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Overview of the Laser Megajoule first experiments

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LMJ is part of the Simulation Program

Simulation Program = three components

Improvement of physics data & models	Numerical simulation	Experimental validation
		

The Baseline Calculation is the heart of the Program

- Reference data + Physics models + Numerical methods
- Regularly upgraded

LMJ offers unique capabilities for the Simulation Program

- High Energy Density Physics: Validation of the advanced theoretical models of the Simulation Program
- Basic Science : Equation of state, Atomic data, Nuclear data…

A large panel of experiments will be done:

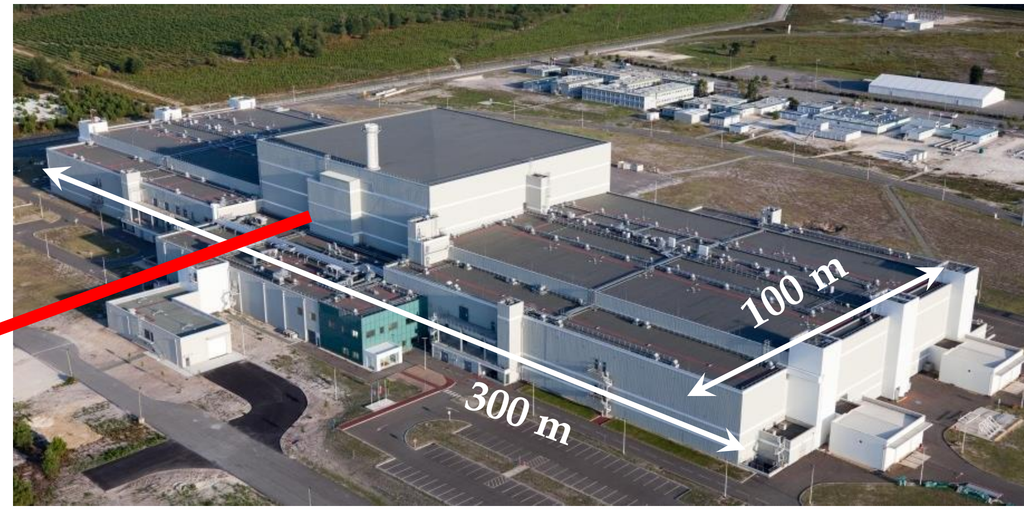
- Temperature : some 100 eV up to 100 keV
- Pressure : several thousands of Mbars
- Ignition is the most exciting challenge: ICF experiments set the most stringent specifications

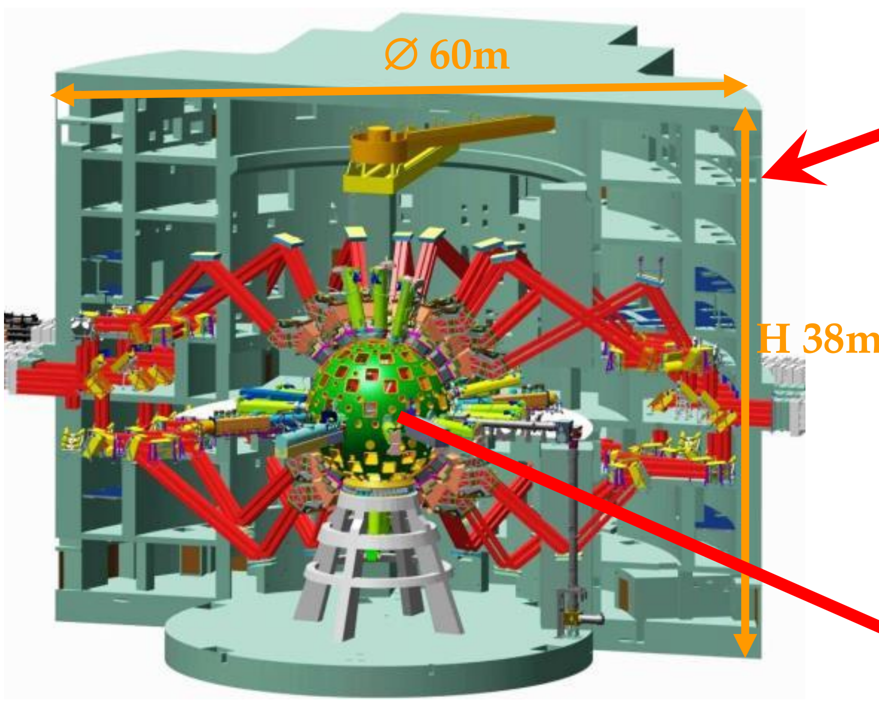
PETAL, a multi-PW beam coupled to LMJ, will offer the opportunity to study a wider field of physics

Laser MegaJoule main characteristics

4 Laser bays

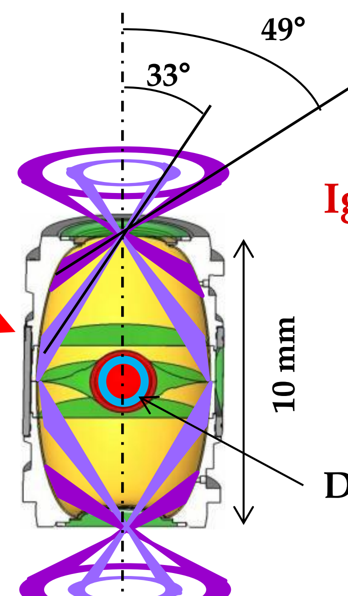
- Glass Nd laser, frequency tripled : λ = 0.35 µm
- Designed for 240 beams, 176 will be installed
- Laser energy ~ 1.5 MJ, Power ~ 400 TW
- Pulse duration : from 0.7 to 25 ns





Target bay

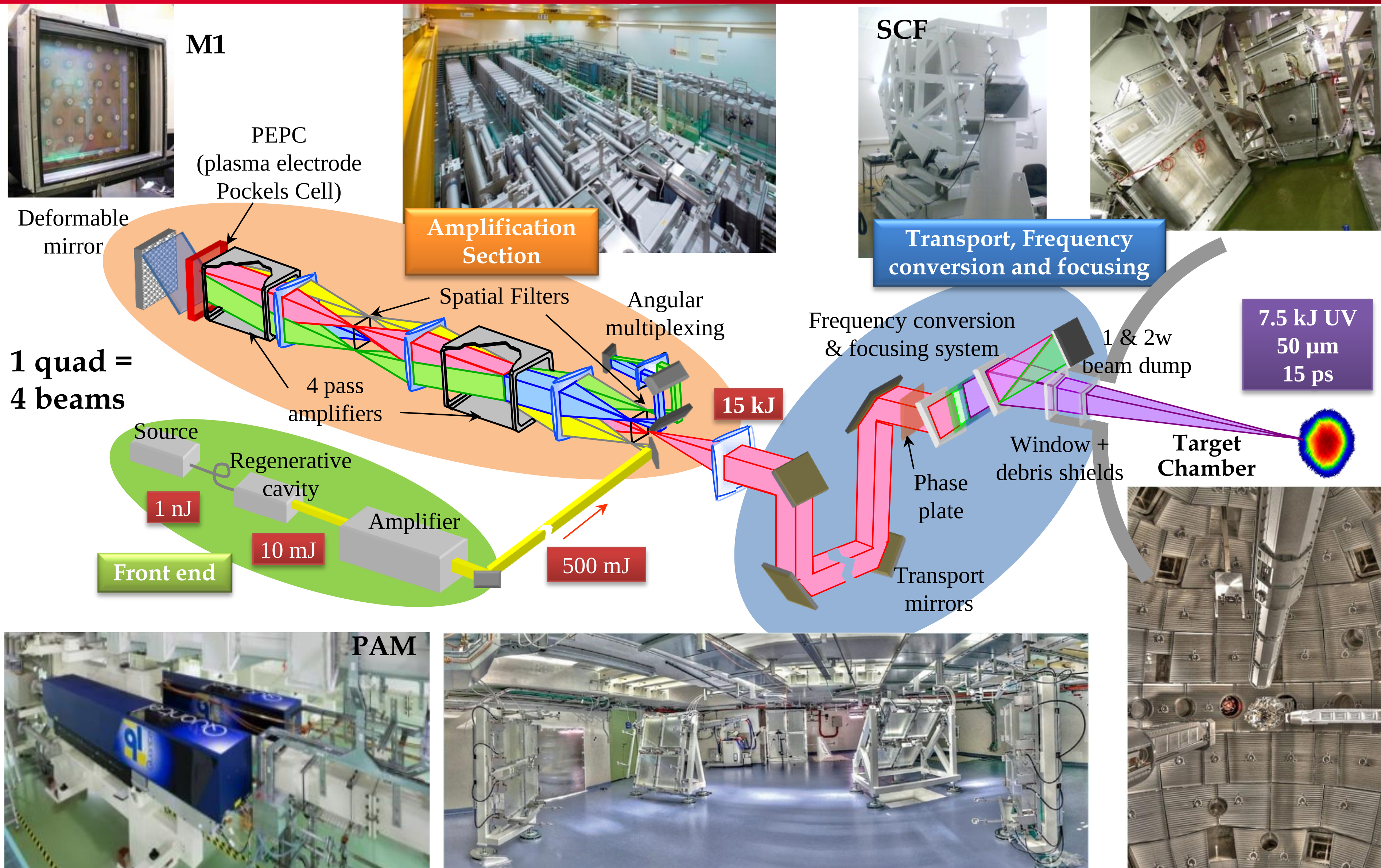
- Biological protection : 2 m thick concrete
- Target chamber Ø 10 m
- 200 ports for laser beams and diagnostics



