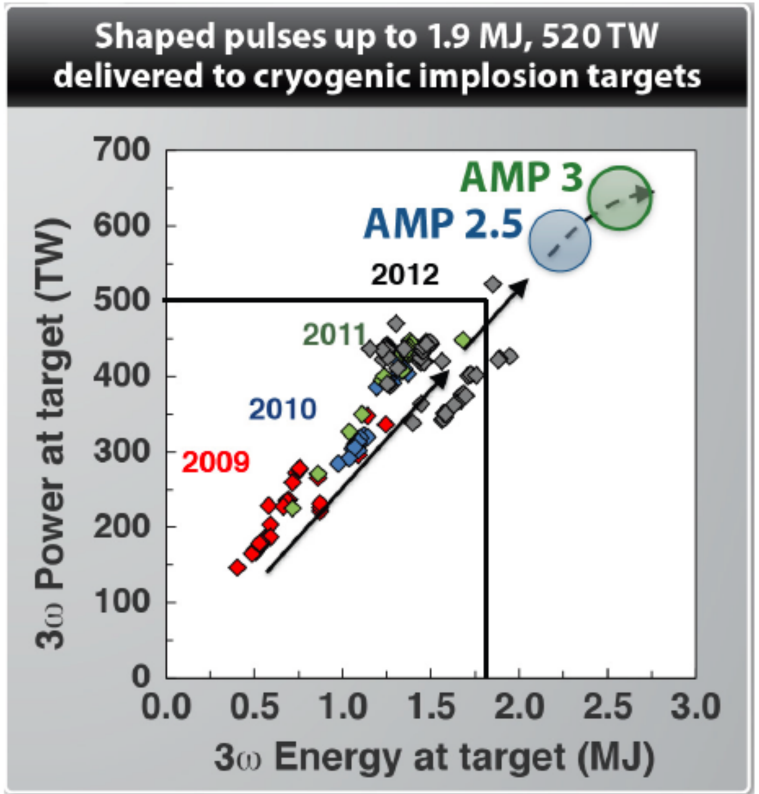
Summary
INERTIAL FUSION ENERGY

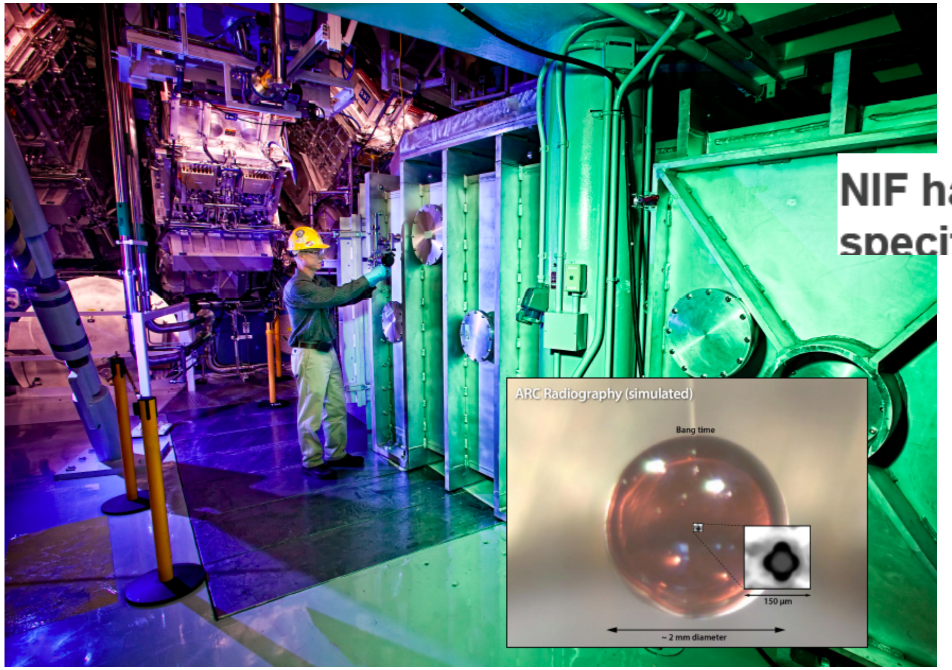
J. M. Perlado
Director
Instituto Fusión Nuclear
Universidad Politécnica de Madrid

Index

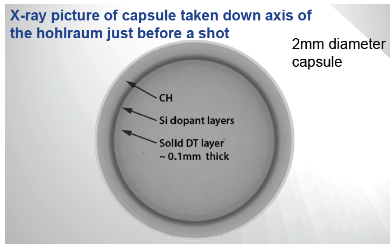
- National Ignition Facility: operation and results
- Laser MegaJoule: start and planning
- LMJ-PETAL and Shock Ignition
- FIREX-I and Fast ignition
- Other new physics in targets
- Going to Repetitive operation==== ENERGY
  - Lasers
  - Targets manufacturing and injection



NIF has now exceeded its original laser performance specifications – and is set to increase further

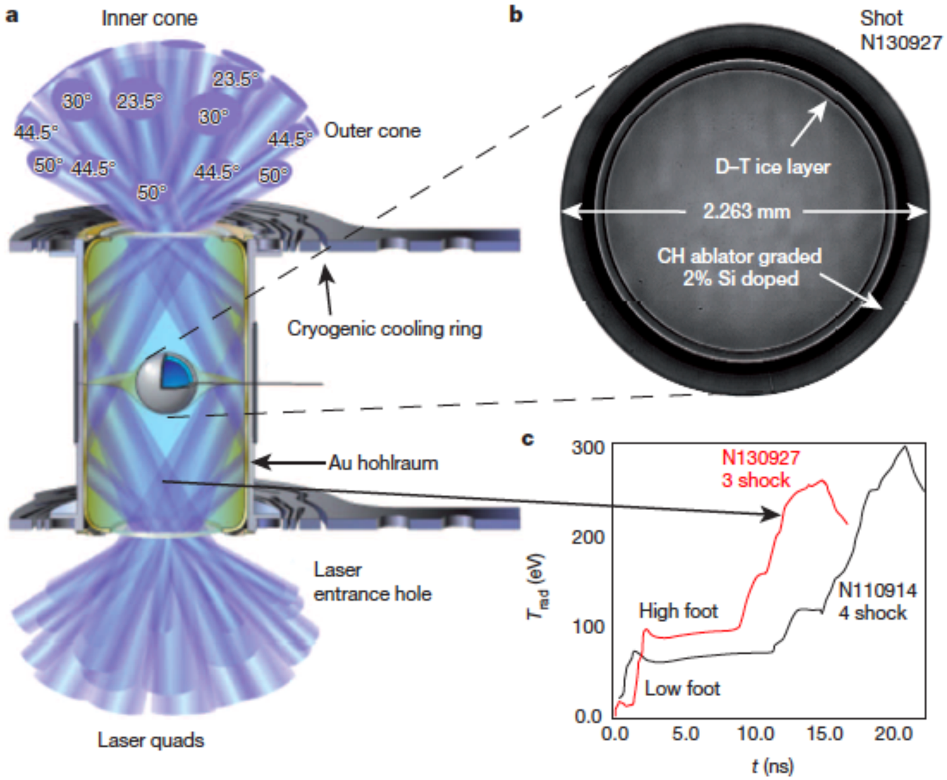


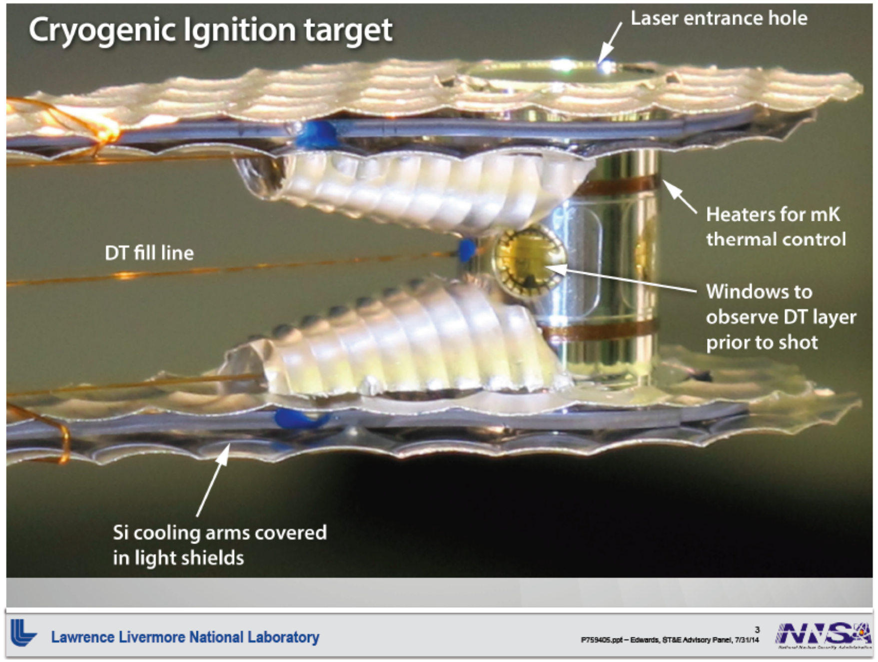
ARC
Advance
Radiographic
Capability
Petawatt laser
fully incorporated
to diagnosis

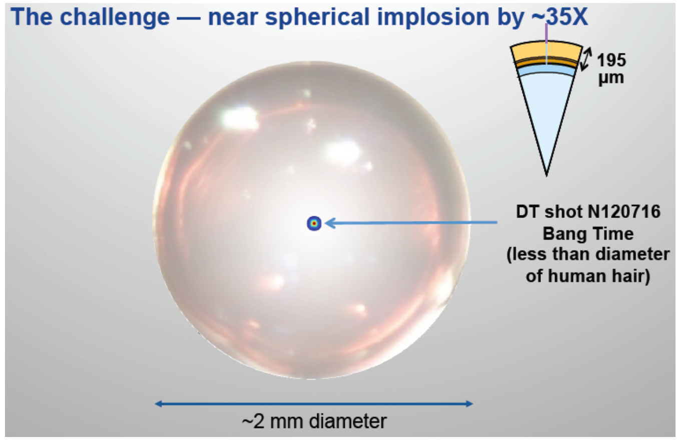


T. Anklam, J. Edwards, LLNL, 2013, 2014

NIF from Low Foot to High Foot model







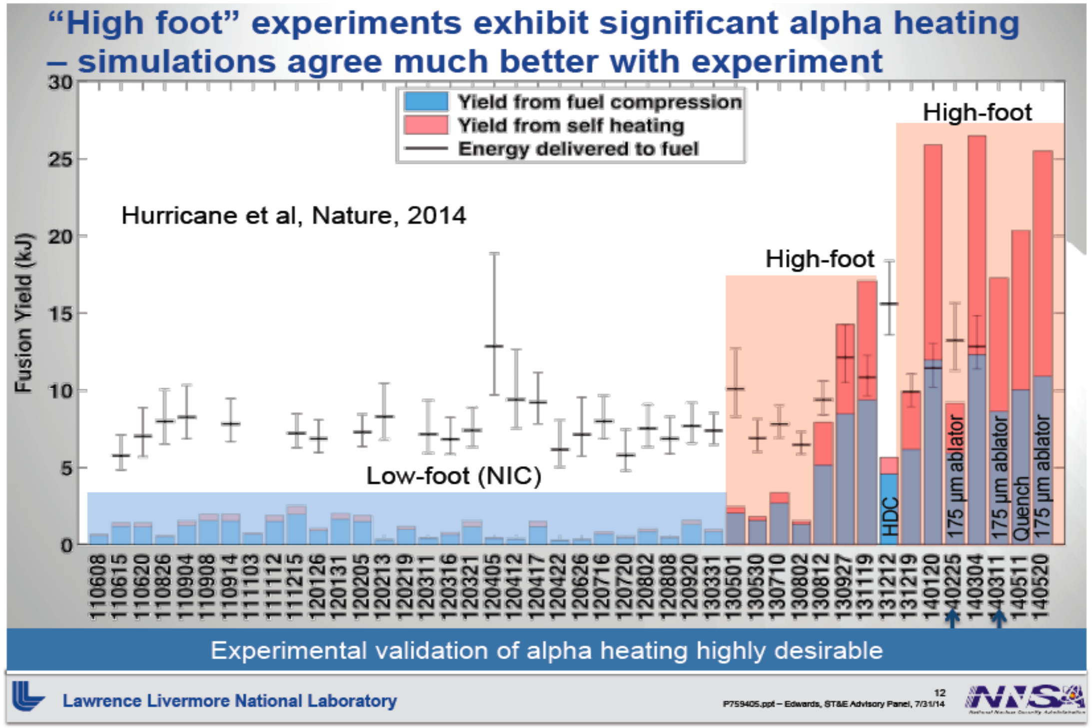
Hurricane,
Nature (2014)

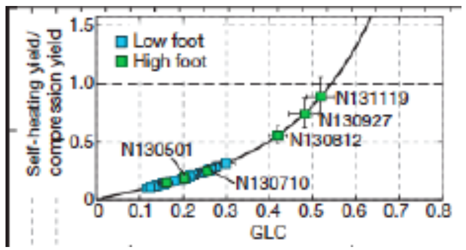
Table 1 | Measured and derived implosion performance metrics

Quantity	$N131119^{425\,TW}_{1.9\,MJ}$	$N130927^{390\,TW}_{1.8\,MJ}$	N130927[25]	N130927[26]	N130927 (sim.)
Y_{13-15} (neutron)	$(5.2 \pm 0.097) \times 10^{15}$	$(4.4 \pm 0.11) \times 10^{15}$	—	—	7.6×10^{15}
T_{ion} (keV) D–T	5.0 ± 0.2	4.63 ± 0.31	—	—	4.2
T_{ion} (keV) D–D	4.3 ± 0.2	3.77 ± 0.2	—	—	3.9
DSR (%)	4.0 ± 0.4	3.85 ± 0.41	—	—	4.1
τ_x (ps)	152.0 ± 33.0	161.0 ± 33.0	—	—	137
$P0_x$, $P0_n$ (μm)	35.8 ± 1.0, 34 ± 4	35.3 ± 1.1, 32 ± 4	—	—	32
$P2/P0_x$	-0.34 ± 0.039	-0.143 ± 0.044	—	—	—
$P3/P0_x$	0.015 ± 0.027	-0.004 ± 0.023	—	—	—
$P4/P0_x$	-0.009 ± 0.039	-0.05 ± 0.023	—	—	—
Y_{total} (neutron)	6.1×10^{15}	5.1×10^{15}	—	—	8.9×10^{15}
E_{fusion} (kJ)	17.3	14.4	—	—	25.1
r_{hs} (μm)	36.6	35.5	34.4–42.3	35.7–36.0	32.2
$(\rho r)_{hs}$ (g cm^{-2})	0.12–0.15	0.12–0.18	0.13–0.19	0.1–0.14	0.15
E_{hs} (kJ)	3.9–4.4	3.5–4.2	3.7–5.5	3.71–4.56	4.1
E_{α} (kJ)	2.2–2.6	2.0–2.4	2.0–2.4	2.0–2.5	2.8
$E_{DT,total}$ (kJ)	8.5–9.4	10.2–12.0	10.0–13.9	10.92–11.19	13.4
G_{fuel}	1.8–2.0	1.2–1.4	1.04–1.44	1.28–1.31	1.9

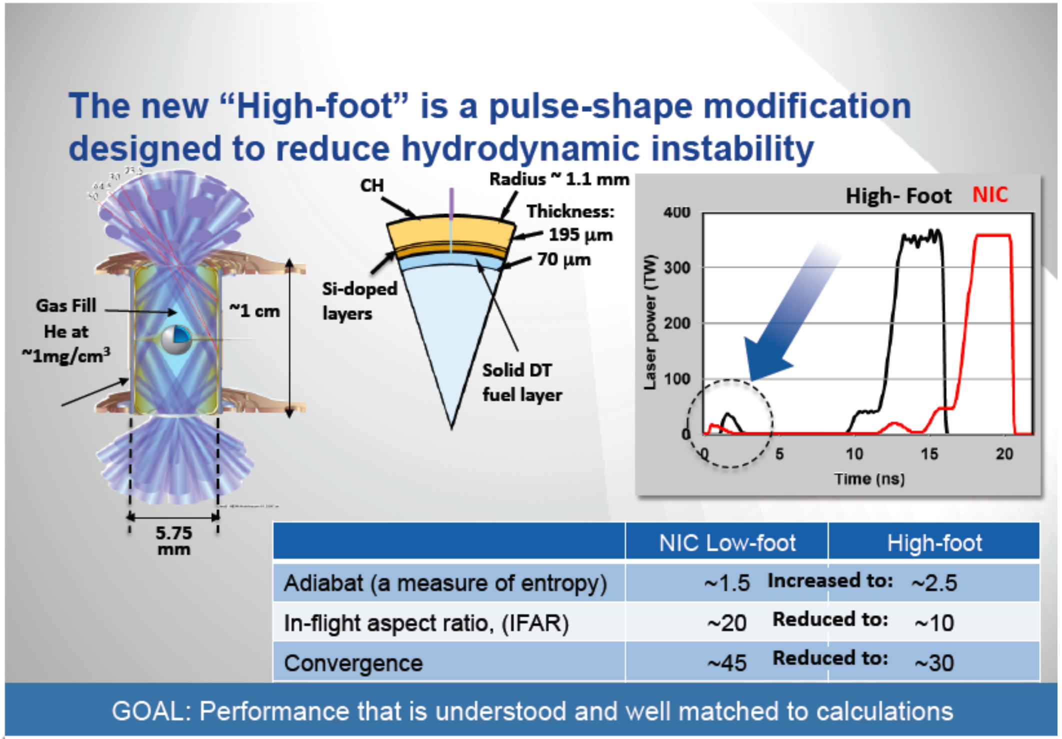
Lines 1–9 for columns 2 and 3 are directly measured quantities; others are derived from the data. Columns 4–6 show results from two data-driven models and simulation, respectively.

