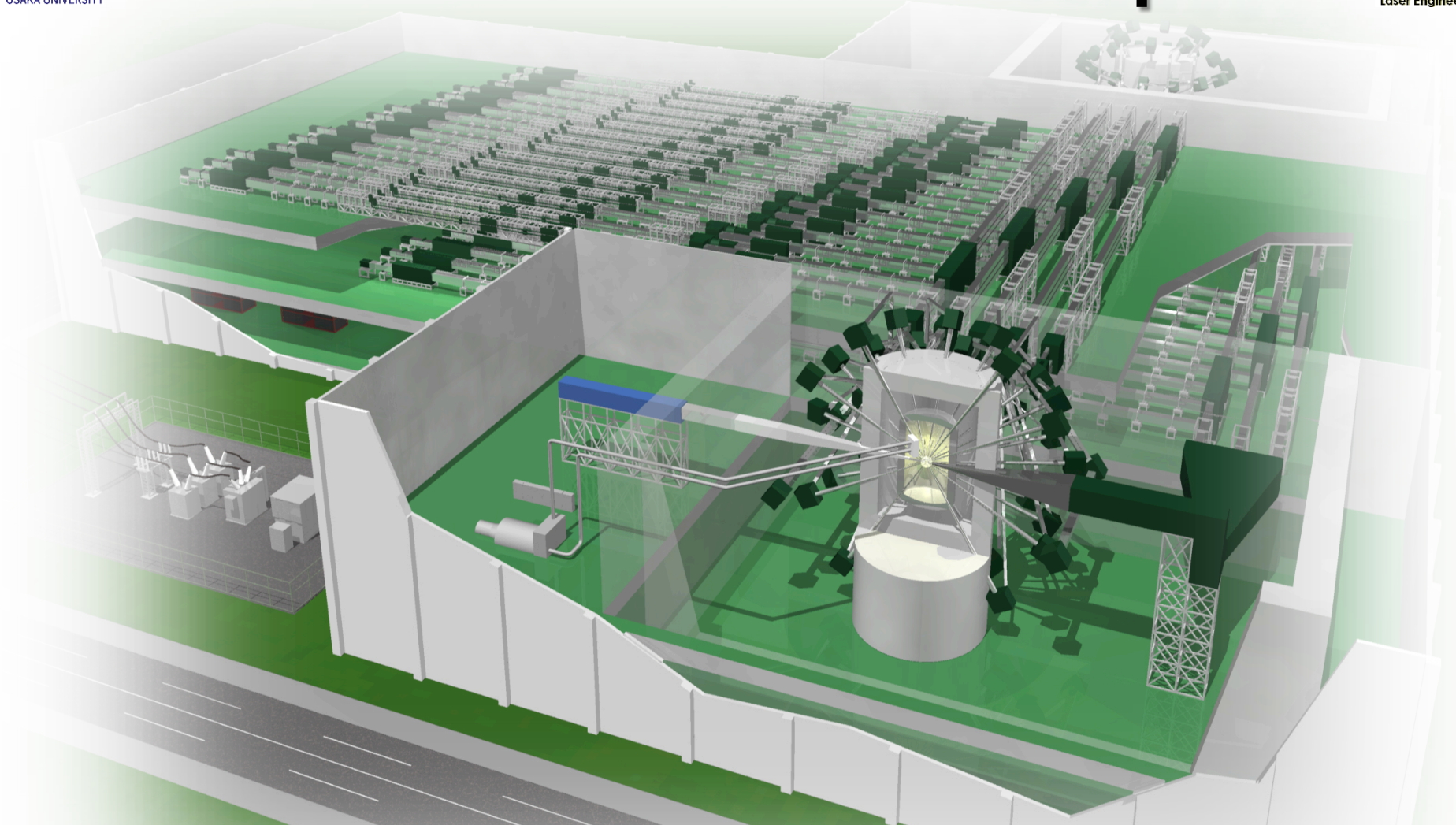
Laser Fusion Status in Japan



Hiroshi AZECHI
Director, Institute of Laser Engineering, Osaka University
Fusion Power Associates 2015.12.15
Hyatt Regency Capitol Hill, Washington DC

Energy Development by Laser Energy Science

✓ Fast Ignition Plasma

Reactor technology

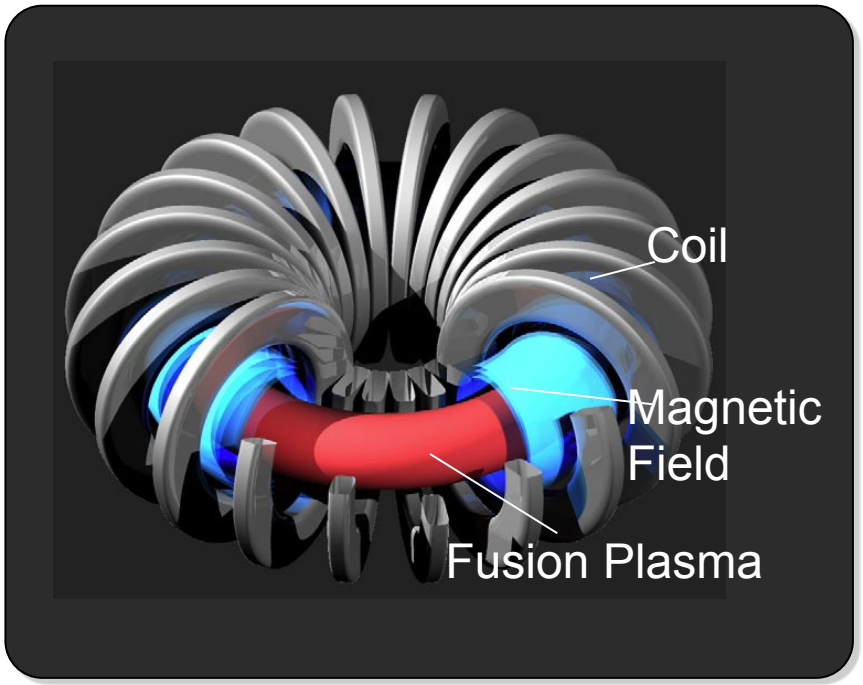
Current topics
- Meteorite Collision
- Collision-less Shock
- High Magnetic Field

Driving Force of Large Scale Lasers

Summary

Magnetic and Laser Fusion

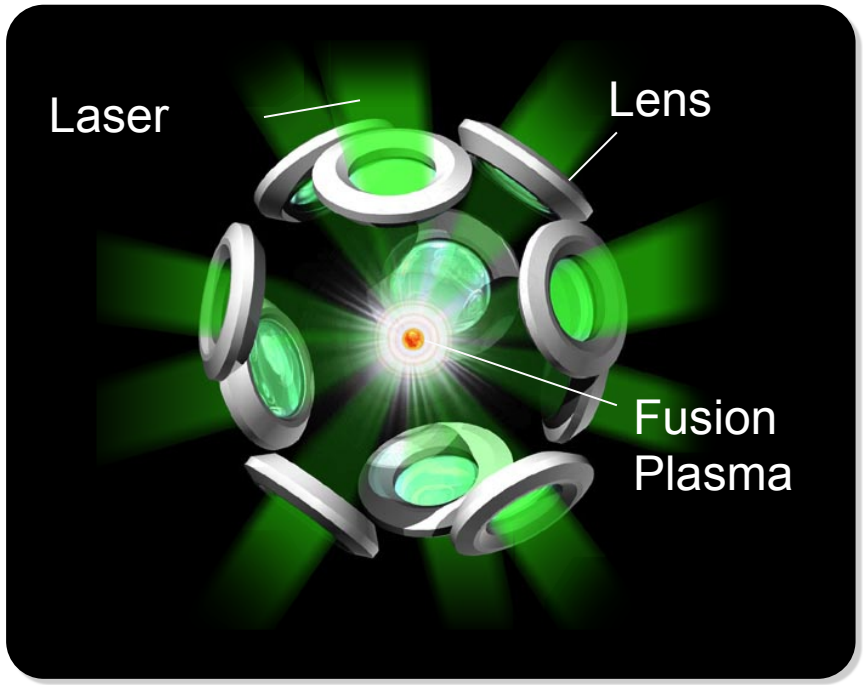
Magnetic Fusion



One Billionth of Solid Density (10^{-9})
Fuel Diameter: 10 m
Steady State Reactor→ Base-load

ITER Organization
Japan Atomic Energy Agency
National Institute for Fusion Science

