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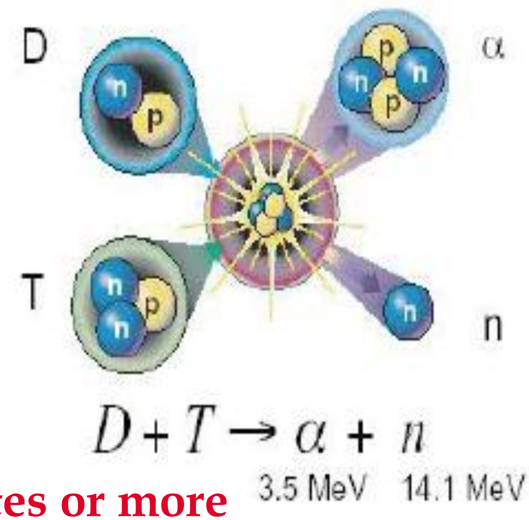
What is

Inertial Confinement Fusion?

Inertial Confinement Fusion: dense & short-lived plasma



Fusing D and T requires

- temperature – to overcome Coulomb repulsion
- density & confinement time – to maximize number of reactions

MCF: low density plasma confined by B fields over minutes or more

ICF: high density plasma confined – very briefly – by its own inertia

→ ICF is a *pulsed* process

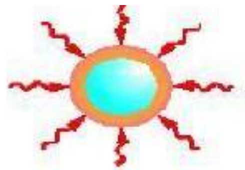
Areal density (ρR) is a key parameter

- for efficient burn (fuel burns before it deconfines)
- for reasonable driver & yield energies

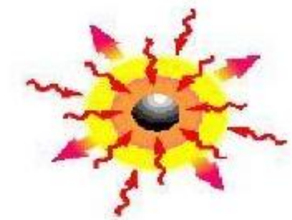
Hot spot ignition needed to make up for low laser and hydrodynamic efficiencies:
fusion reactions start in heated fuel and spread to neighboring cold fuel

Laser-driven ICF uses intense laser beams to compress and heat a small pellet of DT fuel