NIF Fuel Gain and Alpha Heating

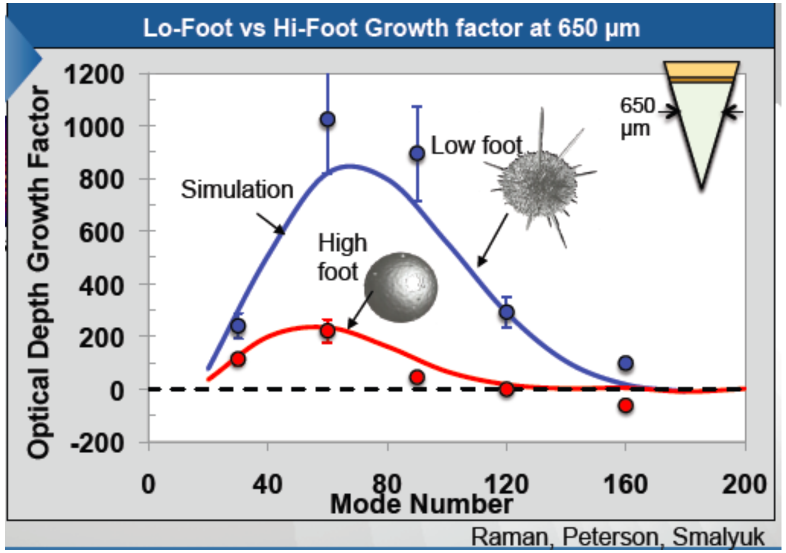




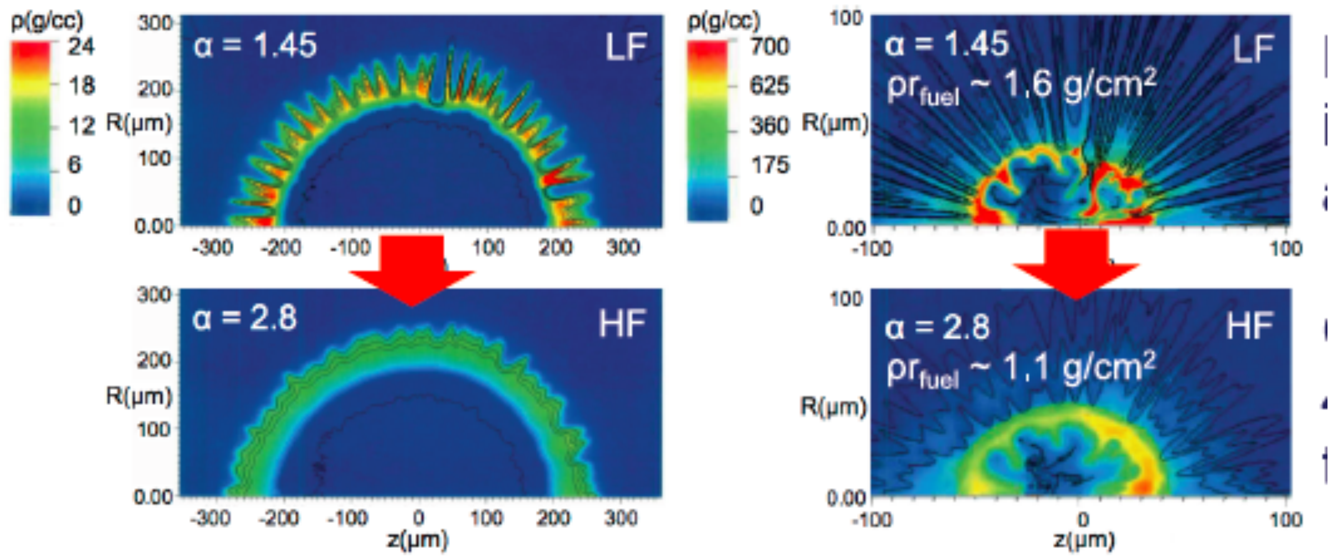
Hurricane, Nature (2014)

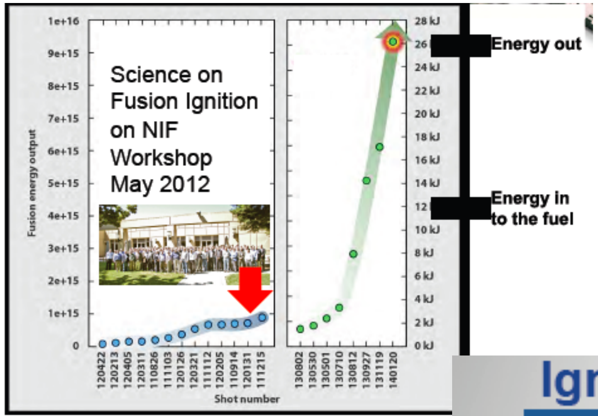


	NIC Low-foot	High-foot
Adiabat (a measure of entropy)	~1.5	Increased to: ~2.5
In-flight aspect ratio, (IFAR)	~20	Reduced to: ~10
Convergence	~45	Reduced to: ~30



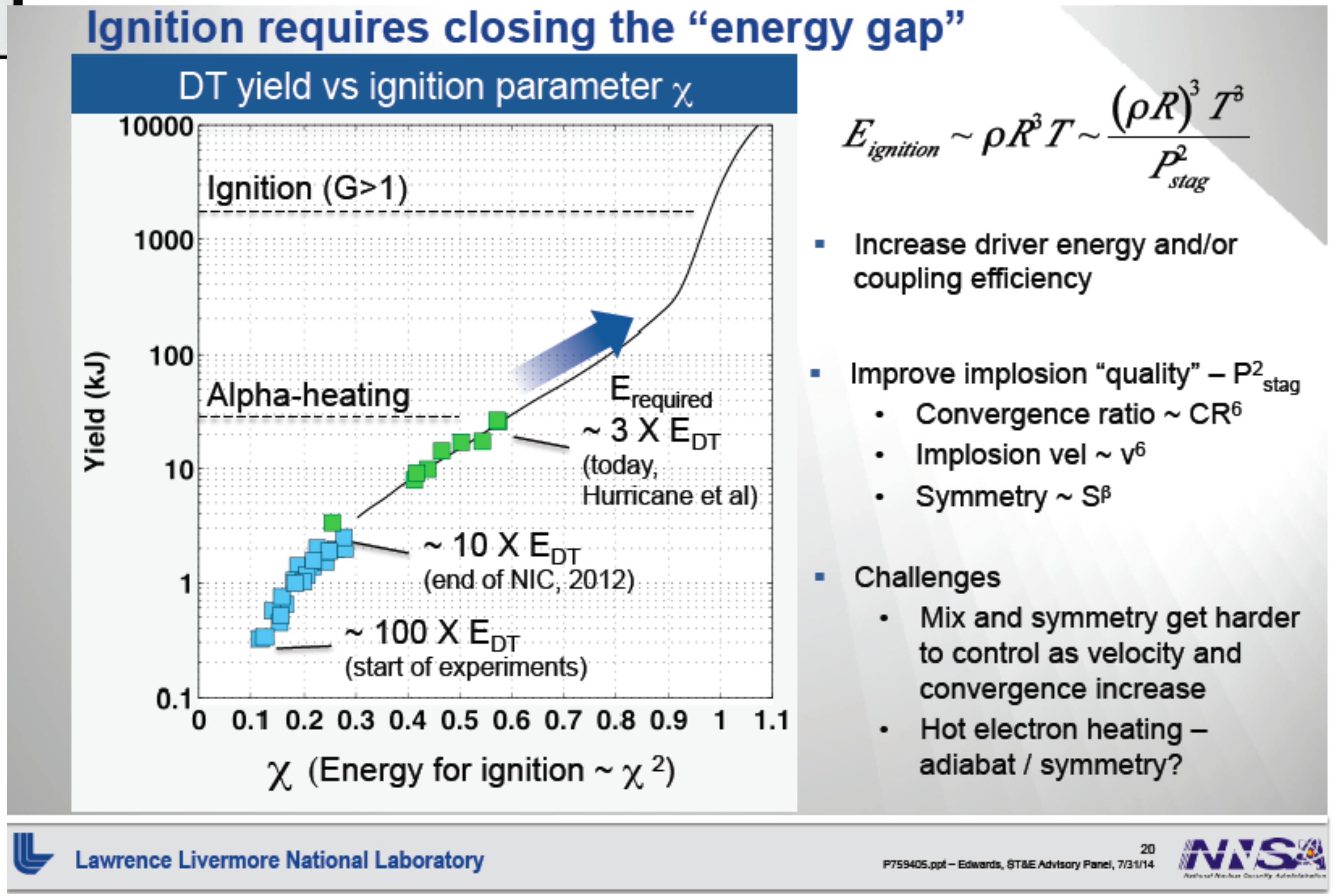
T. Anklam, J. Edwards, LLNL, 2014
Reduce Hydro Instabilities, but
Reduce Convergence

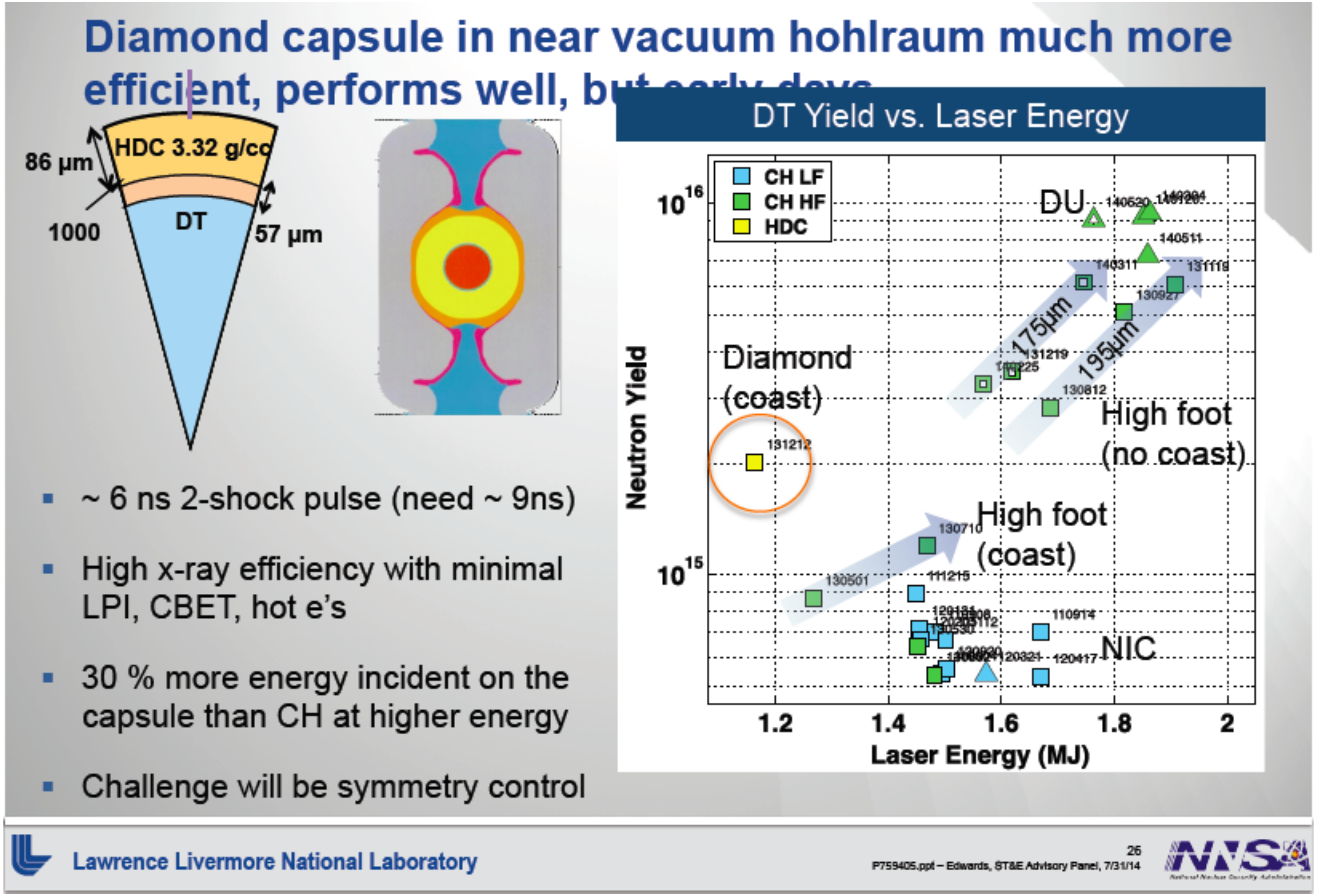




T. Anklam, J. Edwards, LLNL, ICTP- IAEA Trieste 2014

A factor > 2
Fusion out
vs.
Energy in the fuel
(MARCH 2014)