Laser Fusion

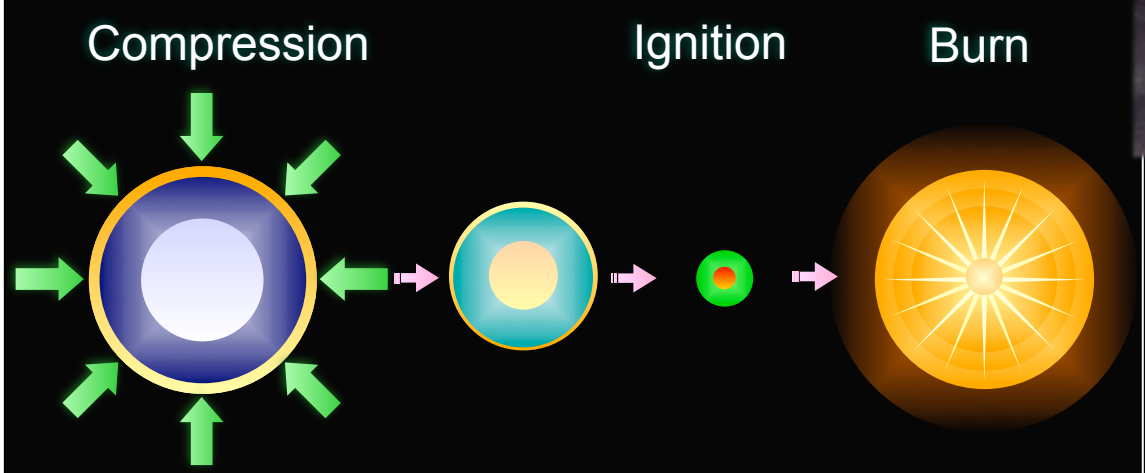


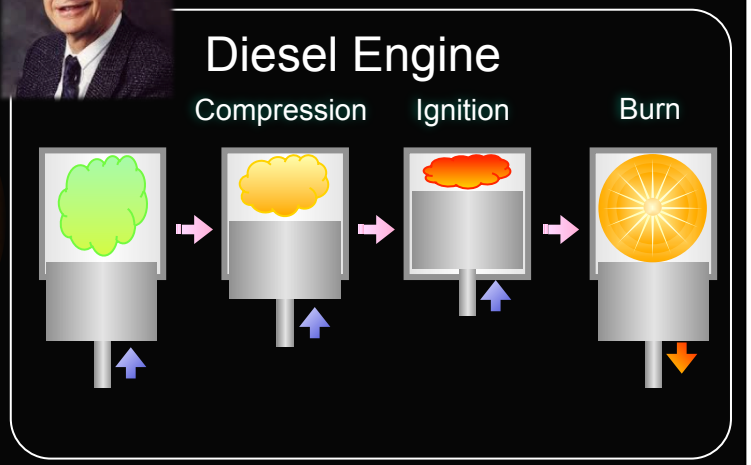
Thousand Times Solid Density (10^{3})
Fuel Diameter: mm→ Compact
Pulse Reactor→ Load Followability
→Peak-load

Lawrence Livermore National Laboratory
French Atomic Energy Commission
University of Rochester
Osaka University

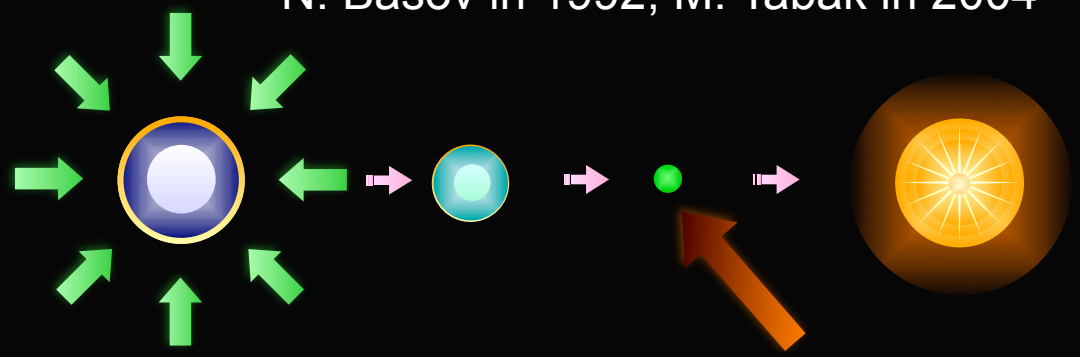
Central and Fast Ignition Schemes

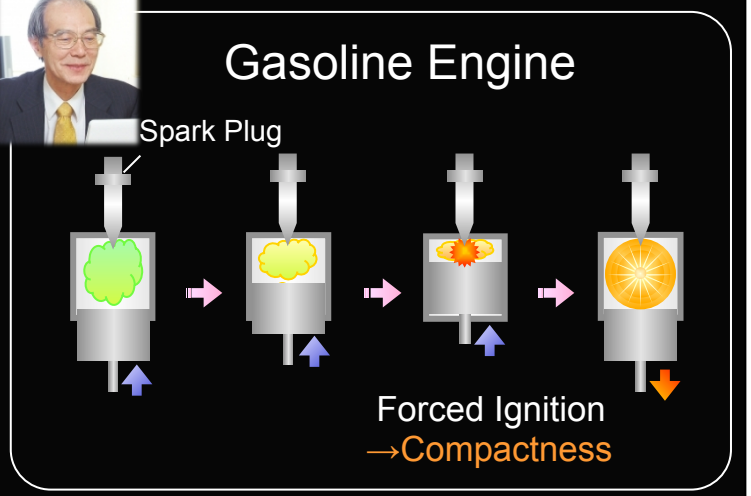
Central Ignition proposed by J. Nuckolls in 1972





Fast Ignition proposed by T. Yamanaka in 1983
N. Basov in 1992, M. Tabak in 2004





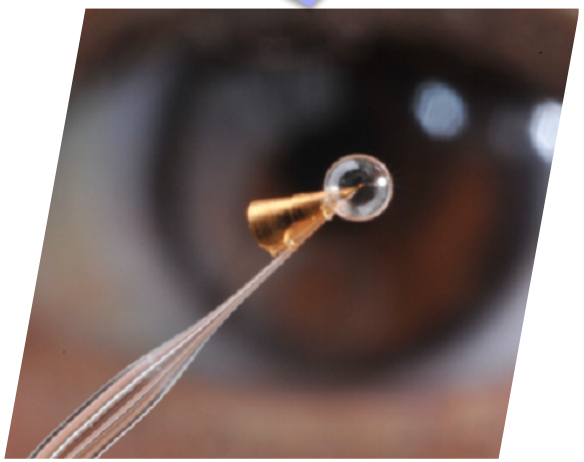
Compact fusion will accelerate inertial fusion energy development.