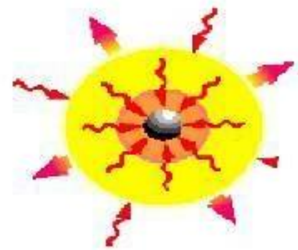
HEATING
& ABLATION



COMPRESSION

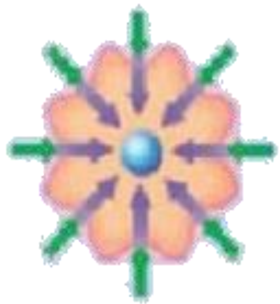


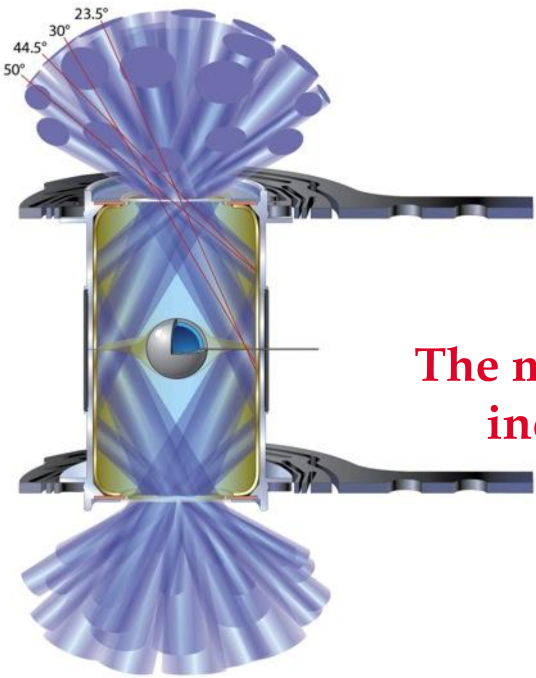
IGNITION



BURN
PROPAGATION

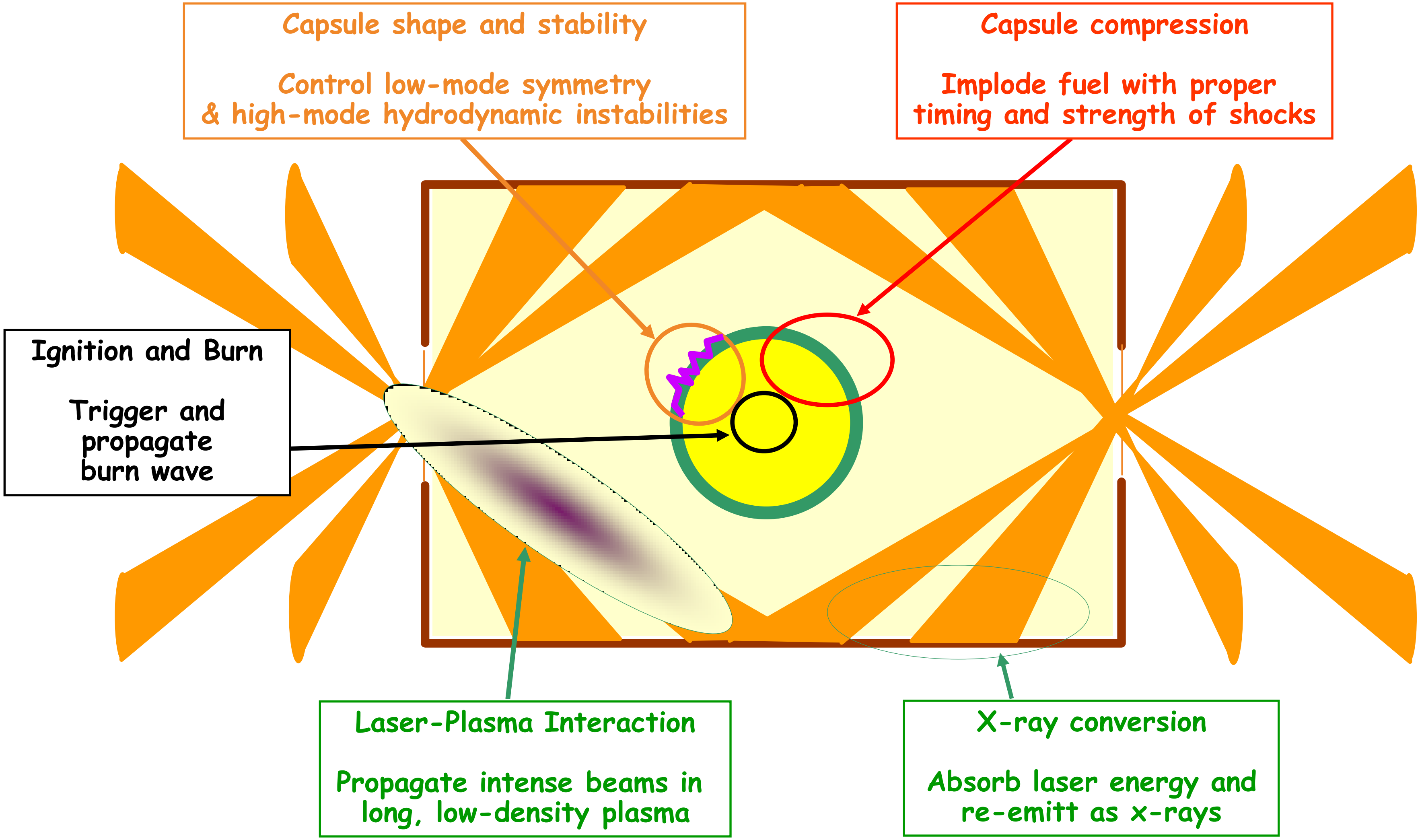
The obvious way:
direct drive





The mainstream way:
indirect drive

Physics issues associated with indirect-drive ICF



Design relies heavily on complex, multiphysics, radiative hydrodynamics codes

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ICF research status

the National Ignition Facility (USA)

