LMJ

Laser MegaJoule

PETAL

PETawatt Aquitaine Laser

User Guide

Version 1.3. Release April 2017
Updated version available at http://www-lmj.cea.fr/en/ForUsers

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Front page picture : Antennae Galaxies ESA/Hubble

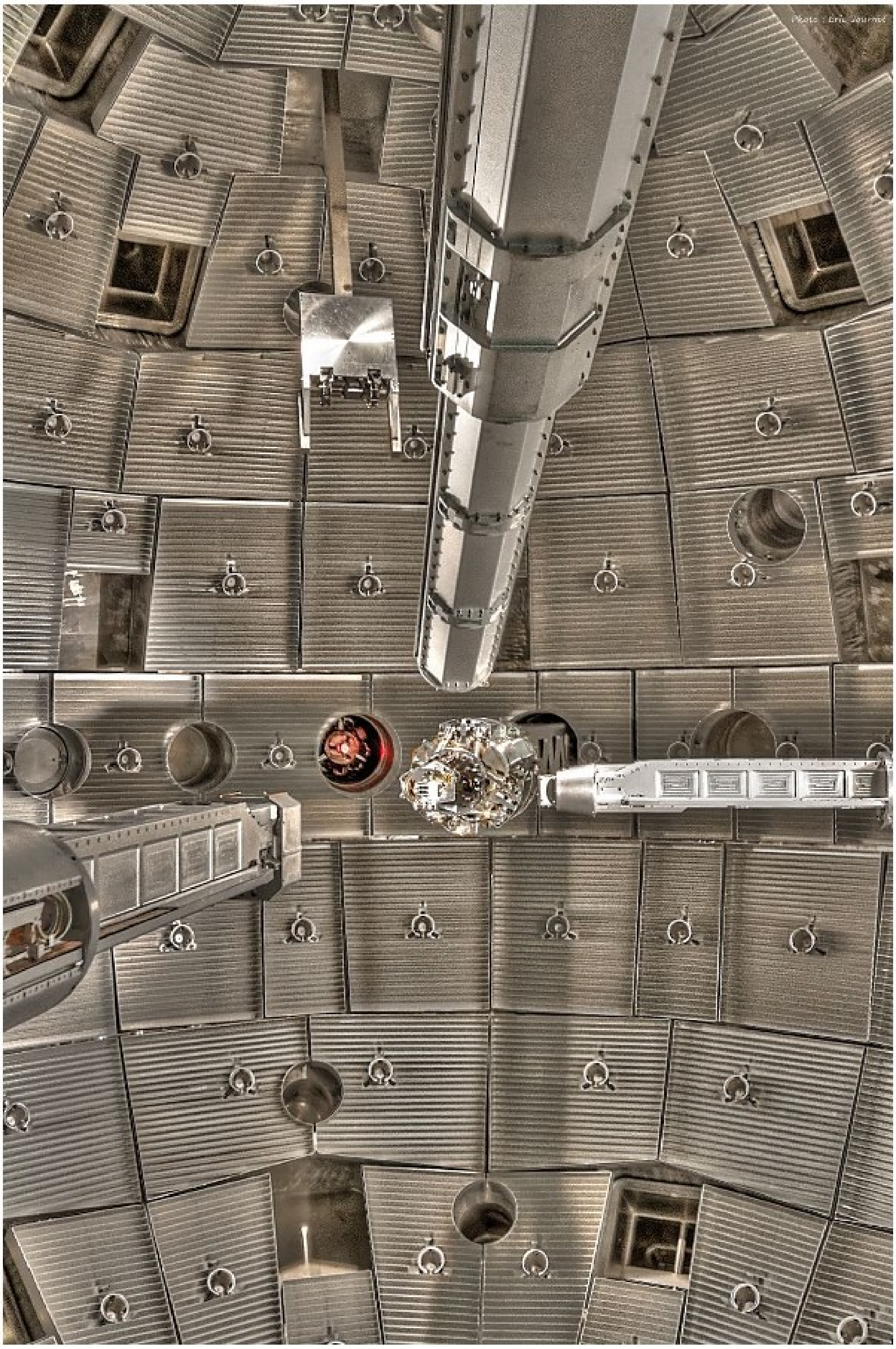
Disclaimer

This document describes the status of the LMJ-PETAL facility and provides the necessary technical references to researchers intending to perform experiments on LMJ-PETAL.

Some devices presented in this document are under development; the data given here, concerning their characteristics, correspond to the specifications. Some small differences could exist between the specification and the realization.

All the presented devices should be available at the beginning of 2019, but some delays are possible.

The performance obtained by the facility so far, and reported in this document, do not commit the future performance.



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I- Introduction

The Military Applications Division of the French Alternative Energies and Atomic Energy Commission (CEA-DAM) has promoted for several decades collaboration with national and international scientific communities [1-31]. Regarding laser facilities, according to the decision of the French Ministry of Defense, the CEA-DAM has given access to the scientific communities to the LIL facility, the prototype of Laser Megajoule (LMJ), for a period of 9 years since 2005 until 2014. Ten types of experimental campaigns and a total of one hundred laser shots on targets in collaboration have been performed on the LIL during this period [32-37]. With the LMJ [38] and PETAL facilities [39], the CEA-DAM is once again in a position to welcome national and international teams, in perfect accordance with its legal obligations to confidentiality.