Ignition target

- 2 x 2 cones irradiation : 33° & 49°
- Rugby-shape Hohlraum
- Capsule Ø ~ 2 mm

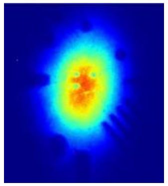
LMJ beamline
Most of the components have been qualified on the LIL prototype



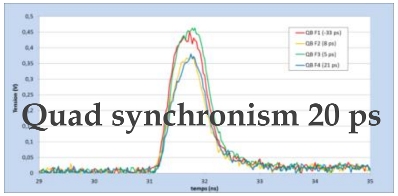
LMJ commissioning and operation
A good start for a long and difficult race

LMJ official commissioning on 2014, October 23rd

- The LMJ has demonstrated that it meets all specifications required for the beginning of experiments with the first operational bundle (2 quads, 8 beams)



Pointing accuracy < 75 µm

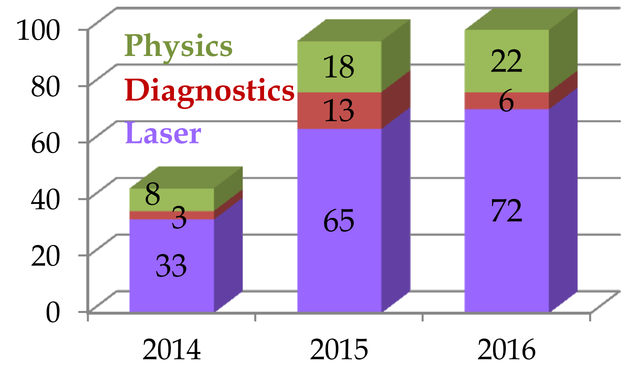


The official commissioning was declared by French Prime Minister Manuel Valls

Feedback of 2 years of LMJ operation

- 78 shots on target (Beams pointing + diagnostic qualification + physics)
- Mean pointing accuracy = 52 µm
- Beams synchronization = 28 ps RMS
- 75 % shots delivered the required energy with < 10 % discrepancy
- Pulse shape : very good reproducibility
- Shot-to-shot cycle time : Laser shots: 3 h 30 / Target shots : 7 h 00

Time history of 3ω shots

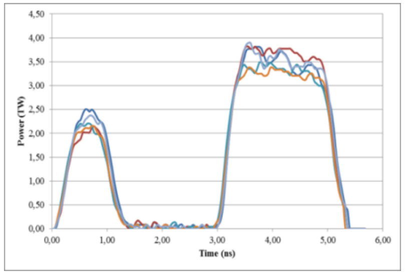


LMJ schedule during the mounting phase

- Three main activities are performed during the year
  - Mounting of new bundles
  - Activation / qualification of the previous assembled bundles
  - Plasma experiments

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st Shift	Mounting			Mounting		Mounting			Mounting		Mounting	
2nd Shift	Activation/Qualification			Experiments					Activ/Qualif		Experiments	

Pulse shape for radiography



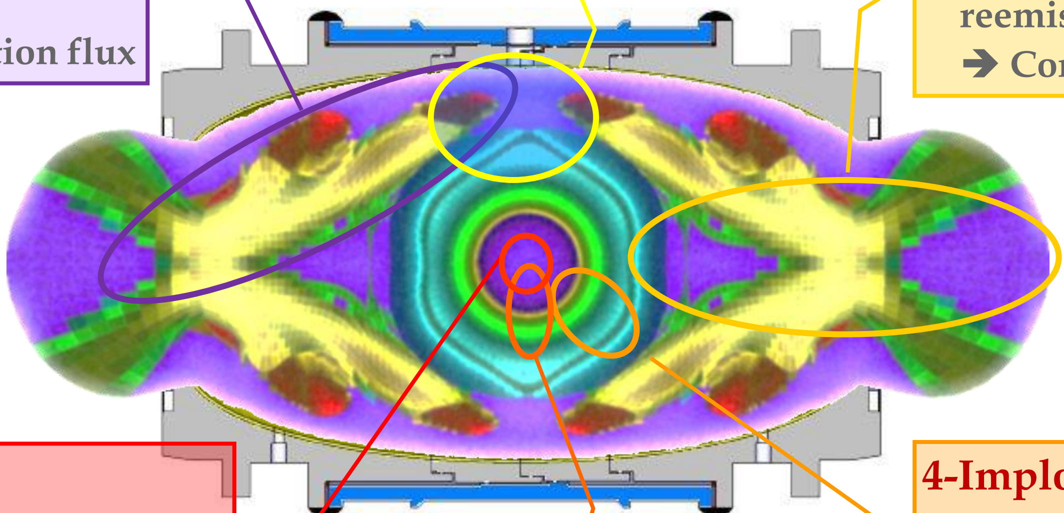
- Usually, only one shift is dedicated to experiments => 1 shot/day
- In the next years : 50 Physics shots + 30 preparation shots per year

Program overview

- The 8 experimental topics
- First experimental campaigns

The 8 experimental topics of the Simulation Program

A stairway to heaven



1-Hohlraum energetics
Laser plasma interaction,
X-ray conversion
➔ Control of radiation flux

2-Fundamental data
EOS, Opacities…
➔ Control of matter's behavior under HP and HT

3-Radiation transport
X-ray absorption, loss, reemission
➔ Control of energy transport

4-Implosion hydrodynamics
Implosion velocity, Shock tuning
➔ Control of compression

5-Hydrodynamic Instabilities
Instabilities growth, turbulence
➔ Control of mixing

6-Fusion studies
Thermodynamic conditions, initiation of fusion reactions
➔ Control of ignition conditions

7-Ignition studies
Study of different kind of ignition targets
➔ Control of DT burning

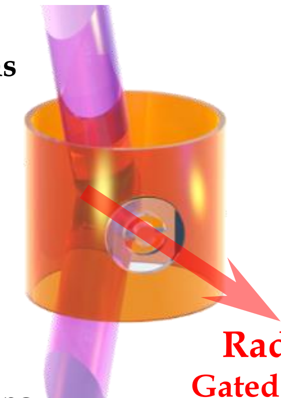
8-Applications
Coupling of an ignition target with another target
➔ Control of complex powerful system

The first LMJ Campaign : Radiation transport
Dynamics of slot closure (October 2014)

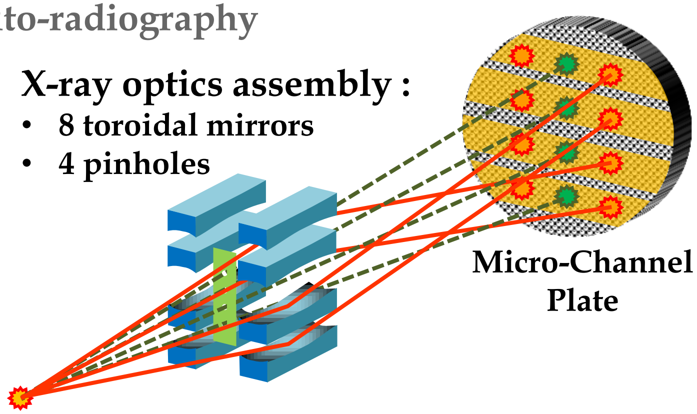
1. **Demonstration of LMJ capabilities to perform experiments for Simulation Program**
2. **Control of radiative energy in leaking hohlraum (Laser Entrance Holes, diagnostic holes, …)**

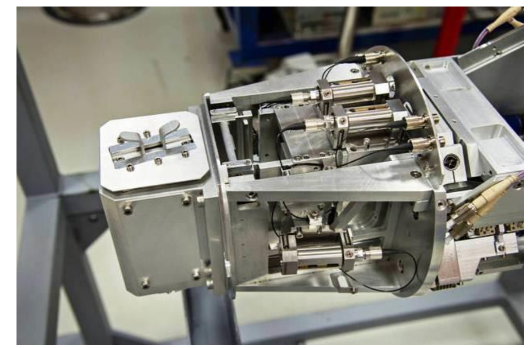
➔ **Study of dynamics of slot closure, in well-controlled material, due to the radiative flux of a cylindrical gold hohlraum**