FIREX

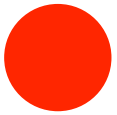
Fast Ignition Realization EXperiment

Nanosecond Implosion Laser
GEKKO-XII

Picosecond Heating Laser
LFEX

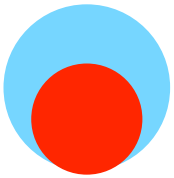


①FIREX-I/Heating



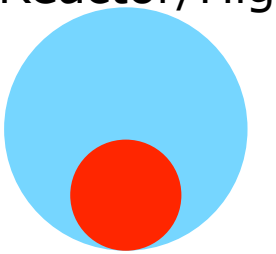
$\rho R \sim 0.2$ g/cm^2

②FIREX-II/Ignition



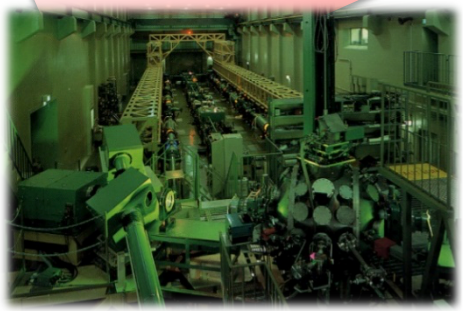
$\rho R \sim 1.2$ g/cm^2

③Test Reactor/High Gain



$\rho R > 2.0$ g/cm^2

Increase of Heating Laser Energy



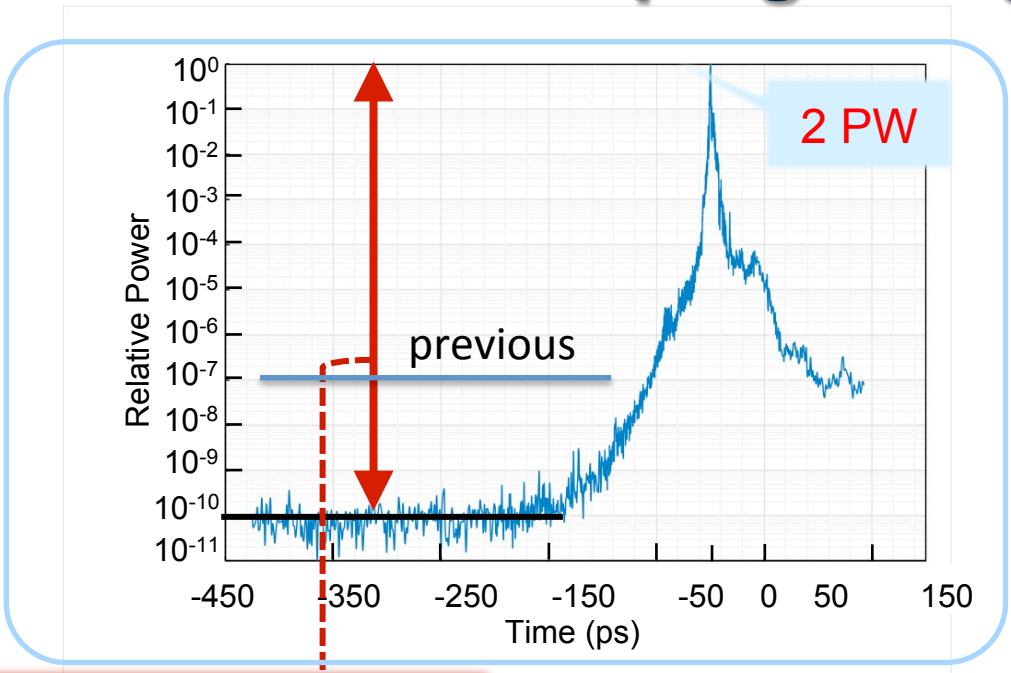
GEKKO-MII-Short Pulse
1991
30 J / 1 ps

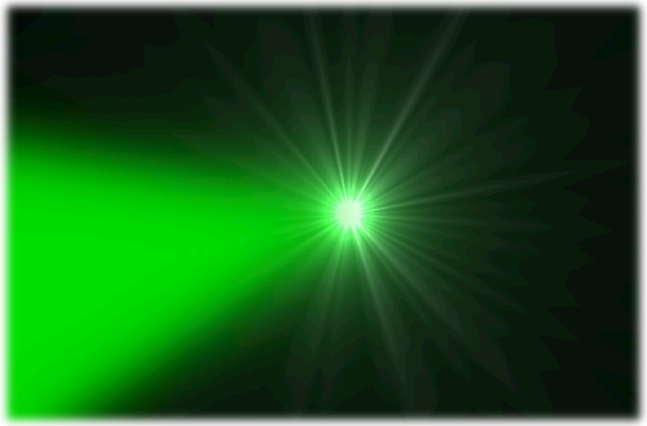
PetaWatt 1996
PetaWatt 2001
0.5 kJ / 0.5 ps