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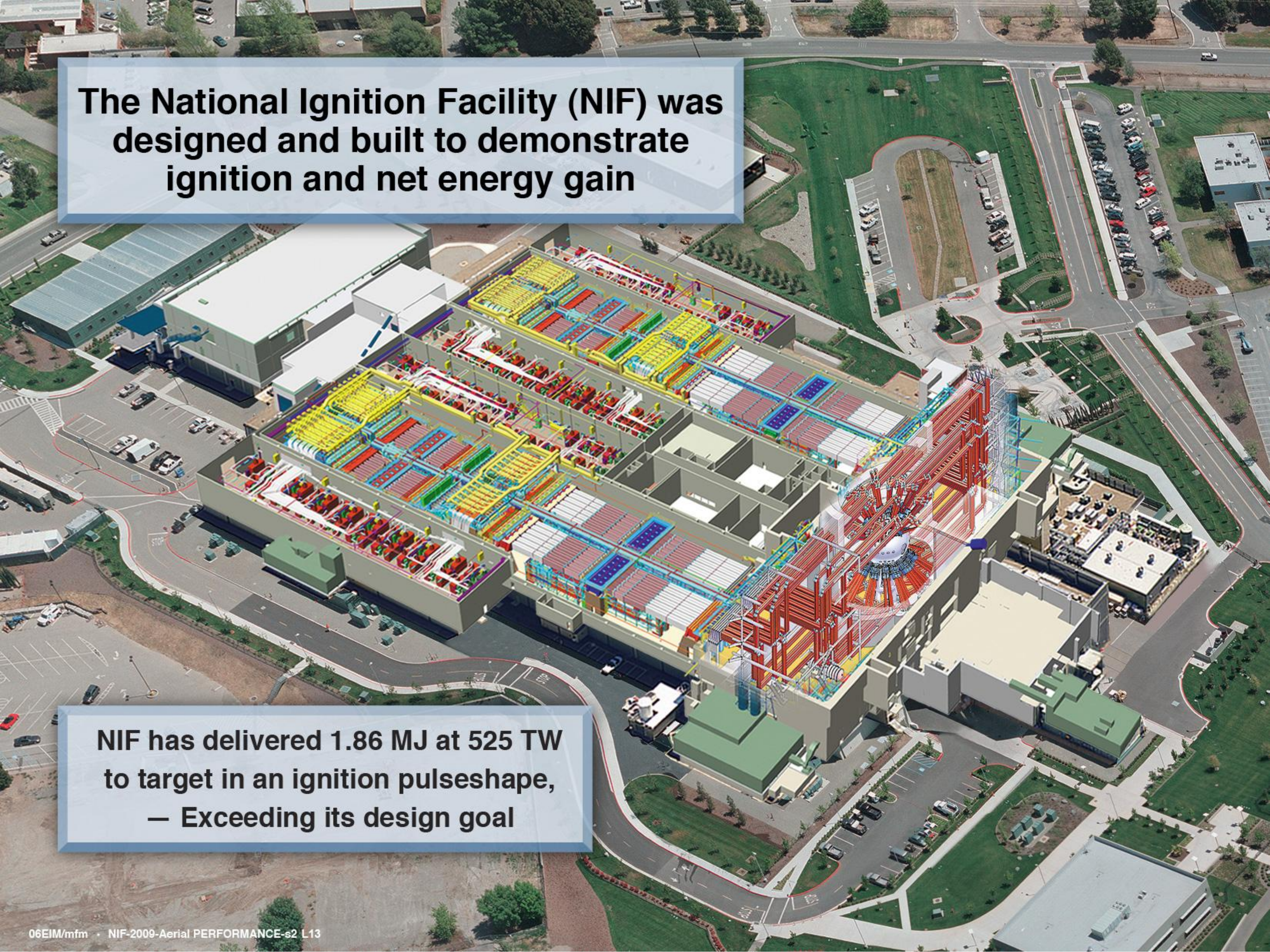
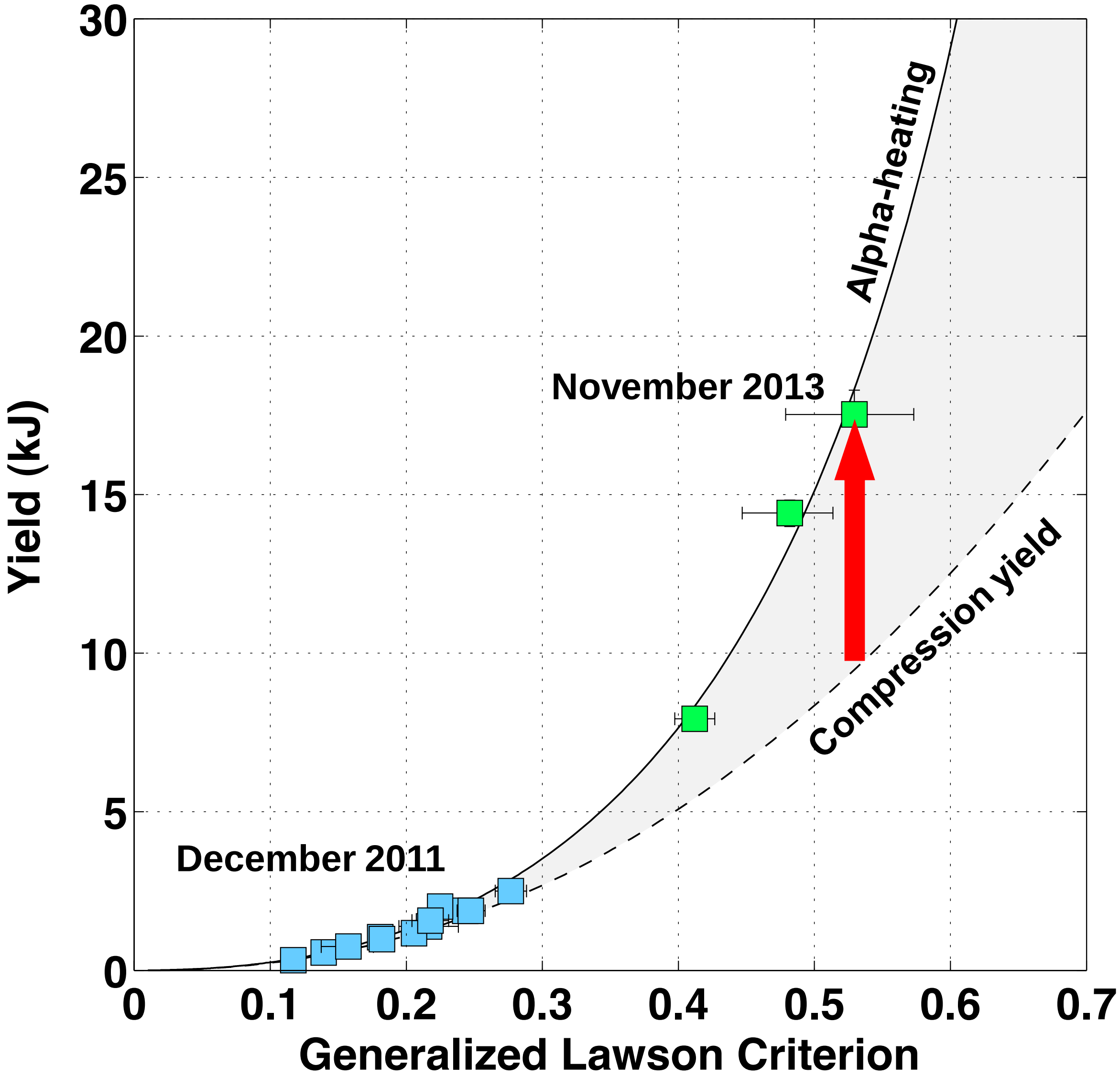