Figure I.1 : LIL and LMJ aerial view

The Laser Megajoule is part of the French “Simulation Program” developed by the CEA-DAM. The Simulation program aims to improve the theoretical models and data used in various domains of physics, by means of high performance numerical simulations and experimental validations.

LMJ offers unique capabilities for the Simulation Program, providing an extraordinary instrument to study High Energy Density Physics (HEDP) and Basic Science. A large panel of experiments will be done on LMJ to study physical processes at temperatures from 100 eV to 100 keV, and pressures from 1 Mbar to 100 Gbar. Among these experiments, Inertial Confinement Fusion (ICF) is the most exciting challenge, since ICF experiments set the most stringent specifications on LMJ’s attributes [40, 41].

The PETAL project consists in the addition of one high-energy multi-Petawatt beam to LMJ. This project has been performed by the CEA under the financial auspices of the Aquitaine Region ("maître d'ouvrage", project owner), of the French Government and of the European Union. PETAL provides a combination of a very high intensity beam, synchronized with the very high energy beams of LMJ. LMJ-PETAL is an exceptional tool for academic research, offering the opportunity to study matter in extreme conditions.

LMJ-PETAL is open to the academic communities, as the previously mentioned LIL. The academic access to LMJ-PETAL and the selection of the proposals for experiments is done by Institut Laser & Plasmas (ILP) through the PETAL international Scientific Advisory Committee.

This document provides the necessary technical references to researchers for the writing of Letter of Intent (LOI) of experimental proposals to be performed on LMJ-PETAL. Regularly updated version of this LMJ-PETAL User guide will be available on LMJ website at **http://www-lmj.cea.fr/en/ForUsers**.

II- LMJ-PETAL Overview

LMJ is now under commissioning at CEA-CESTA at a stage of 176 beams (44 quads).

LMJ is a flashlamp-pumped neodymium-doped glass laser (1.053 µm wavelength) configured in a multi-pass power amplifier system. The 1.053 µm light is frequency converted to the third harmonic (0.351 µm) and focused, by means of gratings, on a target at the center of the target chamber. LMJ will deliver shaped pulses from 0.7 ns to 25 ns with a maximum energy of 1.5 MJ and a maximum power of 400 TW of UV light on the target.

The main building includes four similar laser bays, 128-meter long, situated in pairs on each side of the central target bay of 60-meter diameter and 38-meter height.

The 176 square 37 x 35.6 cm^2 beams are grouped into 22 bundles of 8 beams. In the switchyards, each individual bundle is divided into two quads of 4 beams, the basic independent unit for experiments, which are directed to the upper and lower hemispheres of the chamber.

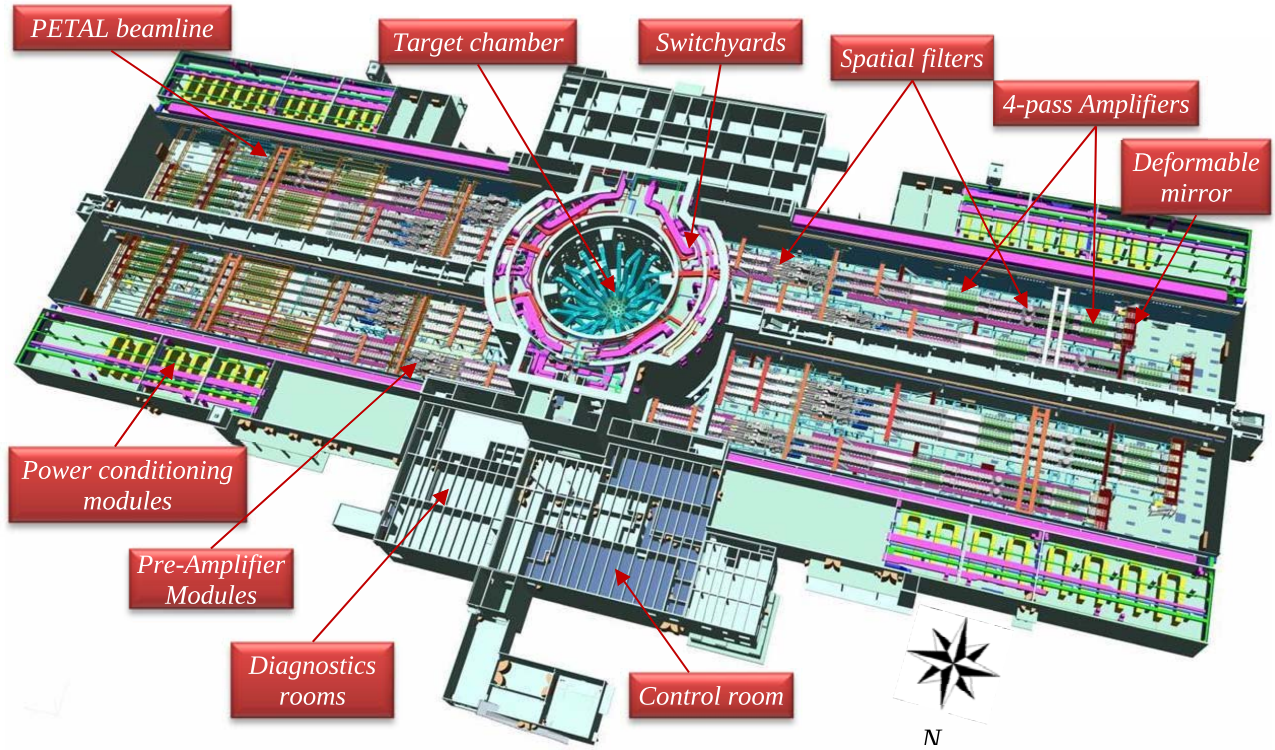


Figure II.1: Schematic view of the Laser Megajoule showing the main elements of the laser system

At the center of the target bay, the target chamber consists of a 10-meter diameter aluminum sphere, equipped with two hundred ports for the injection of the laser beams, the location of diagnostics and target holders. It is a 10 cm-thick aluminum sphere covered with a neutron shielding made of 40 cm thick borated concrete. The inside is covered by protection panels for X-ray and debris.

