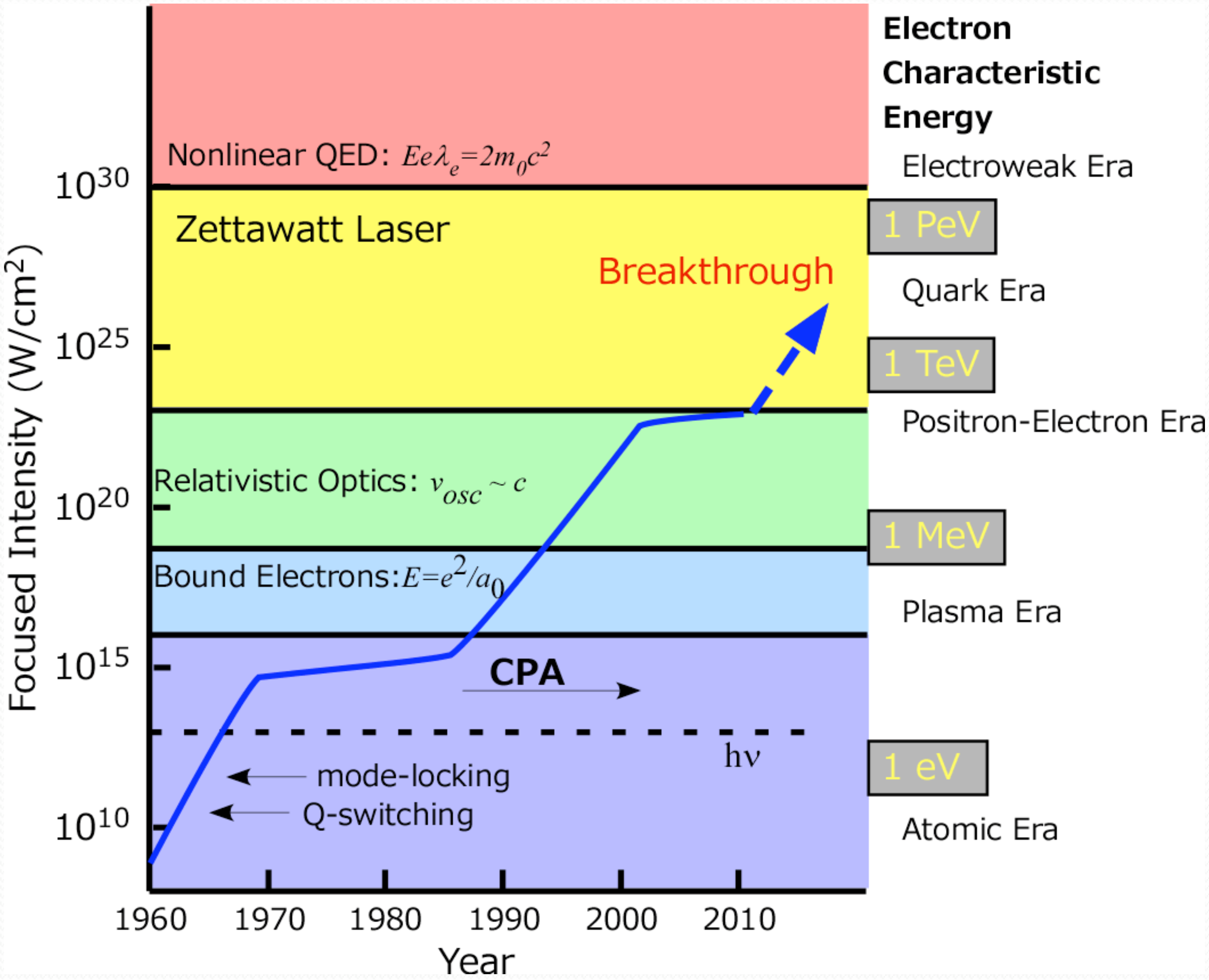


Sakabe, Fus. Plasma Res. **4**, 41 (2009)



Compact neutron source

Challenge to higher energy physics



Modified from Tajima, PRST AAB 5, 031301 (2002)