- **Slot dynamics is diagnosed by auto-radiography**

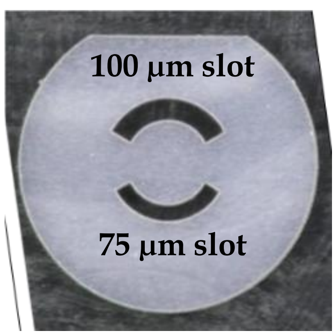


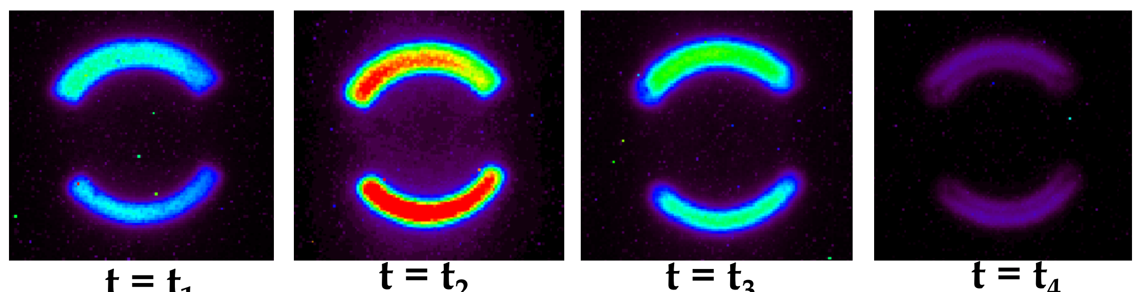
X-ray optics assembly :
- 8 toroidal mirrors
- 4 pinholes



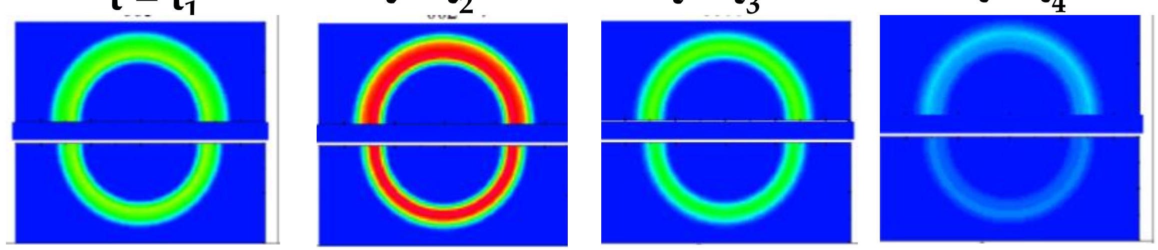


First shot with Ta_2O_5 aerogel sample, 200 µm thick



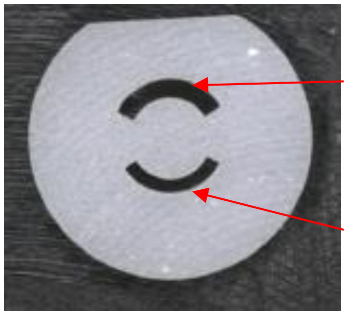


2D simulations before shot



Dynamics of slot closure
Variations on the sample and simulations

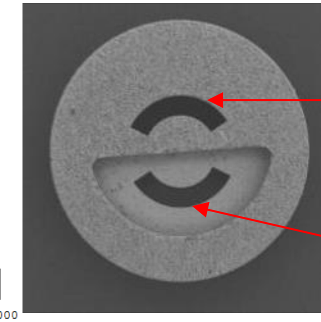
Ta_2O_5 aerogel sample:



125 µm

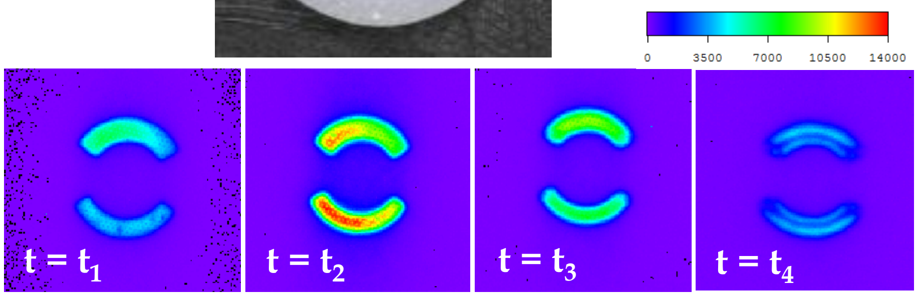
200 µm - thick

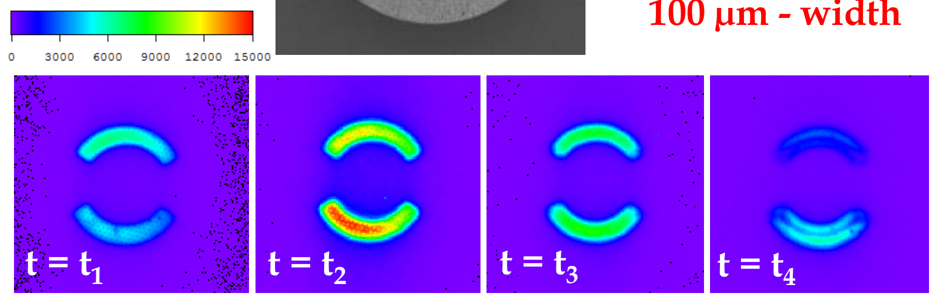
100 µm



200 µm - thick, 100 µm - width

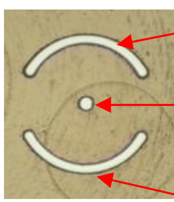
100 µm - thick, 100 µm - width





Gold sample:

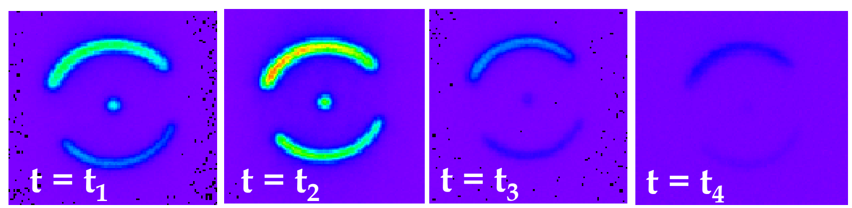
100 µm - thick

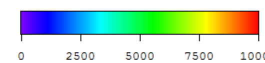


50 µm

50 µm

30 µm

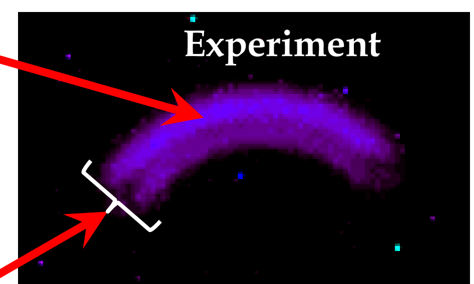




Details of the phenomena are well predicted by simulations

- Late phenomena of the closure dynamics

Stagnation area (Plasmas collision)



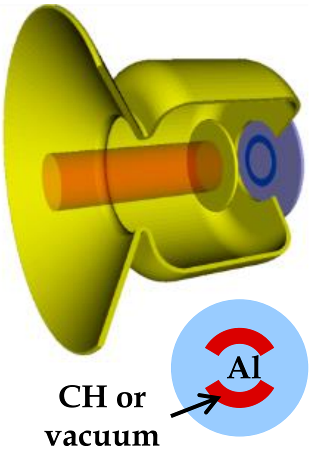
Closure dissymmetry

Further campaign : Radiative losses

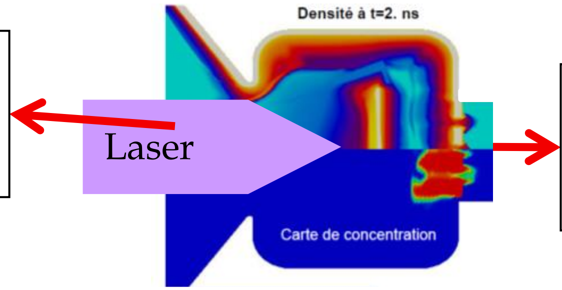
One more step : the Angels' share

Slot closure dynamics, with quantification of losses through the slot

- X-ray conversion in a gold hohlraum with LEH shield => 2D symmetry
- Samples with empty slots or filled with CH (delayed closure)

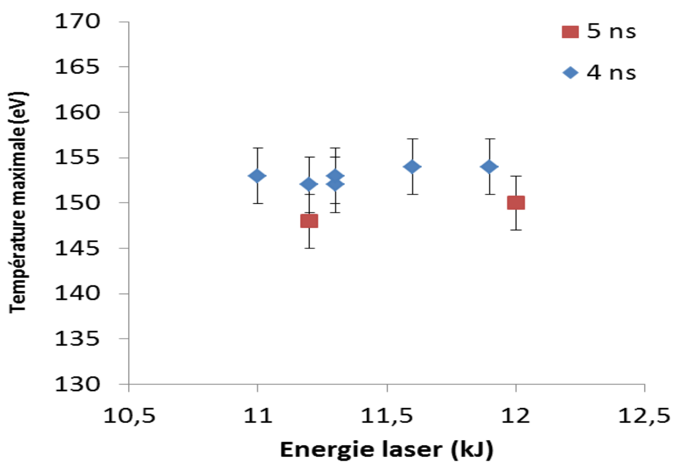


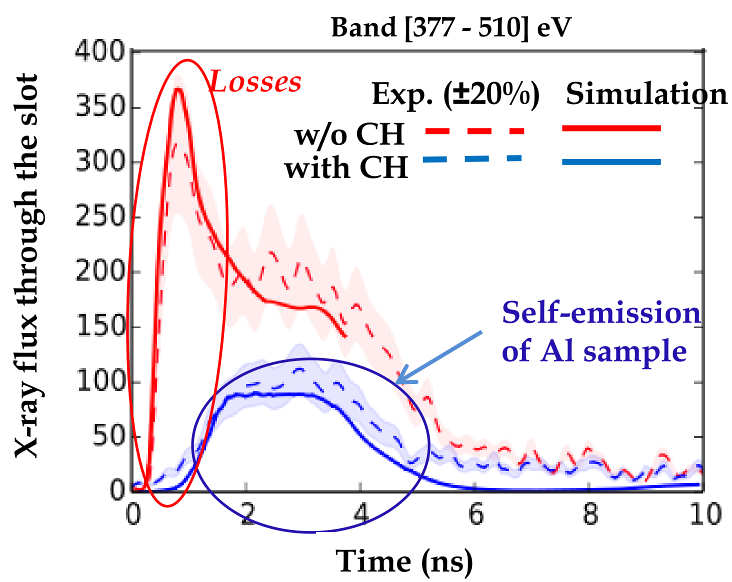
DMX
Broadband spectrometer
20 channels 0-20 keV
=> Hohlraum Temp.



