FCI in France
status and perspective

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Fusion Power Associates – Washington DC – 1-2 December 2010

Outline

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- ICF in France : a long history of successes
- ICF for energy : a place in the French energy vision ?
- LMJ / PETAL a key facility for the IFE in Europe
- How France scientific community participates in HiPER (European program for IFE faisability demoinstration)
- The French strategy
- A world wide forum is necessary for IFE

ICF reserach in France was initiated at Ecole Polytechnique, In 1964 with the support of CEA-Limeil

In 40 years, 5 national generations of lasers were commissioned,

Rubis laser :

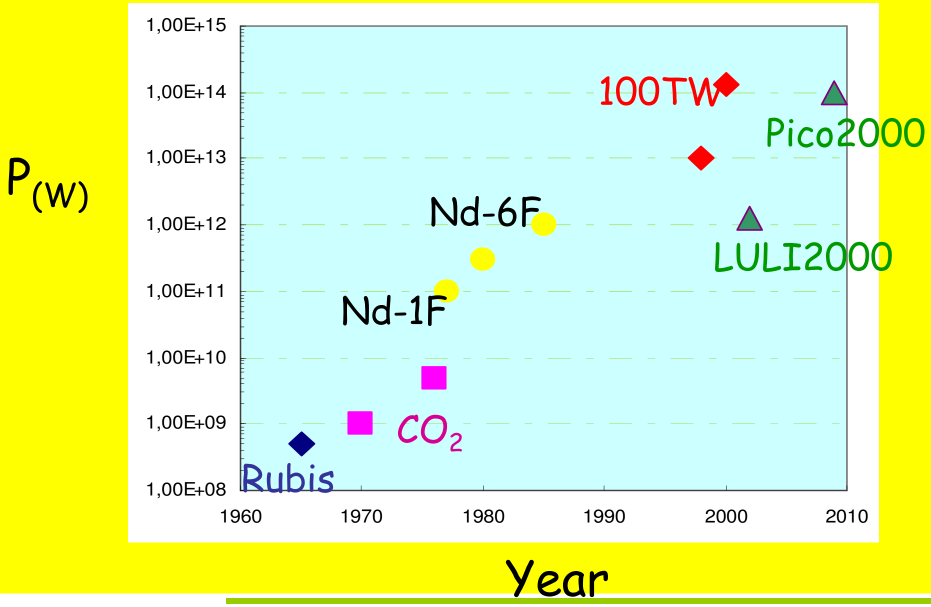
CO2 laser :

Nd laser : 2 beams-200 J – 600 ps (w, 2w, 4w) (1980)

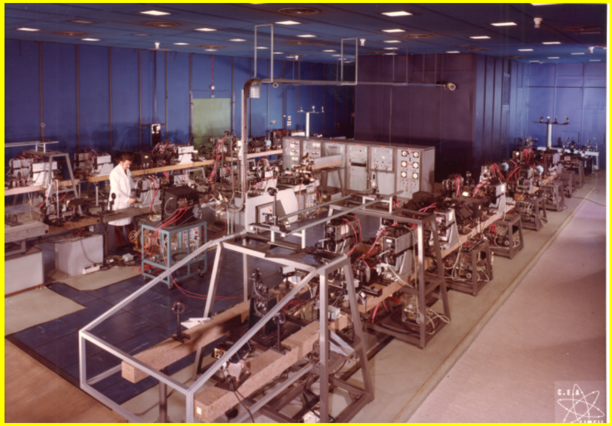
Nd laser : 6 beams – 600 J -600 ps (w, 2w, 4w) (1985-2002)

Ti/Sa : 100 TW

LULI2000 : 2 beams – 2 kJ – 1.5 ns (w, 2w, 3w)



In 1968 the first fusion events are observed



C6 laser, delivering up to 600 J

Today several critical laser facilities and labs in France

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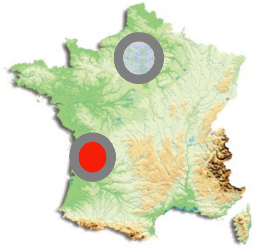
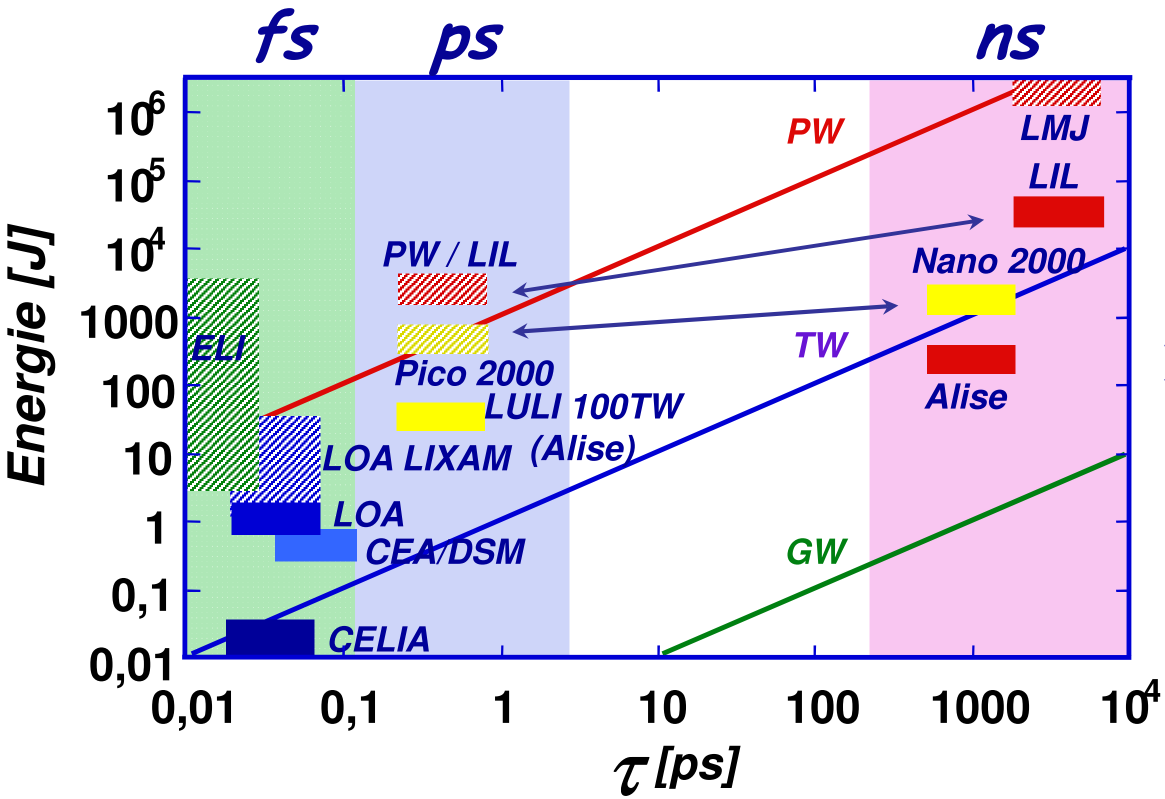
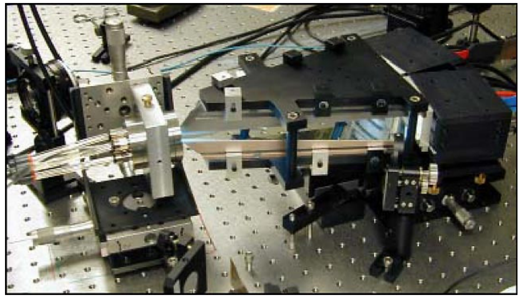
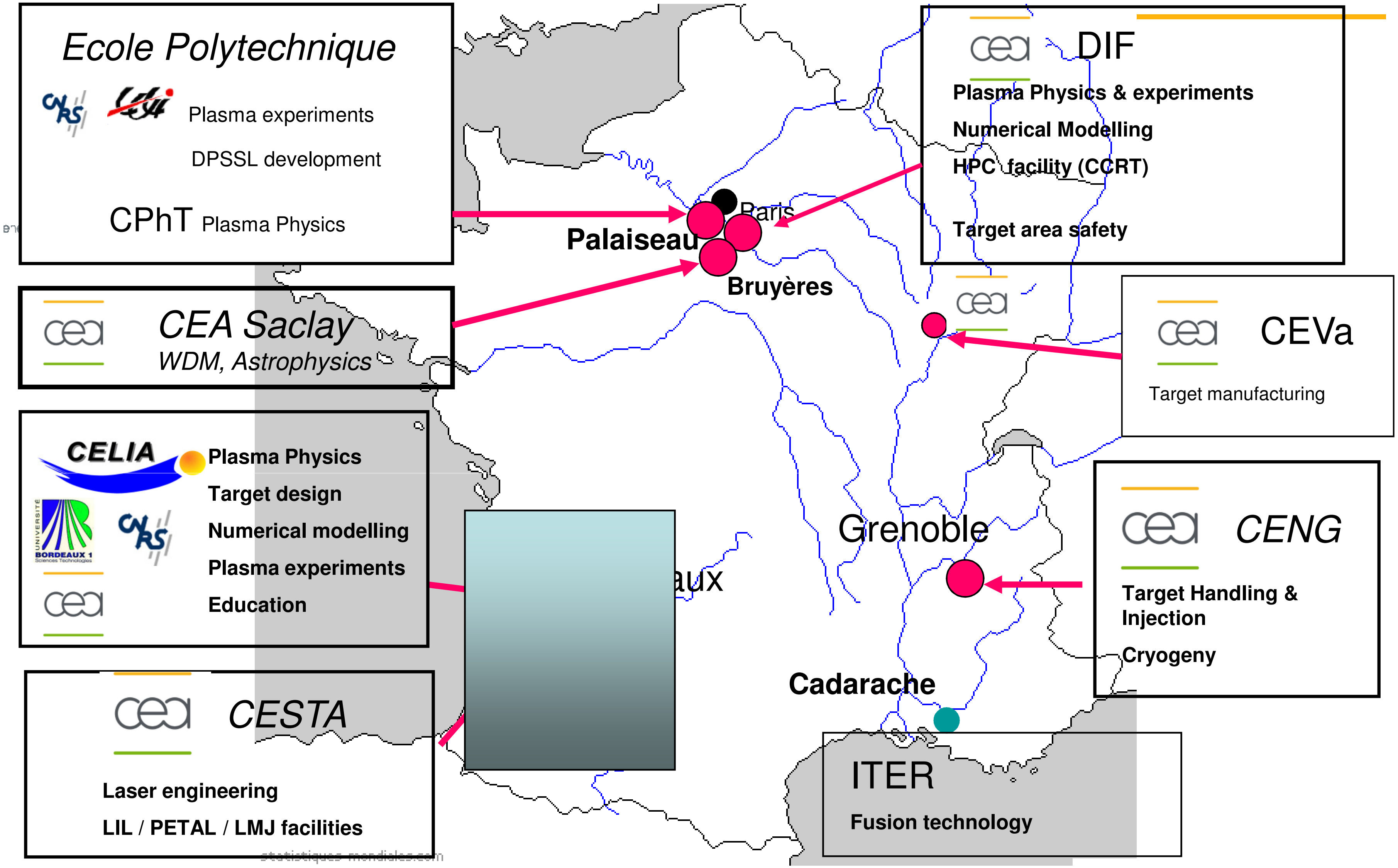
- Ecole Polytechnique {LOA, LULI},
- CELIA (Bordeaux)
- CEA (Bruyeres, Saclay and Bordeaux)
- LCD/ENSMA