<u>Scalability</u>

<u>Progress envisioned through:</u>

Efficient Energetic, High X-Ray absorption, small pdV work on capsule

Large Mass Ablation rate; Using other Materials

T. Anklam, J. Edwards, LLNL

ICTP-IAEA Trieste 2014

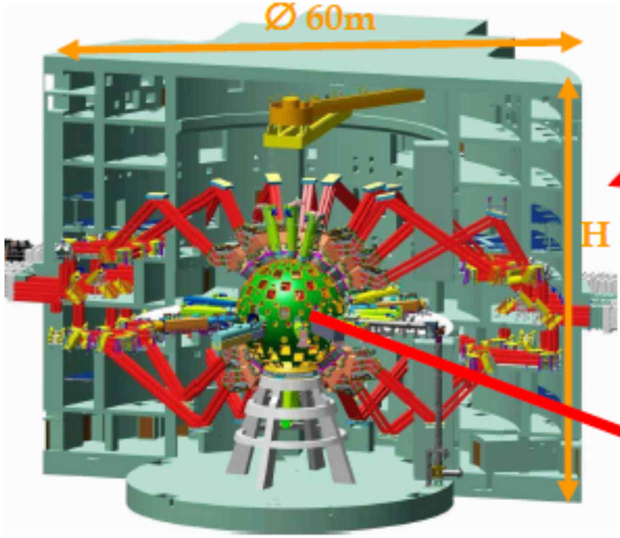
LMJ START

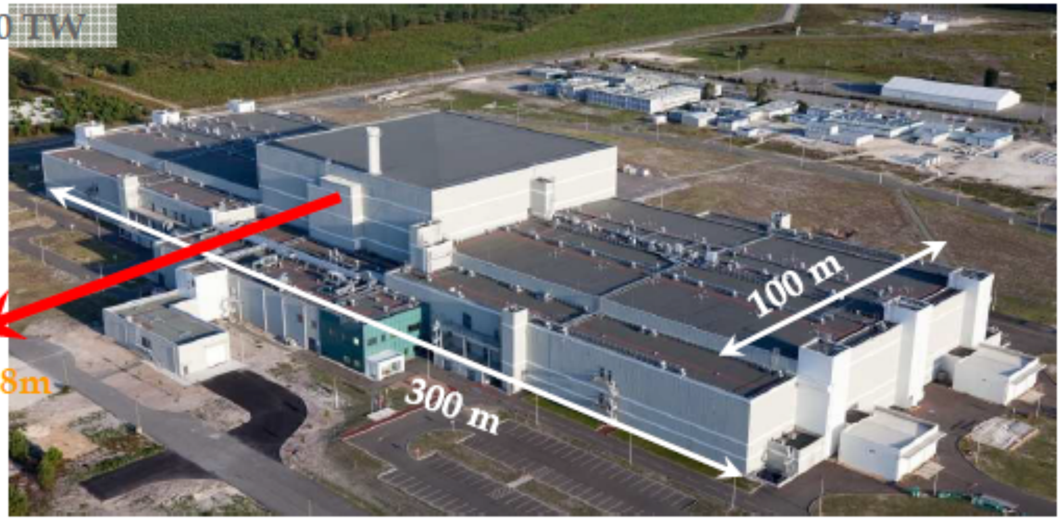
Courtesy J.L. Miquel (CEA)

Laser MegaJoule main characteristics

4 Laser bays

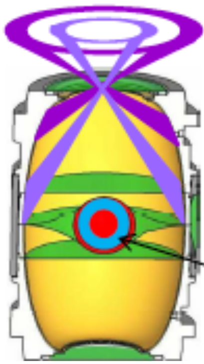
- Glass Neodymium laser, frequency tripled : $\lambda = 0.35\ \mu m$
- Designed for 240 beams, 176 will be installed
- Laser energy ~ 1.5 MJ, Power ~ 400 TW
- Pulse duration : from 0.7 to 25 ns





Target bay

- Biological protection : 2 m thick concrete
- Target chamber Ø 10 m
- 200 ports for laser beams and diagnostics



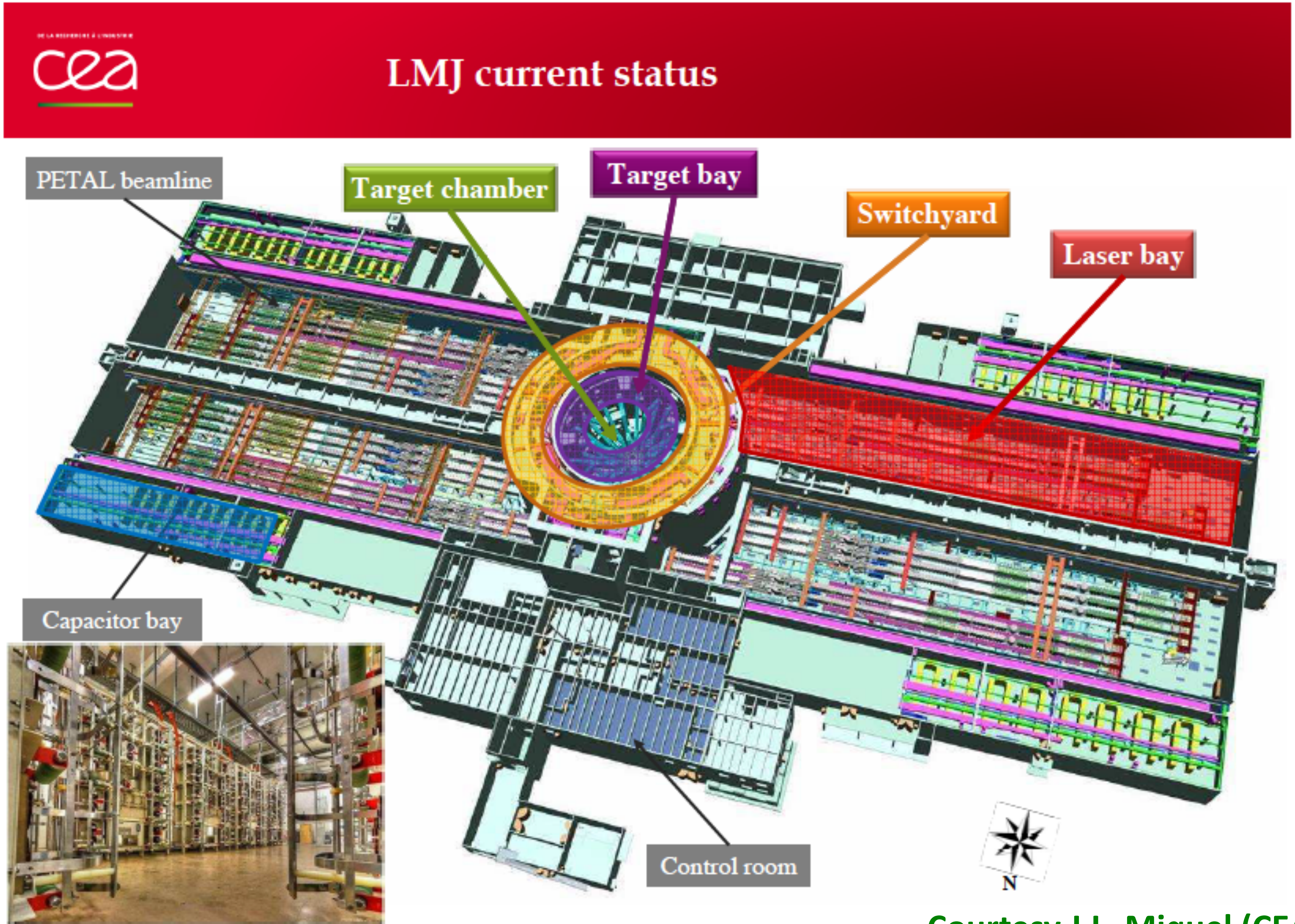
Ignition target

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

State-of-art construction

A large panel of experiments will be done:

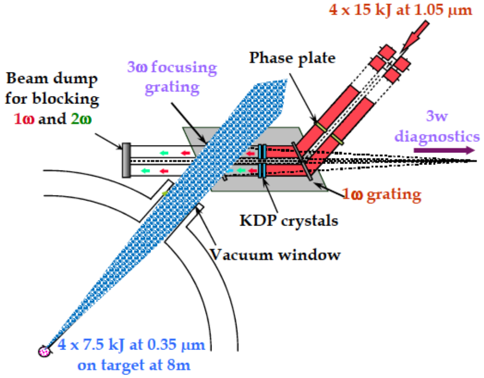
- Temperatures : some keV up to 100 keV
- Pressures : several thousands of Mbars



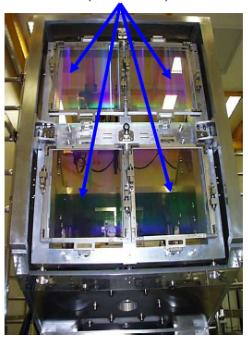
Courtesy J.L. Miquel (CEA)

Beam focusing is achieved by "3ω gratings"

- These gratings select and deflect only 3ω light inside the target chamber

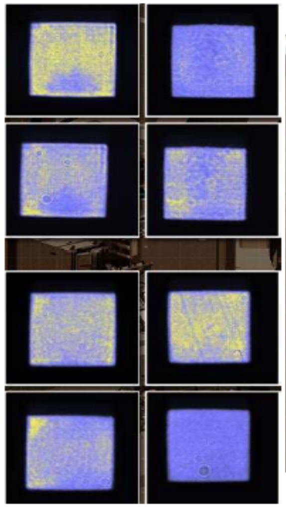


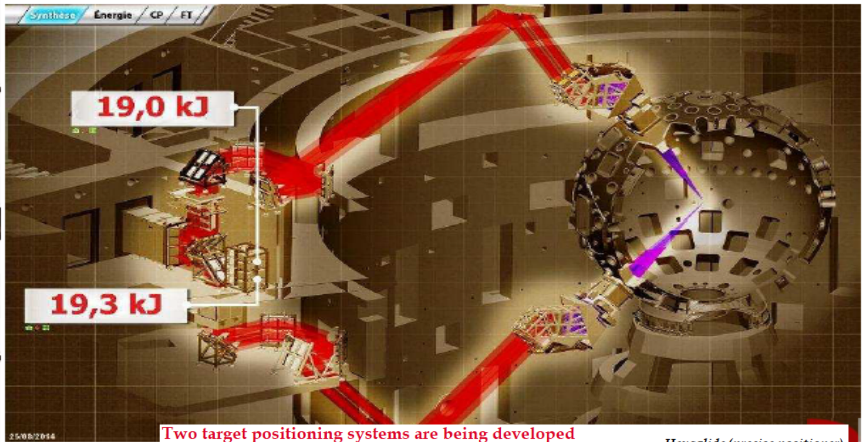
3ω focusing gratings (40x40 cm²)



First high energy test shots at 1ω were performed last week :

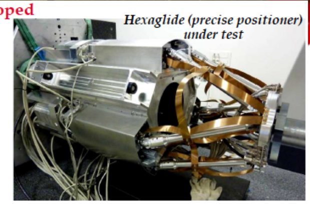
- ~5 kJ (± 5 %) per beam in 3 ns
- Good spatial uniformity





Two target positioning systems are being developed

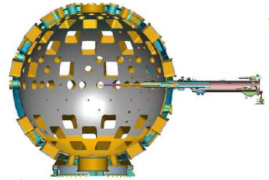
- The first one (room temperature) is installed



- The Cryogenic one will be installed later for the ignition

Courtesy J.L. Miquel (CEA)

Target bay : The first SID has been qualified



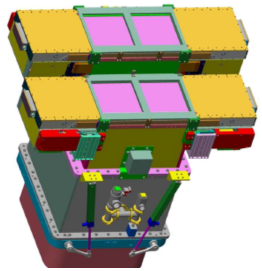
Diagnostic :
3 m length
30 cm diameter
150 kg weight
20 μm precision

Laser bays : the framework and equipment of the four laser bays are completed

Target chamber : Half of the Final Optics Assembly are installed

Final Optics Assembly include :

- Vacuum windows
- Protective optics
  - Each FOA allows up to 10 protective optics to be installed
- Devices to inspect damages on optics



LMJ characteristics & status

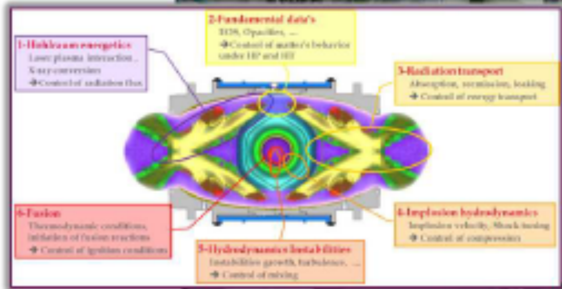
- The laser bays and target bay are complete
- The first bundle (8 beams) is under test
- High energy test shots at 3ω has begun last week

PETAL characteristics & status

- The PW beamline, compressor and focusing system are complete
- Alignment process is in progress
- Test shots at PW level will be performed next year

Program overview

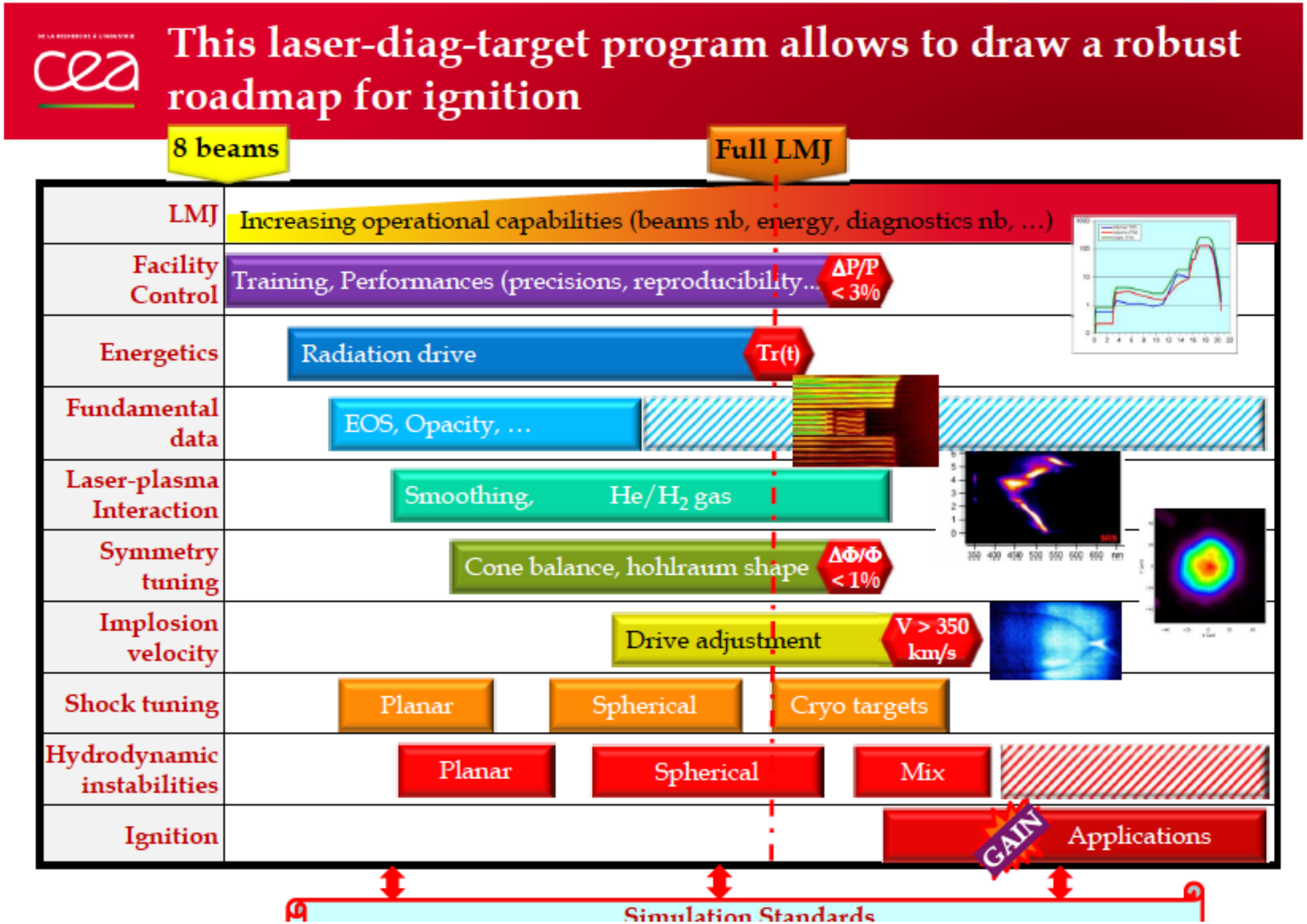
- We are developing a thematic approach on LMJ
- Ignition target design is being consolidated with dedicated experiments
- Diagnostic and target development support the program
- The first experiments will be carry out on December 2014