LFEX 2009-
2-10 kJ /1-10 ps

Increase of Heating Laser Energy

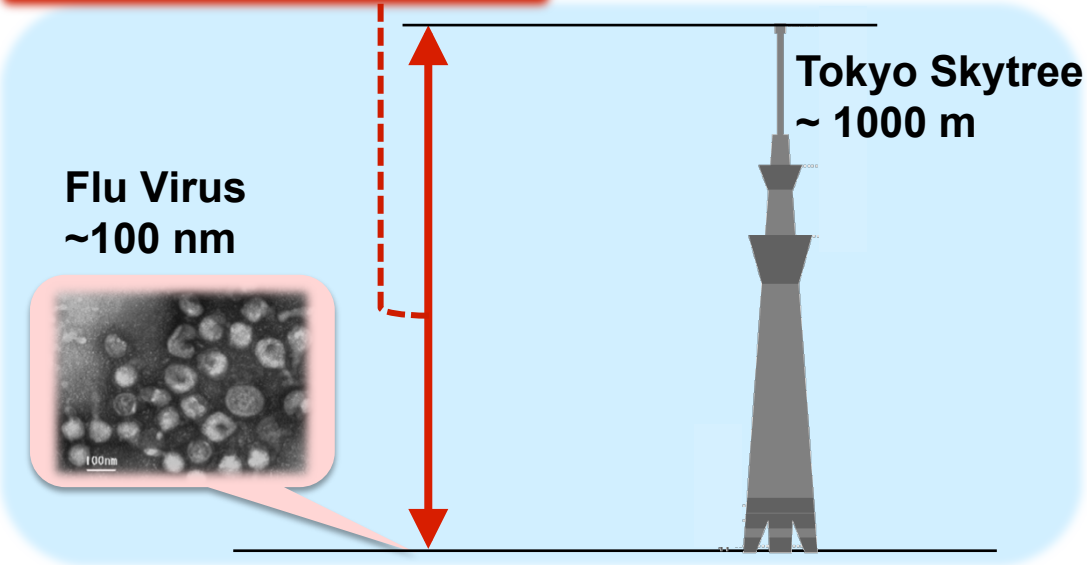
Cool REB Campaign: Highest Contrast





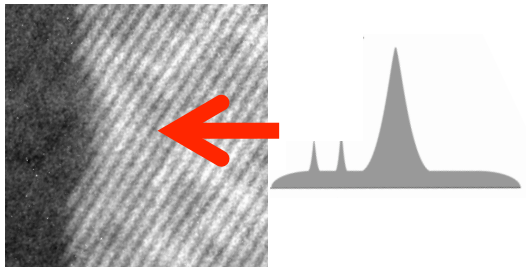
>10 orders of magnitude

Pedestal : Peak ≈ Virus : Skyscraper

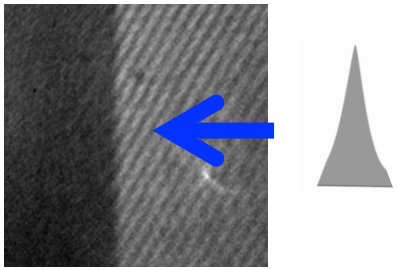


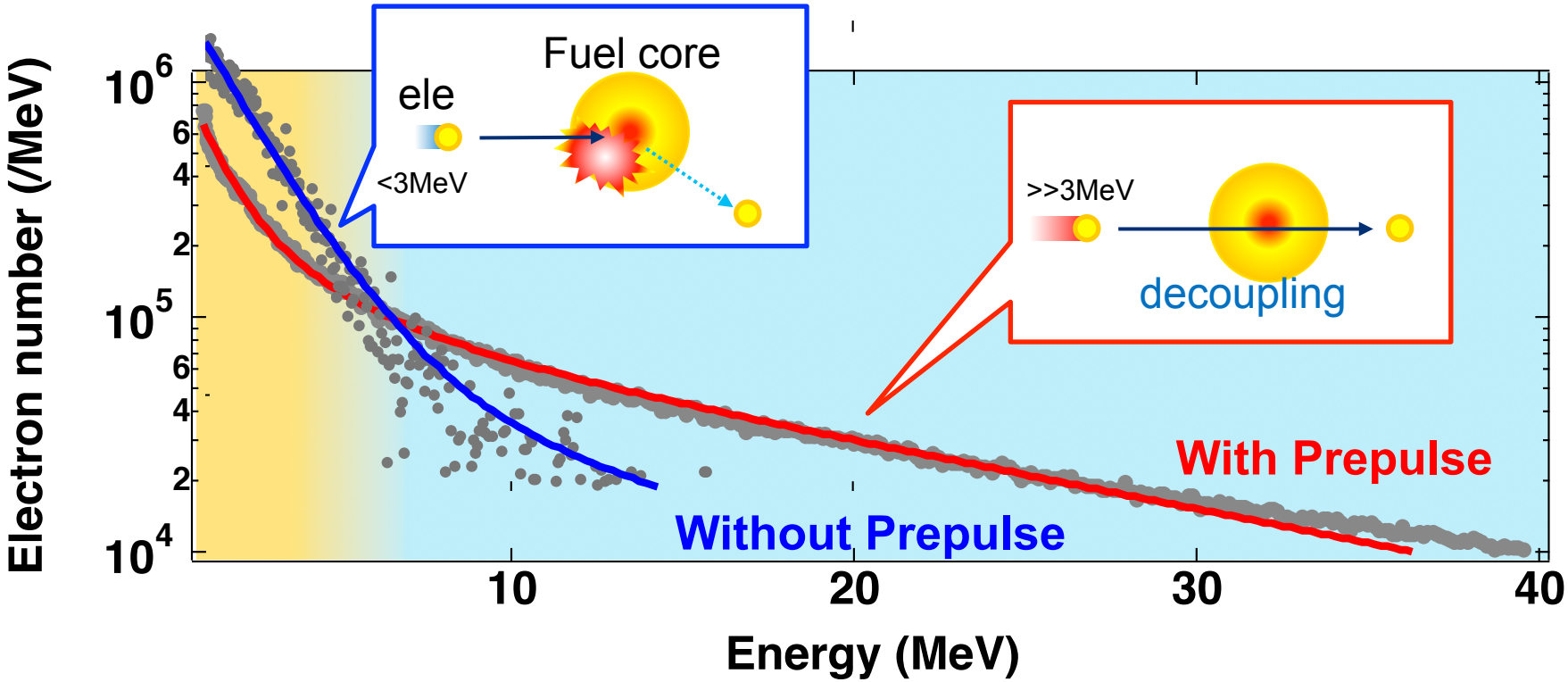
Cool REB Campaign: Results

With Prepulse
@1.5 ns before main pulse



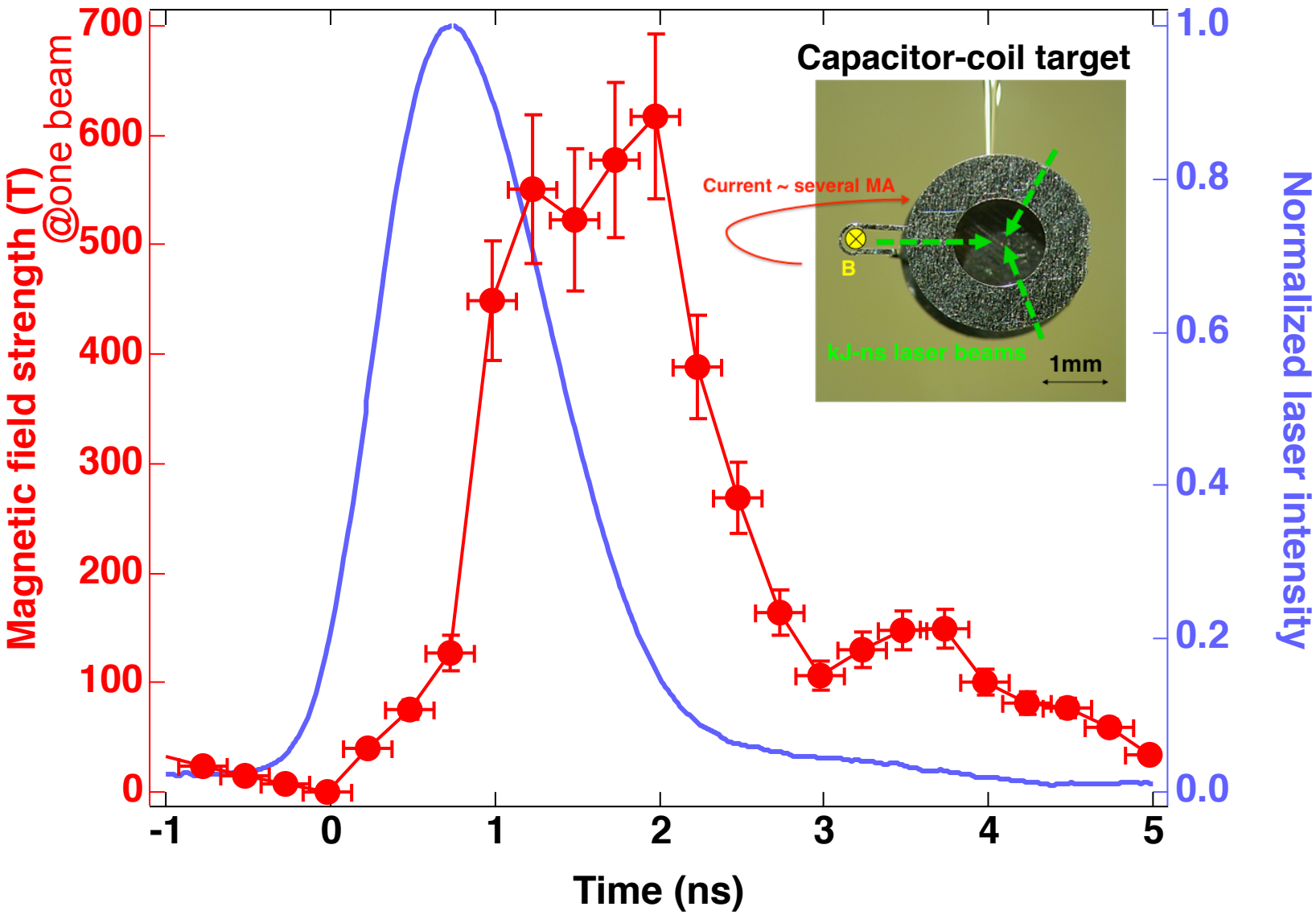
Without Prepulse
@0.15 ns before main pulse





Low energy component of REB increased dramatically.

Guiding REB Campaign

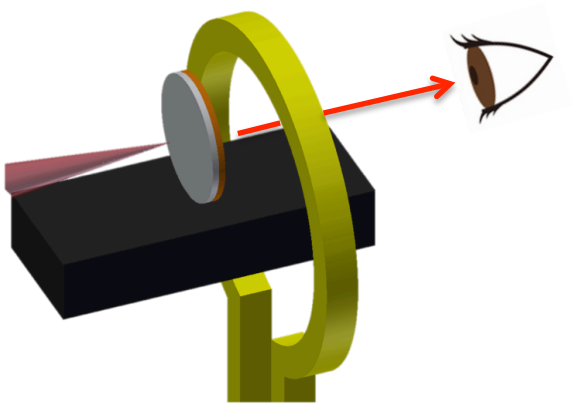


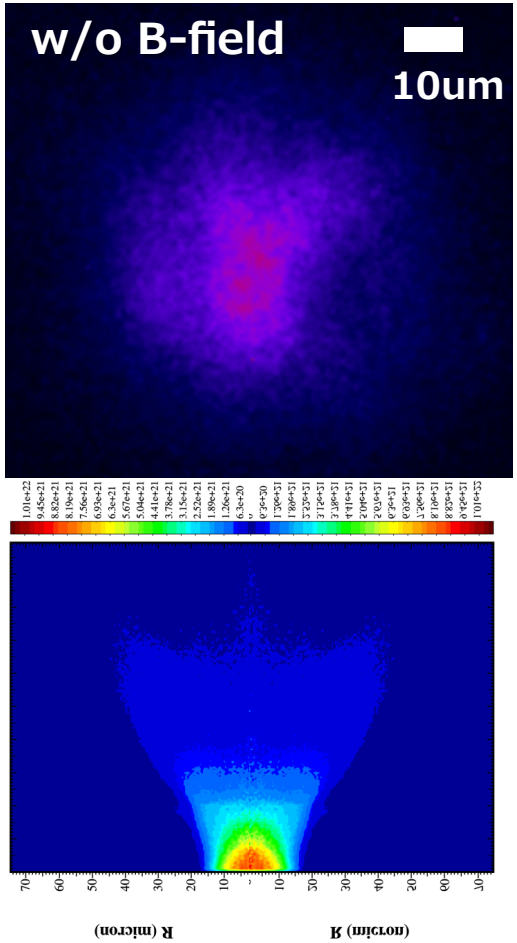
Laser driven Capacitor-coil target generated strong (kilo Tesla) magnetic field

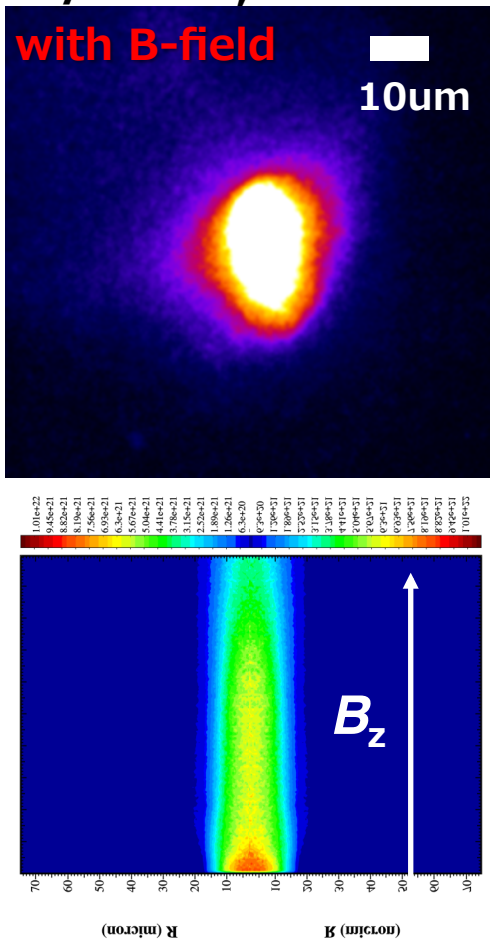
Guiding REB Campaign

Spatial spread of REB after long distance traverse

X1/2 size, X8 intensity







Kilo Tesla magnetic field guides relativistic electron beam.