miniDMX
Broadband spectrometer
12 channels 0-5 keV
=> Losses

- Reproducible laser conditions from shot to shot
  ➔Stable radiative temperatures for 2 pulse shapes

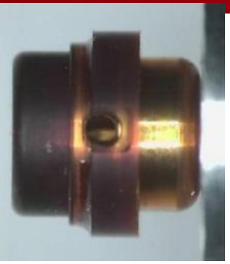




Good agreement with simulations

- If the exact characteristics (thickness, slot width, …) of the sample is taking into account

Implosion Hydrodynamics : effect of asymmetric drive
The world is not perfect

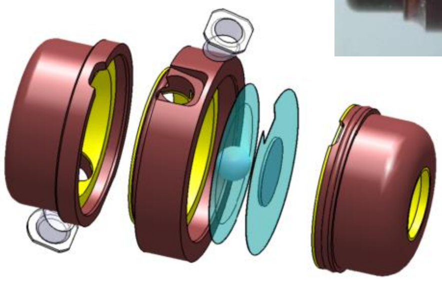


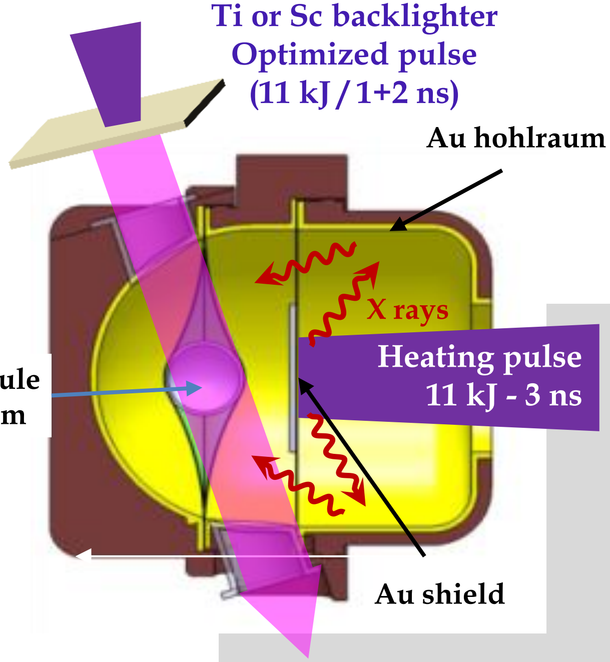
Study of the effect of an asymmetric drive on the imploded capsule shape

1. First LMJ implosion : hohlraum with LEH shield heated by one quad => 2D symmetry
2. Qualification of the radiographic capabilities of LMJ
   - 2nd quad used for Ti and Sc backlighter with an optimized pulse

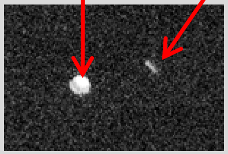
Target complexities

- 2 diagnostic holes in 3D geometry for radiographic axis
- 3D plastic plugs have been used to avoid diagnostic hole closing
  - 50 µm wall thick, ∅ 500 µm

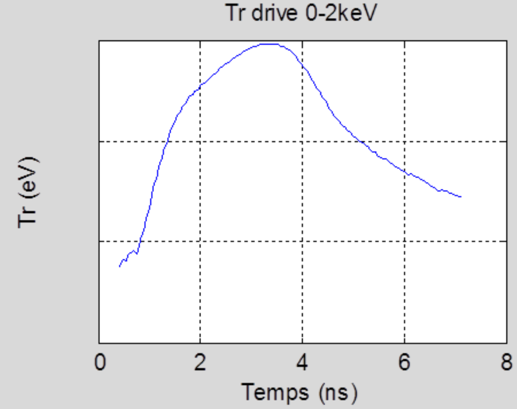


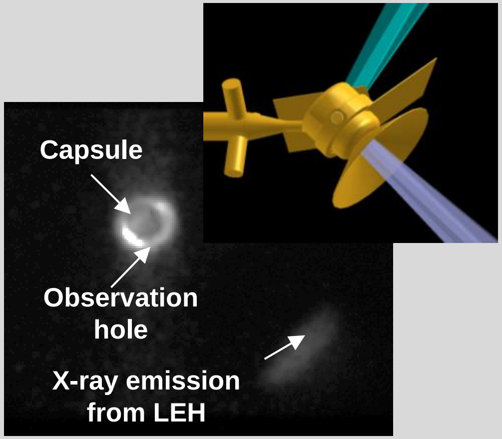


Gated X-ray imager 2 : Beams pointing monitoring



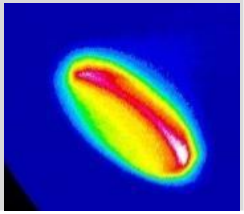
DMX: Rad. Temp. measurement





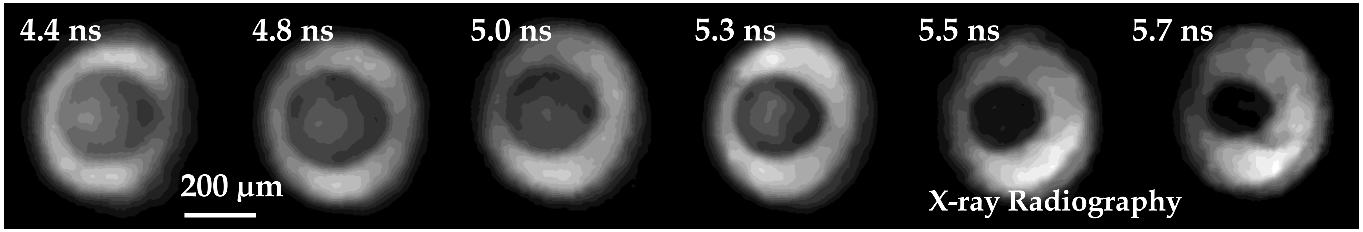
Gated X-ray imager 1: Implosion geometry

DMX: LEH time integrated picture

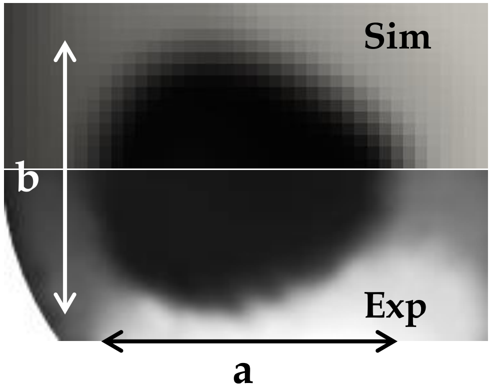


Implosion with asymmetric drive :
Variations on capsule position and shield size

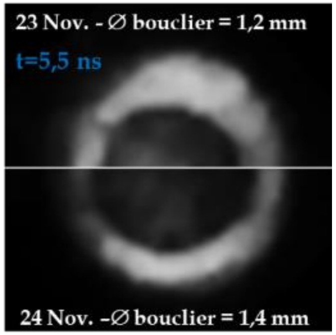
Radiography of capsule is well controlled over 6 ns