LMJ is configured to operate in the "indirect drive" scheme, which drives the laser beams into cones in the upper and lower hemispheres of the target chamber. Forty quads enter the target chamber through ports that are located on two cones at 33.2° and 49° polar angles. Four other quads enter the target chamber at 59.5° polar angle, and will be dedicated to radiographic purpose.

The 44 laser beam ports include the final optics assembly: vacuum windows, debris shields and device to check the damages on optics.

Many pieces of equipment are required in the target area:

- a Reference Holder (RH) is used for the alignment of all beams, diagnostics and target,
- a Target Positioning Systems (TPS) for room temperature experiments is operational,
- a cryogenic TPS for ignition target will be installed later,

- a set of visualization stations for target positioning (SOPAC stations, as System for Optical Positioning and Alignment inside Chamber),
- a set of about ten diagnostics manipulators, called Systems for Insertion of Diagnostic (SID), will be installed, they will position 150-kg diagnostic with a 50-µm precision.

The PETAL project consists in the addition of one short-pulse (500 fs to 10 ps) ultra-high-power, high-energy beam (few kJ) to LMJ. PETAL offers a combination of a very high intensity multi-petawatt beam, synchronized with the nanosecond beams of LMJ. PETAL expands the LMJ experimental field on HEDP.

The PETAL design is based on the Chirped Pulse Amplification (CPA) technique combined with Optical Parametric Amplification (OPA). Furthermore, it takes the benefits of the laser developments made for the high-energy LMJ facility allowing it to reach the kilojoule level.

Over 30 photon and particle diagnostics are considered with high spatial, temporal and spectral resolution in the optical, X-ray, and nuclear domains. Beside classical diagnostics, specific diagnostics adapted to PETAL capacities are available in order to characterize particles and radiation yields that can be created by PETAL [42, 43]. The set of equipment, delivered in 2016 and 2017, has been specified by the academic community in the framework of the PETAL+ project[*] and is developed by the CEA. It consists of: one spectrometer for charged particles (SEPAGE), two electron spectrometers (SESAME), one hard X-ray spectrometer (SPECTIX) and three diagnostics manipulators (SID).

The first CEA-DAM physics experiments on LMJ have been performed in October 2014 with a limited number of beams and diagnostics. The operational capabilities (number of beams and plasma diagnostics) will increase gradually during the following years. The first academic experiments on LMJ-PETAL are performed in 2017-2018 with 16 beams (4 quads) and PETAL beam, 3 SID and 12 diagnostics. The next ones will be performed in 2019-2020 with 56 beams (14 quads) and PETAL beam, 4 SID and 18 diagnostics.

History	*Date*
Beginning of the construction of the LIL facility	*1996*
First laser shots on LIL	*2002*
Beginning of the construction of the LMJ facility	*2003*
First target physics experiments on LIL	*2004*
Beginning of PETAL on LIL	*2005*
First academic experiments on LIL	*2005*
LMJ target chamber installed	*2006*
LMJ building commissioning	*2008*
Decision of coupling PETAL with LMJ	*2010*
Last academic experiments on LIL & closure of LIL	*2014*
First target physics experiments on LMJ with 2 quads	*2014*
PETAL most powerful laser beam with 1.2 PW	*2015*
First associated LMJ and PETAL shot	*2015*
First PETAL test shots on target	*2017*
First academic experiments on LMJ with 4 quads and PETAL	*2017*

Table II.1: History of LIL, LMJ and PETAL facilities,
from the beginning of the LIL to the academic opening of LMJ-PETAL

[*] The development of PETAL diagnostics takes place within the Equipex project PETAL+ of the University of Bordeaux, funded by the French Research National Agency (ANR) within the framework of the "Programme d'Investissement d'Avenir" (PIA) of the French Government.

III- Policies and Access to CEA-CESTA and LMJ facility

III.1- Driving Directions and Accommodations

The LMJ-PETAL facility is located at CEA-CESTA, 15 avenue des Sablières, CS 60001, 33116 Le Barp Cedex, France. GPS coordinates are given in the appendix.

In Figure III.1, directions are given for visitors traveling from either the Bordeaux Merignac Airport, or SNCF Bordeaux railway station. The A63 highway provides direct access to CEA-CESTA. The driving distance from Bordeaux is 35 km, approximately 30 minutes in normal traffic conditions. Note that it is compulsory that all visitors satisfy the badging policy described in Section III.2-.