The National Ignition Facility (NIF) was designed and built to demonstrate ignition and net energy gain

NIF has delivered 1.86 MJ at 525 TW to target in an ignition pulseshape,
— Exceeding its design goal

NIF has made good progress towards demonstrating target and laser performance required for ignition



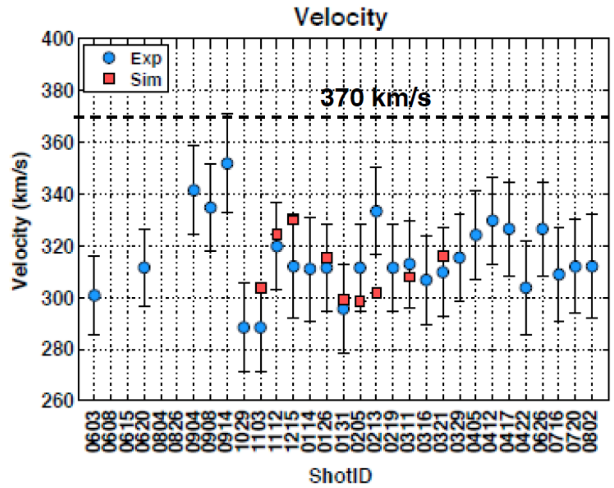
The latest shot had a total yield of 6.2×10^{15} at a Tion = 4.9 keV

The α (or self heating) yield equaled the compression yield

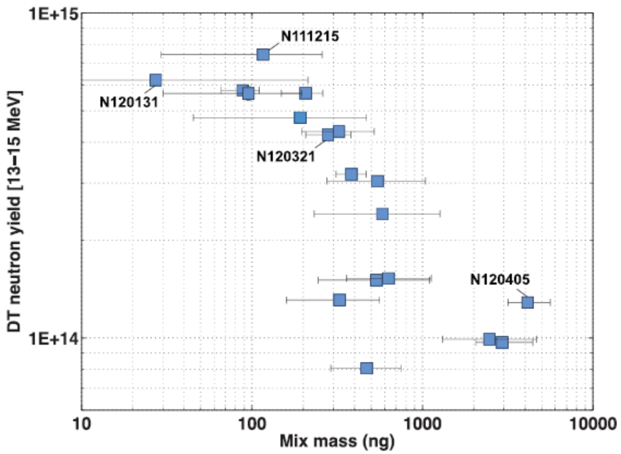
This "α-doubling" is an important step towards achieving fusion ignition

The National Ignition Campaign on NIF had to face two major difficulties: velocity and mix

- ▶ Radiation drive produced in the hohlraum is in reasonnable agreement with predictions, but implosion velocity of capsule systematically below prediction



- ▶ Pressure in hot spot and yield remain low, suggesting more mix of ablator in fuel than expected, quenching fusion

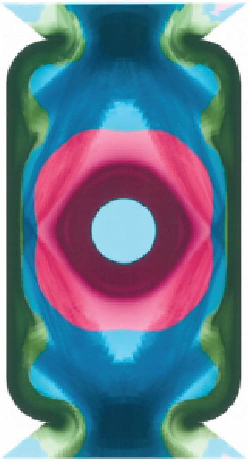


- Changing the pulse shape has improved mix control, and enabled record neutron yields, but scheme does not extrapolate to ignition target
- Clear experimental progress, but offset with simulation still holds

M. J. Edwards (LLNL), IFSA 2013:

We are pursuing 2 paths to improved performance

Gas-filled design

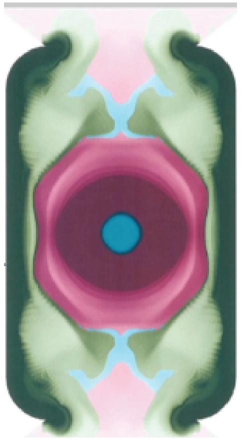


Challenge
Inner beam propagation for symmetric drive

Strategy

- **Lower density plasma**
  - **Hohlraum geometry eg "Rugby"**
- **Higher temperature plasma**
  - **Higher Z fill**
  - **B-fields**

Near vacuum design



Challenge
Implosion before hohlraum fills

Strategy

- **Higher density ablators**
  - **HDC**
  - **Be**
- **Optimal drive with shorter laser pulses**

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ICF research status

the Laser Mégajoule (France)