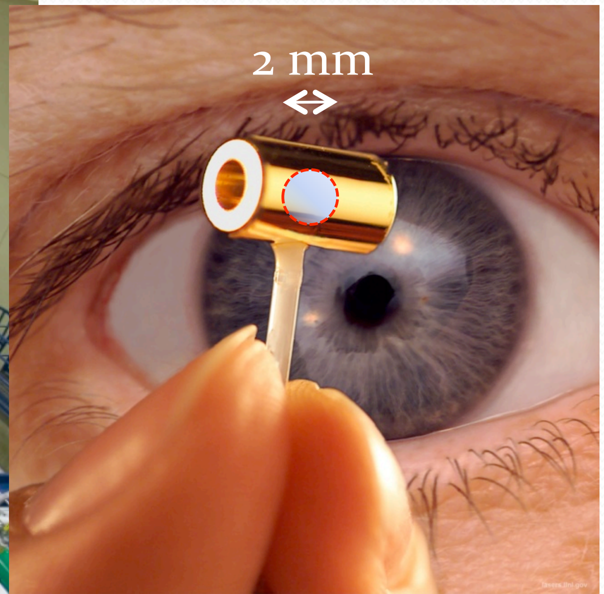
Summary

- Intense ultrashort lasers are developed to reach the intensity of > 10^{18} W/cm^2 in a laboratory scaled system.
- Relativistic electrons and high energetic radioactive particles can be emitted from laser-irradiated matters.
- High energetic ion beams induced by laser pulse is expected to be applied to many fields.

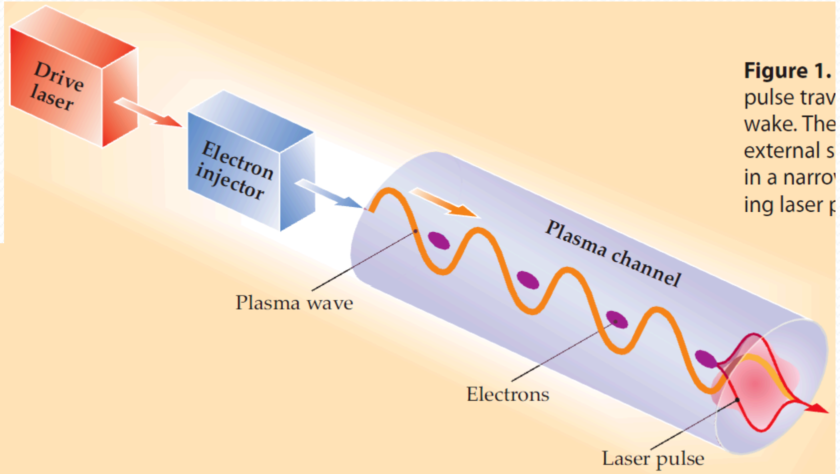
National ignition facility is about to realize the breakeven of nuclear fusion