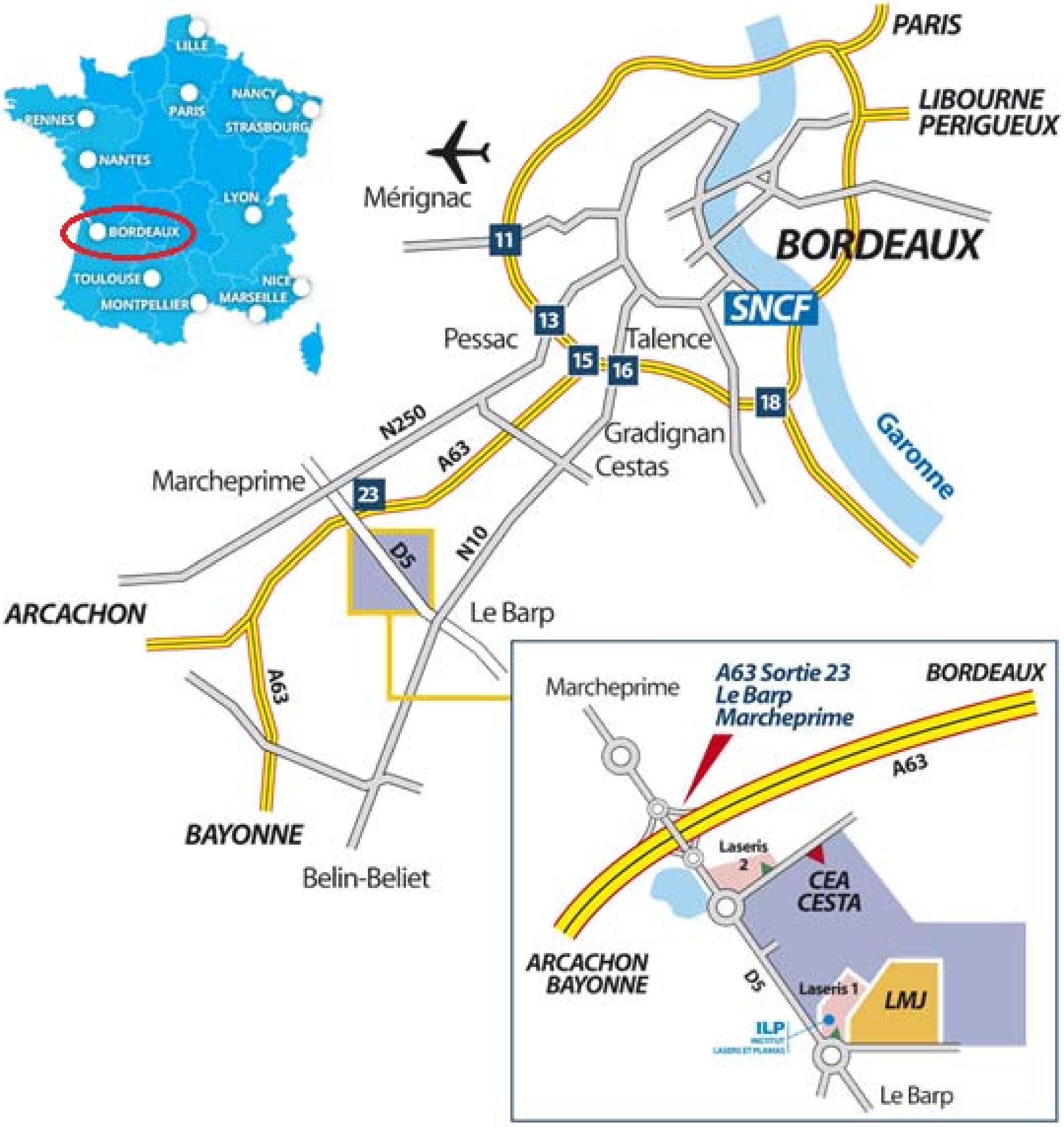


Figure III.1: Map of Bordeaux South area and transportation routes to CEA-CESTA and LMJ

There are some hotels close to CEA-CESTA, but numerous hotels can be found in the city of Bordeaux or in the area of Arcachon (seaside). A list of hotels is given in the appendix.

III.2- Office Space at ILP Campus and Computer Access

To provide comfortable working conditions to worldwide researchers preparing their experiments, the "Institut Lasers & Plasmas" (ILP) and CEA-CESTA offer a large office space, Internet access and administrative assistance inside the ILP Campus Building. This building is located just outside CEA-CESTA. Meeting rooms are available as well as a 150 places amphitheater which could be used for workshops. The ILP building is located 2 km away from LMJ Control Room. A cafeteria for lunch is also accessible at walking distance, as well as supermarket, restaurants and food services located in Le Barp city, 3 km away.

Figure III.2: Photograph of the ILP Campus building located on the open zone,2 km away from LMJ-PETAL building

III.3- CEA-CESTA Access and Regulations

CEA-CESTA is a national security laboratory with regulated entry. Visitors must make prior arrangements at least 8 weeks before any visit. The experimental campaigns on LMJ-PETAL will be planned at least 6 months in advance, and the access to CEA-CESTA could be extended up to a 3 months period. In order to gain admittance, the requested information is the following:

Last name, first name, place of birth, nationality (dual nationality if any), nationality of birth, passport number and date of validity (CNI number and validity for French citizen), home address, name and address of employer, research institution, funding agency, professional phone number, professional email, contact in case of emergency.

Please notice that access to LMJ-PETAL is of CEA responsibility only. Acceptance of an experimental proposal by ILP doesn't automatically grant access to CEA for all of the collaborators. According to confidentiality rules, no justifications would be given in case of denied access to the facility.

Professional computers may be authorized on-site provided that the MAC address and physical address of the computer were given with the aforementioned personal information. Internet connectivity will be provided in a dedicated room; however no Wi-Fi capabilities are available inside CEA-CESTA.