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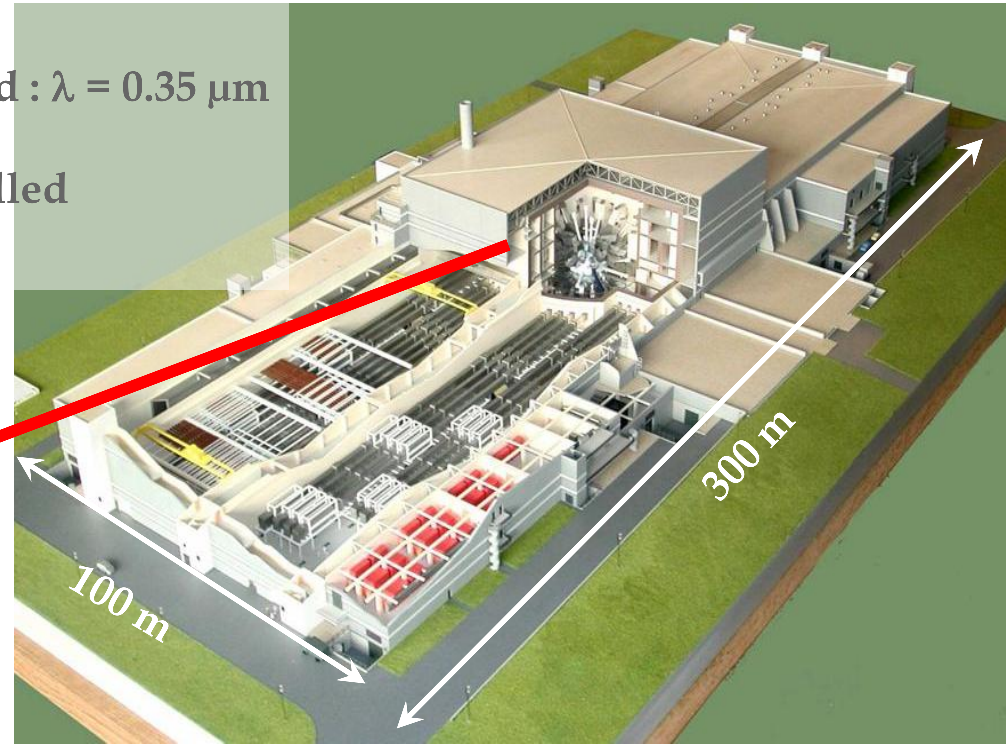
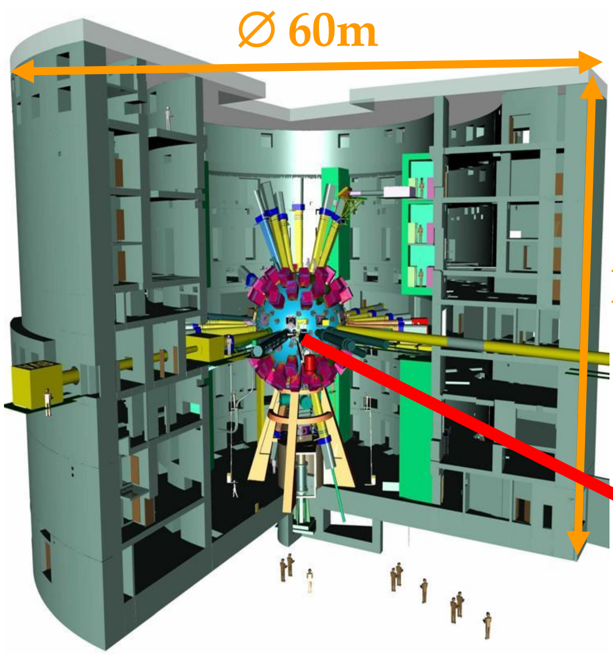
Laser Mégajoule main characteristics

4 Laser bays

- Glass Neodymium laser, frequency tripled : λ = 0.35 µm
- Pulse duration : from 0.3 ns to 25 ns
- Designed for 240 beams, 176 will be installed
- Laser energy > 1.3 MJ, Power > 400 TW