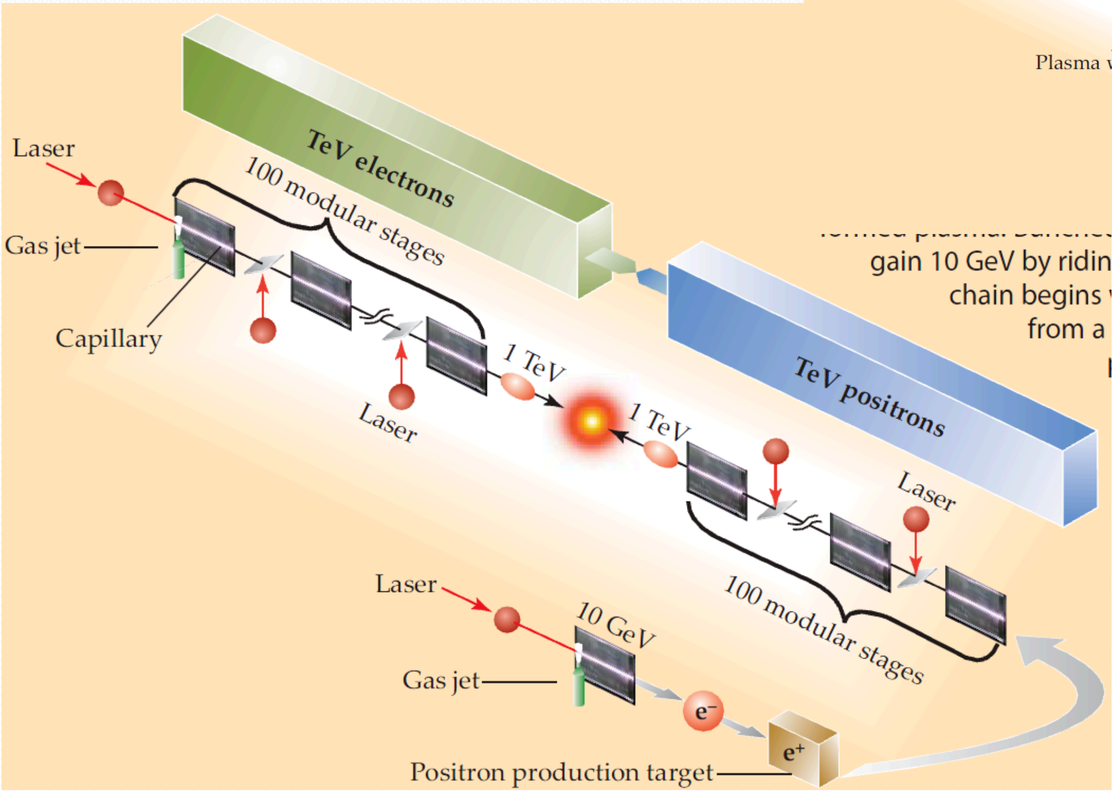
3 MJ/192 beams

are focused onto

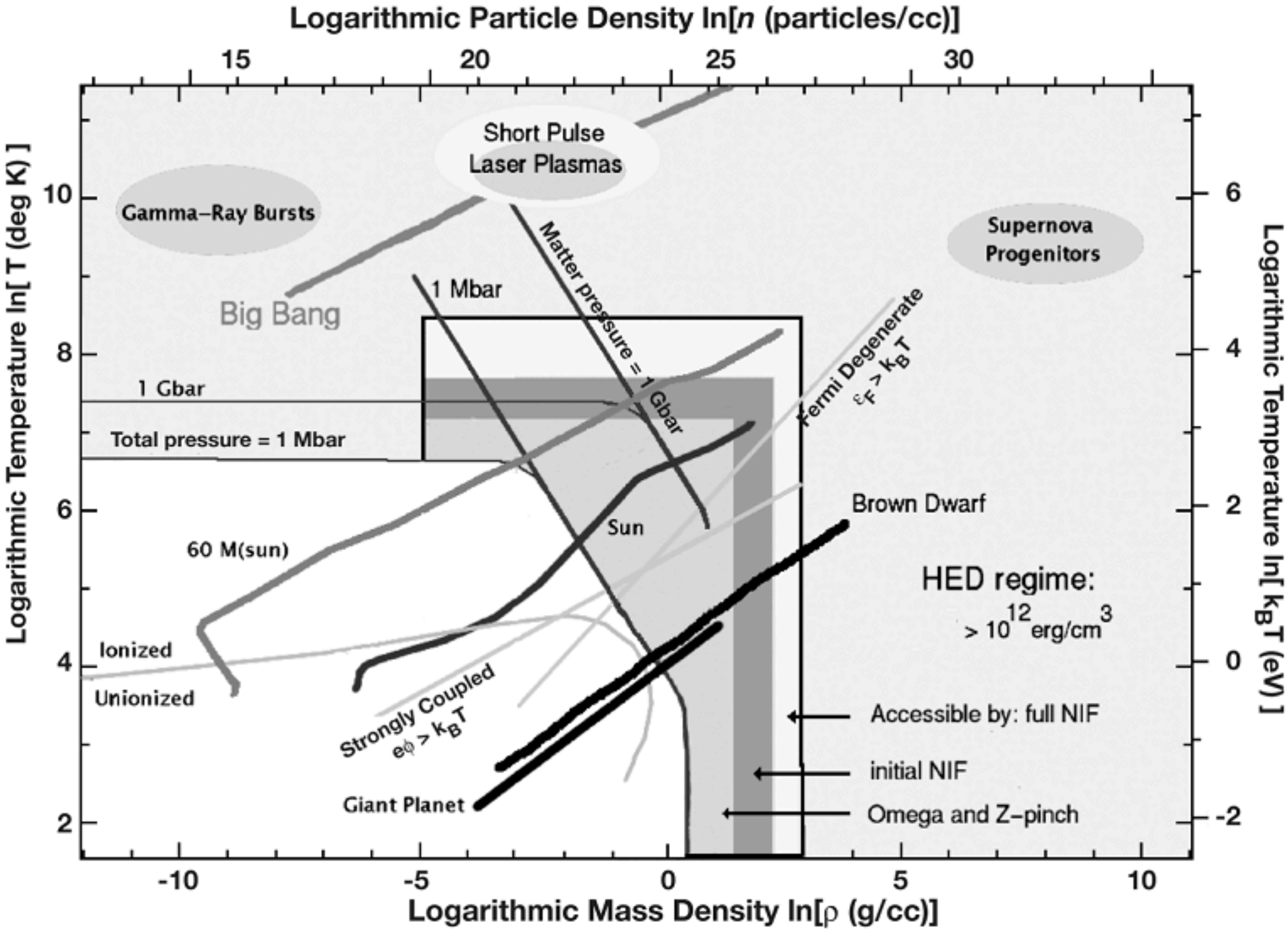


Future prospect: e-/e+ collision induced by laser acceleration





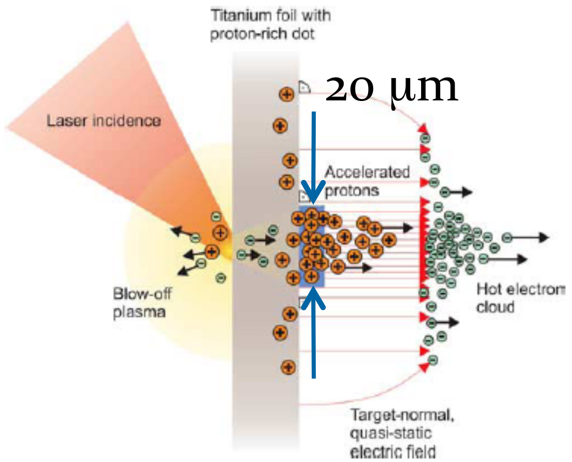
Physics today, 2009

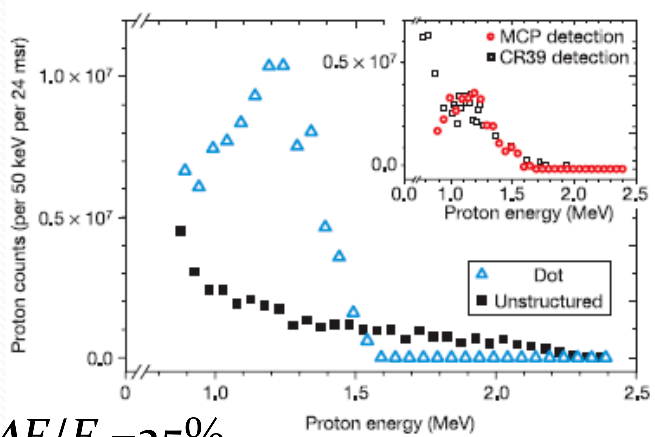


the NRC Report:
"High Energy Density Physics: The X-Games of Contemporary Science"

Quasi-mono-energetic proton beam is generated from locally limited targets

Microdot target with thin foil

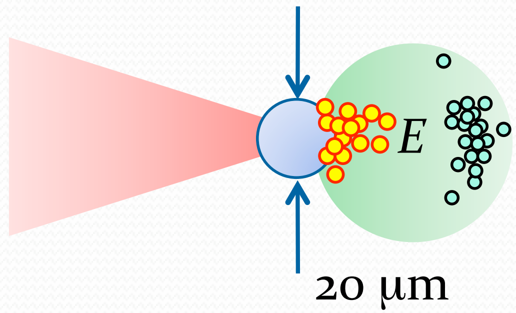


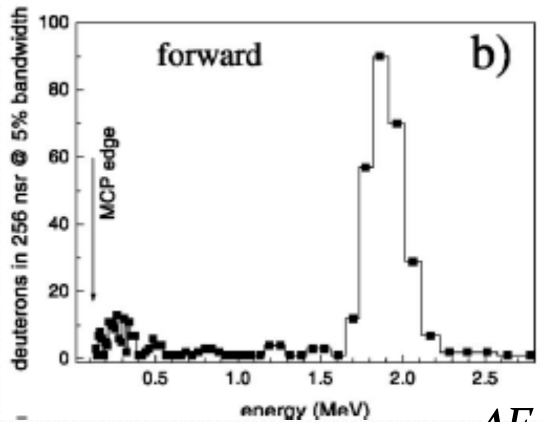


$\Delta E/E$ =25%

Schwoerer, et al., nature **439**,445 (2006)