Academic access to LMJ-PETAL

- LMJ-PETAL will be open to the scientific community in 2017

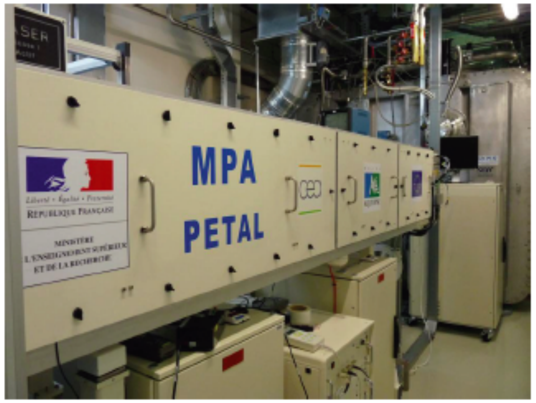
Courtesy J.L. Miquel (CEA)



Courtesy J.L. Miquel (CEA)

PETAL

- PETAL: coupling a PW laser to LMJ



The pre-amplification module of PETAL

Characteristics of the PETAL laser system

- Energy * 3.5 kJ,
- Wavelength : 1053 nm,
- Duration 0,5 ps - 10 ps,
- Intensity on target > 10^{20} W/cm^2,
- Intensity contrast : 10^{-7} at -7 ps,

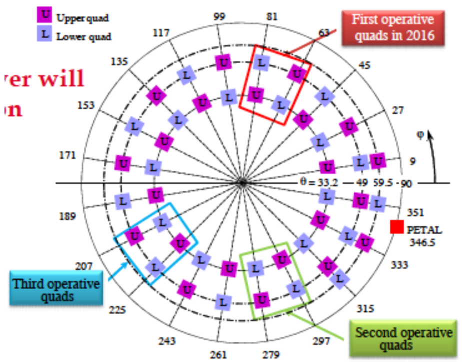
Configuration LMJ-PETAL
End 2016 –begin 2017
Open Academic

* Limited to 1 kJ at
damage threshold

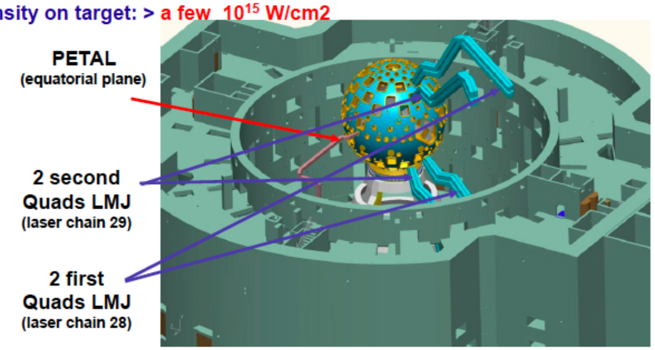
Coupling a 7 PW laser system to a MJ ns laser

PETAL - Energy ≈ 3.5 kJ, Wavelength: 1053 nm,
Duration: 0,5 ps to 10 ps, Intensity on target: > 10^{20} W/cm2

Quad LMJ - Energy > 30 kJ, Wavelength: 351 nm,
Duration: a few ns, Intensity on target: > a few 10^{15} W/cm2



Configuration 2016 / 17



Courtesy of
D. Batani

Physics with PETAL

- **PETAL for fast ignition experiments** (generation of electron and/or ion beams, study of fast electron propagation)
- **PETAL to study secondary sources** (protons, X and γ rays, …)
- **PETAL as a physics tool**

- Create WDM states by short-pulse ("isochoric") heating [LMJ can be used as a time-continuous backlighter]
- Create intense proton / ion beams and study their propagation (stopping power) in WDM samples created with LMJ
- To study electron acceleration and High Energy Physics
- etc. etc. …

Courtesy of
D. Batani (CELIA, ILP)

Possible expts on LMJ/PETAL

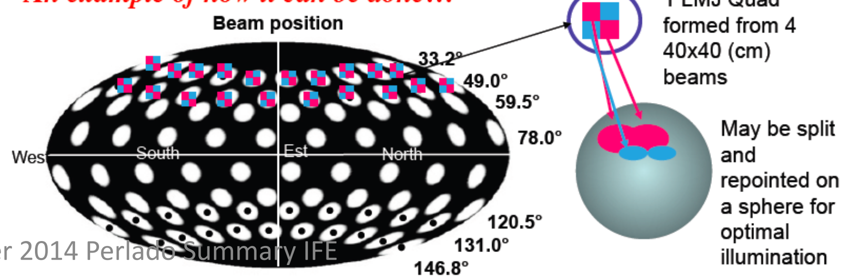
- **PETAL as a back lighter of LMJ**

Probing by proton-radiography the magnetic fields B created on the holhrum walls; Assessing magnetic fields reconnection (astrophysics)

Preparation of shock ignition experiments on LMJ :
Characterizing the max pressure that can be achieved with a LMJ Quad : 300 Mbar regime ?
Using x-ray radiography + VISAR

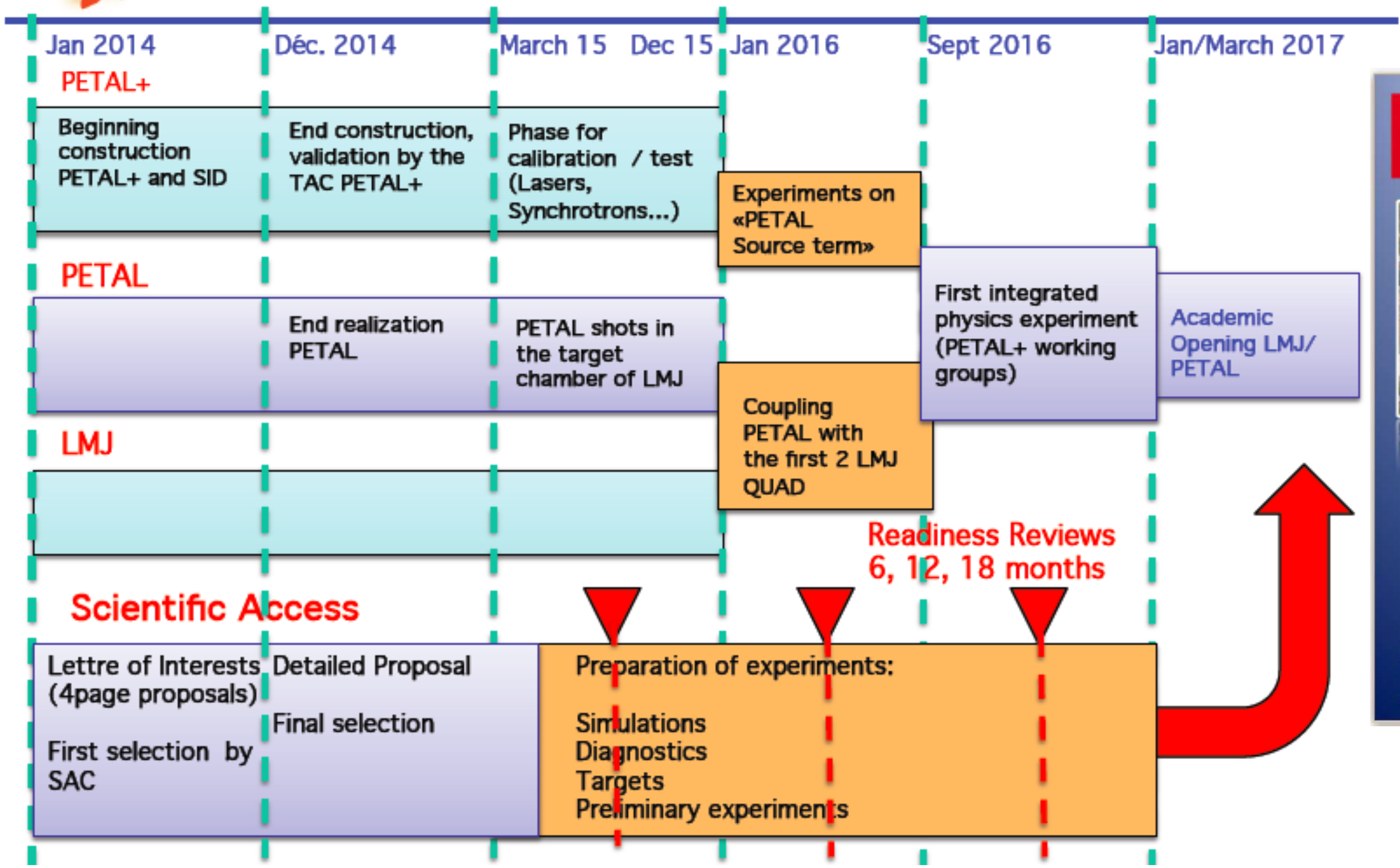
Assessing Polar Direct Drive (PDD) at LMJ

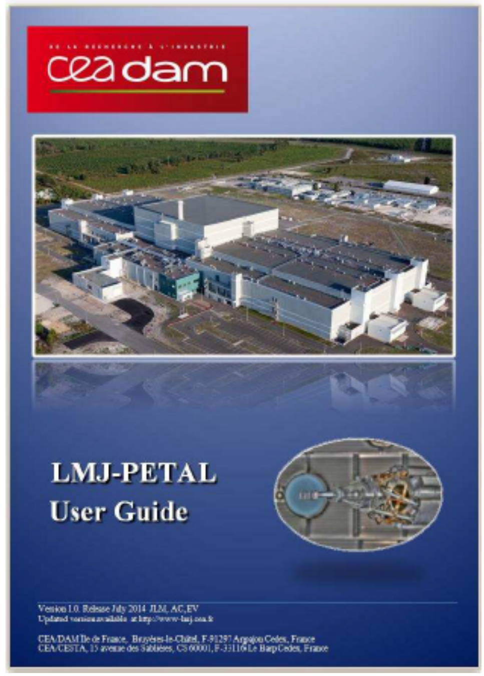
An example of how it can be done…



Petal

Academic Community Access





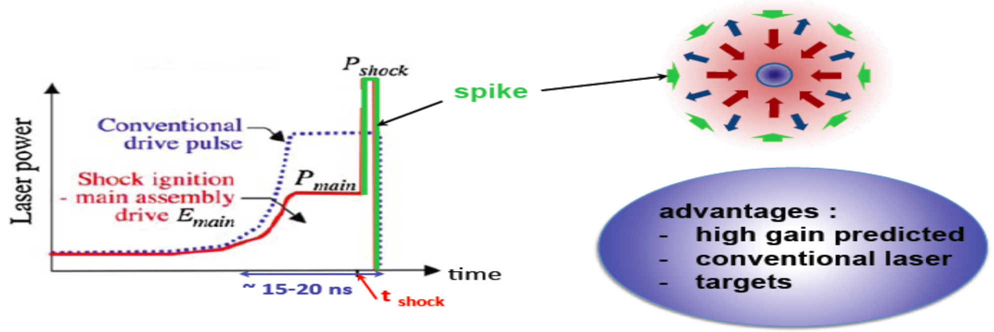
Courtesy of D. Batani, J.L. Miquel

Shock Ignition : an alternative scheme for ICF

Scheme proposed by Shcherbakov (1983) and more recently by Betti (2007)

2 separated phases : compression and ignition

moderated compression — Strong convergent shock



V.A. Shcherbakov, Sov. J. Plasma Phys. 9(2) 240 (1983)
R. Betti et al., Phys.Rev. Lett. 98, 155001 (2007)

Two main questions :

- possibility to launch high pressure shock ? => 300 to 400 Mbar
- parametric instabilities and hot electrons ?

For I > 10^{15} W/cm^2
- SBS => energy loss
- SRS, TPD => hot electrons*

Good ? ⇐ < 150 keV ⇐ T_h ⇒ > 150 keV ⇒ Bad

Courtesy of
S. Baton (LULI, E.P.)

Experiments are necessary to answer these key points **

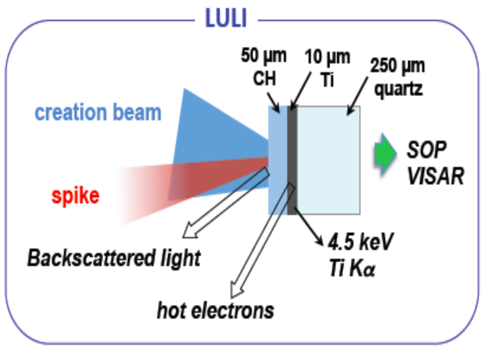
Experiments in planar geometry : LULI - PALS - OMEGA

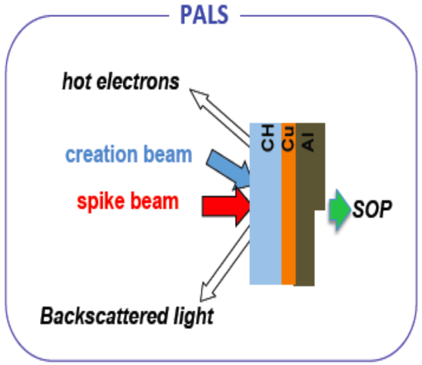
Also experiments in VULCAN (CLF)

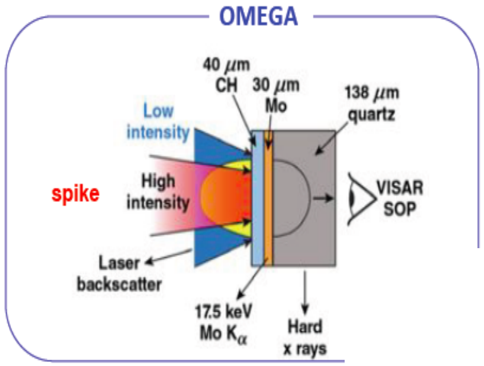
2 beam experiment

⇒ to generate a large plasma *at low intensity*

⇒ to launch strong shock *high intensity spike*







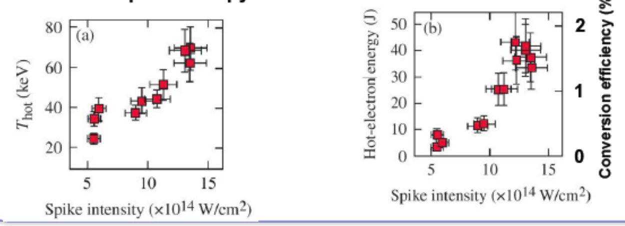
	=> plasma	=> spike	VISAR	SOP	Hot electrons	Backscattered En.
LULI	0.53 µm, 2ns, 300 J I ~ 7 10^{13} W/cm^2, HPP Ø 400 µm	0.53 µm, 2ns, 300 J I ~ 10^{15} W/cm^2 Ø 100 µm	✓	✓	✓	✓
PALS HiPER	1.3µm, 250 ps, 30J I ~ 10^{13} W/cm^2, RPP Ø 900 µm	0.44 µm, 250 ps, 250 J I ~ 10^{16} W/cm^2 RPP Ø 100 µm		✓	✓	✓
OMEGA UR LLE FSC	0.35 µm, 1.5 ns, I ~ 2 10^{14} W/cm^2 PP Ø 900 µm	0.35 µm, 0.5 ns, I ~ 0.5 – 1.5 10^{15} W/cm^2 PP Ø 600 µm	✓	✓	✓	✓

Courtesy of S. Baton

Hot electrons : 1-2 % conversion efficiency with T_{hot} 50-70 keV

OMEGA

- multi-channel hard X-ray detector
- Mo-Kα spectroscopy



Th ~ 70 keV
< 2% conversion

PALS

Estimated from
- X-ray photon counting
- Kα image

Th ~ 50 keV
~ 1 % conversion

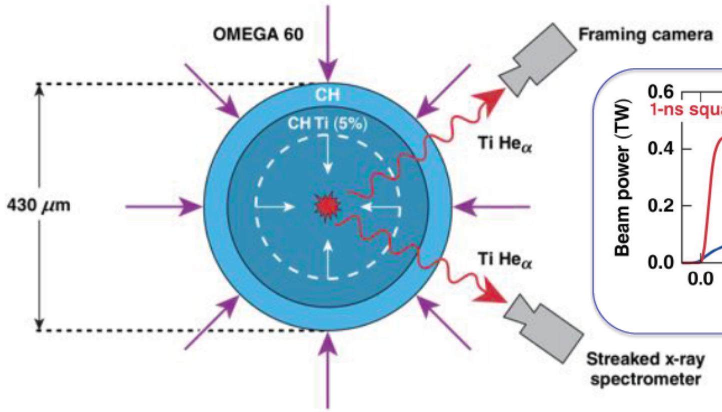
LULI

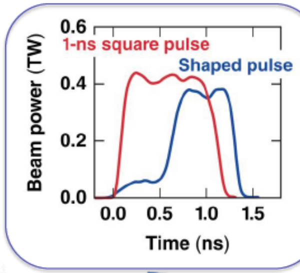
Kα signal < noise level
(for electrons > 60 keV)

Courtesy of S. Baton

Recent experiment* at OMEGA used a new platform developped to study strong shocks in SI scheme

=> observation of X-ray flash generated when the shock converges in the center

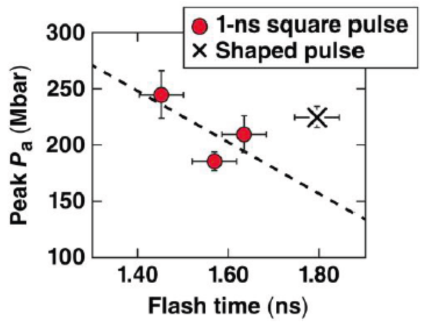




60 high intensity beams with smoothing
$I \sim 3 \times 10^{15}$ W/cm²
2 different pulses : square or shaped

* *R. Nora, R. Betti, W. Theobald*

Peak ablation pressures up to 270 Mbar at ~ 3×10^{15} W/cm²



Peak ablation pressures of up to 270 Mbar are inferred from hydrodynamic LILAC simulations *including hot electrons*

Hot electrons generated by TPD instability

Thot (keV) : 105 ± 30

~ 10 % conversion

HiPER Orion: a new laser facility in UK

- 5 kJ 3ω in 10 long pulse beams
- 2 orthogonal PW beams for heating and diagnostics
- 100J 200TW 2ω; (ultra-high contrast ~ 10^{12} : 1)
- Suite of TIM-based diagnostics
- Available for collaboration; (currently over-subscribed!)