Lucia : objectif : 100 J – 10 Hz



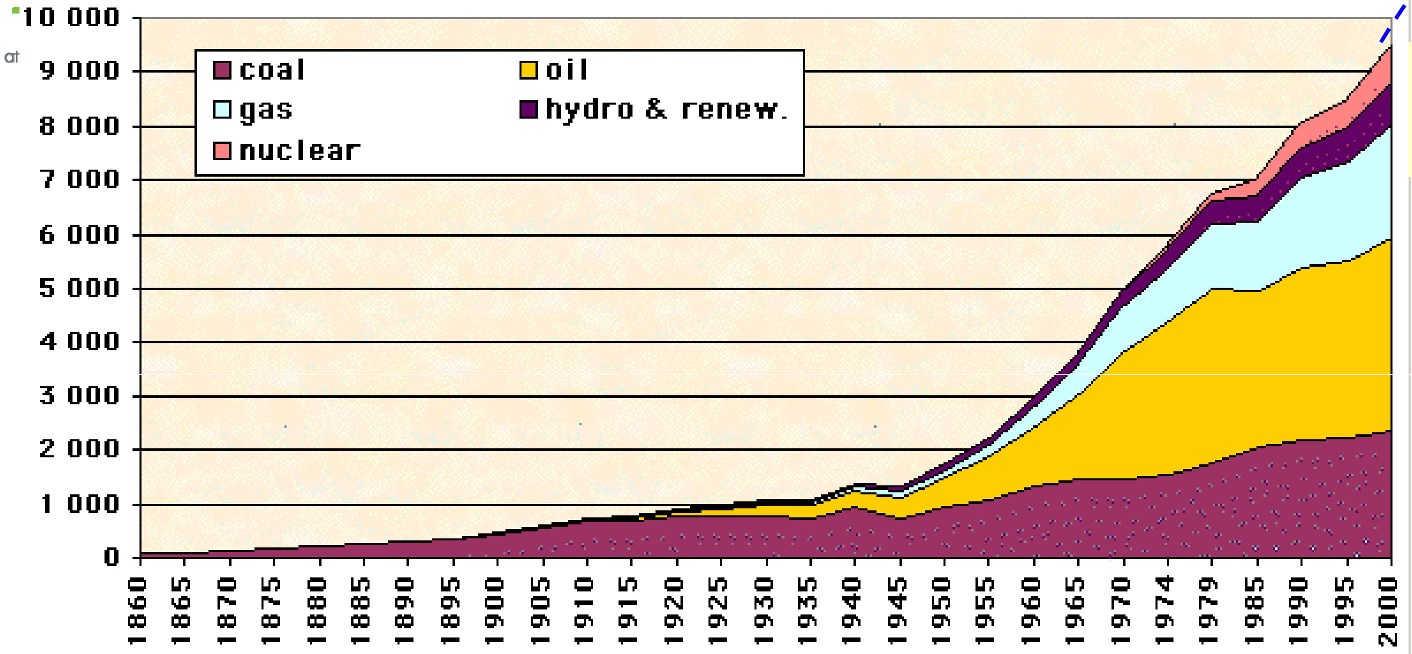


French Contributors to IFE are coordinated by ILP

INSTITUT LASERS ET PLASMAS

Why ICF should go for Energy ?

We are facing a huge challenge :



To accomodate the world demand

To find sustitutes for GHGE

- A global increase in energy demand is inevitable
- Fusion offers critical advantages : no carbon emission, no air pollution, unlimited fuel, intrinsically safe
- IFE in France aims to demonstrate that fusion by lasers is a credible alternate energy source complimentary with magnetic fusion not a competition.

*A global response from the nuclear industry : fission **and** fusion*

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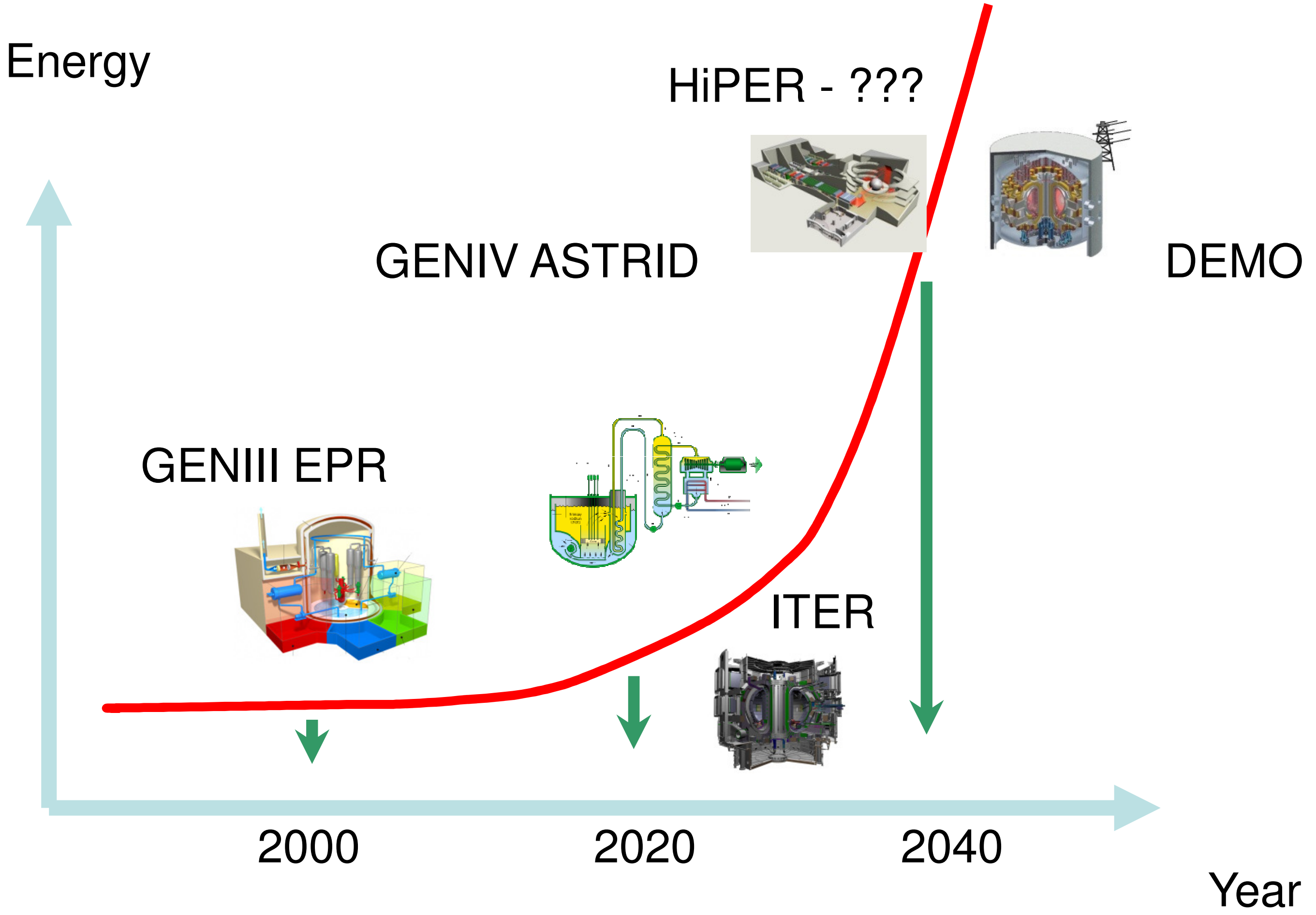