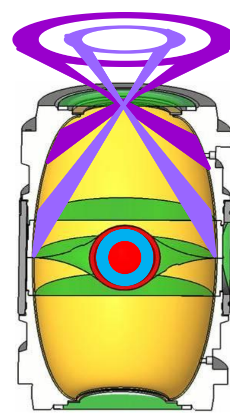




Target area

- Biological protection : 2 m thick concrete
- Target chamber Ø 10 m

Ignition target

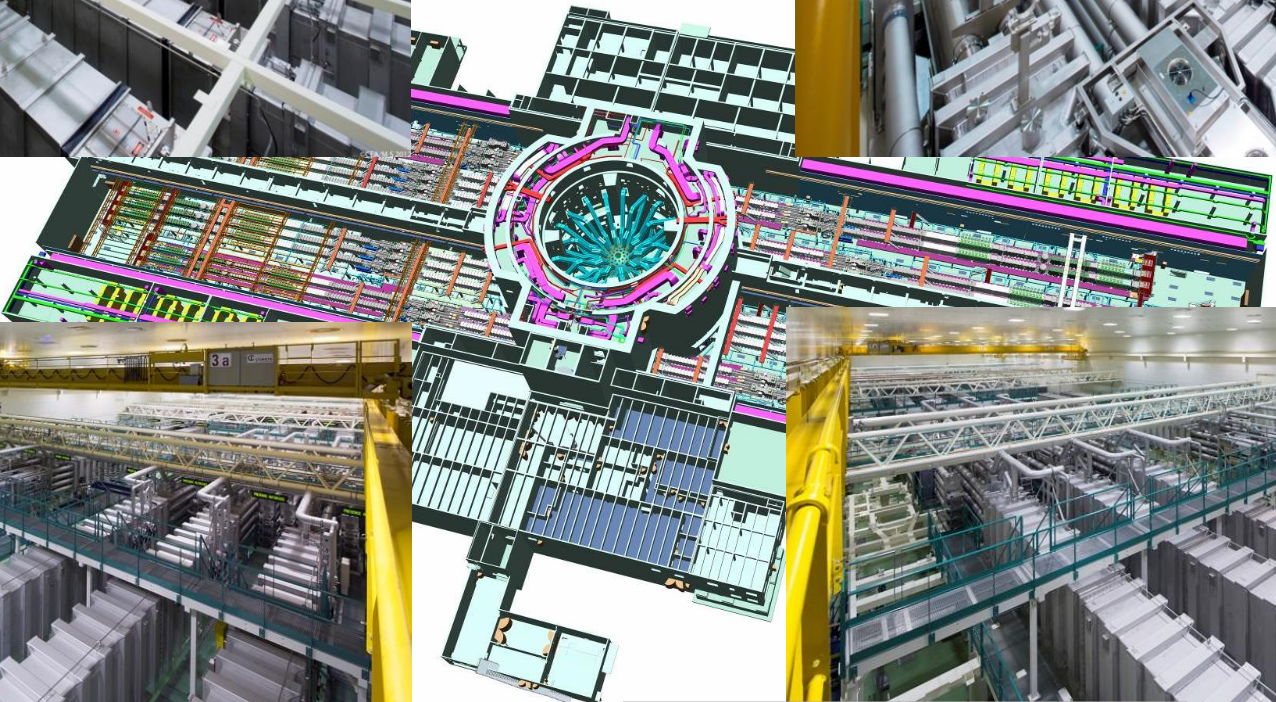


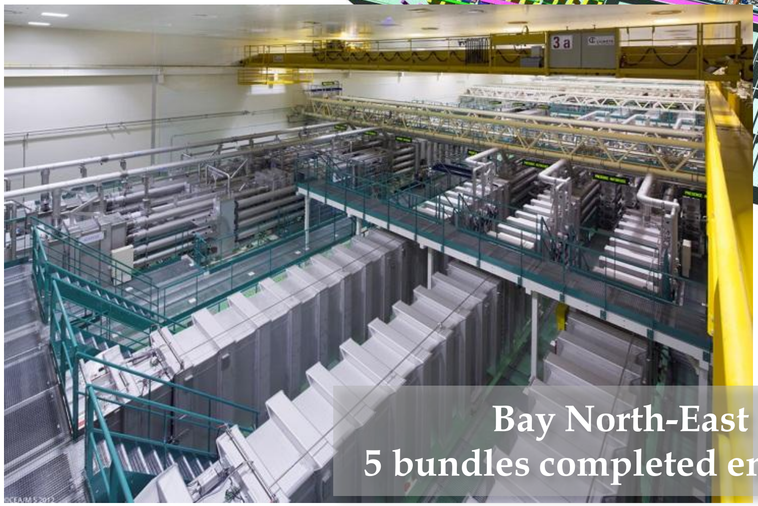
- 2 X 2 cones irradiation : 33° & 49°
- Hohlraum length ~ cm
- Capsule Ø ~ 2 mm

The four laser bays are (nearly) complete

Bay South-East
7 bundles+ PETAL completed end 2011

Bay South-West
6 bundles will be completed end 2013



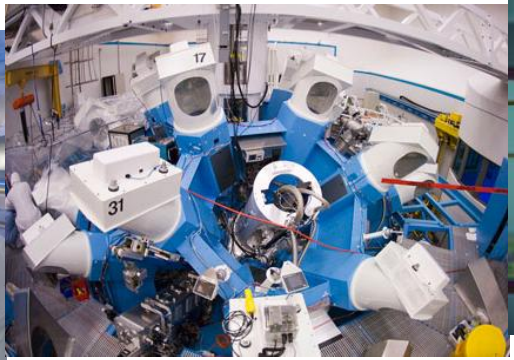


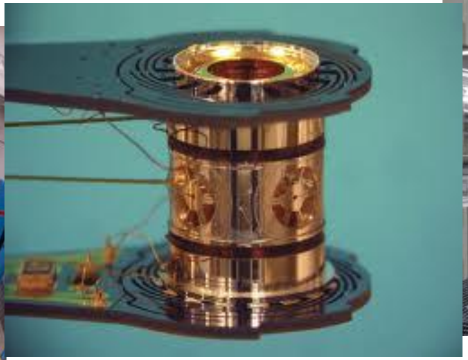
Bay North-East
5 bundles completed end 2011

Bay North-West
5 bundles completed end 2012

LMJ is a key component of the CEA « Simulation Program » to guarantee a safe and reliable French Deterrent w/o testing

- Design and Guarantee of nuclear warheads now relies on numerical simulation codes
- Progress in physical models and numerical tools is obtained through prediction and comparison with dedicated experimental results
- This experimental program is executed on
  - LIL – a prototype LMJ quad delivering 15 kJ (CEA, Cesta, France), shut down 2014
  - Omega – a 60 beam, 30 kJ facility at LLE (U. Rochester, USA),
  - uses NIC results as much as possible
  - will benefit from initial LMJ experiments starting at the end of 2014