All types of cellular telephones are forbidden. This restriction also applies for CEA people inside restricted areas, like the LMJ-PETAL building. The cell phones should be kept secured in a cell phones garage at the badging center entry.

III.4- Confidentiality Rules

The CEA-DAM would be pleased to promote a wide participation of the academic communities to the scientific and technologic researches which will be performed on the LMJ-PETAL facility. However, as an organism which is in charge for the control of scientific disciplines involved in nuclear deterrence, the CEA-DAM has to follow the protection rules regarding National Defense.

As a consequence, some information and data obtained from laser experiments have to be protected according to the "Guide on the sensitiveness of information in the field of Inertial Confinement Fusion"[†].

[†] General Secretary for Defense and National Security: Document #3235/SGDSN/AIST of May 30, 2012

That is why some indications are given below to prevent or reduce any risk of reject of proposal according to confidentiality rules.

Most of research themes can be carried out on LMJ-PETAL without any restriction: optics, laser-plasma interaction, plasma physics, particles transport, thermal conduction, mechanics in continuous media, general hydrodynamics, nuclear physics, etc.

Some other research fields are considered as sensitive: Equation of State (EOS), atomic spectra and opacities, constitutive relations and damage laws of materials, radiative hydrodynamics, turbulent hydrodynamics, X-ray radiation transfer, mixing physics in convergent flows, actinides studies, etc.

Some specific studies included in the previous list may be considered not sensitive. EOS and opacities are notably concerned.

Regarding EOS and constitutive relations and damage laws, simple elements or mixture can be studied at any pressure if their atomic number is lower or equal to 71. For atomic number between 72 and 91 (included), the pressure is limited to 1000 GPa. For atomic number greater than 91, the domain is considered as sensitive at any pressure.

Atomic spectra and opacities can be studied for any temperature for element whose atomic number is lower or equal to 36. For other elements, the temperature is limited to 50 eV.

The open domains for experiments are summarized in the figure III.3.

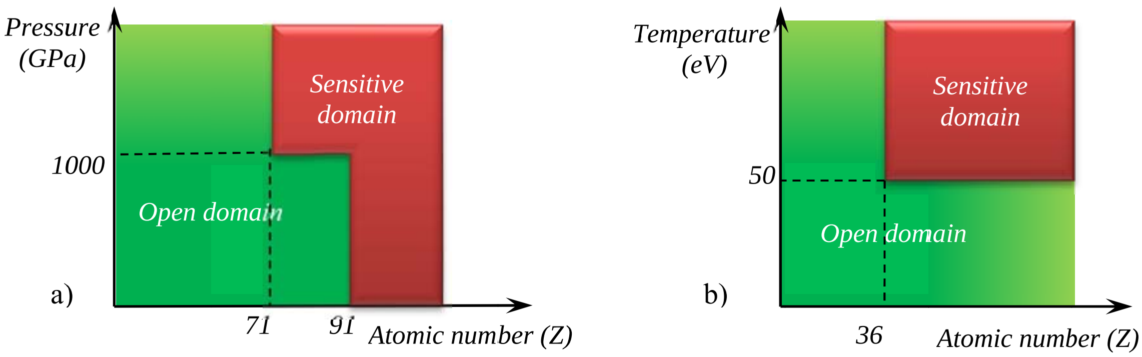


Figure III.3: a) Accessible pressure and atomic number for Equation of State experiments b) Accessible temperature for Opacities experiments

III.5- Selection Process

A call for proposals for experiments on the LMJ-PETAL laser facility will regularly be issued on an annual basis by ILP, CEA and Aquitaine Region.

Depending on the experiment complexity, experiments will be approved on a one-year or two-year basis. The more complex selected experiments will be given a few laser shots in the first year, intended to demonstrate the feasibility of the experiment. On the basis of the results of the campaign of the first year, more laser shots will be assigned on the second year.

The selection process for experimental proposals on LMJ-PETAL is the following:

- First a Letter of Intent (LOI) or preliminary proposal should be addressed by research groups to ILP (Z.A. Laseris – 1 avenue du Médoc – F-33114 Le Barp, **ILP-LMJ-call@cpht.polytechnique.fr**). This preliminary proposal should describe the purpose of the experiment, the research groups involved in the experiment, the laser requirements (energy, power, pulse shape, etc.), the diagnostic requirements, the target requirements, the number of laser shots requested (limited to 6 per campaign).

A pre-selection of the most pertinent experiments is done by the International Scientific Advisory Committee of PETAL (ISAC-P), established by ILP.

- Secondly, a full proposal should be sent to ILP (**ILP-LMJ-call@cpht.polytechnique.fr**) and CEA-DAM (**userLMJ@cea.fr**) by the pre-selected groups.

This report will include:

1. The experimental configuration at the target chamber center, including realistic target dimensions and position of additional targets (backlighter if any).

2. The laser configuration

2.1. *For LMJ beams*:

- The desired spot sizes (see Table V.2) and optical smoothing conditions (2 GHz or 2 + 14 GHz);
- The laser pulse shape per quad (P (TW) as a function of time) and Energy (kJ) per quad (the Energy-Power diagram is presented in Figure V.9);
- The laser aim points per quad.

2.2. For PETAL beam:

- Pulse duration (between 0.5 and 10 ps);
- Energy (the current transport mirrors limited the available energy on target at 1 kJ for the 2017-2018 timeframe). For 2019, more energy could be expected;
- Best focus position.