Bringing IFE on the roadmap for Energy in France

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Alliance Nationale de Coordination de la Recherche pour l'Énergie

In France the National Coordination for Energy Research (2010)…

- Builds the national roadmap for energy research
- Identifies the necessary breakthrough technologies and the scientific issues
- Promotes transverse collaboration within the various sources
- Promotes the emergence of national champions insuring long time safe and durable supply of energy (AREVA, GDF SUEZ, TOTAL…)
- Proposes scientific programs to ANR
- …In conjunction with the European Energy Research Alliance

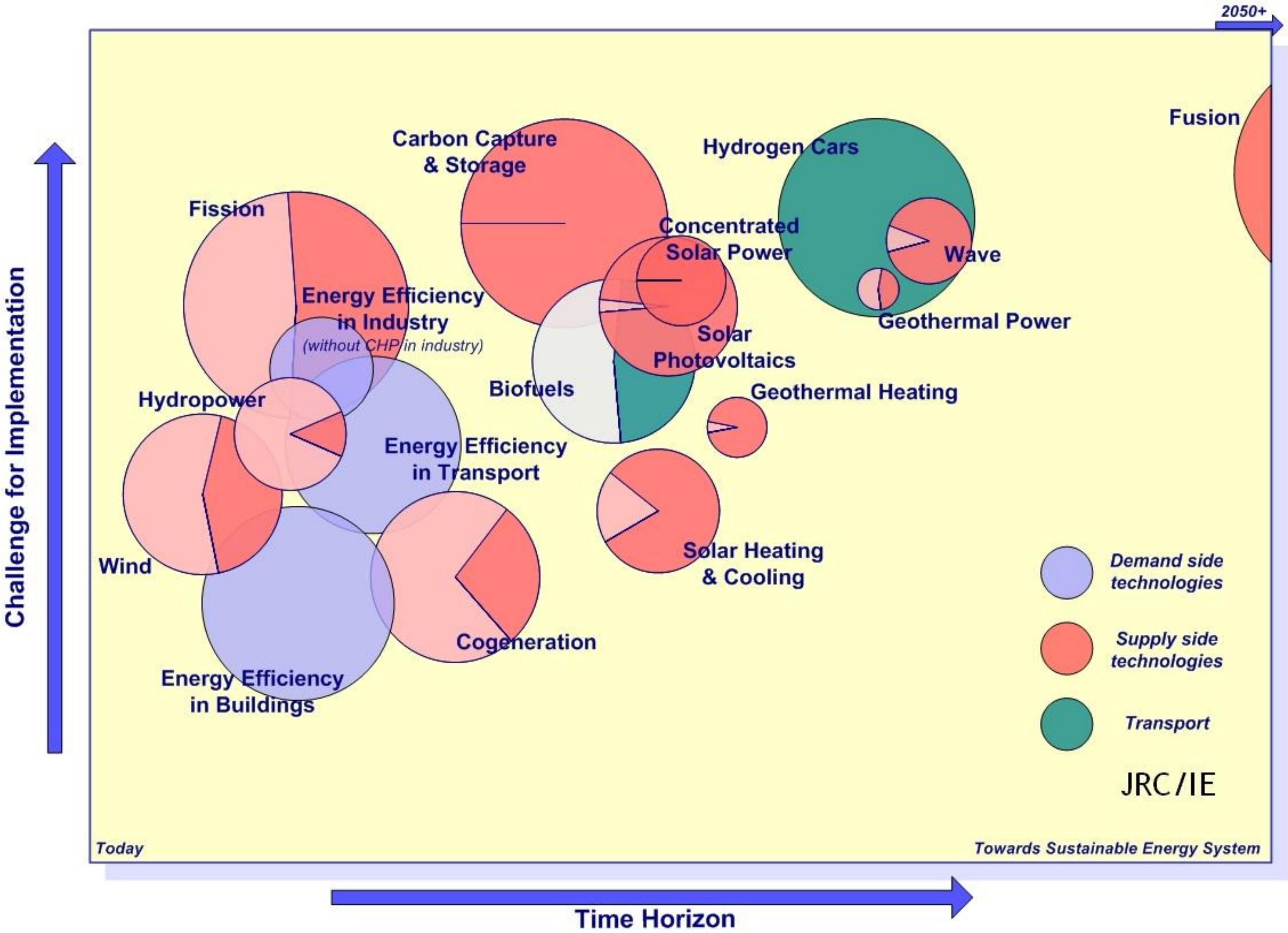
IFE groups have applied to participate in ANCRE working groups

Member of the Consortium

Founders: CNRS, CEA, CPU, IFP Energies nouvelles

Associates: ANDRA, BRGM, CDEFI, CEMAGREF, CIRAD, CSTB, IFREMER, INERIS, INRA, INRETS, INRIA, IRD, IRSN, LNE, ONERA ...

Key technologies for a low carbon energy system



Source SET-Plan UE

President Nicolas Sarkozy October 2010 at LMJ site

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«

« By choosing to build the PETAL laser next to the LaserMegaJoule, we open the way to explore a new type of energy. With ITER and PETAL, France is now a world leader for the production of energy by fusion. This is a major program that you are opening here»

Petal
PETAWATT AQUITAINE LASER

PETAL Project objectives

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Coupling a petawatt class laser PETAL to quads of LIL or LMJ
1 quad = 30 kJ / ns / 3 ω

- **Energy : 3 kJ,**
- **Wavelength : 1053 nm,**
- **Pulse duration between 0,5 and 10 picoseconds,**
- **Intensity on target : 10^{20}- 10^{21} W/cm², **
- **Intensity contrast (short pulse) : 10^{-7} at -7 ps,**
- **Energy contrast (long pulse) : 10^{-3}.**

REGION AQUITAINE

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RÉPUBLIQUE FRANÇAISE

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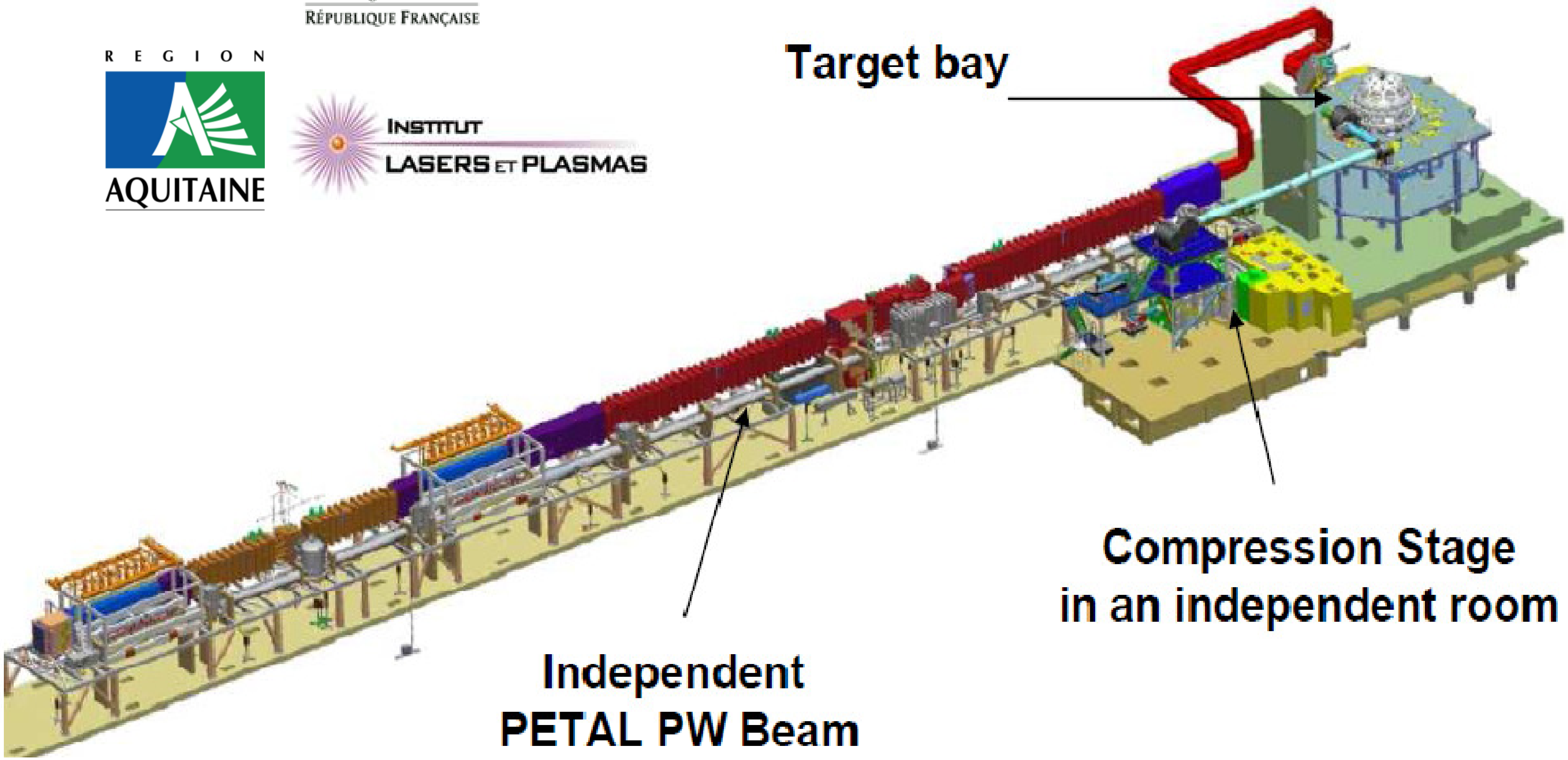
HiPER