Comparison Experiment / Simulation at 5.1 ns

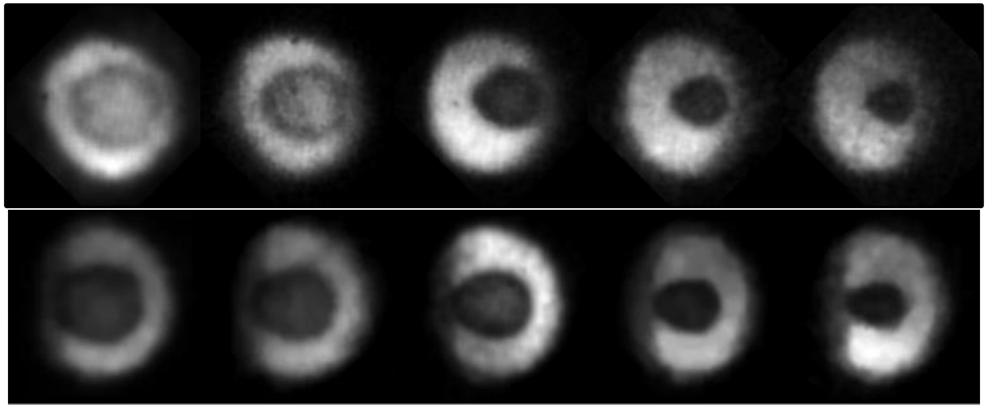


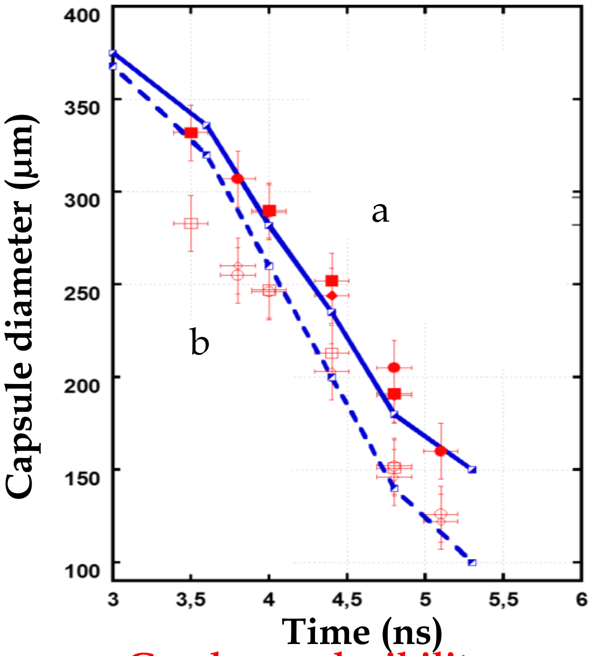
The egg shape, predicted by simulation, is due to the anisotropic distribution of the drive around the capsule.



GXI-1: less convergent implosion with big shield

GXI-1: Implosion geometry depending on capsule-shield distance





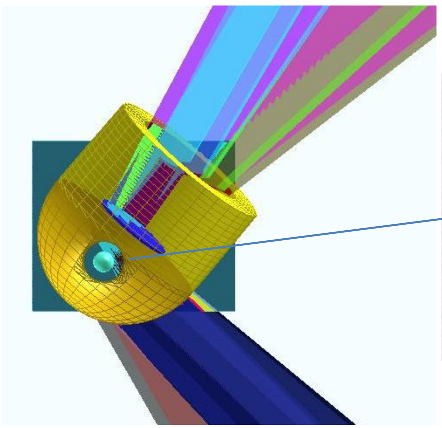
Good reproducibility

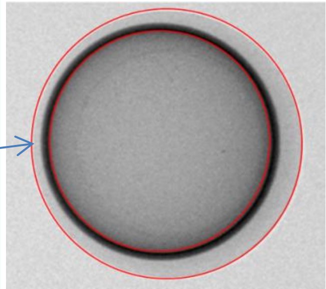
Further study : Implosion with corrected shell

One step closer to square the circle

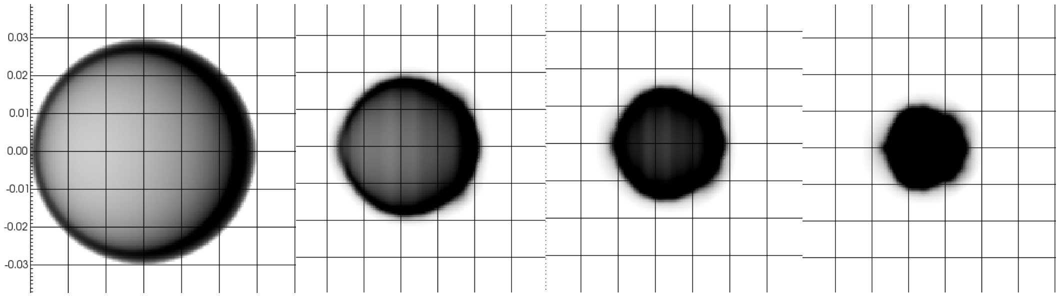
The next campaign (~ may 2017) will use capsule with corrected shell in order to balance the asymmetric drive

- At higher energy : 2 quads to heat the hohlraum (25 kJ)





Simulations



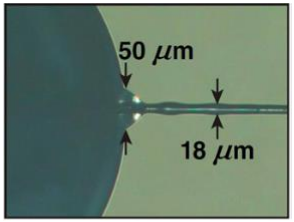
- This first attempt will use a simple correction (uncentered spherical shapes)
- Later, a more precise correction of the shell will be applied

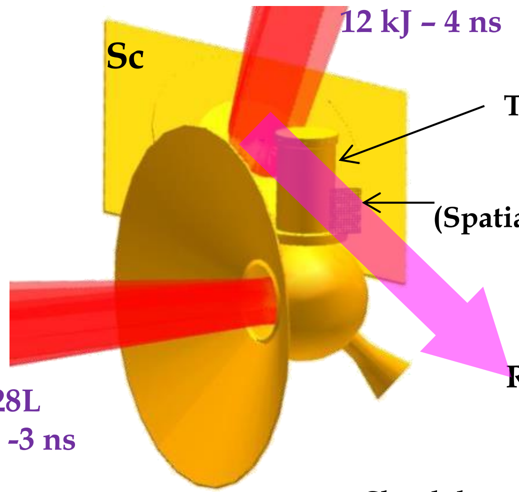
Remark :

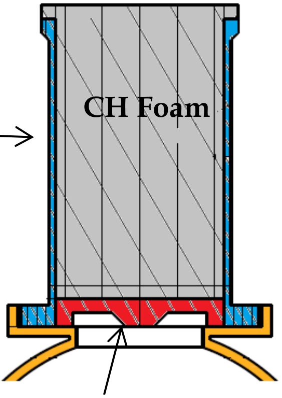
- This kind of design is in fashion :
  - Mitigating the impact of hohlraum asymmetries in NIF implosions using capsule shims
    - D. S. Clark et al., PHYSICS OF PLASMAS 23, 072707 (2016)
  - Asymmetric-shell ignition capsule design to tune the low-mode asymmetry during the peak drive
    - Jianfa Gu et al., PHYSICS OF PLASMAS 23, 082703 (2016)

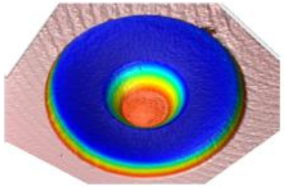
Study of the effect of a technological singularity present on a laser target

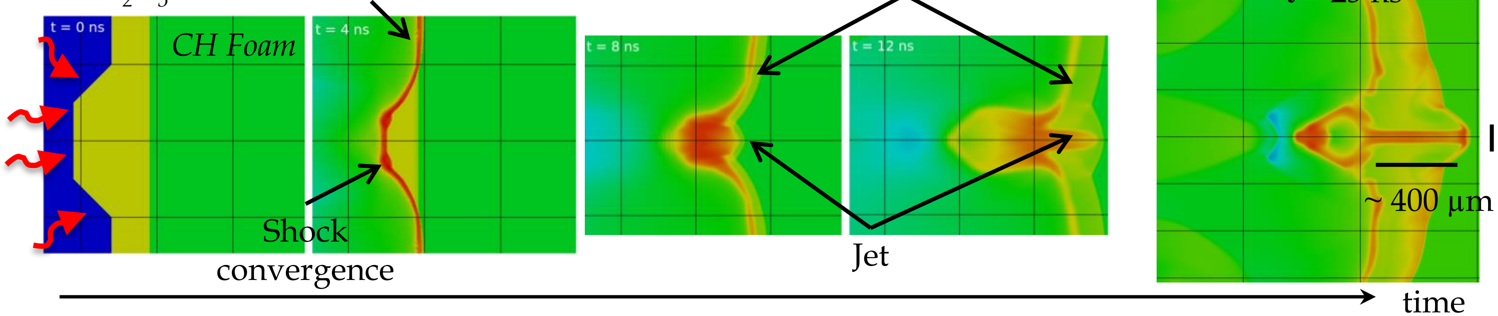
- Two configurations : X-ray conversion in a gold spherical hohlraum or direct drive.
- Shock propagation in Ta_2O_5 disk (radiographic contrast) including the singularity.
- Shocks coalescence and inversion of the defect, which leads to a jet in a CH foam.
- Multi-time late radiography of the jet with Scandium backlighter.