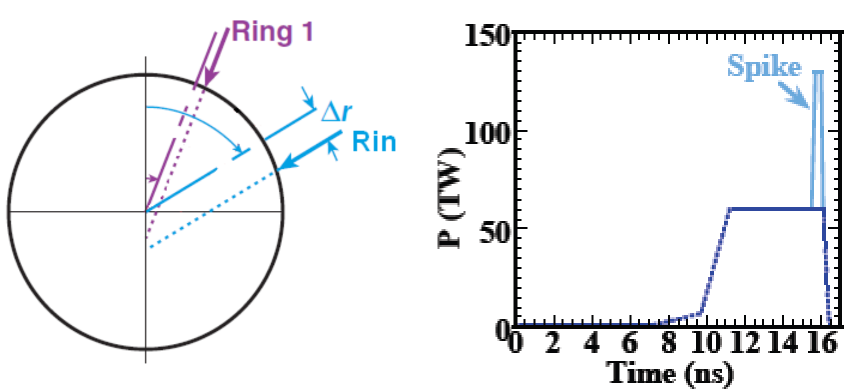


- Gain demonstration on LMJ is a long term objective – simulation codes must first be improved to be consistent with NIF results

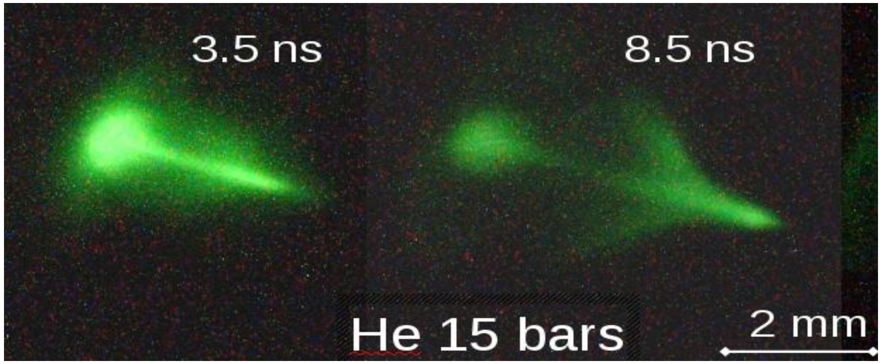
20% of LMJ time will be open to academic access

The « Institut Laser et Plasmas » brings together the French academic community on laser plasmas, and will organize access to LMJ for civilian research