Former planned configuration : PETAL-LIL Coupling



Front-end, amplifier prototype, spatial filter vessel

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Compression stages on the LIL facility

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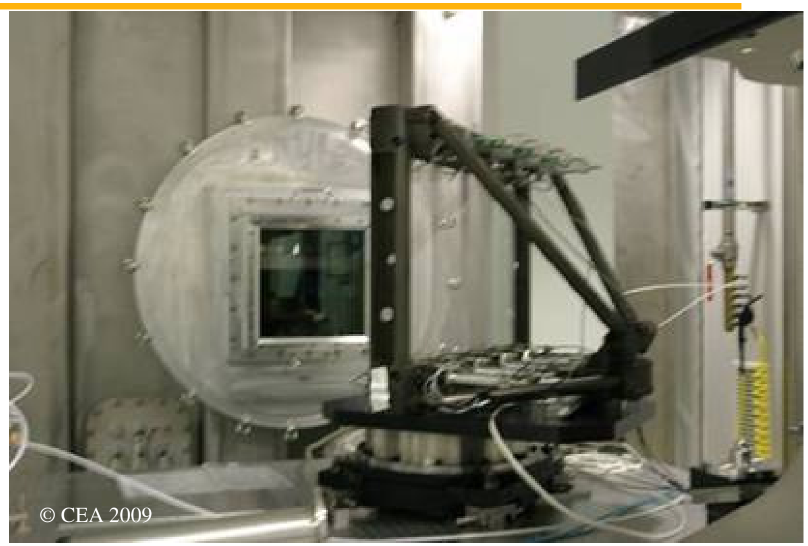
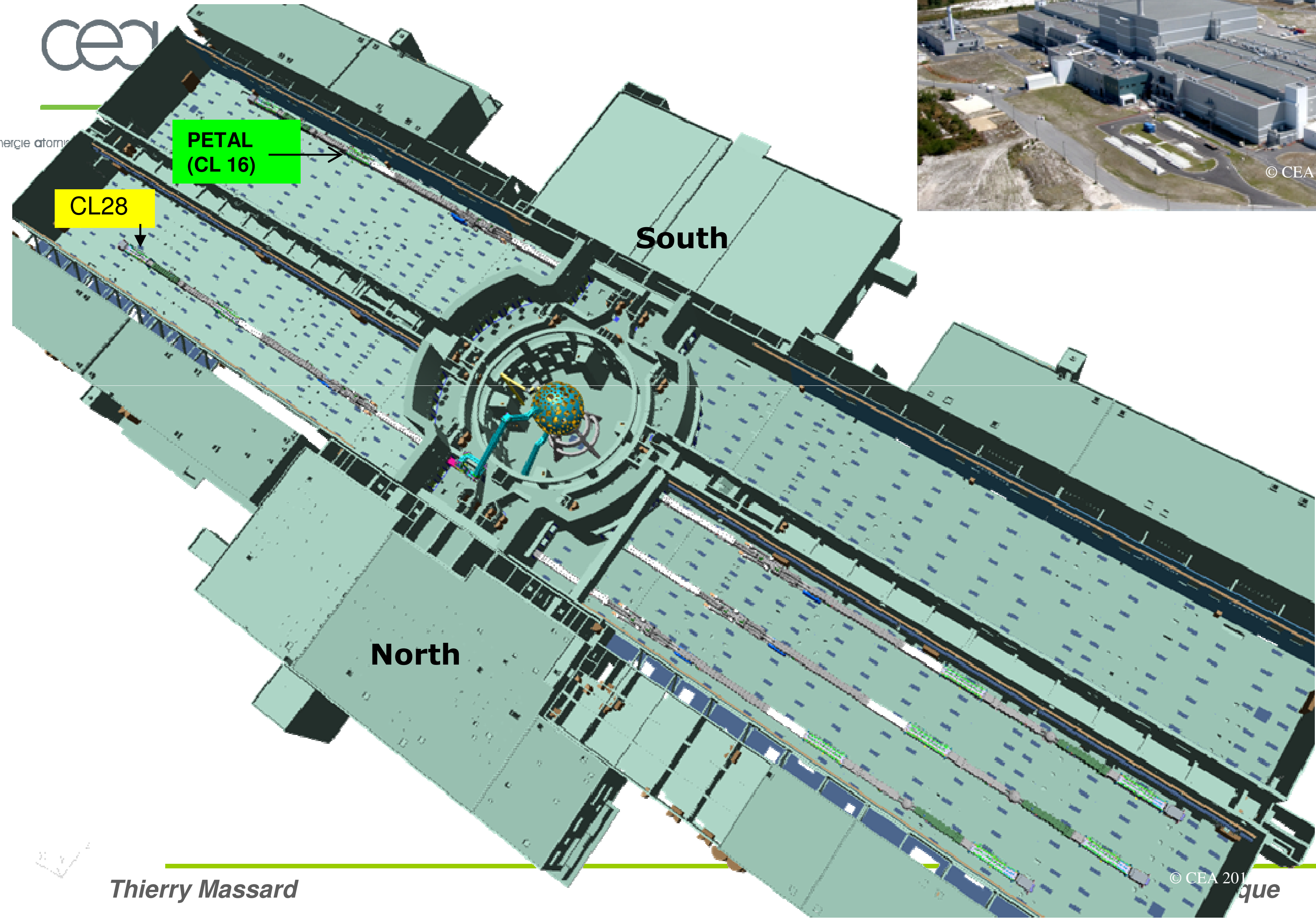
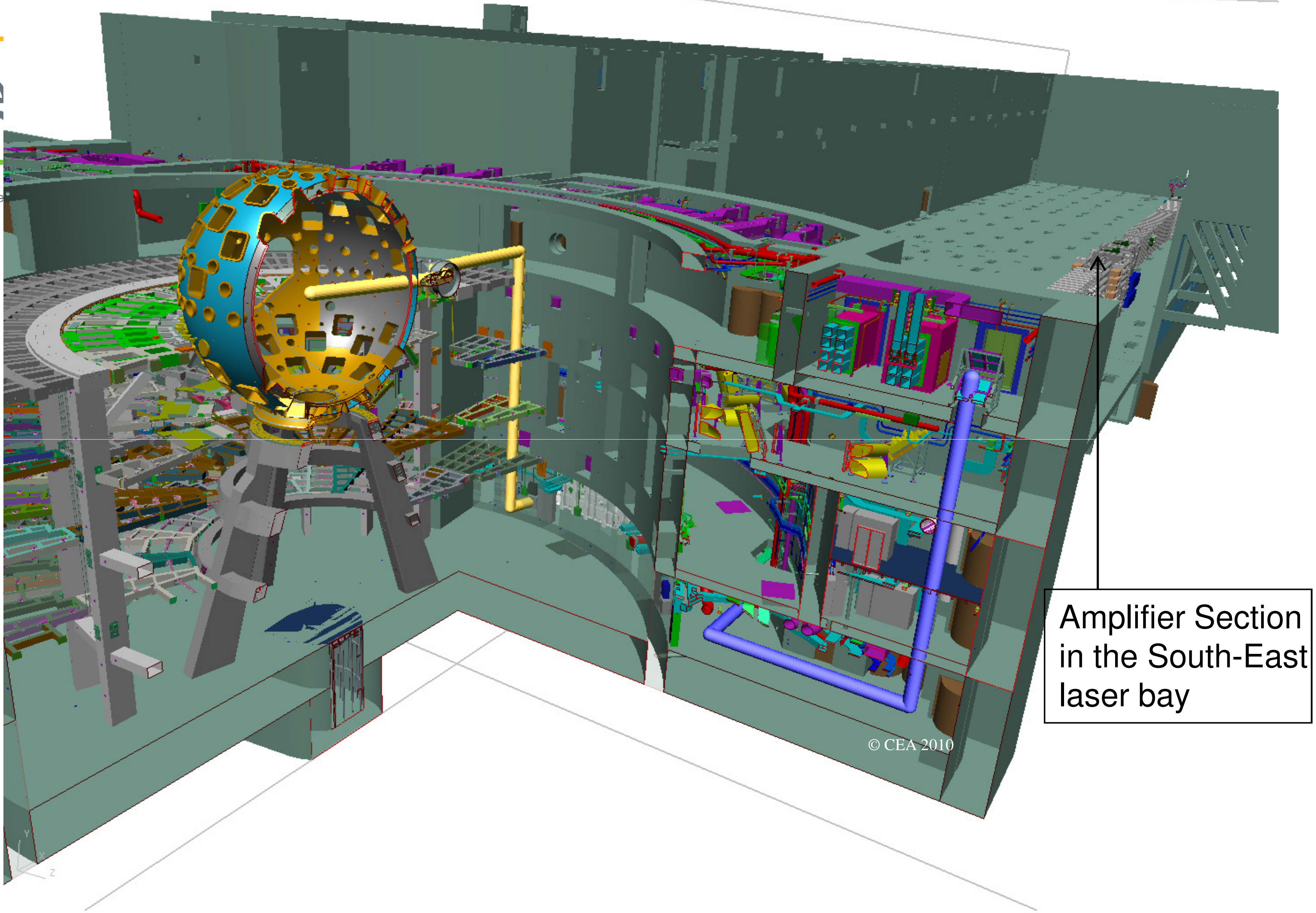