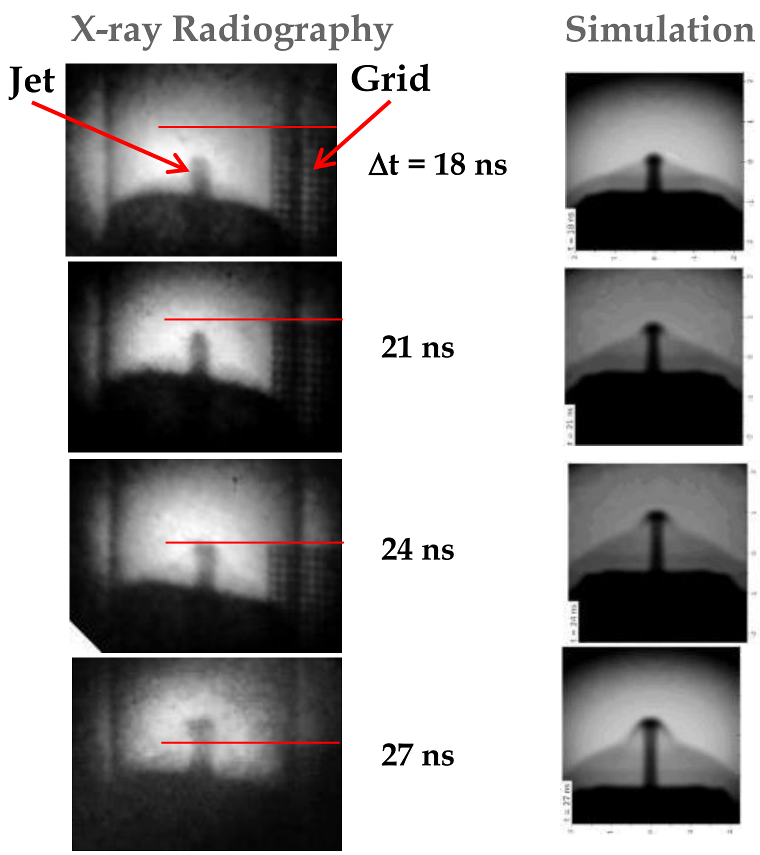


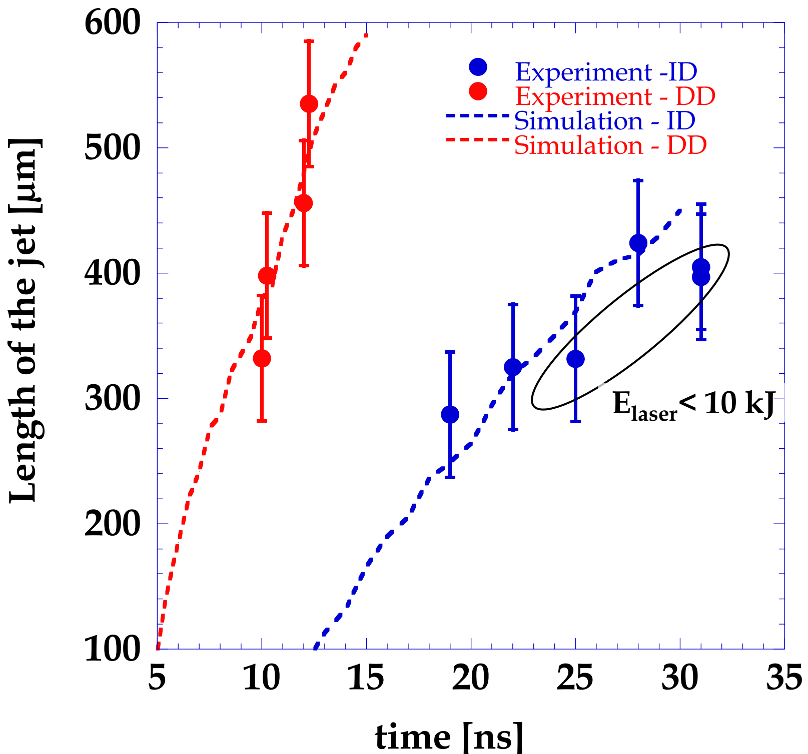
Target singularity :
Jet dynamics and simulations

Length of the jet in good agreement with simulation in direct and indirect drives

- Some shot discrepancies due to a lower laser energy (debris deposit on final optics)

GXI-1: Measurements / Simulation comparison at different times



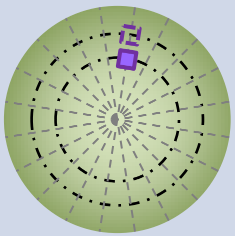
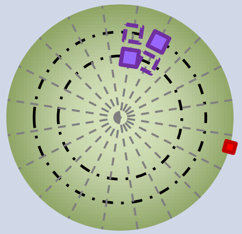
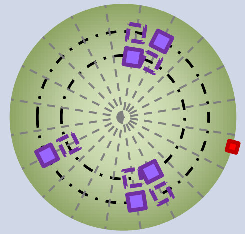
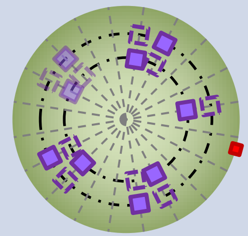
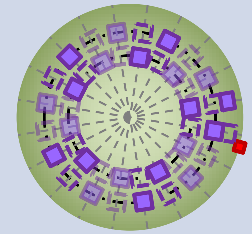
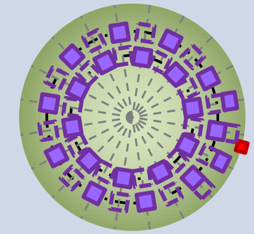


Deduced jet speed :

- 43 μm/ns for indirect drive
- 107 μm/ns with direct drive

Program to come : the 6 experimental configurations

Step by step

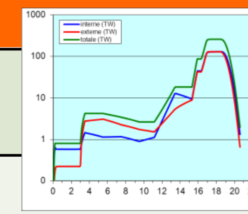
	1st config.	2nd	3rd	4th	5th	6th
	2 quads 25 kJ	4 quads+PW 60 kJ	10 quads+PW 150 kJ	14-18 quads+PW 250-320 kJ	22-40 quads+PW 0,53-1 MJ	44 quads+PW 1,5 MJ
Diagnostics						
X-ray imager	2 GXI-1 GXI-2	3 SSXI	4 SHXI	7 ERHXI UPXI-LPXI GSXI	9 SHXI-2 GXI-3	9+ …
X-ray spectrometer	2 DMX miniDMX	3 SPECTIX*		4 HRXS	7 SRSXS miniDMX2 SRHXS	7+ …
Optical diagnostic			2 FABS1 NBI	4 FABS2 EOS pack	5 Thomson Scattering	5+ …
Particles diagnostics		2 SESAME* SEPAGE*		3 Neutron pack	4 Neutron pack 2	4+ …
Physics addressed	Mainly dedicated to rad. transport, coupled with hydrodynamics	Improved exp. on rad. transport Starting of academic access	Fully diagnosed hohlraum energetics exp. Hydrodynamics and instabilities	3-ord. symmetry ➔ 1st implosions (D_2/Ar gas) with neutr. production Fundamental data	5-ord. symmetry Cryogenic Target More precise diag. ➔Fusion studies & Ignition preparation	Full axial symmetry ➔ Ignition studies All experimental topics at high E

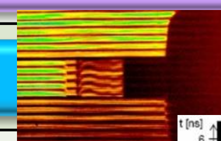
*Development of PETAL diagnostics takes place within the Equipex PETAL+ funded by the French National Agency for Research (ANR)

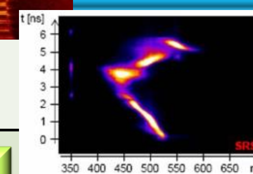
This program allows to draw a robust roadmap for ignition

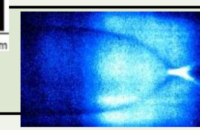
8 beams — Full LMJ

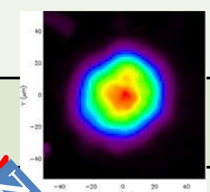
LMJ	Increasing operational capabilities (beams nb, energy, diagnostics nb, …)
Facility Control	Training, Performances (precisions, reproducibility… ΔP/P < 3%
Radiation transport	Losses, Energy Balance, Radiative drive Tr(t)
Fundamental data's	EOS, Opacity, …
Hohlraum Energetics	Smoothing, CBET, He/H_2 gas
Implosion hydrodynamics	Planar · Spherical · Cryo targets
Hydrodynamic instabilities	Planar · Spherical · Mix
Fusion studies	Drive adjustment V > 350 km/s
Ignition	GAIN · GAIN
Applications	Applications











Baseline Calculation

PETAL status
and
Academic access

PETAL : a PW beam coupled with LMJ
An opportunity to study a wider field of physics

Petal PETAWATT AQUITAINE LASER

PETAL is a part of the opening policy of CEA

- It will be dedicated to the scientific community

INSTITUT LASERS ET PLASMAS

PETAL was supported by

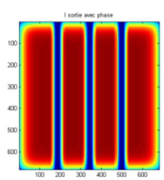
REGION AQUITAINE

Liberté • Égalité • Fraternité RÉPUBLIQUE FRANÇAISE

PETAL goals	versus LMJ (1 beam)
Energy : up to 3 kJ *	Energy : up to 7.5 kJ (x 176 = 1,3 MJ)
Wavelength : **1053 nm** (526 nm option)	Wavelength : 351 nm
Pulse duration : **from 0,5 to 10 ps**	Pulse duration : from 0,3 to 25 ns
Intensity on target : **~ 10^{20} W/cm²**	Intensity on target : ~ 10^{15} W/cm²
Power contrast : 10^{-7} at -7 ps	
Energy contrast : 10^{-3}	