3. The diagnostic configuration

The primary and secondary diagnostics for the physics goal must be specified.

Concerning diagnostics in SID: 4 SID are available in the 2019. The Table VII.1. indicates the available locations.

The fixed diagnostics, if needed, are: DMX in MS8, SESAME 1 and SESAME 2, UPXI, LPXI, FABS, NBI, Neutron Pack (see VIII- LMJ Diagnostics).

4. The target description

Sketch of the targets, including their dimensions, and the manufacturer of the targets must be provided. The CEA/CESTA Target Laboratory is in charge of the alignment of the targets at target center chamber (TCC).

5. The preliminary nuclear safety analysis

In order to later fulfill the CEA LMJ nuclear safety rules, the following information are required:

- A rough estimate of the X-ray and/or electrons and/or ions emitted spectra, with their angular distribution;
- The list of all the constitutive target materials with estimated mass.

6. Preparation requirements

The list of the experimental capabilities which need to be commissioned prior to the physics experiment is requested: specific ns shaped pulse, PW laser contrast, characterization of specific hard X-ray or proton backlighting sources, etc.

7. Shots logic and draft failure modes

The order of the shots (6 shots per campaign at maximum) is required, as well as the logic of the shots and the main possible failure modes (and backup plan).

Final selection of the most pertinent experiments is done by the ISAC-P in accordance with CEA-DAM.

III.6- Experimental Process

Once the experiments have been selected, the experimental campaigns are included in the schedule of the facility by the CEA-DAM Programming Committee. The selected groups are informed of this planning approximately 2 years in advance of the experimental campaign. At the same time, Experiment Managers from CEA (MOE, see III.7) are designated in order to prepare the experiment in close collaboration with the selected groups.

The key milestones in the PETAL-LMJ experimental process will include several reviews in order to evaluate the experimental preparations and readiness.

- The **Launch Review** is conducted approximately 24 months in advance of the experimental campaign. The selected group, assisted by the MOE, presents the experiment proposal in front of CEA-DAM experts. The primary purpose of this review is to ensure the proposed experiment meet the LMJ-PETAL requirements and to identify additional studies. CEA-DAM will analyze the proposals in terms of confidentiality rules, security rules and feasibility. At this point CEA-DAM could ask the research group to amend their proposal if it does not match the rules or if a feasibility matter is identified.

Following the Launch Review, the selected groups will prepare a detailed report to be sent to CEA-DAM (**userLMJ@cea.fr**) approximately 18 months in advance of the experimental campaign. This report will complete the full proposal with feasibility studies, simulation results (including X-ray and particles emissions), detailed target description, etc.

- A **Follow-up Review** occurs approximately 6 months later. The selected group exposes the advances of the experimental preparations and results of identified extra studies. This review is based on the abovementioned detailed report. Depending on the progresses made, other Follow-up Reviews may be scheduled.
- The **Design Review** is conducted approximately 12 months in advance of the experimental campaign. In addition to the previous specified data's (laser and diagnostic configurations, target description, shots logic …). This review provides all information required by the facility: consideration of target debris, nuclear safety analysis, diagnostics predictions, etc. This Review also updates the agenda of deliveries (e.g. targets).
- The **Readiness Review** occurs approximately 1 month prior to the date of the experiment. It is the final check to ensure that all preparations for execution of the experiment are complete.

III.7- Responsibilities during Shot Cycle

Several people will be in charge of the management of the experiment, each of them having a specific responsibility.

The Principal Investigator (PI) is in charge of the scientific design of the experiment; he may be assisted by a co-PI from ILP (for ICF studies for instance).

The practical design of the experimental project, taking into account the facility capabilities and the expected results (laser energy, pulse shape, laser beams, diagnostics, alignment, debris from target, etc.) comes under the responsibility of the CEA Experiment Manager (MOE); he will work in close collaboration with the PI.

The making of the experimental campaign is under the responsibility of the CEA Experiment Coordinator (RCE); he is in charge of the target and laser bay functioning and performance taking into account all inherent risks for the operation crew and material.

The laser shots during the campaign are under the responsibility of the LMJ Shot Director who is responsible for the LMJ safety.

The PI will not be in direct contact with the LMJ Shot Director. Decisions related to the effective performance of the experimental campaign are taken according to the PI's wishes; however communications with the Facility and LMJ Shot Director are the sole responsibility of the MOE and RCE.

III.8- Access to LMJ-PETAL during Shots

Access to the LMJ-PETAL facility requires half-day training to LMJ security rules and general information. This course is usually given on Monday.

To ensure personnel and equipment safety, it is mandatory that the LMJ Control Room remains a quiet area during shot operations. Shot preparation is a long process and will take a few hours which include some phases not relevant for physicists. A dedicated meeting room will be available close to the LMJ Control Room for the PI for the final shot phase when his presence is necessary.

To limit administrative duties and escort procedures, the number of external users allowed to follow one shot is limited to 4 people maximum, typically the PI, co-PI (if any), one PhD student and diagnostics expert (for PETAL+ diagnostics for instance). Those people could rotate during the week or the experimental campaign (providing the access procedures have been followed).