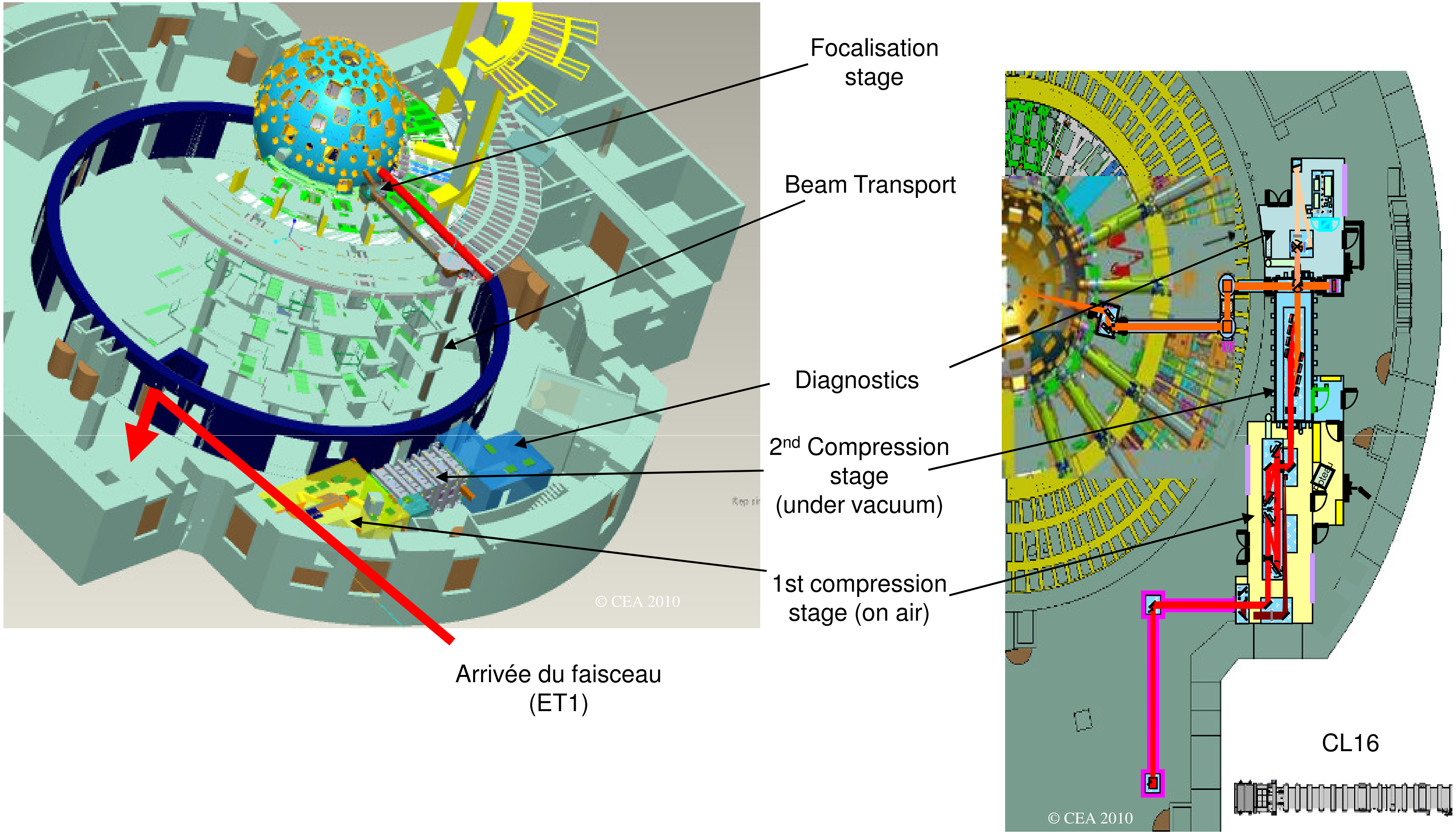
New configuration : PETAL-LMJ Coupling



PETAL beamline thru the LMJ building



Compression and focusing stages




HL ES
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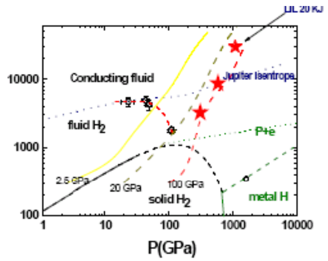
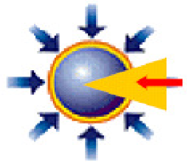
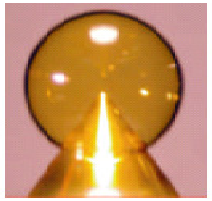
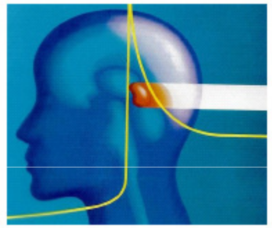
crucial issues for the European IFE project HiPER








Formation d'étoiles dans la Carène (HST)



Warm dense matter | Theoretical physics | **Inertial Fusion Energy** | Astrophysics | Societal issues

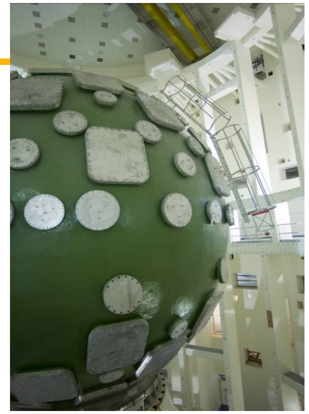
Particle acceleration from high power, multi ps pulse

Transport of relativistic electron beams in plasmas

Optimization of laser to electron converter

High energy hydro expts + high resolution diagnostics

LMJ-PETAL is on the track to Fusion Energy



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PETAL

Adress design issues of fast ignition :

-electron sources

-Transport and fuel heating

-target design

-**High Resolution diagnostics** of DD implosions

Input from

Omega EP + FIREX

LMJ

2/3 LMJ

Radiation Driven Implosions(ID)
Validate
Ignition Physics
Hydrodynamics
PDD SI implosion with G~10 gives Proof of principle of SI

+ Input from NIF

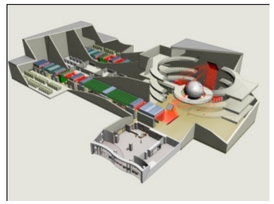
Full LMJ

Direct Drive Implosions + Shock Ignition demonstrate **G=100**

HIPER design

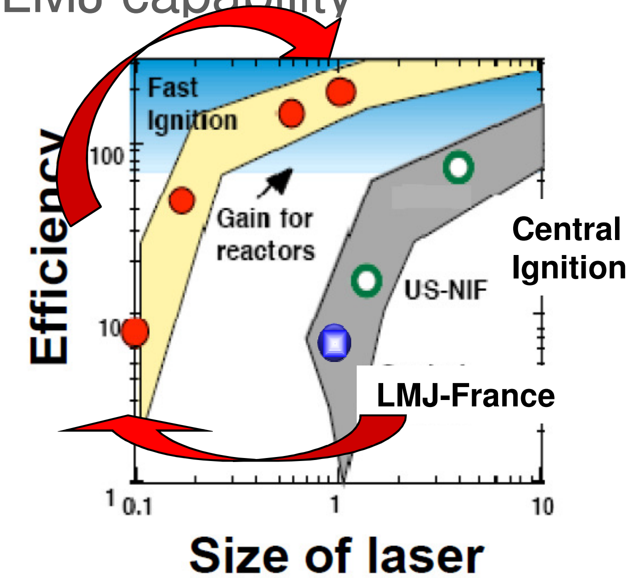
IFE DEMONSTRATION

HiPER



The IFE French Strategy

- As a EU requirement, we keep a clear separation between IFE and "sensitive" weapon science (non proliferation)
  - No use of Weapon codes in the European programs
  - No benchmarking of physics code with weapons code
  - Not in favor of indirect drive capsule option in the European program for sensitivity issues.
  - French-UK guide for good practices in laser exp. approved
- Initial Design point in accordance with LMJ capability
  - Shock ignition nominal
  - Fast ignition option is investigated (PETAL)



- Optimal design goes towards :
  - Lower laser Energy (<1MJ)
  - Higher Target gain (> 100)

In order to aim a positive favorable energy balance.