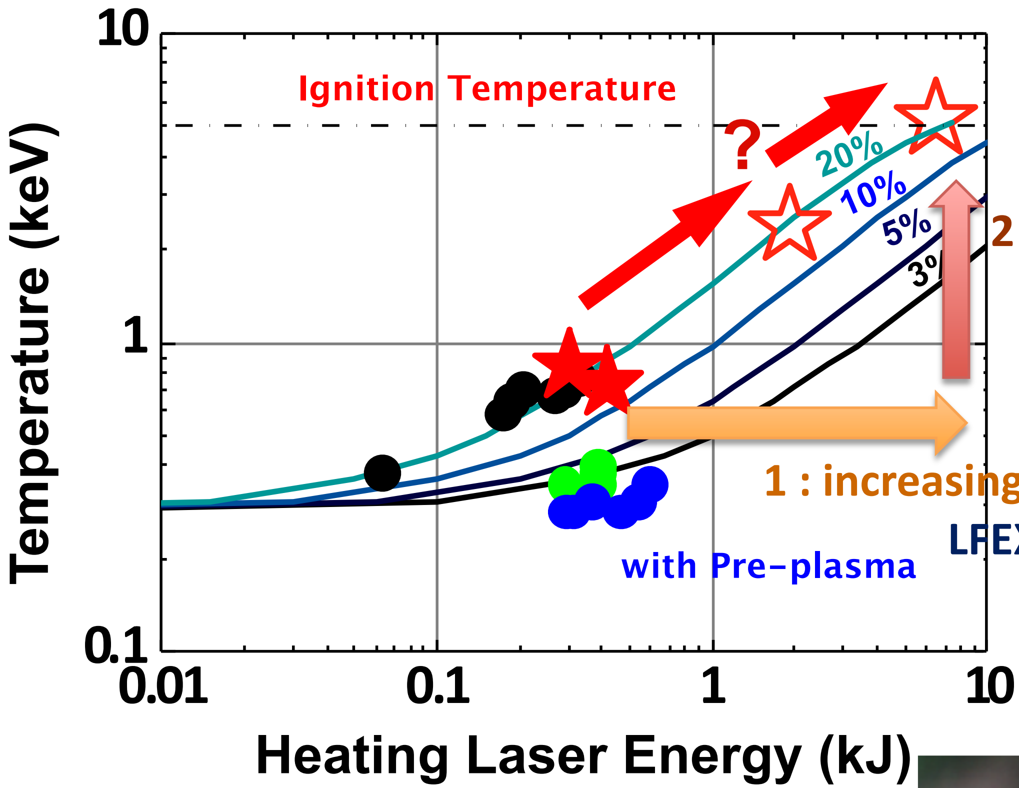
HiPER Orion: 5m target chamber

Courtesy
Ch. Edwards
(CLF,UK)

Approach to ignition temperature

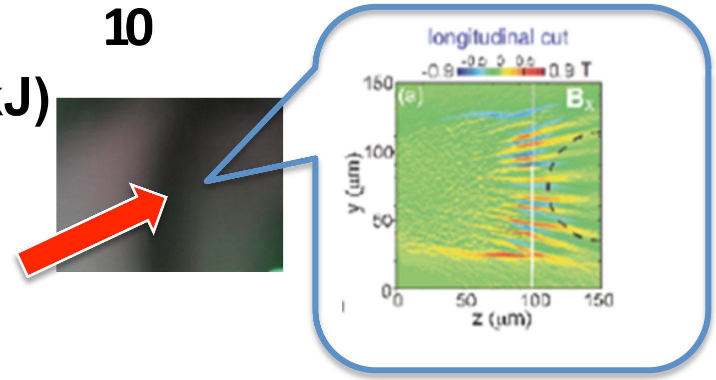
INSTITUTE
OF
LASER
ENGINEERING
OSAKA
JAPAN

Courtesy
H. Azechi
(ILE, Japan)



2 : increasing heating efficiency
Fast Electron Guiding by B Field

1 : increasing laser energy
LFEX: 1 beam to 4 beams



FIREX-I STRATEGY

FAST IGNITION

Fiscal Year		
2014		Heating Basics
2015	4-Beam operation	Heating Scaling
201x		5-keV Heating
201x	Check-and-Review of FIREX-I	

1 : increasing laser energy
2 : increasing heating efficiency

1: increasing laser energy

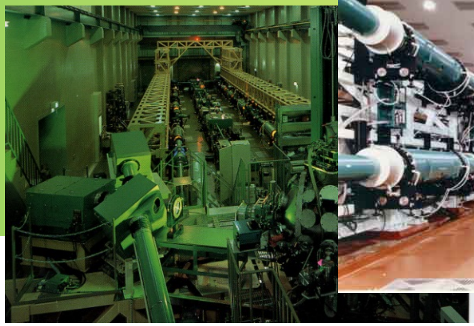
OSAKA UNIVERSITY

Institute of Laser Engineering

Giant Lasers developed in the past 40 years

Courtesy H. Azechi

GEKKO-MII 1979
GEKKO-IV 1977
GEKKO-II 1973



2 kJ 1ns

GEKKO-XII 1983

10 kJ 1ns

Peta Watt 1996

0.5 kJ 0.5 ps

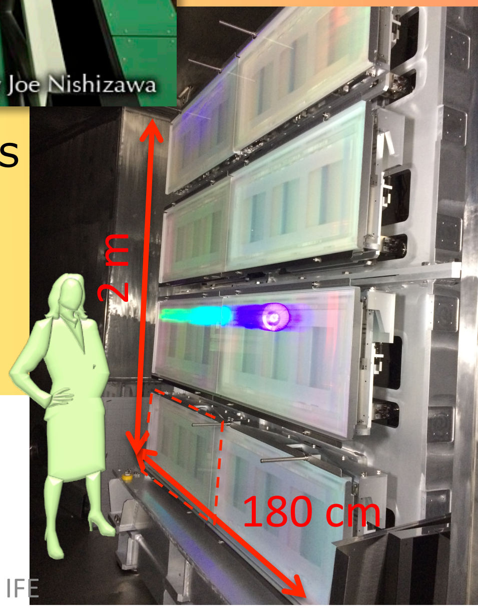
LFEX 2009

10 kJ 10 ps

2014
4 beams
10 kJ /10ps

2013
3 beams
2011
2 beams
2009
1 beam

Precision gratings ensure high energy output.



Fujioka and Zhang (ILE)

Summary of FI Basic Experiment

Heating efficiency is evaluated with measured divergence, energy distribution and flux of REB.

ILE, Osaka

Heating efficiency estimation

(Laser- Electron Conversion Efficiency X Electron Transmittance) X (Fuel cross section / E-beam cross section @fuel) X (2 x Fuel rho-R / Range of e-beam)

Fuel cross section = π (50/2 μm)²

E-beam cross section @fuel = π (100/2 μm)²

2 x Fuel rho-R = 0.11 g/cm²

Range of e-beam = 4.4 g/cm² (weighted for 1 & 15 MeV)

Heating Efficiency = 40 %* X 25 % X 2.5 % !!!

= **0.3%**

Reduction of T_e is essential for efficient heating.

2 : increasing heating efficiency

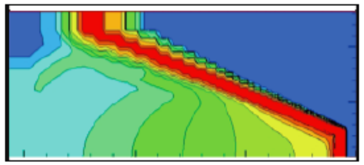
DIMINISH GENERATION OF VERY ENERGETIC REB AVOIDING LONG SCALE PRE-PLASMA FORMATION

Suppression of Too Energetic REB Generation

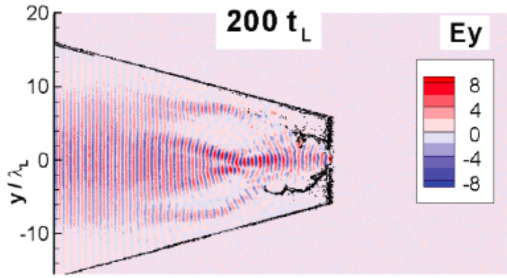
Too energetic electrons are generated in a long-scale plasma generated by foot of the heating laser pulse.

ILE, Osaka

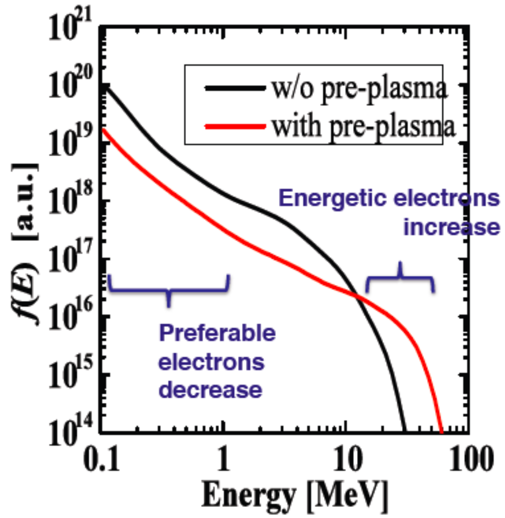
Long-scale plasma generated by foot pulse



Laser filamentation in a long scale plasma



Long-scale plasma generated by foot pulse



Morace (ILE)

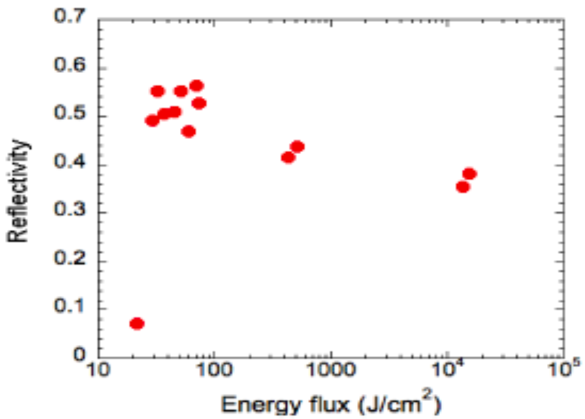
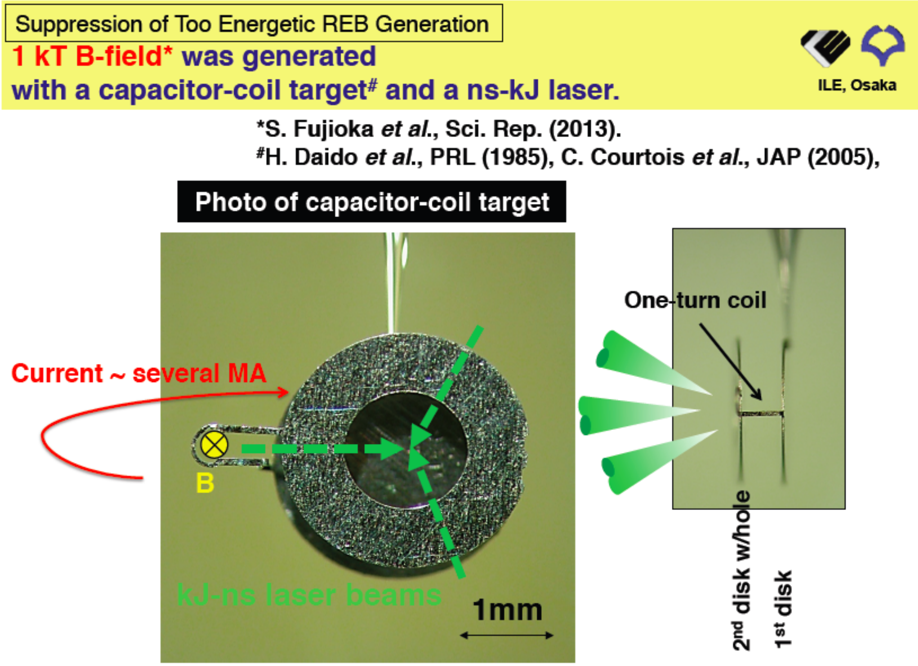
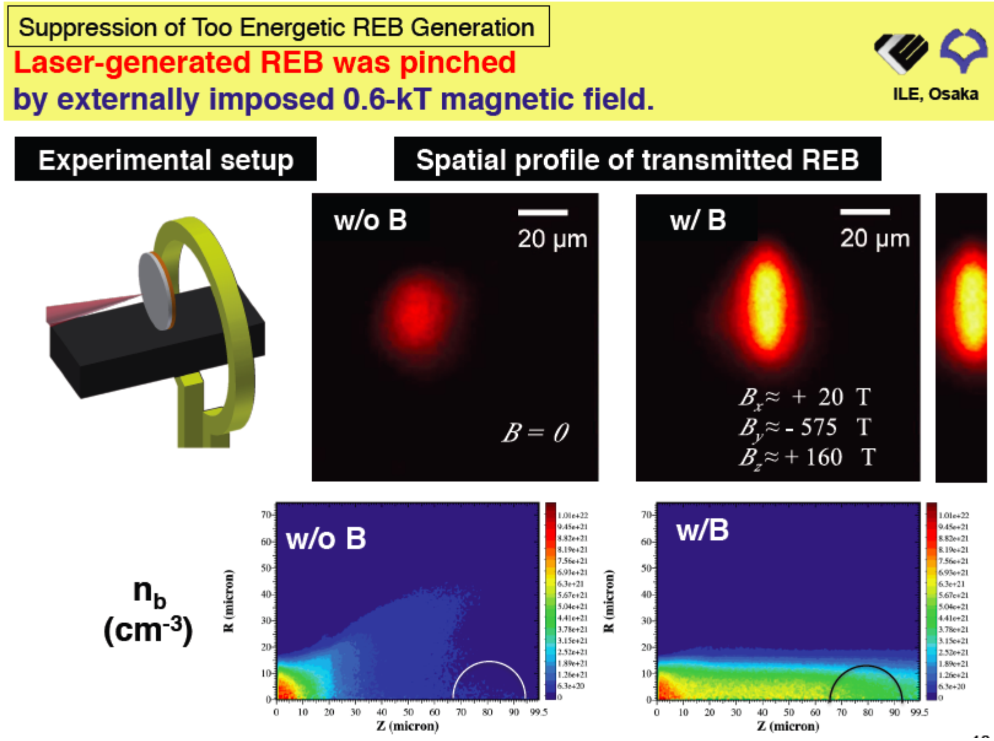


Figure 2: Plasma Mirror reflectivity versus laser energy fluence.