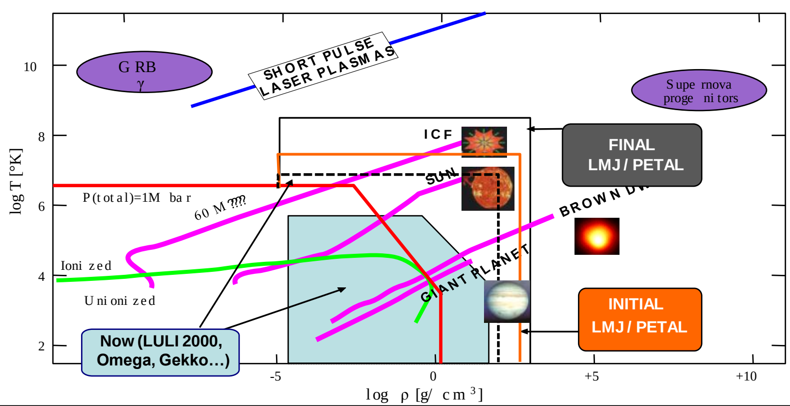
Direct-drive ICF



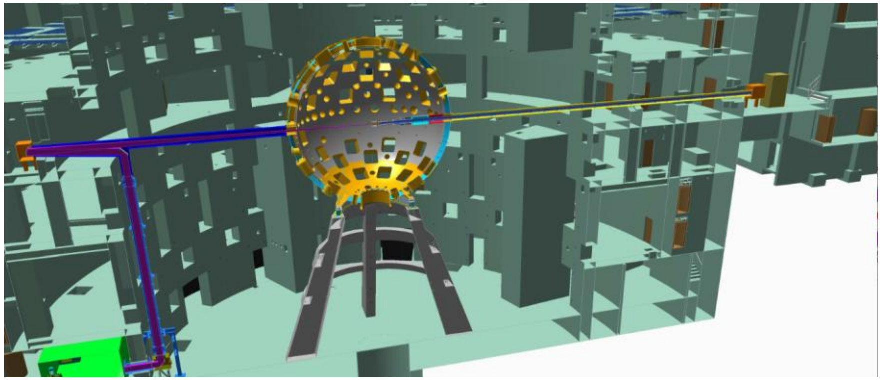
Laboratory Astrophysics



Materials and High Energy Density Physics



Acceleration and High Energy Physics



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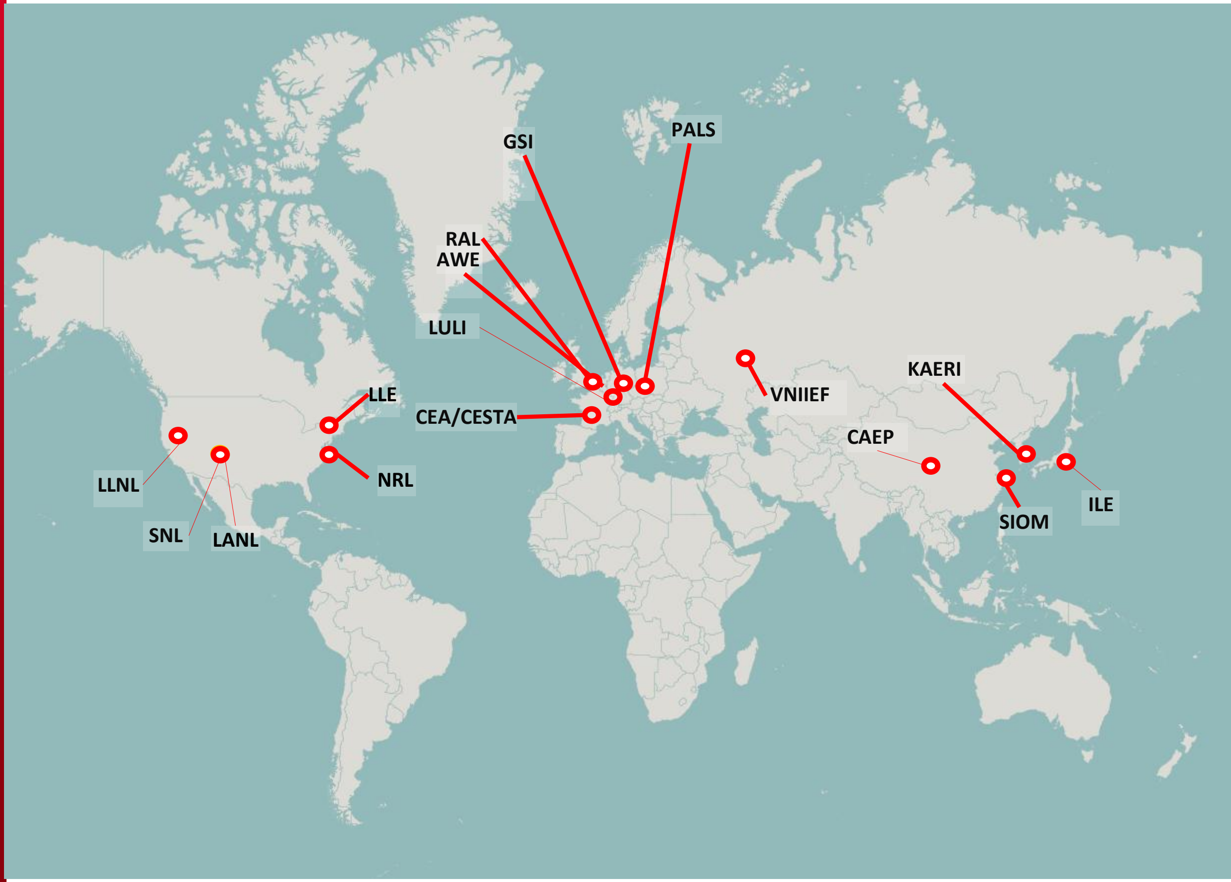
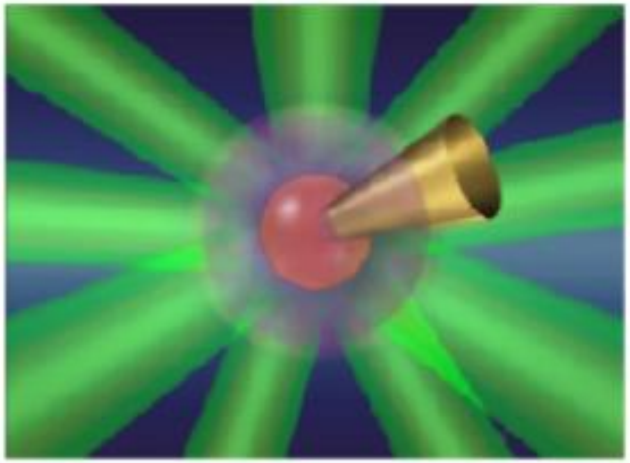
ICF research effort worldwide

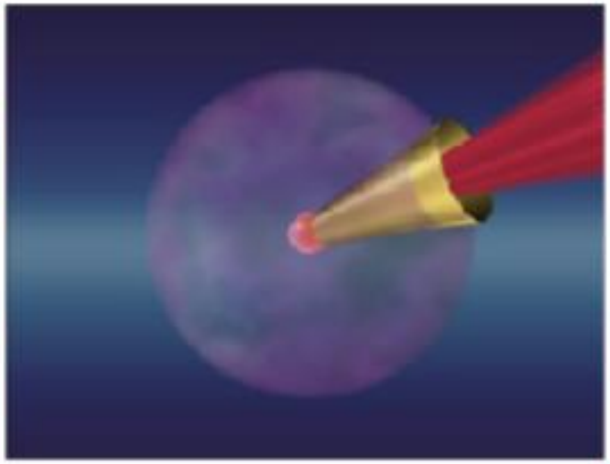


Location of the major High Energy Density laser facilities worldwide

Fast Ignition

Compression | Fast heating | Ignition and Burn





Compactness of fast ignition will accelerate inertial fusion energy development.