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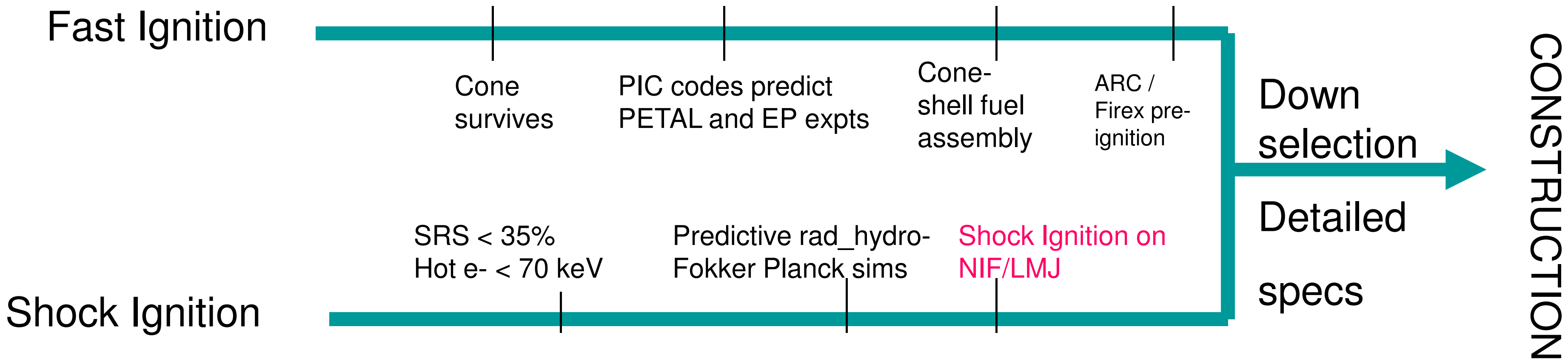
The major milestone on the HiPER road map is demonstration on NIF/LMJ



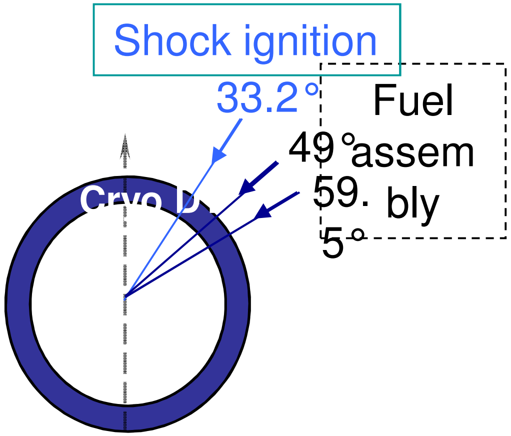
	2010-2012	2013 - 2017	2017 - 2019	**2019**	**2020**
Physics milestones	Part validation expts RAL Luli Alisé PALS	PETAL expts Omega EP expts PDD demo on NIF	LMJ/NIF DD ignition	**Down selection**	Decision **for construction**
Design steps	Preliminary specs	**Validated physics**	Validated design		

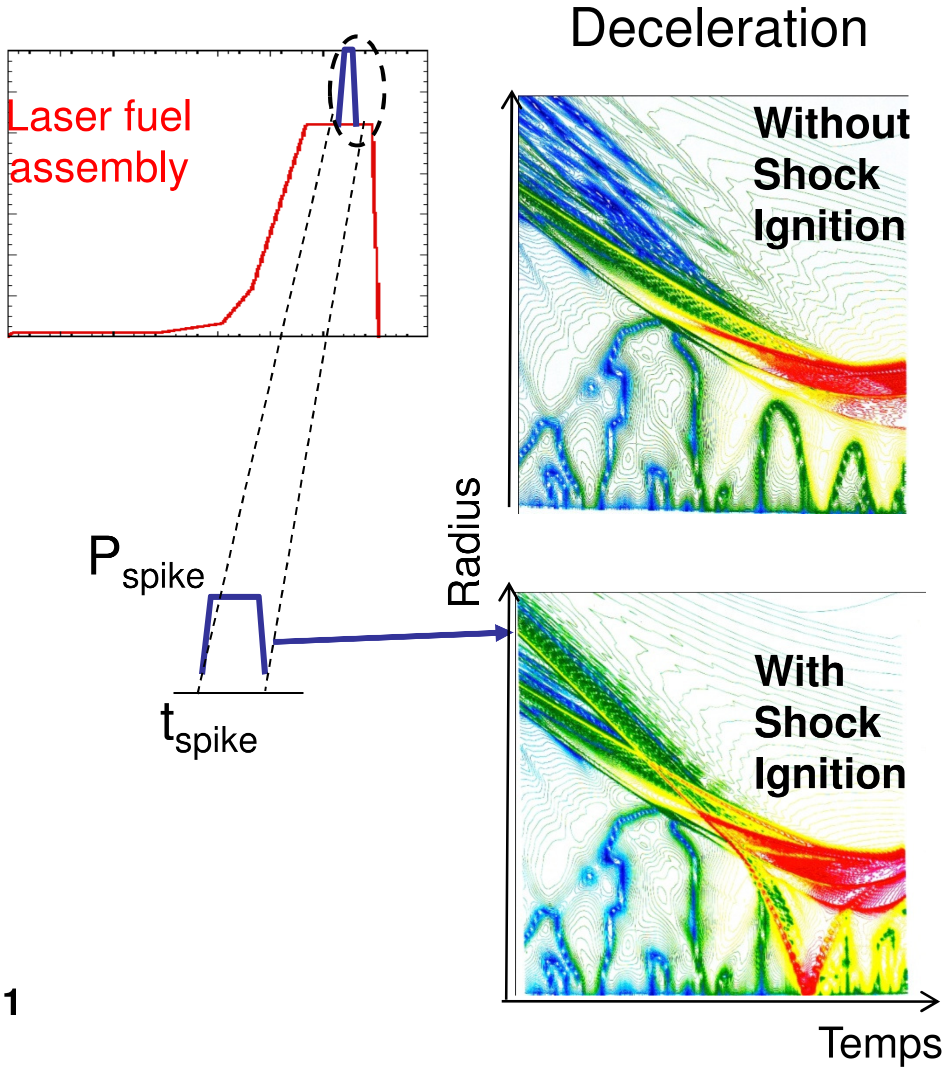
NiF commisioning

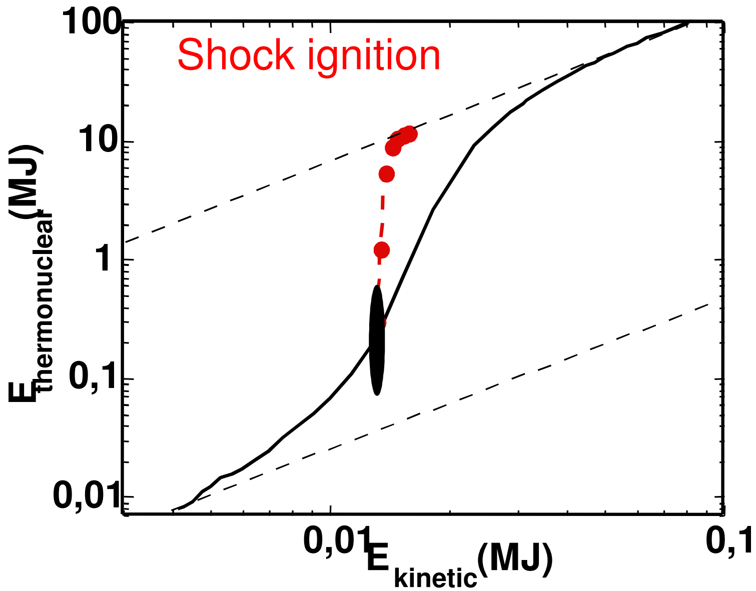
LMJ commissioning

LMJ ignites

Shock ignition becomes the baseline scheme for direct-drive fusion.