Energy Development by Laser Energy Science

Fast Ignition Plasma

✓ Reactor technology

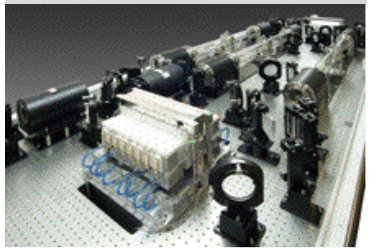
Current topics
- Meteorite Collision
- Collision-less Shock
- High Magnetic Field

Summary

Three Innovations for High Repetition Laser

From Flush Lamps to Diodes

Flash Lamps
Broad spectra
→Inefficienty

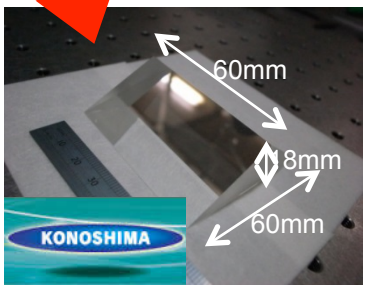


Laser Diodes
Emission lines≈
absorption lines

X100 efficiency

From Glasses to Ceramics

Laser Glasses
- Large optics
- Low thermal conductivity

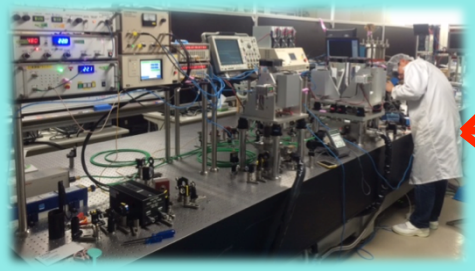


Yb: YAG Cooled Ceramic Crystal
- Large optics
- High thermal conductivity

X100 thermal conductivity

GEMBU Laser 1J, 100Hz

Cooled Ceramic Crystal Laser developed in ILE becomes a Global Standard.

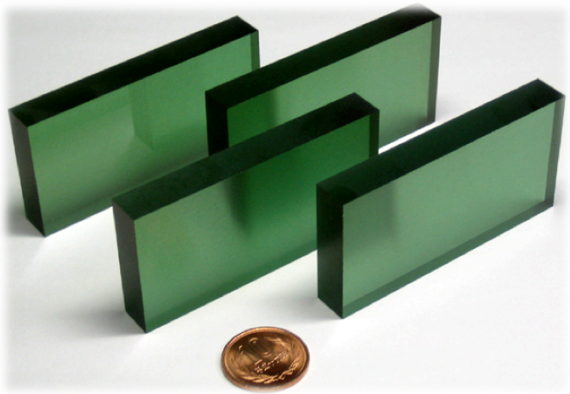


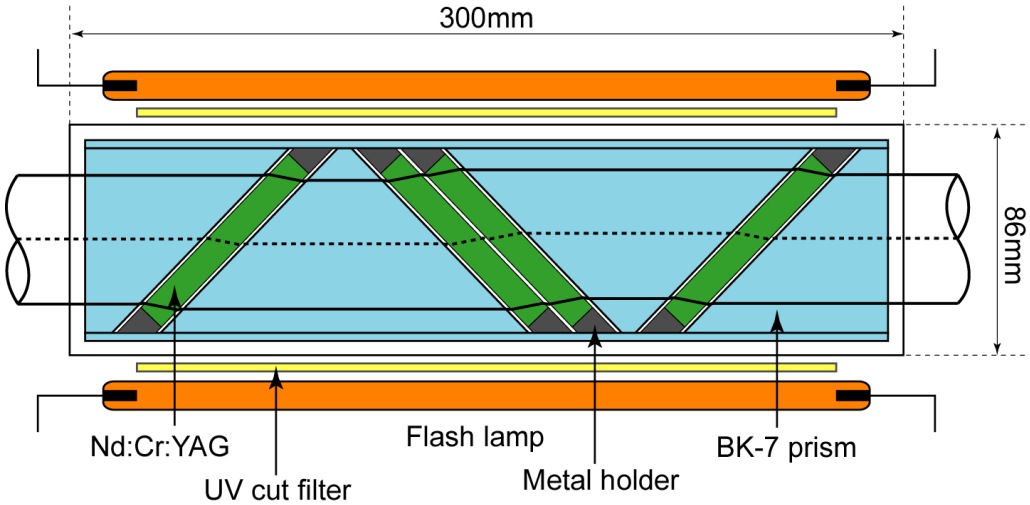
Outflow

- DiPOLE (UK Rutherford Lab.) 10J, 10Hz
- Lucia (France LULI) >10J, 10Hz
- ELI Beamlines (Czech) L2: 100J, 10Hz

Split Disk : a New Breakthrough in Repeatable High Power Laser

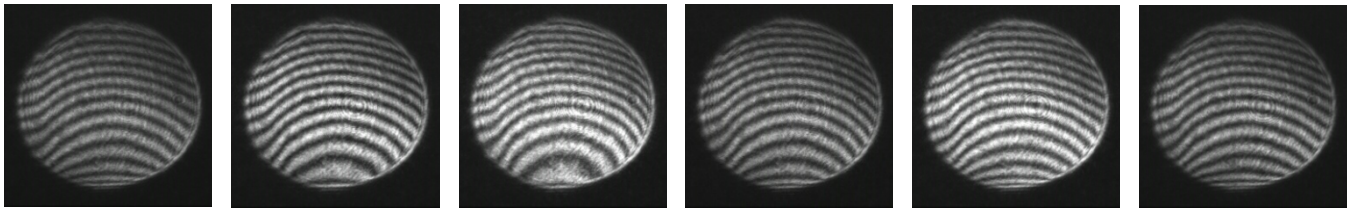
Nd:Glass or
Ceramic Nd:Cr:YAG (Nd: 0.8at% Cr: 0.1at%)