Figure III.4: View of the LMJ Control Room

III.9- Data Access

The laser pulse shapes and raw laser energy are immediately observable after the shot, like X-ray images acquired on X-ray framing camera or streaked camera when they are directly recorded on electronic devices (CCD). The consolidated laser energy will be communicated at the end of the experimental campaign because it requires evaluation of the vacuum window transmission which could have been modified by laser-induced damages. For data requiring digitizing or scan (like Image Plate) the data release will not be possible immediately after the shot, but a few hours later. It is also the case for data depending on material handling inside target bay area, which is regulated by safety procedures for contamination control and radiation monitoring.

Raw experimental data and/or data translated into physics units will be accessible to the PI and his experimental team as soon as possible after the shot. The data release is of CEA responsibility. The release of detailed response functions of some diagnostics, like for example the detailed response functions of DMX-LMJ channels, may be considered as classified information. This is why only consolidated data in physics units will be delivered to the PI in such a case. By any way the CEA Experiment Manager will ensure that all essential physics data are delivered to the PI. He is responsible for the quality of the experimental data.

Data support will be either USB keys for the data directly available after the shot or CD-ROM for consolidated and scanned data. The baseline data format of LMJ data is a custom hdf5. CEA will provide hdf5 structure description and if necessary basic tools to extract the information.

III.10- Publications and Authorship Practices

Results of LMJ-PETAL experiments are expected to be published in major journals and presented in scientific conferences. The PI should inform CEA-DAM of any publication a few weeks before any major conference (APS DPP, IFSA, EPS, ECLIM, ICHED, HEDLA, HTPD, etc.) using the email address **userLMJ@cea.fr**. It is of PI responsibility to judge who made a significant contribution (or only a minor) to the research study. However CEA Experiment Manager (MOE) and CEA Experiment Coordinator (RCE), as well as CEA Diagnostics leaders, should be co-authors of the first publications of the campaign they have been involved in. A statement acknowledging the use of LMJ-PETAL should be included in all publications. The sources of financial support for the project (ANR, ILP, ERC, etc.) should also be disclosed.

III.11- Calls for Proposals History

The first call for proposals was launched in July 2014: 16 proposals have been received. In November 2014 the ISAC-P has preselected 7 proposals, and in May 2015, after the selected groups have provided their full proposals, the ISAC-P has selected 4 proposals which have been approved by CEA-DAM and included in the schedule of the facility. They are dedicated to astrophysics phenomena and ICF studies. The first shots are planned in 2017.

The second call for proposals was launched in April 2016, for shots planned in 2019-2020. 9 proposals have been received in June 2016. The ISAC-P has pre-selected 6 proposals in September 2016. The full propositions were received on January 2017 and the final selection in March 2017 has retained 2 proposals.

The next call will be launch in the beginning of 2018.

IV- LMJ Building Description

The LMJ building covers a total area of 40 000 m^2 (300 m long x 100 to 150 m wide). It includes four similar laser bays, 128 meters long, situated in pairs on each side of the central target bay. The target bay is a cylinder of 60-meters diameter and 38-meters height, with a 2-meters thick concrete wall for biological protection.

At the center of the target bay, the target chamber consists of a 10-meters diameter aluminum sphere, fitted with two hundred ports for the injection of the laser beams and the location of diagnostics and target holders. The four lasers bays, completed by the end of 2013, are now equipped with all the supporting optics infrastructures and the final optical components are currently being installed.

The PETAL laser beam takes the place of one classical LMJ bundle inside the South-East laser Bay.