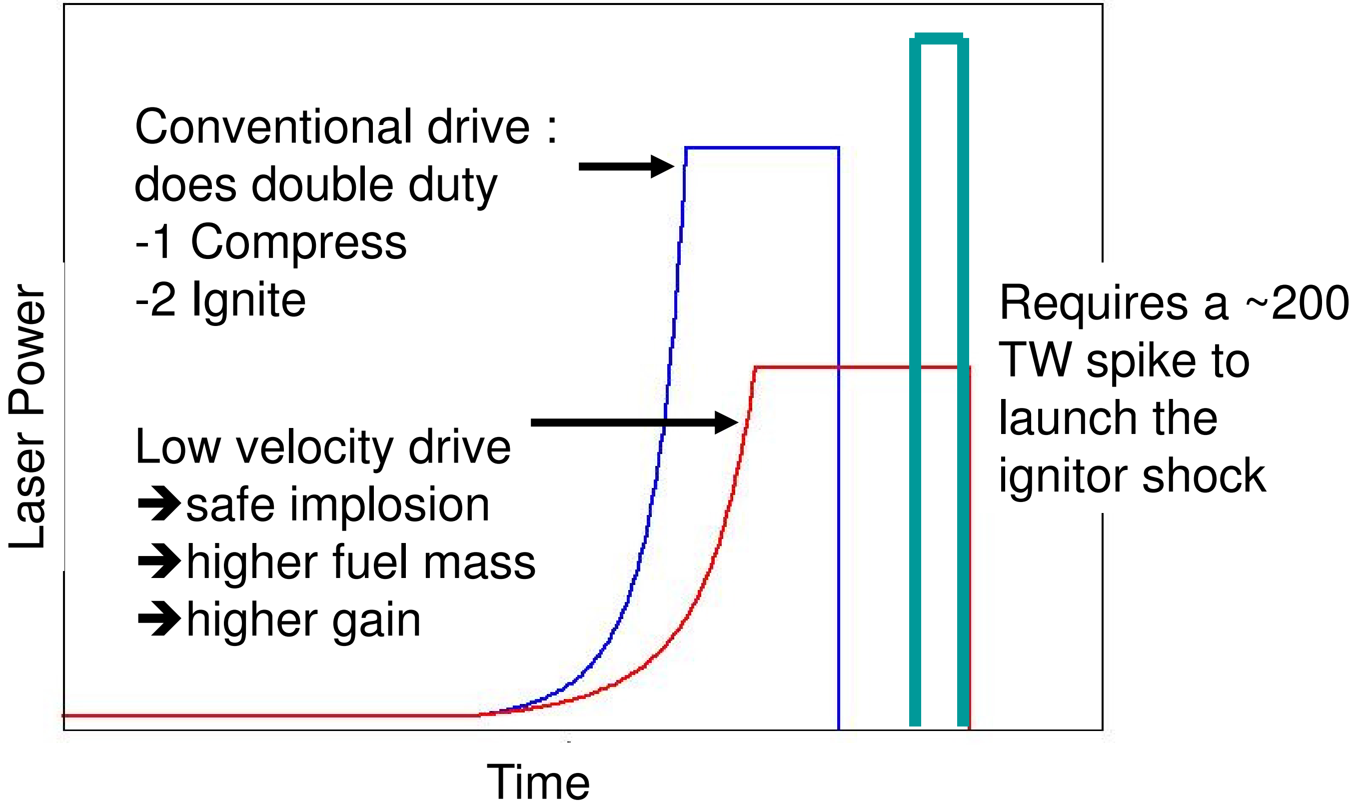




(α=2,v=400km/s)-Direct-drive marginally igniting target can be shock ignited with high gain.

B. Canaud. *et al*, New J. Phys., 12, 043037 (2010)

Shock Ignition : ignite from a converging shock launched from a final spike in the laser pulse



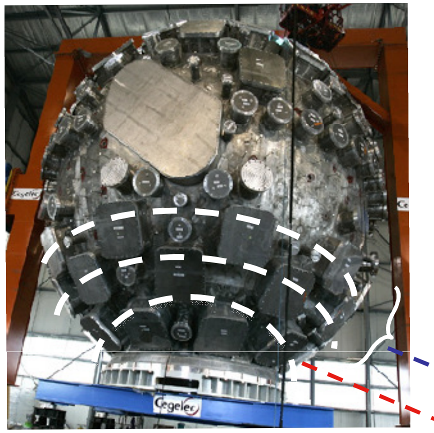
Same benefit as Fast Ignition but :

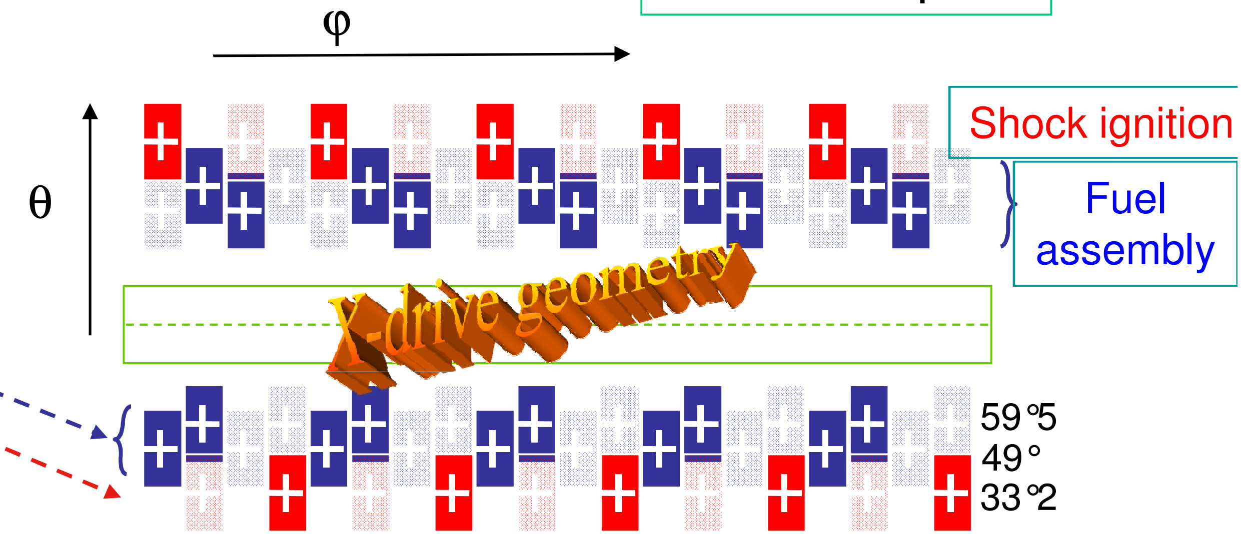
- ***classical LMJ like laser technology***
- ***Simple spherical targets***
- ***Hydro modelling***

Direct-Drive Shock-Ignition is still possible with 30 quads.

- 120 beams grouped in 30 quadruplets

- E_{max}= 0.9 MJ
- P_{max}= 300 TW
- λ= 0,351 µm



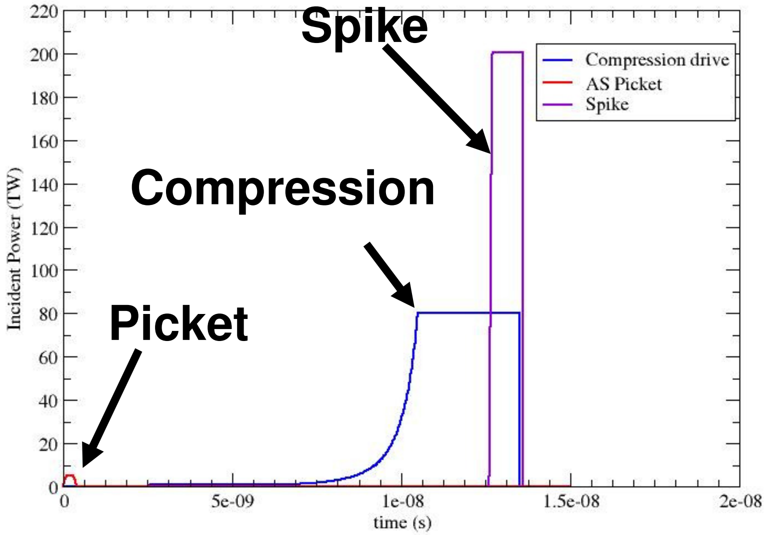


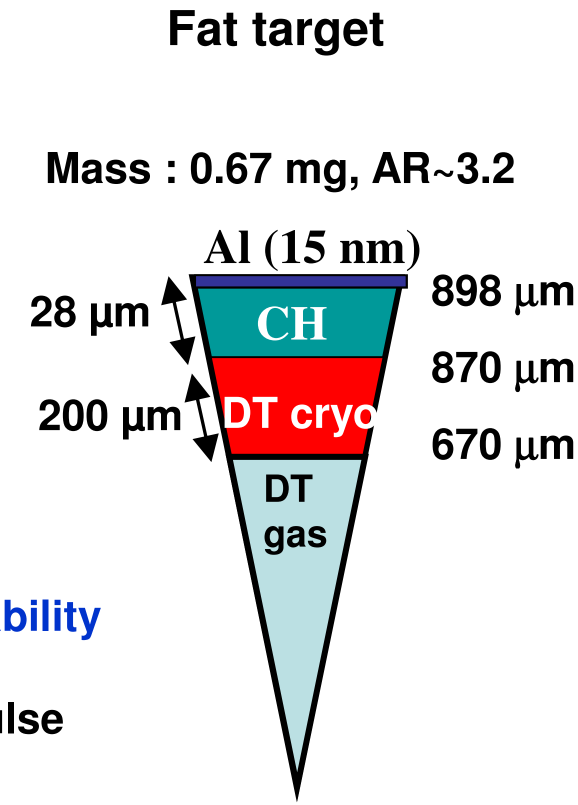
Direct-drive fuel assembly is still done with beams at 49° and 59°5 WITHOUT PDD (*).
=> the angle @ 59°5 (French specificity) allows a good laser-target coupling efficiency but with reduced fuel assembly energy (≤600 kJ).

Shock ignition should be achieved with beams at 33.2° but with a little available laser power (≤100 TW) => thermonuclear gain < 50, risky.