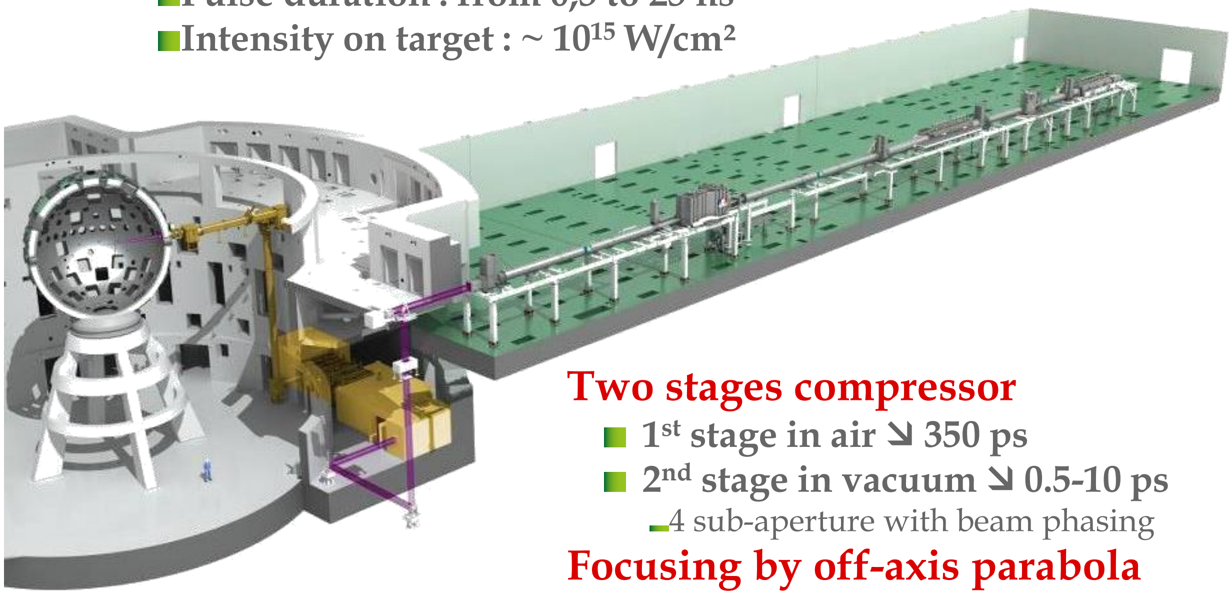
Front end

- Ti:Sapphire oscillator
- Offner stretcher
- OPA stage
- Spatial shaping
- 100 mJ / 8 nm / 4.5 ns @ 1053 nm



Amplifier section

- LMJ architecture
- 6 kJ / 3 nm / 1,7 ns
- Chromatism Corrector



Two stages compressor

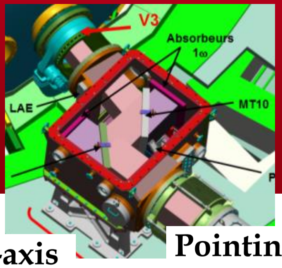
- 1^{st} stage in air ↘ 350 ps
- 2^{nd} stage in vacuum ↘ 0.5-10 ps
  - 4 sub-aperture with beam phasing

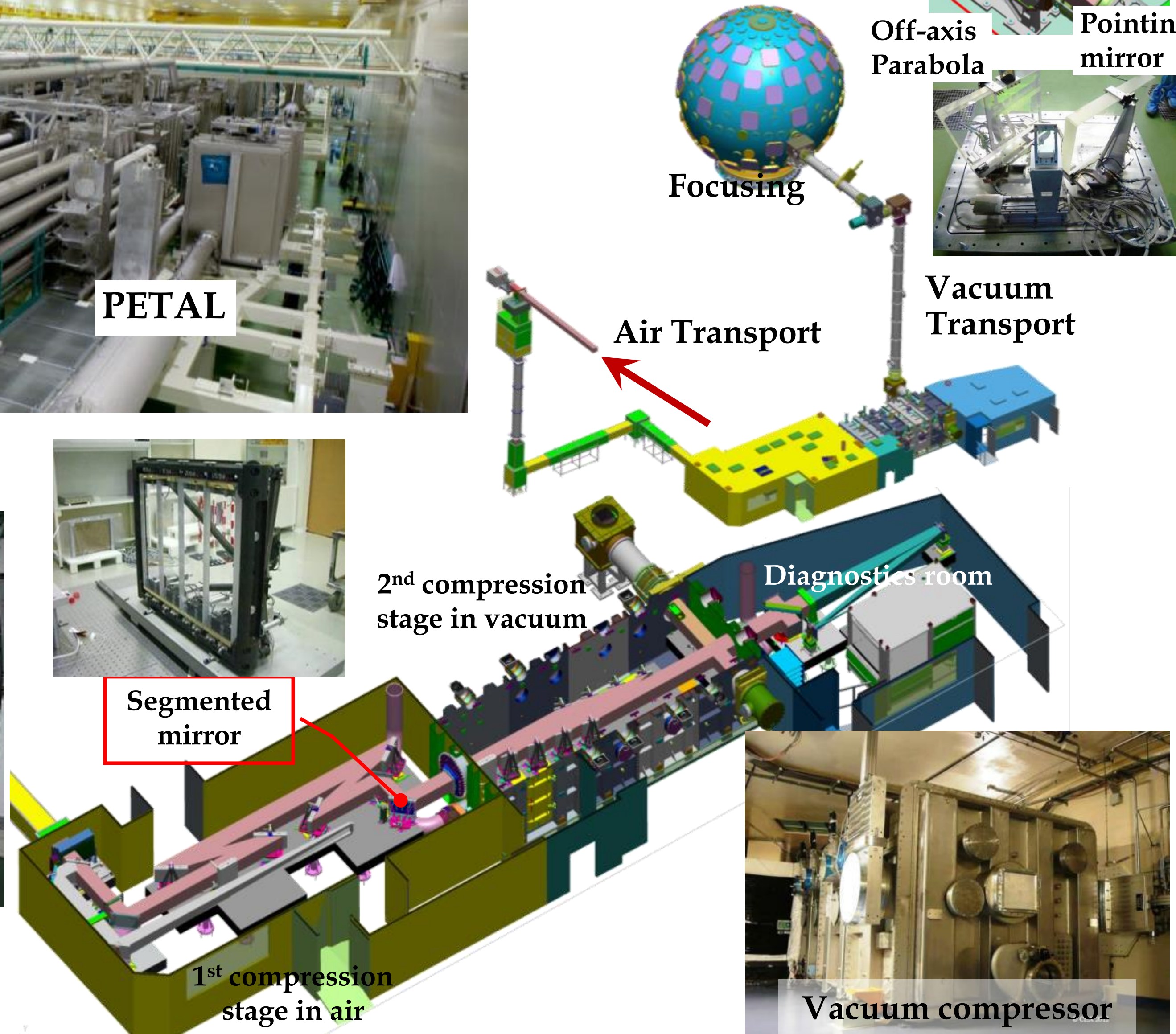
Focusing by off-axis parabola

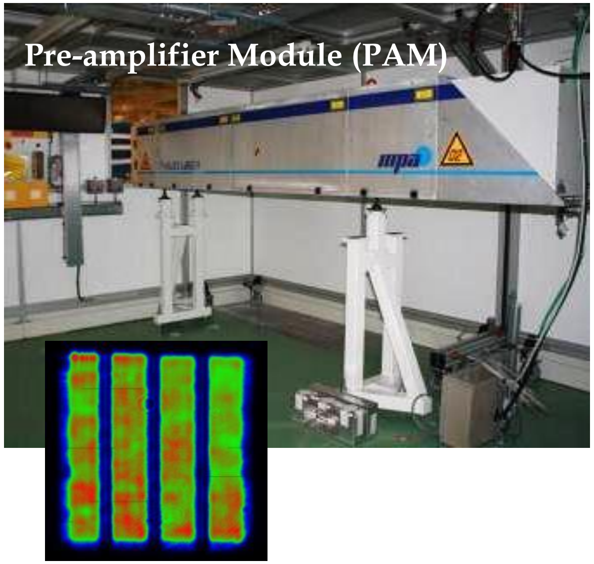
- 7,8 m focal length, 90° deviation
- Focal spot ~ 50 µm => 10^{20} W/cm²

* limited at the beginning to 1 kJ due to the damage threshold of the transport mirrors

PETAL laser system



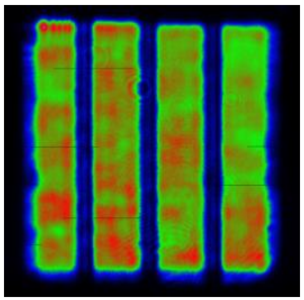




First high energy shots in May 2015 : 1,2 PW - 846 J / 700 fs

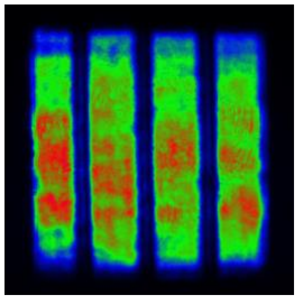
Experimental results May 29th

PAM output profile



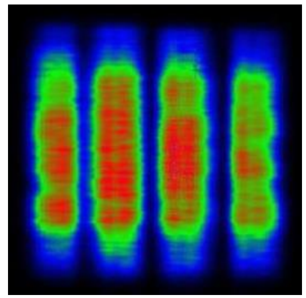
20,3 mJ

Amplifier output



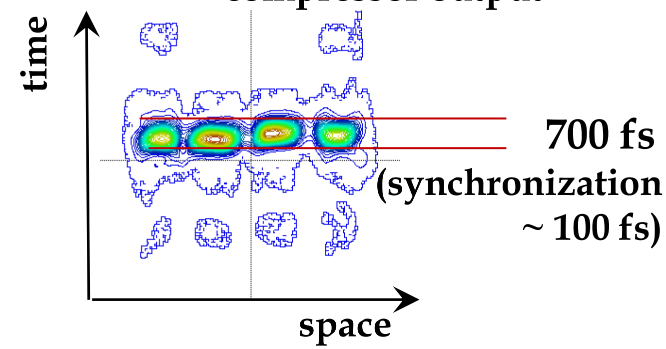
1,24 kJ

Compressor output



846 J

Spatio-temporal profiles at compressor output



=> 1.2 PW record

Qualification during 2016 :