X100 heat removal

10l/min (0.5m/sec), 800J, 10Hz, 100pulse



Interference fringe of water

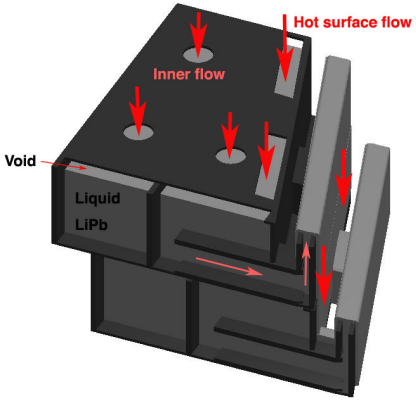
0s 5s 10s 15s 30s 40s

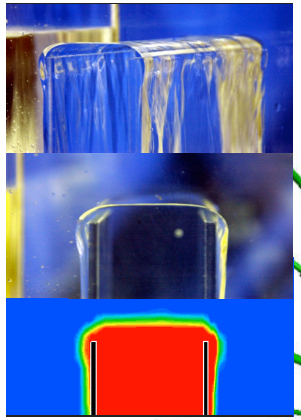
excitation

kJ/0.1-0.01 Hz module will be coming soon

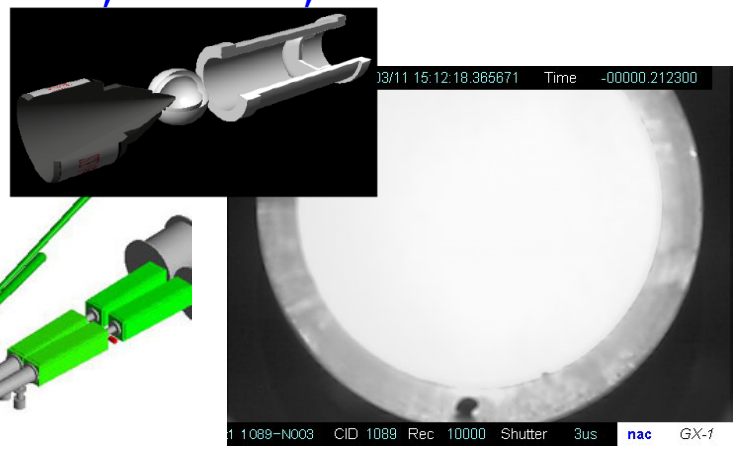
Reactor Technology

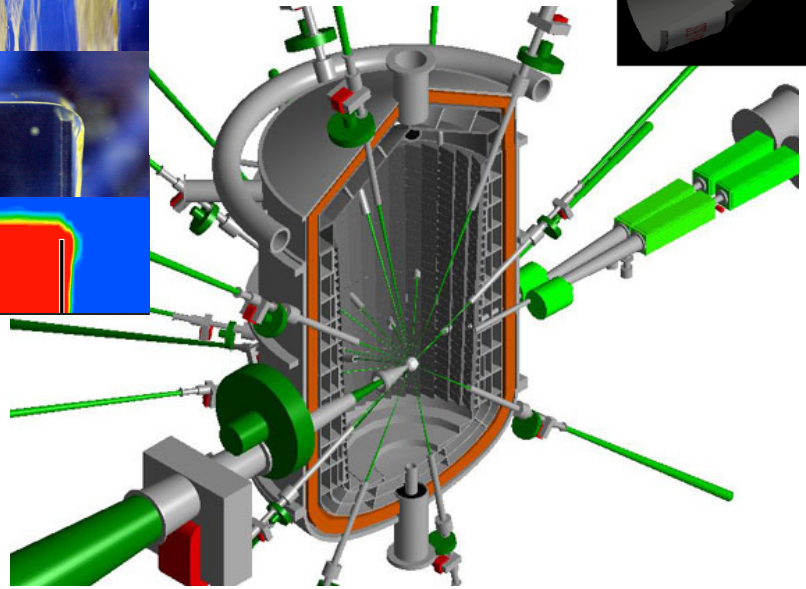
- Liquid Wall, Kyoto U
  Stability of free surface



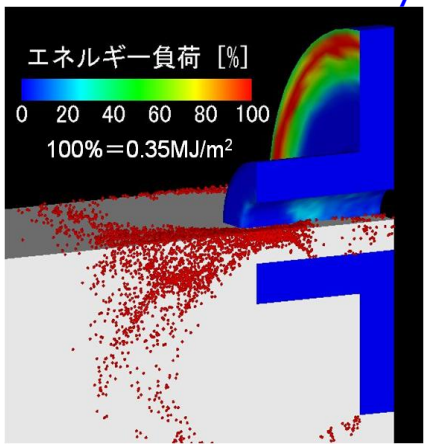


- Injection, Tracking, Steering
  Hiroshima, Gunma, Gifu U's



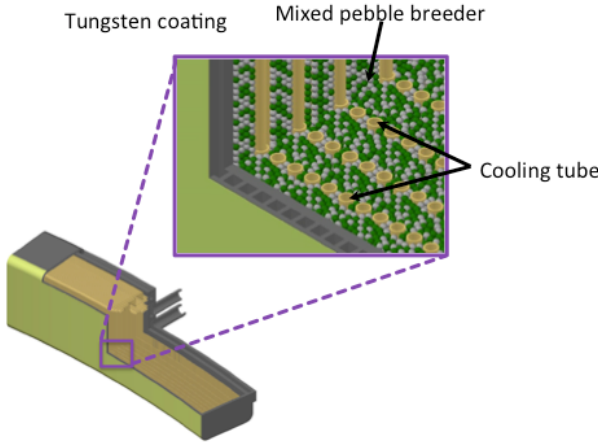


- Protection of optics
  Kyoto U
  Plasma exclusion by B



- Repetition Laser
  Photon science center
  Hamamatsu Photo.

- Tritium Technology
  Kyushu, Toyama U's



Reactor technologies are developed in parallel cooperation with various organizations.

Energy Development by Laser Energy Science

Fast Ignition Plasma

Reactor technology

✓ Current topics
- Meteorite Collision
- Collision-less Shock
- High Magnetic Field

Driving Force of Large Scale Lasers

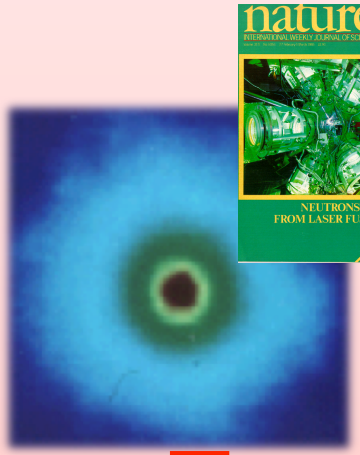
Summary

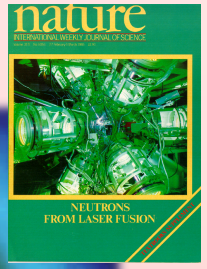
Opening New Basic Science

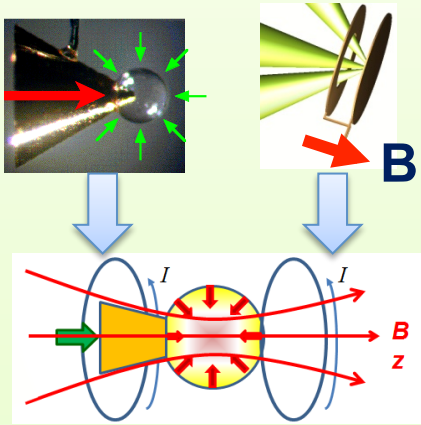
OSAKA UNIVERSITY

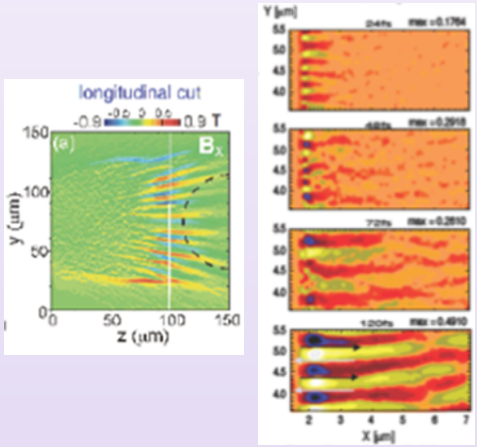
Institute of Laser Engineering

	Hydrodynamics	High Field	Plasma Phys.
Fusion	**Implosion**	**Efficient Heating**	**Electron Stream**
Science	**Meteorite Collision**	**Magnetic Field**	**Collisionless Shock**





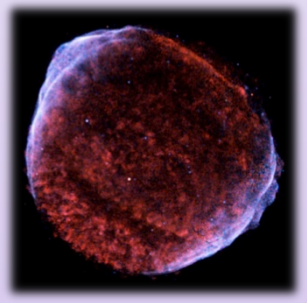


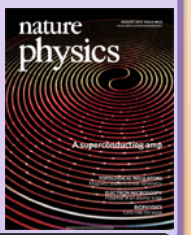


Nature Geosci. 2014

- Nonlinear Zeeman
- Landau Quantization
- Vacuum Breakdown

Sci. Report 2013

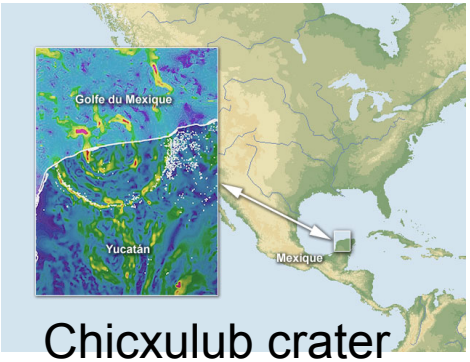




Nature Physics 2012, 2015

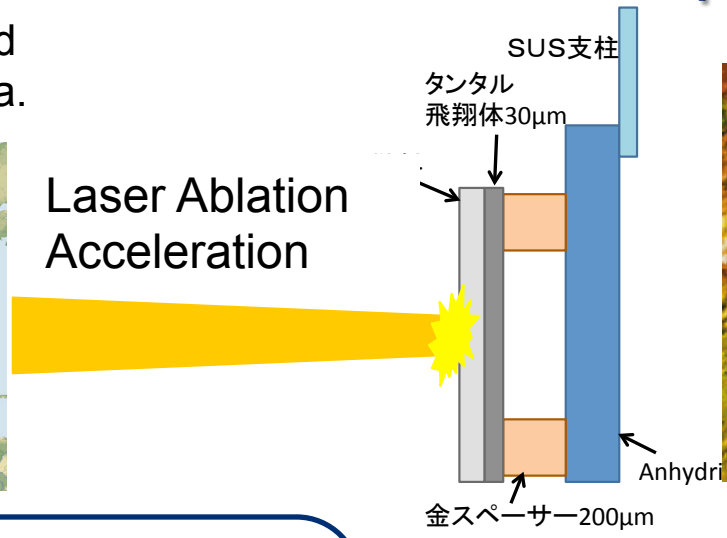
Meteorite Collision
at the end of Cretaceous period

A big meteorite collided with Yucatan Peninsula.