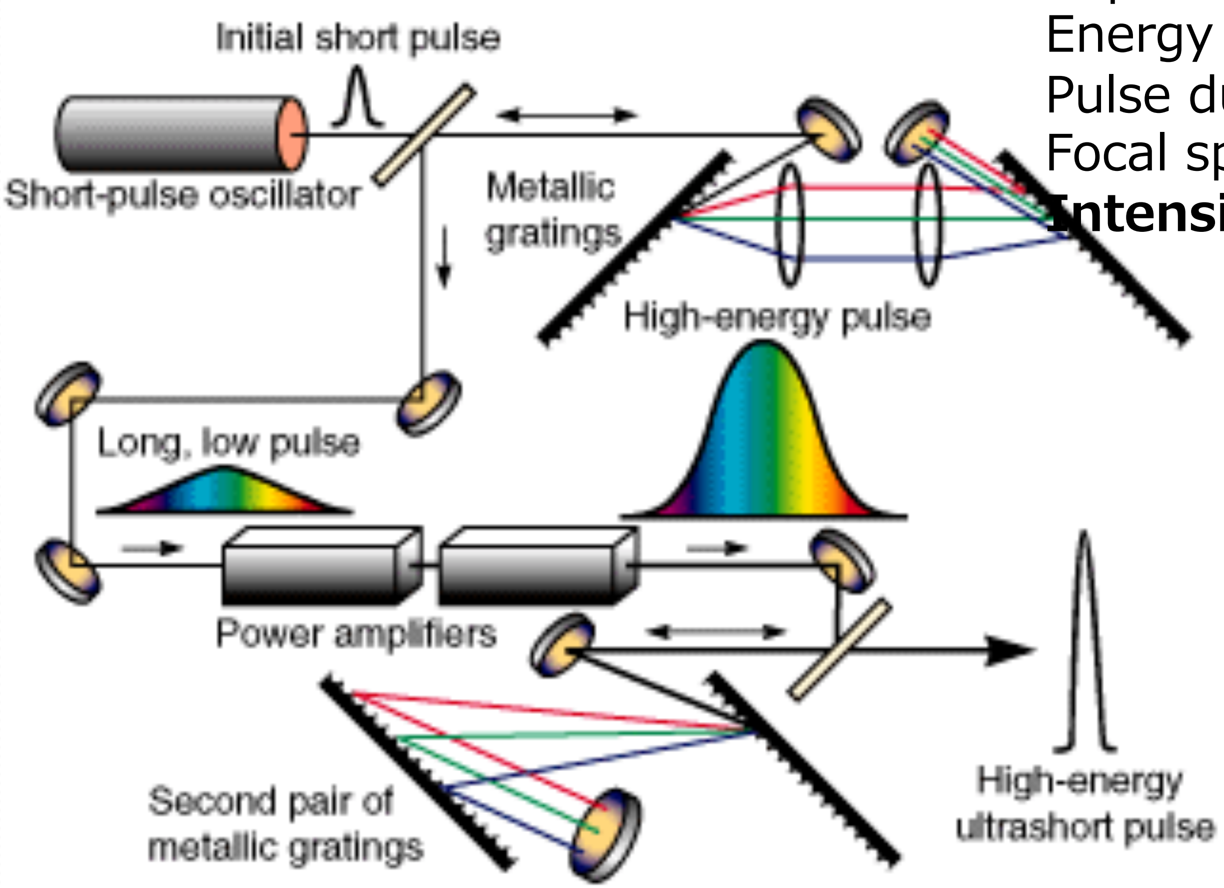
Micro droplet target





$\Delta E/E$ =20%

Ter-Avetisyan, et al., PRL 96, 145006 (2006)



Wavelength : 800 ± 10 nm
Repetition rate : 10 Hz
Energy : 100 mJ / pulse
Pulse duration : 150 fs
Focal spot : 3×5 μm
Intensity : ~3×10^{18} W/cm^2