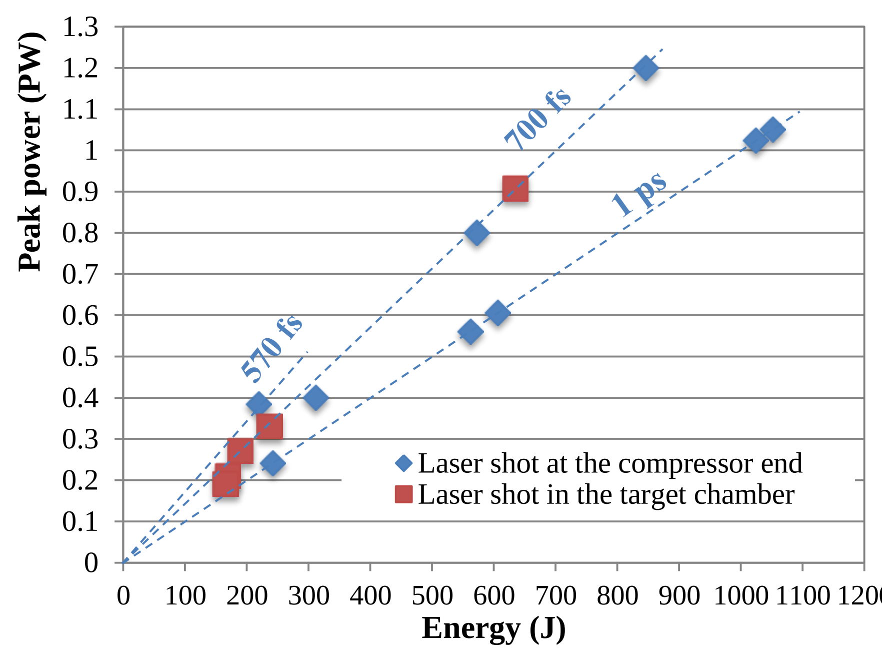
- Compression optimization : 570 fs ☺
- New diagnostics installed :
  - Contrast : Energy contrast : 10^{-3} ☺
    Power contrast : 10^{-6} @ -200 ps 😐
  - Focal spot < 50 µm ➔ I > 4.10^{19} W/cm^2 with 1 kJ

Improvements are going on :

- Wave front correction (toroidal mirror)
  => better focal spot
- Spatial uniformity will be upgraded
- The filling of sub-aperture will be improved

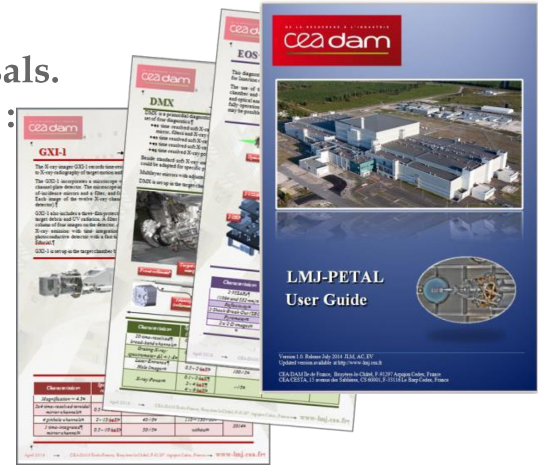
Target shots in 2017

- Nuclear safety authorization underway



Access of the Academic Community to LMJ-PETAL

LMJ-PETAL User Guide (+ Diagnostic forms)



- Provides the necessary technical data for the writing of experimental proposals.
- Regularly updated version of this User guide is available on LMJ website at : http://www-lmj.cea.fr/en/ForUsers

Academic access and selection of the proposals :

- Coordinated by Institut Laser & Plasmas (ILP) with the help of the International Scientific Advisory Committee of PETAL (ISAC-P).

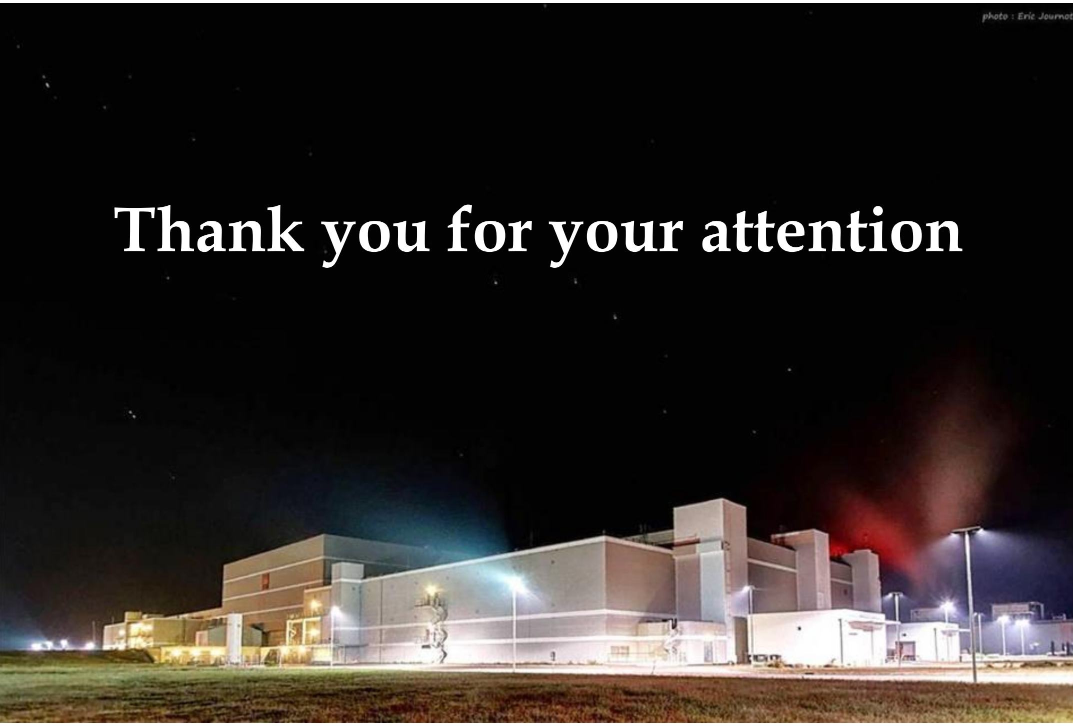
First call for experiments:

- The configuration (end 2016) includes 4 quads and the PETAL beam
- 4 experiments have ben selected (2017-2018) among 16 proposals
  - Amplification of B fields in radiative plasmas : Magnetogenesis and turbulence in galaxy
    - PI : Prof G. Gregori, University of Oxford
  - Interacting radiative shock : an opportunity to study astrophysical objects in Laboratory
    - PI : Dr M. Koenig, LULI
  - Study of the interplay between B field and heat transport in ICF conditions,
    - PI : Dr R. Smets, LPP
  - Strong Shock generation by laser plasma interaction in presence or not of laser smoothing
    - PI : Dr. S. Baton, LULI ; X. Ribeyre, CELIA, Univ. Bordeaux

Second call: (launched on April 2016)

- The experiments will take place in 2019 and 2020, with 14 quads and 16 diagnostics
- 6 experiments (among 9 proposals) pre-selected by ISAC-P (Sept. 2016)
- Deposit of the full proposals December 2016, and final selection in February 2017.

Thank you for your attention



2nd European Conference on
Plasma Diagnostics

Bordeaux, France

18th – 21st April 2017

Topics and Scientific Committee

Magnetic Confinement Fusion:
Angelo A. Tuccillo (chair), Liqun Hu, Mikhail Kantor, Michael Walsh

Beam Plasma & Inertial Fusion:
Dimitri Batani, Jean-Luc Miquel, Keisuke Shigemori

Low Temperature & Industrial Plasmas:
Dietmar Block, Walter Gakelman, Svetlana Ratynskaia

Basic & Astrophysical Plasmas:
Marco Ferodi, Jan-Willem den Herder, Olivier Limousin

Local Organising Committee

Dimitri Batani (chair), Pauline Aussel, Eric Cormier, Sophie Heurtebise, Katarzyna Jakubowska, Jean Lajzerowicz, Didier Mazon, João Jorge Santos, Emmanuelle Volant

MP1208

EPS endorsement pending

More information available at https://ecpd2017.sciencesconf.org