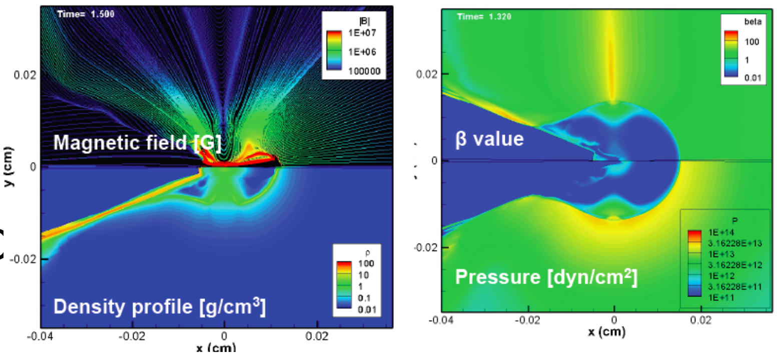
2 : increasing heating efficiency
BEAM DIVERGENCE

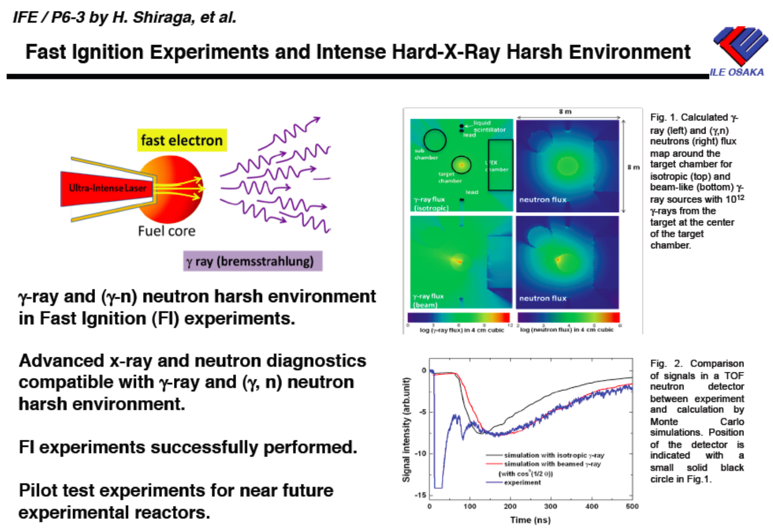


Courtesy
S. Fujioka

EXTENSIVE NUMERICAL SIMULATION BY:

JOHZAKI
SUNAHARA
NAGATOMC



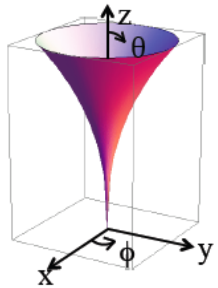


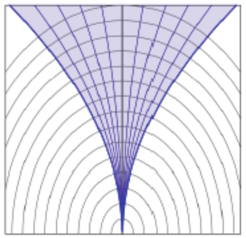
High Density Compression of Matter by Hyperspherical Shock Waves and Application to Impact Ignition

IFE/P6-7

M. Murakami et al. ILE, Osaka ,Japan

- A novel compression scheme is proposed, in which hollow targets with specifically curved structures initially filled with uniform matter, are driven by converging shock waves.
- Substantially higher densities and high pressures can be obtained compared with spherical cases.
- Linear stability analysis has revealed for spherical (cone) geometry that there exist cut-off mode numbers over which the imploding fluid is stable.
- This compression scheme can be applied to Impact Ignition.





C. K. Li (MIT)
Species diffusion and Anomalous Fusion Yield Degradation

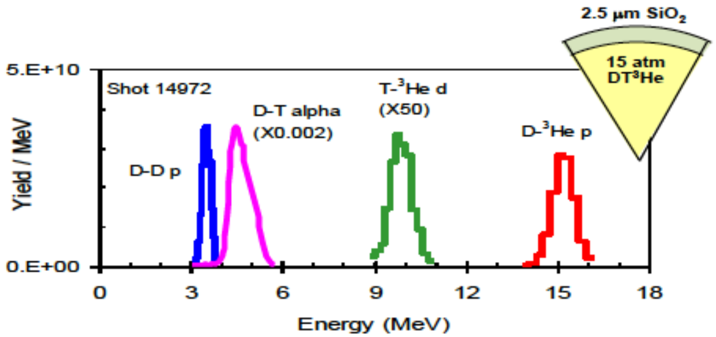


FIG. 2. : The first energy spectra measured using CPS-2 from OMEGA shot 14972. This is a D-T-^{3}He shot with a 2.0-μm glass shell. In addition to D-D protons, D-^{3}He protons, and T-^{3}He deuterons, we have also obtained D-T alphas with much higher yield (in the order of 2×10^{13}). Note that in order to give better showing, the spectrum of T-^{3}He deuterons has been multiplied a factor of 50, while that of D-T alphas has been multiplied a factor 0.2%.

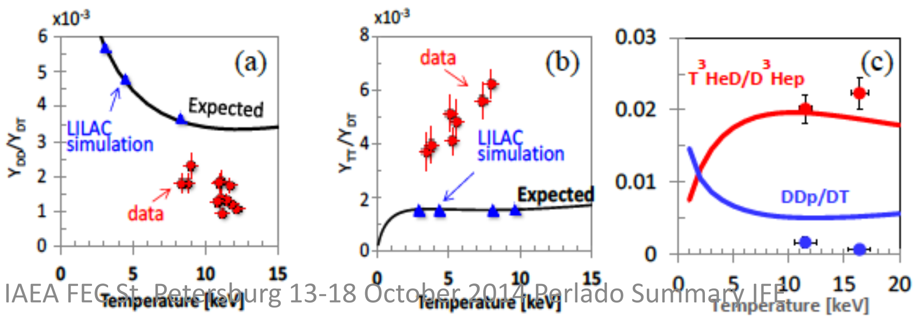
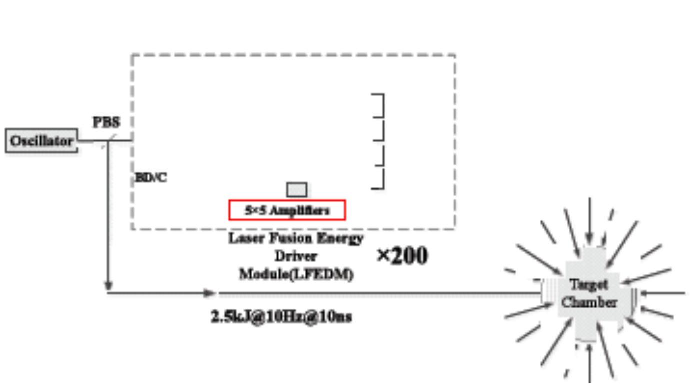
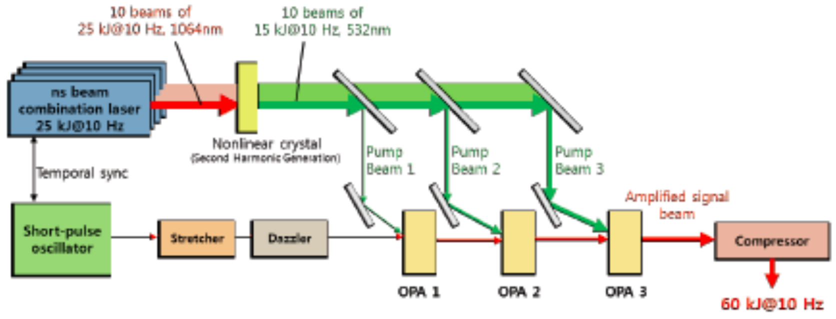


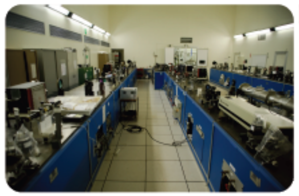
FIG. 3. Measured Y_{DD}/Y_{DT} yield ratios (a), Y_{TT}/Y_{DT} yield ratios (b), and the Y_{T3HeD}/Y_{DHep} and Y_{DDn}/Y_{DT} yield ratios (c) are plotted as a function of ion temperature, respectively. The deviations from the predictions based on cross sections, qualitatively indicate the fuel stratification during shock flash.

OPCPA system using ns beam combination laser is proposed
for the ignition driver of the fast ignition and shock ignition. (H.J. KONG) KAIST, Korea





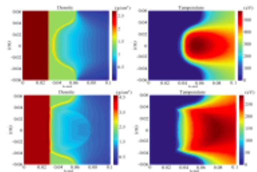
ABC Summary R. De Angelis, ENEA, Italy

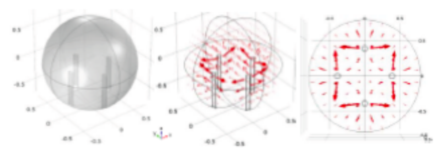


Main beams	
Active medium	Glass Neodimium Phospate
wavelength	≈ 1054 nm
Beam energy	≈ 2*100 J
Pulse duration	≈ 2-5 ns
Max power/beam	≈ 50×10^{9} W
Rising time	≈ 1 ns
Output beam diameter	≈ ø 75 mm
Intensity	≈ 10^{13} ÷ 10^{15} W/cm^{2}
Minimum Focal spot	≈ø 40 μm
Beam integrator Induced Space Incoherence	500×500 μm^{2}

Energy transfer in porous materials, suitable has absorbers/smoothers of intense laser radiation, has been measured from the volume of craters left on Al targets coated with polystyrene foam, after irradiation. This allows the determination of optimum thicknesses of the foams. Laser absorption efficiencies close to 100% can be deduced. Measurements have been performed on overcritical foams .The laser intensities were 10$^{13\text{-}14}$ W/cm^{2}.

Numerical simulations of 2 layer targets have been carried out withg the 2D hydrodynamic code MULTI. The foam was approximated as an homogeneous medium. High transverse plasma velocities of the required simulations in ALE (Arbitrary Lagrangian-Eulerian) scheme. The results showhowthe shock wave propagates through the foam and reflects on the metal surface to the ablated plasma at the interface.





Measurement and modeling of the ElectroMagnetic Perturbations have been performed for ABC. Two types of antennas have been used: *SuperWideBand* (SWB) microstrip antenna, and commercial (GA.107 model by Taoglas) multiresonant monopole (WM). The ABC vacuum chamber was simulated with a COMSOL solver as a resonant cavity and as a non hollow cavity.

Proton-Boron fusion reactions are studied experimentally in ABC with polyethylene targets doped with Boron. The alpha particles products are searched for with CR39 detectors whose analysis is performed by comparison with simulated track patterns and the background discrimination is enhanced by use of cross correlation techniques.

New diagnostics in ABC have been set up by use of Diamond detectors for time of flight and X-rays, and imaging plates . Calibration of imaging plates in X ray have been performed by use of continuous and fluorescent sources

GPI (HAMAMATHU, JAPAN)

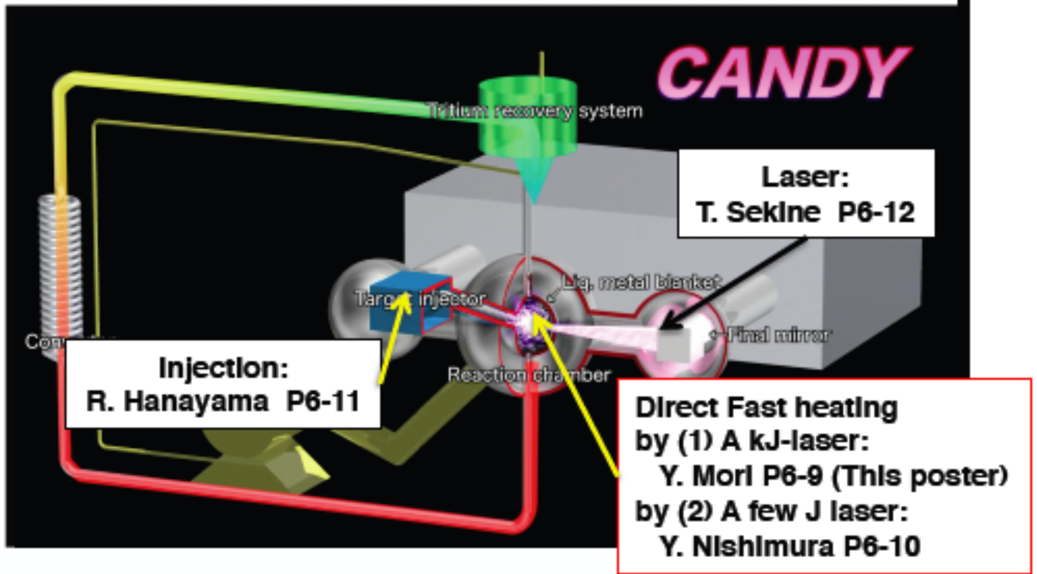
Concept of Direct Ion Heating using 4kJ-10 Hz FI Unified Machine CANDY

Neutron Yield
- D-T : 5×10^{12}/shot
- D-D: 5×10^{10}/shot

Implosion laser
- Energy: 2 kJ/shot
- Wavelength : 500 nm
- Repetition rate : 10 Hz

Fast Heat laser
- Duration: 200 fs or 10 ps
- Energy: 2 kJ/shot
- Wavelength: 1000 nm

Energy Gain [Power]
- D-T : 0.007 [190W]
- D-D:1.5×10^{-5} [0.3W]

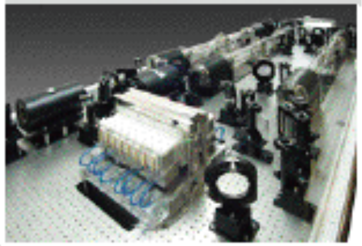


TWO KEY ADVANCES FOR REPETITIVE LASERS ALREADY BEING DEVELOPED

From Flush Lamps to Diodes

Flash Lamps
Broad spectra
→Inefficiency

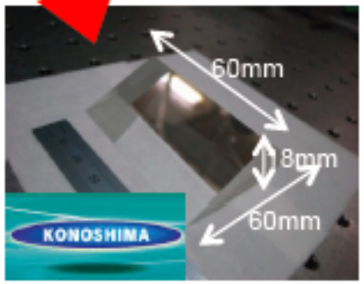
Laser Diodes
Emission lines≈
absorption lines



100 times efficiency

From Glasses to Ceramics

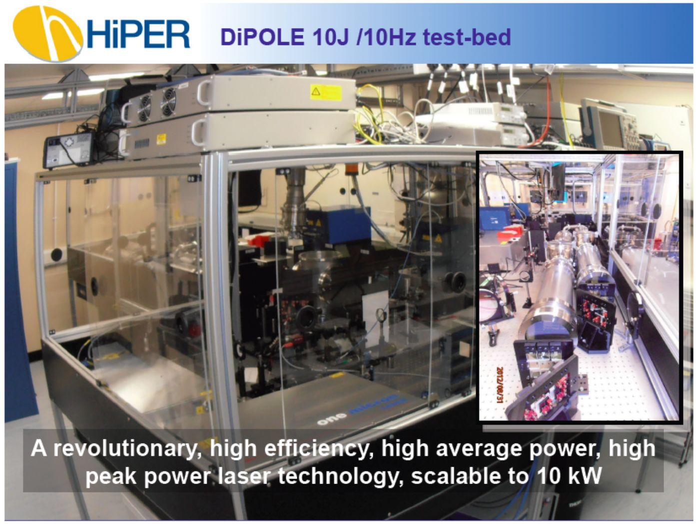
Laser Glasses
- **Large optics**
- **Low thermal conductivity**