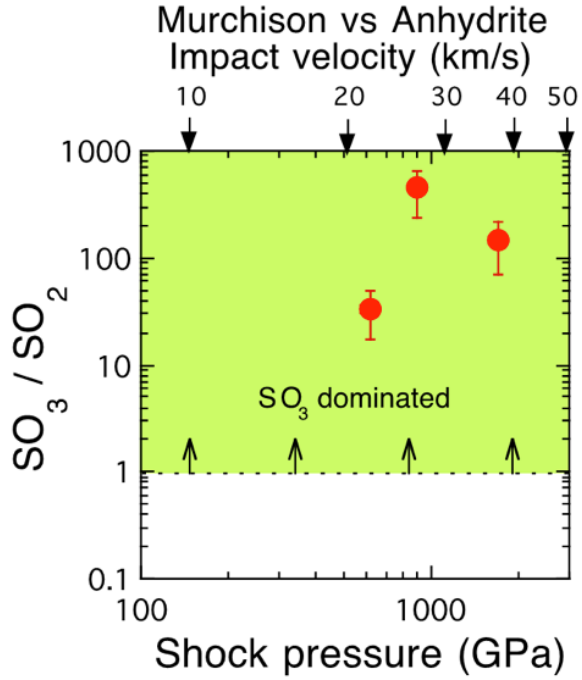
Chicxulub crater

Laser Ablation
Acceleration



Ohno,
Nature Geosci. 2014

SO3: unstable sulphate-rich vapor



Global acid rain, destroying the ecosystem

Dinosaurs Extinction

A huge quantity of sulphur trioxide made the ocean sulfuric acidic.

Strategy Consideration

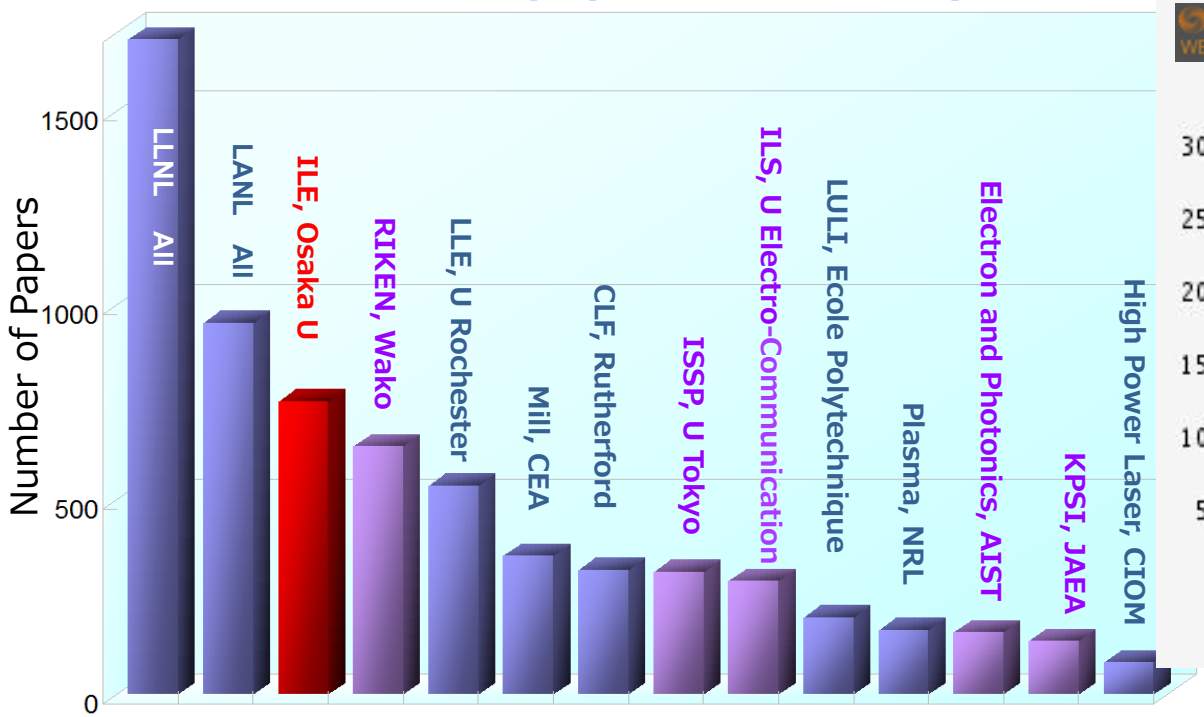
1. Disappearance of “Cold War Engine”
   - Central issue was Nuclear Weapon Race.
   - Basic Science was also driven as national dignity.
     Fermi lab director Wilson said (1969): “It has nothing to do directly with defending our country except to make it worth defending”

2. Exploration
   - Since the way of late 20th Century was anomalous, backing to “Science for science” or “Science for culture” is one possible candidate.
   - Education of people is always public value of science.
   - But these are NOT sufficient to to get understanding of public.

3. What is the next engine?
   - People’s strong support (User’s Facility is one)
   - Truly international cooperation

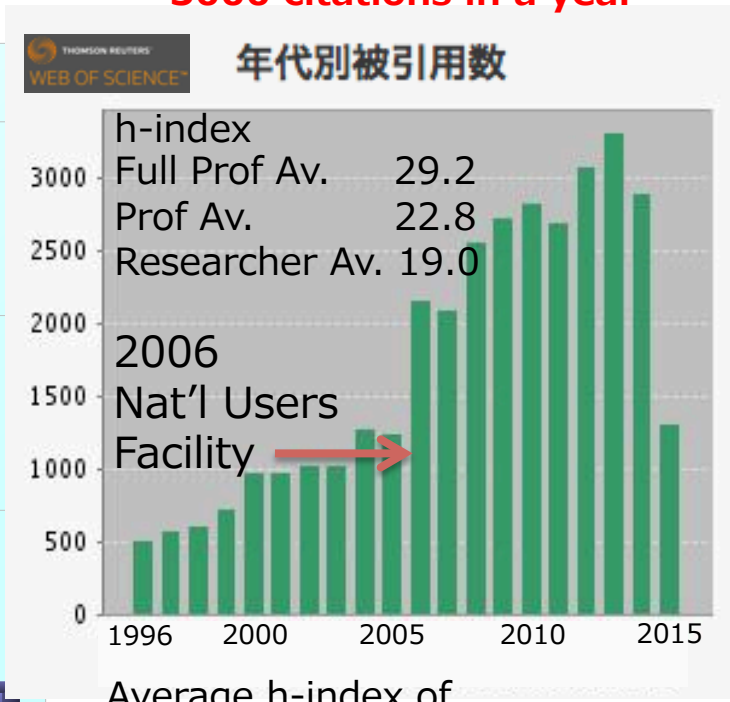
World-Class Productivity

Laser related papers in last 10 years

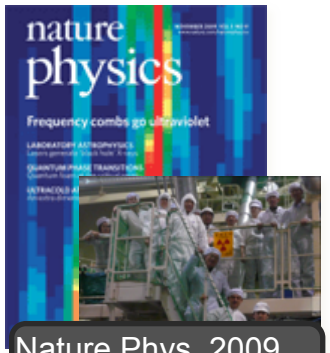


Keyword: "Laser" and authors' organization

3000 citations in a year



Average h-index of Nobel physicists is 41 (2005).