(*) B. Canaud. *et al*, Nucl. Fusion, **47**, 1652 (2007)

A robust target has been designed for SI demonstration on LMJ



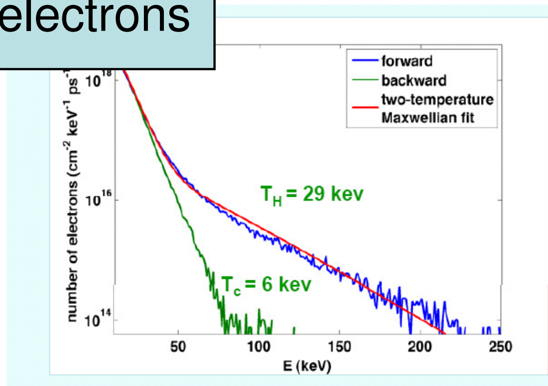


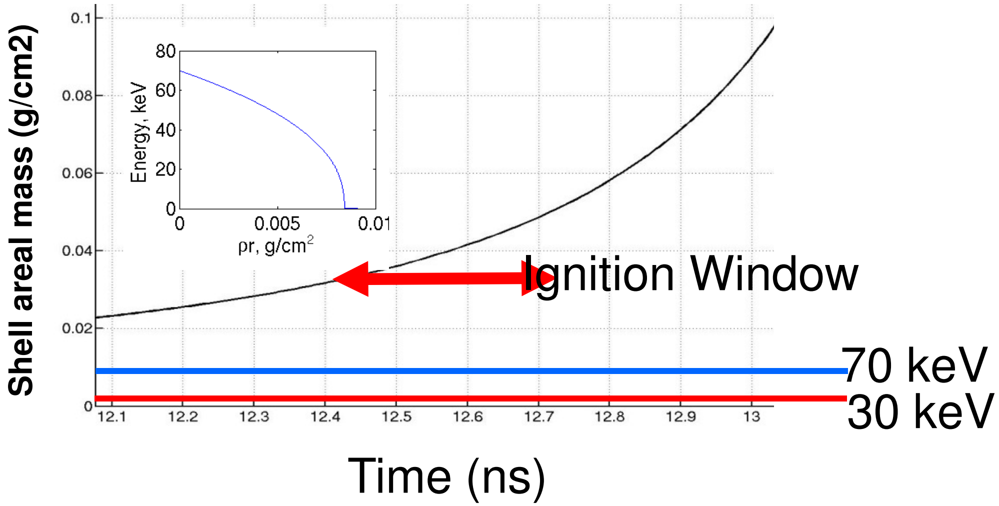
- Low aspect ratio + Picket: Improves Target Stability
  - => max IFAR ~ 32
- Al coating : Target protection from IR and prepulse
- CH ablator : Higher Absorption

Compression	Implosion velocity	Fuel assembly	Shock	Absorption	Yield t_s=12.6ns	Gain	Ignition window
80 TW 255 kJ	240 km/s (η_h~5%)	750 g/cc 1.7 g/cm^2	220 TW 100 kJ	72 %	35 MJ	95	300 ps

No obvious show stopper has been identified so far

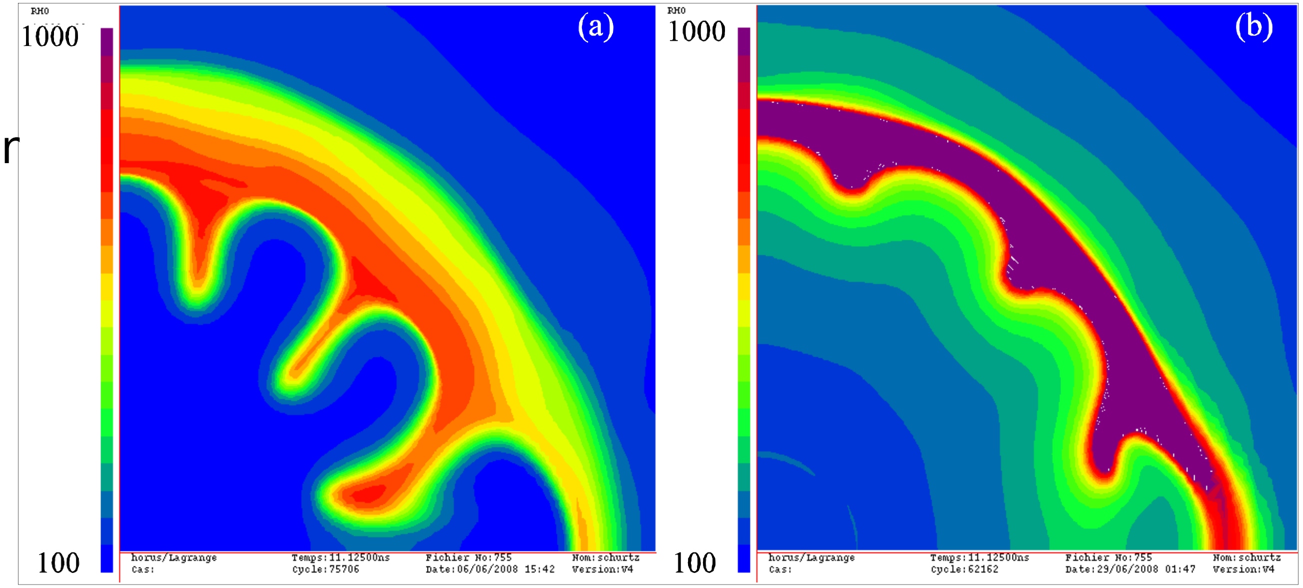
Raman Hot electrons





Rayleigh Taylor Instability at Stagnation

Compression only



Shock + Ignition

Direct-Drive fusion demonstration on LMJ will follow the number of available laser beams

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1. Full LMJ (240 beams, 60 quads) => very high gain > 100, WITHOUT PDD.
2. 50 quad-configuration => high gain (50 < G < 100), WITHOUT PDD.
3. 40 quad-configuration => small gain (G < 20), PDD required.
4. 30 quad-configuration => moderate gain (G < 50), WITHOUT PDD.
5. 20 quad-configuration => no gain.

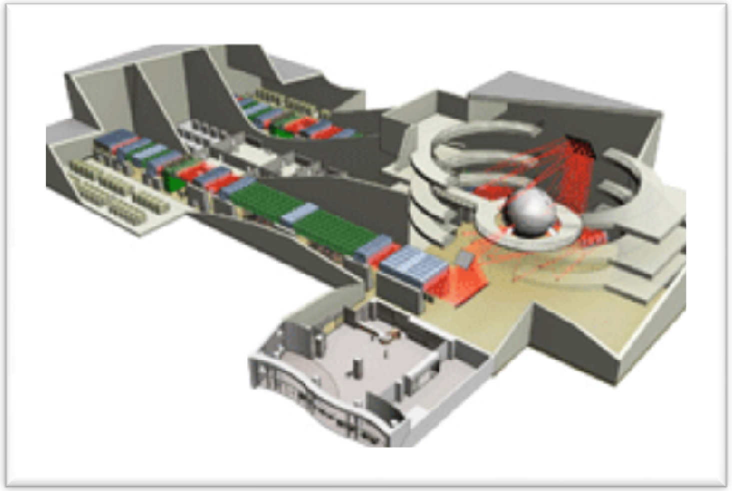
(*) Canaud B. *et al*, Nucl. Fus., **47**, 1642 (2007)

Conclusions on SI ignition option

- **As FAST IGNITION, SHOCK IGNITION allows to ignite ICF targets imploded at low velocities (~60% of self ignition velocity)**
  - More fuel may be as assembled at same energy
  - Large safety margins may be taken to secure the implosion
  - No show stopper identified yet
- **Unlike FI, Shock Ignition does not require specific lasers nor complicated cone-in-a-shell targets**
  - Compression and Ignition use same technology
  - SI physics is laser driven hydrodynamics
- **Robust ignition designs with G~100 are proposed at 500 kJ, 300 TW**
  - Gain G~50 achievable at 320 kJ, 220 TW
  - This is 1/3 of LMJ capabilities
  - May be fielded in the mid term using X-Ray drive final optics
  - Success of Shock Ignition campaigns on LMJ will open the route for IFE
- **International collaboration is needed**
  - Omega experiments + PDD design for NIF
  - Physics and numerical modelling : LPI, electron kinetics, ablator physics
  - High Rep DPSSL high energy lasers
  - Fusion materials
  - Target handling and manufacturing

IFE Engine design

- We need to have a strong conceptual design of a utility before we can decide to build it
- HiPER will make heavy use of the HPC Simulation capabilities to simulate all the possible concepts of engine (DD,SI,FI,ID)
- European teams will have a very large access to HPC through the European Agency PRACE
- The first petaflops computer to be delivered in 2011 will be in Bruyères le Chatel very similar to TERA100 already operating at CEA-DAM



An International forum for IFE ?

- Emerging champions with high level laser facilities :
  - USA :
  - Europe :
  - Japan
  - Others ?

- We need to SHARE and EXCHANGE our experience

- We need to share User-Community Facilites

- Ignition demonstration at NIF could be the right time to announce the launch of the International Forum for IFE which would prepare a global roadmap for inertial fusion for energy

Conclusions and summary

1. France has a strong community in ICF and good laser facilities

2. ICF for Energy (IFE) is emerging as a potential option for the French road map on energy (ANCRE). We are currently looking for new program from the Ministry of research and the Ministry of Industry in charge of Energy.

3. LMJ-PETAL to be a top facility for IFE research involving multi-use capability (X-ray drive, direct drive for FI, direct drive for SI)

4. LMJ-PETAL will be opened for the IFE community for direct drive experiments (FA, SI) according to EU recommendations

5. Institute for Laser and Plasma in carrying the IFE project and is strongly involved in the European HiPER project

6. We propose to create an international forum on IFE to share the strategy