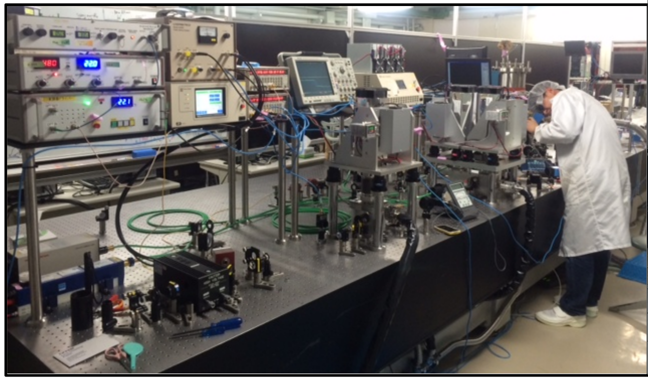
Yb: YAG Cooled Ceramic Crystal
- **Large optics**
- **High thermal conductivity**

1000 times thermal conductivity

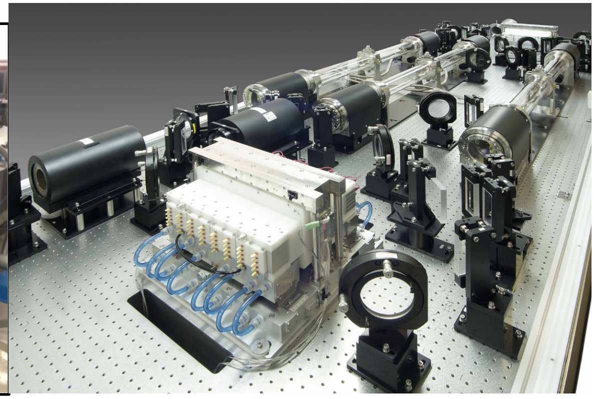
Courtesy
H. Azechi



DIPOLE, CLF, UK



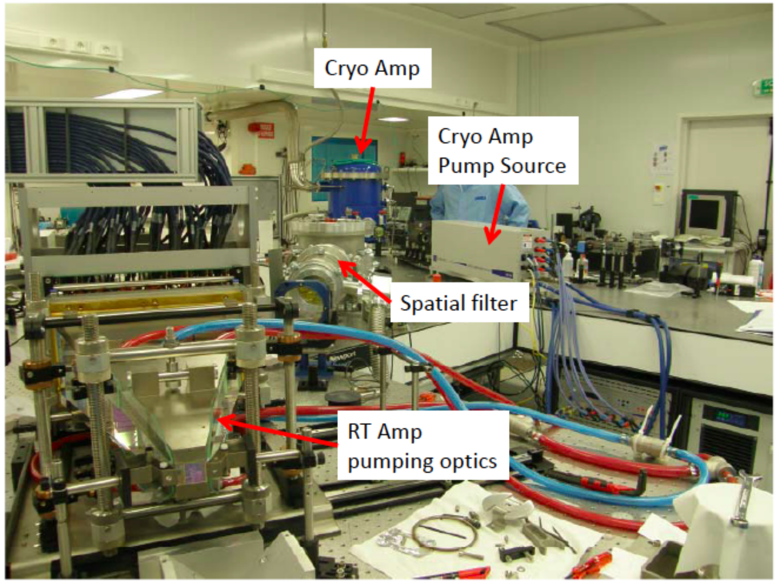
GENBU
Yb:YAG Ceramic / 1J, 100Hz



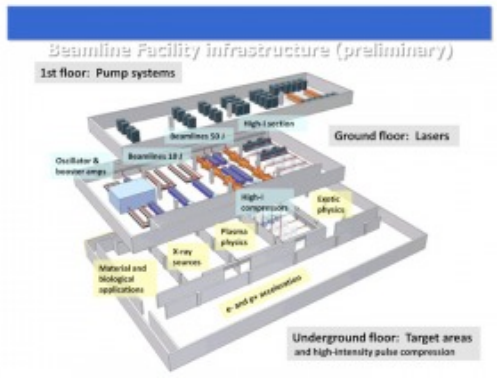
HALNA 20
20J, 10Hz

Institute of Laser Engineering, Osaka, Japan

LUCIA / France 10J / 10Hz

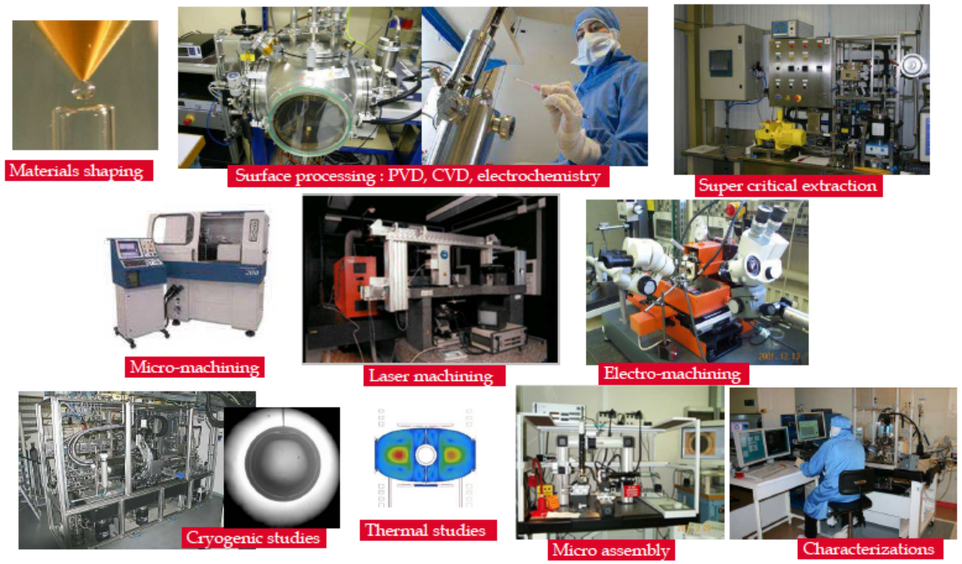


MERCURY, LLNL/USA
50 J /10Hz

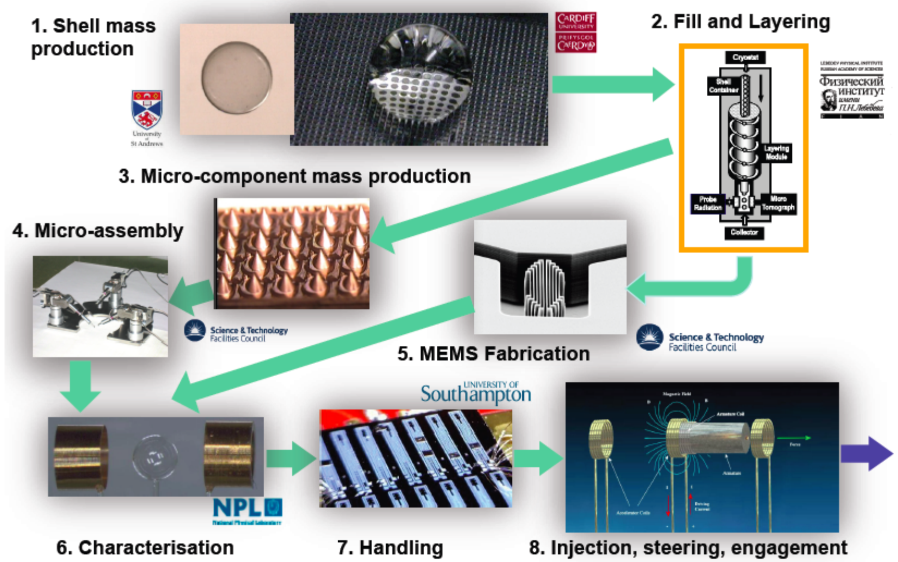


ELI, Czech Rep.
100 J, 100 Hz

The target development requires numerous technologies



HiPER — Target production at the required scale and cost is achievable

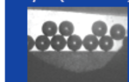


Courtesy M. Tolley (CLF, UK)

Cryogenic Target Factory for IFE/Russian Federation
KORESHEVA Lebedev Physical Institute

- **FST technology has been developed at LPI**, which forms an isotropic ultrafine fuel layer inside moving free-standing targets
- Our studies show that **application of isotropic ultrafine fuel layer makes risk of the layer destruction minimal** during target delivery
- **A full scaled scenario of the FST transmission line operation has been demonstrated for targets under ∅ 2 mm**, namely:
  - ⇒ Fueling a batch of free-standing targets (up to 1000 atm D_2 at 300 K),
  - ⇒ Fuel layering inside moving free-standing targets using FST technology: cryogenic layer up to 100 um-thick,
  - ⇒ Target injection into the test chamber with a rate of 0.1 Hz
  - ⇒ Target tracking using the Fourier holography approach (computer expts)
- **Free-standing target positioning & transport using the quantum levitation effect** of the high temperature superconductors (HTSC) have been proposed. POP experiments have proved the efficiency of this approach **(result 2012-2014)**
- **A prototypical FST layering module for rep-rate production of reactor-scaled cryogenic targets has been designed** based on the results of calculations and mockups testing **(result 2012-2014)**
- **LPI continue developing the of R&D program on CTF** in collaboration with Power Efficiency Center of INTERRAO UES & National Research Center "Kurchatov Institute". **New generation project is under consideration.**

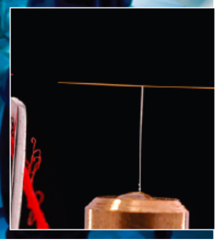

Cryo target with ultrafine fuel layer (∅1.5mm)


Targets rep-rate injection under gravity: 0.1Hz, 5K


Cryogenic gravity injector


HTSC maglev for target positioning & transport

HiPER — Exploitation of target mass production



IFE/P6-11

1Hz Pellets Injection and Laser Synchronous System for Continuous Laser Confinement Fusion and Neutron Generation

Primary author: Ryohei Hanayama(GPI, JAPAN)

We succeeded in injection of spherical deuterated polystyrene bead pellets at 1 Hz and symmetrical engagement and irradiation of them with two ultra-intense laser beams. (i) This is the first demonstration of ultra-intense laser engagement of injected flying pellets. The laser intensity was high enough to produce a DD neutron yield of $9.5 \times 10^4/4\pi$ sr/shot. (ii) We observed channel formation through the free-falling pellets, which might be the evidence to support a scheme for fast ignition.

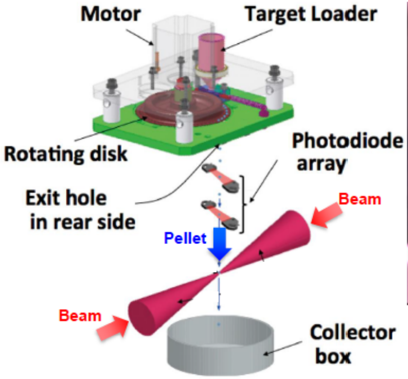


FIG.1 pellet injection and laser synchronous system

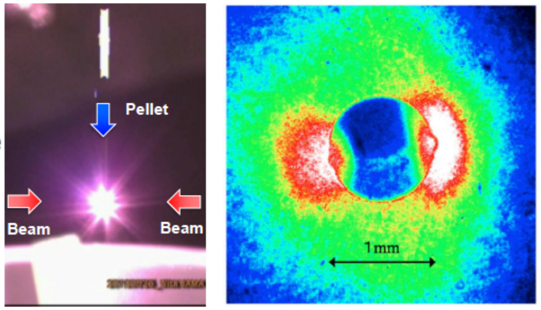


FIG.2 Snapshots of the instant of pellet engagement. (left) a visible image. (right) a shadowgraph using a synchronized 2ω harmonic laser probe.

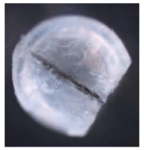
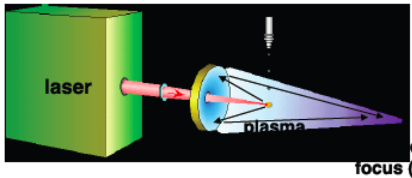


FIG.3
A straight channel along the laser axis was shown inside the irradiated pellet.

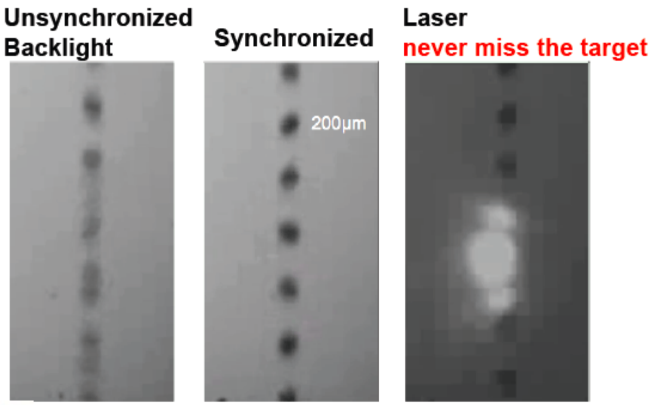
The hit probability was about 70%.
And it has been improved to more than 90 % at the present moment.

EUV project has already demonstrated Target Injection and Beam Pointing



edi
focus (IF)

Institute of Laser Engineering

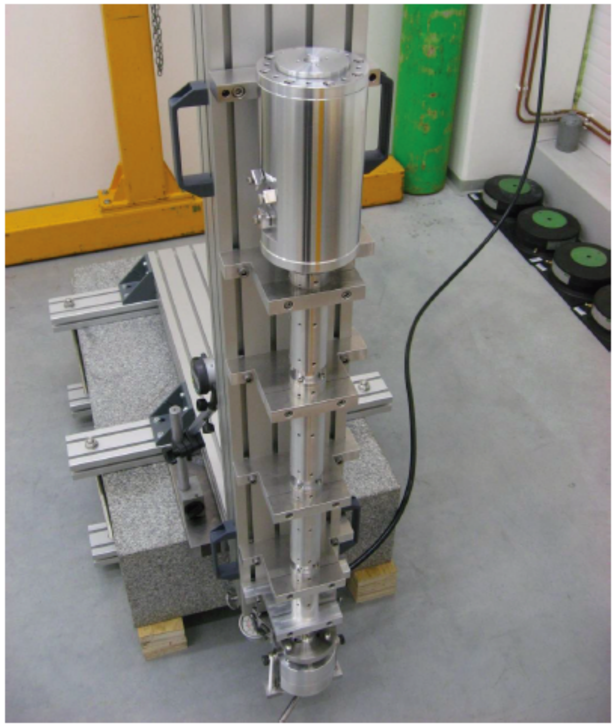


Progress in Target Injection Technology

Industrial engagement

HiPER

Injector prototype in Czech republic

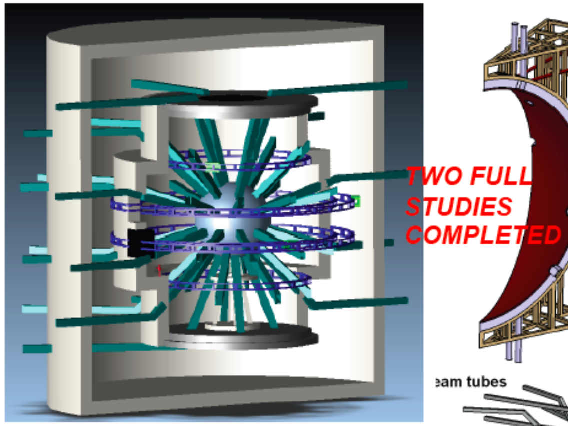


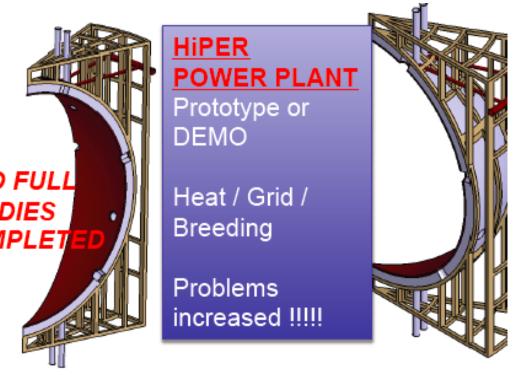
1 meter long segment of the gas-acceleration section of the injector assembled

Diagnostic package to measure precision of the velocity (high-speed camera) and of lateral guiding (interferometer)

Test results: Injector shooting up to the target position, height of ~4 m

1mm precision
50 – 80 m.s^{-1}





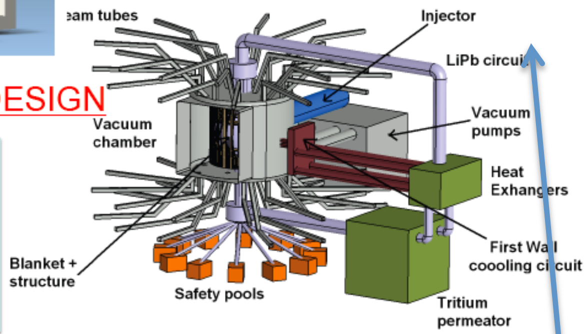
HiPER POWER PLANT
Prototype or DEMO

Heat / Grid / Breeding

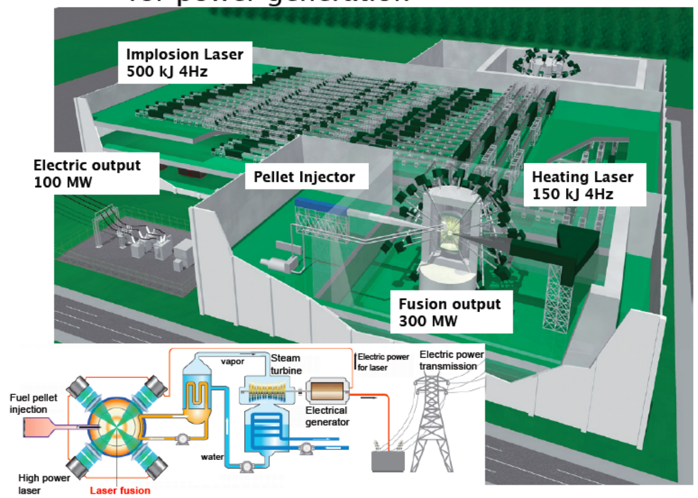
Problems increased !!!!!