Nature Phys. 2009
near a black hole

Nature Phys. 2012, 15
collisionless shock wave

Nature 2012
galactic B fields

Sci. Report 2013
kT magnetic fields

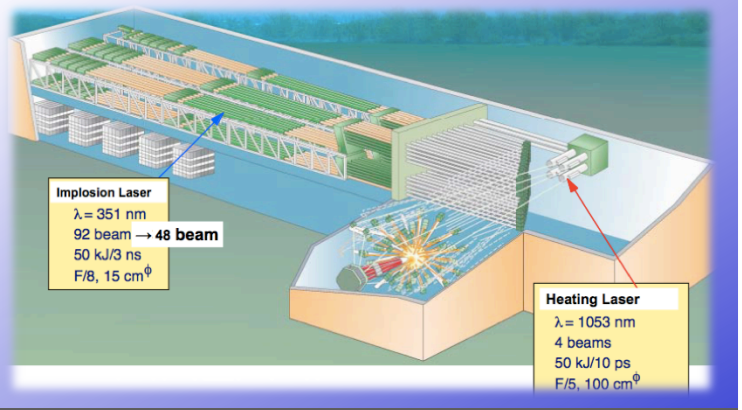
Nature Geosci. 2014
meteorite collision

Strategy towards Fusion Power Generation

~2015

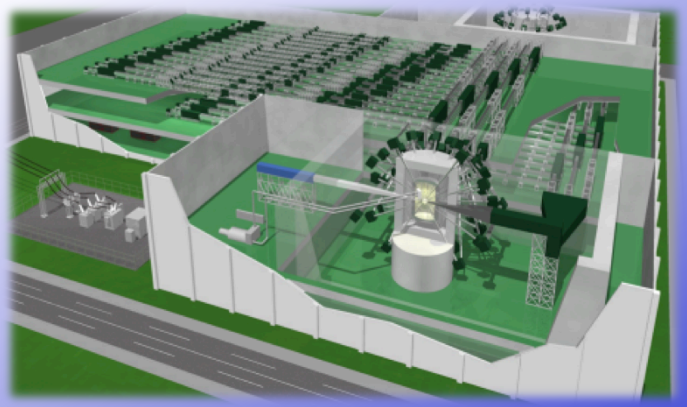
FIREX-I: Ignition Temp

~2025



International Fast Ignition

~2040



LIFT: Power Generation

Atomic Energy Commission of Japan report (Oct. 2005):

"Based on its (FIREX-I) achievement, it will be decided whether the project should advance to its second-phase which will be aimed at realizing of ignition and burning"

*Laboratory Inertial Fusion Test

Next Generation Multi-Purpose Facility

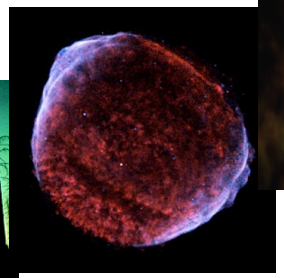
OSAKA UNIVERSITY

Institute of Laser Engineering

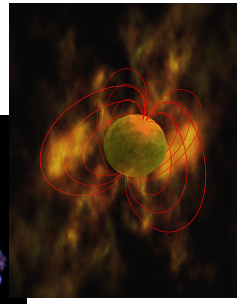
Academia

Dinosaurs Distinction

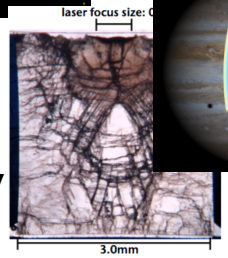
Collisionless Shocks

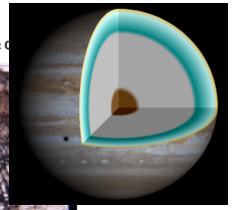


Magnetor



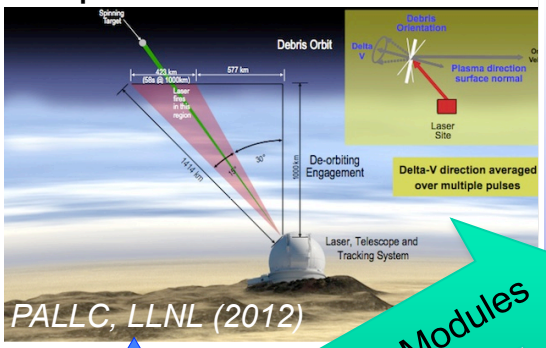
EOS & Planetary Science





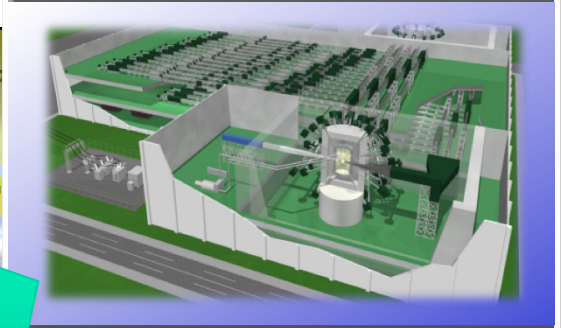
Security

Space debris elimination



PALLC, LLNL (2012)

Energy ~2040



LIFT: Power Generation

160-520 Modules

1.25 kJ
X16 Modules
With
30 Peta Watt

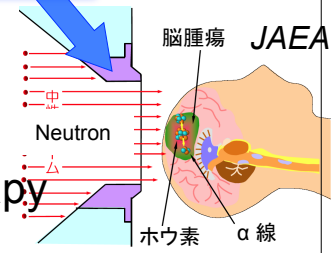
Cooled Ceramics

LD Pump

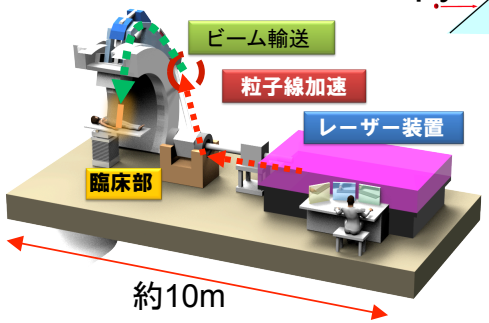
~2015

FIREX-I

Health



Beam Cancer Therapy



NIKKEI Newspaper
JAEA
(2011)

Industrial innovation

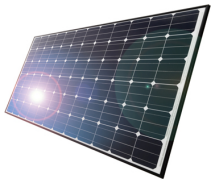
Precision laser peening

Gear

finishing process in 3D printing

Turbine blade

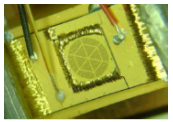
New material technology



Laser surface treatment (a-Si)
Perovskite ceramics

Optical technology evolution

High-power LD,
Ceramic material,
Optical coating



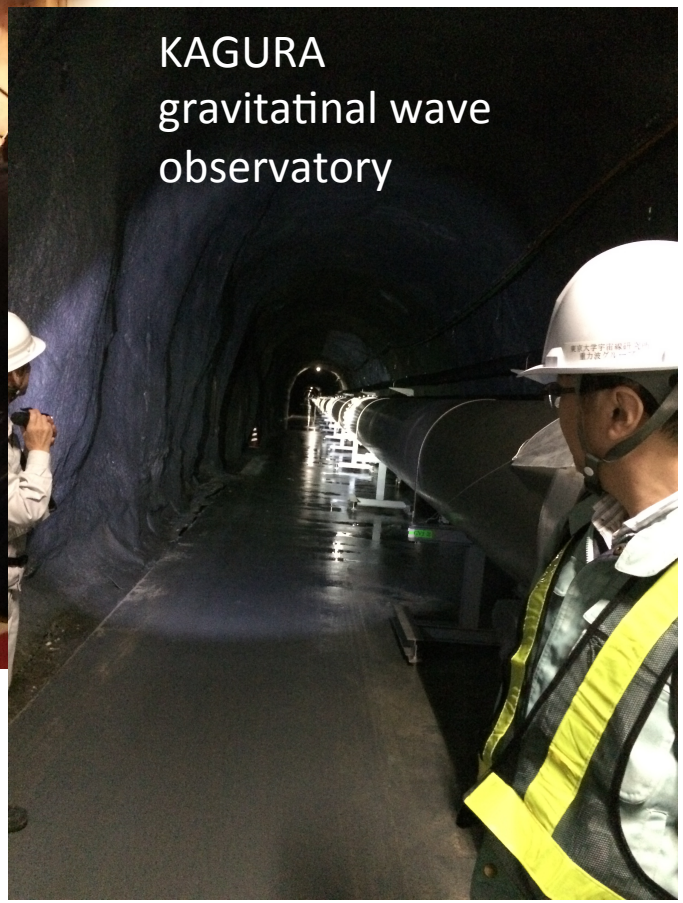
1 kW
VCSEL
(5x5mm)

Summary

- Fast ignition scheme is steadily on going as FIREX-I project.
  We hope to achieve 5-keV temperature within a few years,
  - with decrease of temperature and
  - magnetic field guiding of electron beam,
  - together with full operational of LFEX.

- Towards a future power plant, we are developing high rep. rate laser technologies including ceramic lasers at ILE.

- We need, for our future
  - very strong support from community
  - truly international cooperation of facilities such as FIREX-II.
  - should moved to Multi-Disciplinary Multi-Purpose Facility

Advantage of Inertial Fusion

Separability
Modularity
Commonality