We worked on THREE DESIGN

HiPER Burst facility
Demonstration of some repetitive elements (laser / injection)but
NO power
Problems reduced



Experimental Test Facility, LIFT for power generation

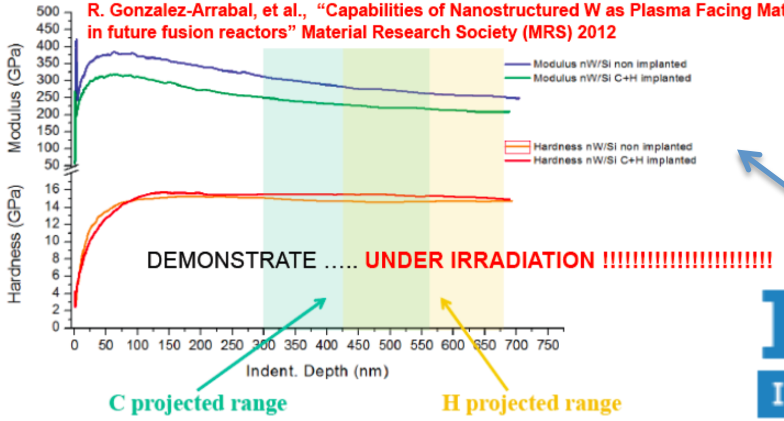


16

Mechanical properties of implanted coatings

INDUSTRIALES ETSII | UPM

R. Gonzalez-Arrabal, et al., "Capabilities of Nanostructured W as Plasma Facing Material in future fusion reactors" Material Research Society (MRS) 2012



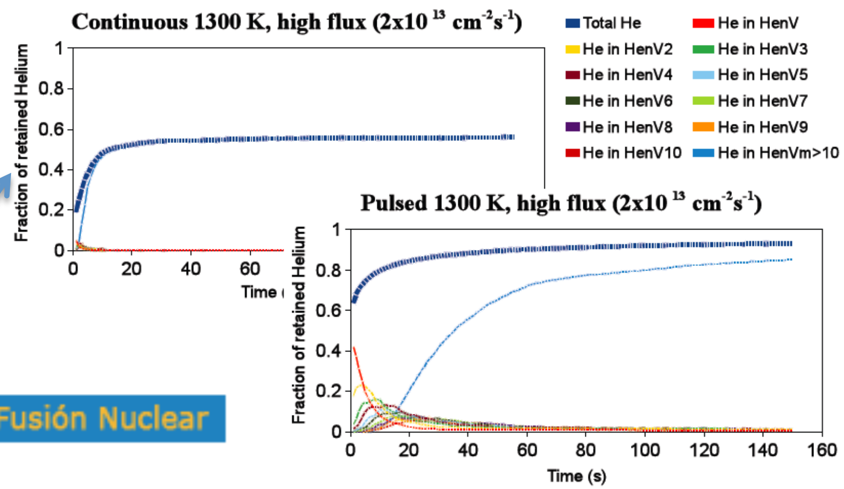
•Irradiation notably decreases the Young´s modulus → lower interatomic cohesion because of the introduction of foreign species

Raquel Gonzalez-Arrabal Erasmus Intensive Course APPEPLA 16 – 27 July 2012 November 25-30, MRS Fall Meeting

IFN
Instituto de Fusión Nuclear

Defect evolution under continuous and pulsed helium irradiation of tungsten: Relevance for armor applications in laser fusion reactors

Results



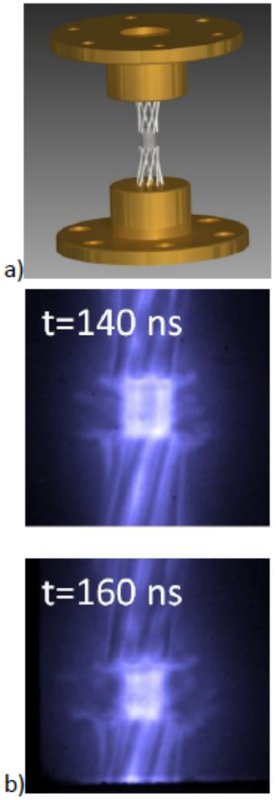
Magnetized Liner Inertial Fusion (MagLIF) concept.

MagLIF is in the class of magneto-inertial fusion targets. In MagLIF, large drive currents produce an azimuthal magnetic field that compresses cylindrical Al or Be liners containing laser-heated and axially-magnetized deuterium or deuterium-tritium fuel. The large drive currents are created by the Z machine, a 22 MJ pulsed power driver capable of delivering 26 MA with a 110 ns risetime. At a radius of 1 mm, that current produces a magnetic drive pressure of about 100 Mbar.

M. Herrmann
P.A. Gourdain

Prior to the Z machine firing, a 900 kJ capacitor bank is used to drive a coil system external to the target produce a nearly uniform axial magnetic field of 10-30 Tesla over a several cm3 volume for several milliseconds. During the liner implosion, just after the liner begins to move (about 40 ns before it stagnates on axis), the Z-Beamlet laser (ZBL) [3] delivers a 1 TW, 2-4 ns laser pulse at 532 nm through a laser entrance hole at the top of the cylindrical liner target,

DD yields of up to 2e12, electron and ion temperatures up to 3.5 keV, and a several mm tall <150 micron diameter heated plasma, a remarkable achievement for a 100 km/s implosion. These results were reproduced in additional experiments in 2014.



a) b)

Figure 1. a) 3D model of the twisted cathode and anode current feeds shown together with the aluminum liner on the mid-plane. b) XUV data showing the implosion of the liner near peak compression using the setup shown in panel a). The twisted pins are clearly visible.

Innovative Concept of the Compression and Heating of the Plasma Targets in the Scheme for Magneto-Inertial Fusion

S.V. Ryzhkov

SUMMARY (1)

NIF is operating even more than expected from energy and feasibility

NIF obtain nuclear fusion fuel gain > 2 with a promising of possibilities to be extended

LMJ is already working and progressing adequately

LMJ-PETAL is almost completed and prepared for open in 2017

Experiments in Shock Ignition have been conducted in different lasers

FIREX-I is increasing LFEX energy to 10 kJ

Fast Ignition experiments are reaching a new promising stage using Magnetic Fields

SUMMARY (2)
Going to repetitive = Energy (reactor)

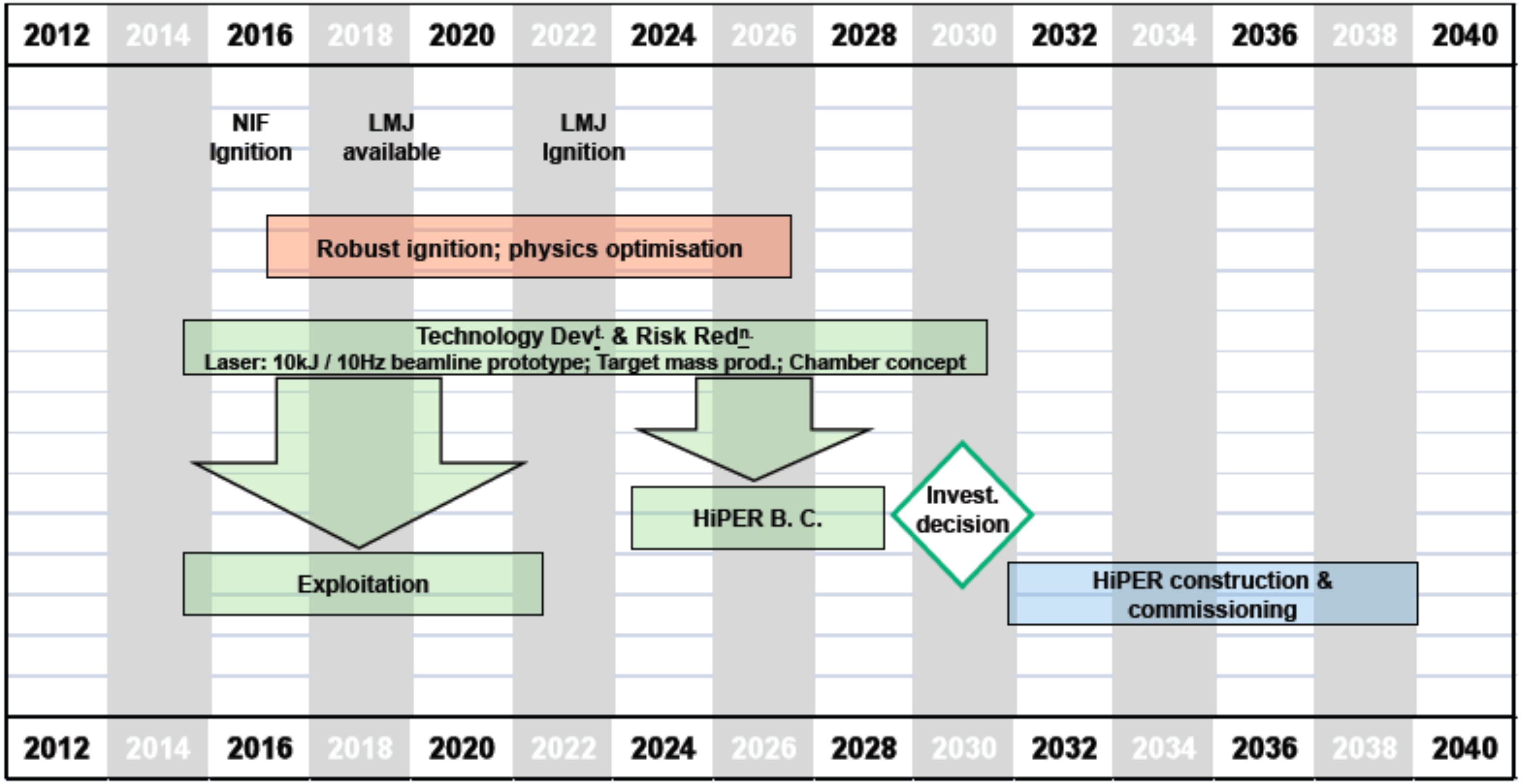
New repetitive lasers are being operating

Target manufacturing is getting a crucial role for massive production

Injection systems have started to appear

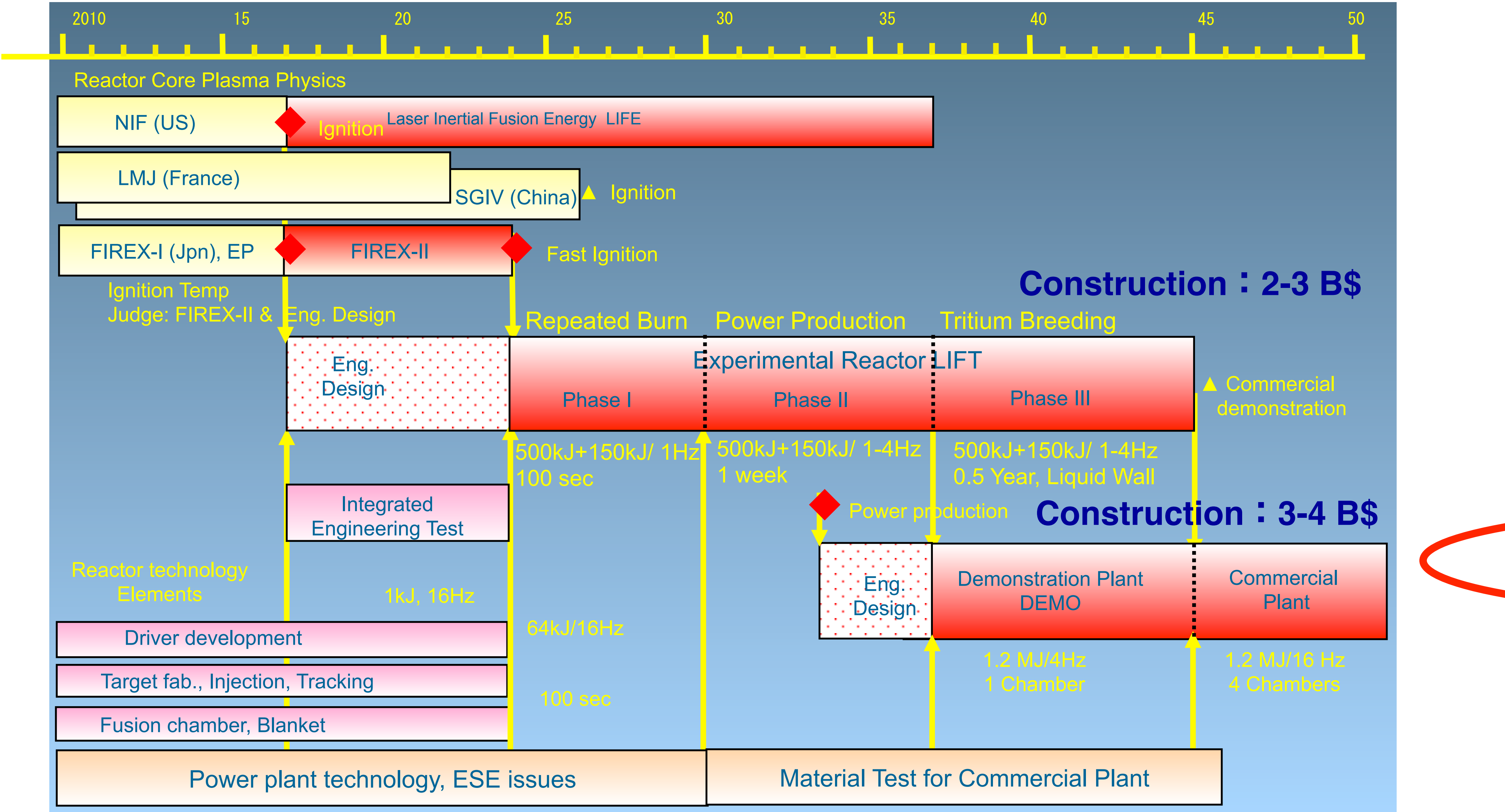
Studies of Chamber and preliminary energy systems have been/ are being conducting

High – level delivery timeline



Courtesy Ch. Edwards

Experimental reactor (i-)LIFT integrates all physics and engineering activities.



Courtesy H. Azechi