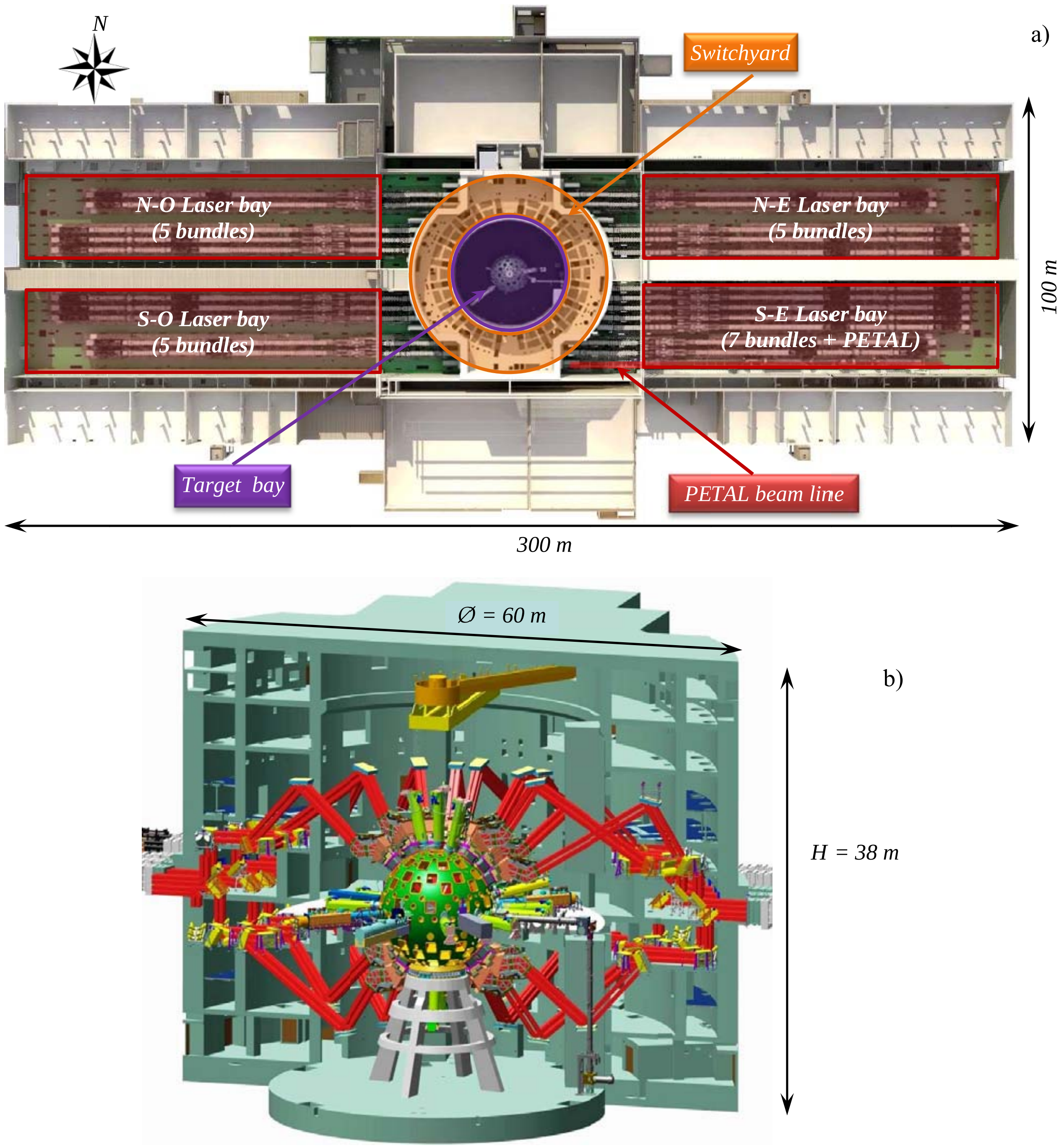


Figure IV.1: a) Drawing of the building with total dimensions

b) CAD of the target bay with transport of the beams, the experimental chamber and its equipment: target positioning system, plasma diagnostics

V- LMJ Laser System

V.1- Laser Architecture

LMJ is under commissioning at CEA-CESTA at a stage of 176 beams. LMJ is a flashlamp-pumped neodymium-doped glass laser (1.053 µm wavelength) configured in a multi-pass power amplifier system. The LMJ 3100 glass laser slabs will be capable of delivering more than 3 MJ of 1.053 µm light, that is subsequently frequency converted to the third harmonic (0.351 µm) and focused on a target at the center of target chamber. LMJ will deliver shaped pulses from 0.7 ns to 25 ns with a maximum energy of 1.5 MJ and a maximum power of 400 TW of UV light on target.

The architecture of one beamline is shown in Figure V.1. The front end delivers the initial light pulse and provides its temporal and spatial shape as well as its spectrum and enables synchronization of all the beams. The front end is made of four sources (one per laser hall), which deliver the first photons (about 1 nJ), and 88 Pre-amplifier Modules (PAM, 1 per 2 beams), including a regenerative cavity and an amplifier, which deliver a 500-mJ energy beam to the amplification section.

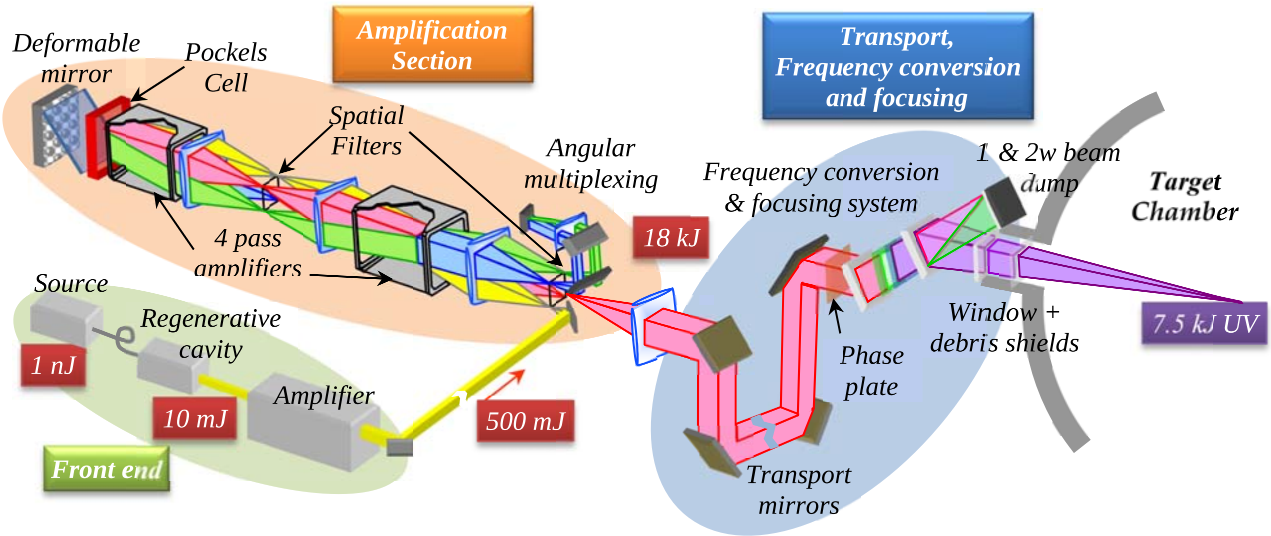


Figure V.1: Architecture of one LMJ beamline.
The basic unit for experiment is a quad made of 4 identical beamlines

Figure V.2: PreAmplifier Module in the North-East Laser Bay

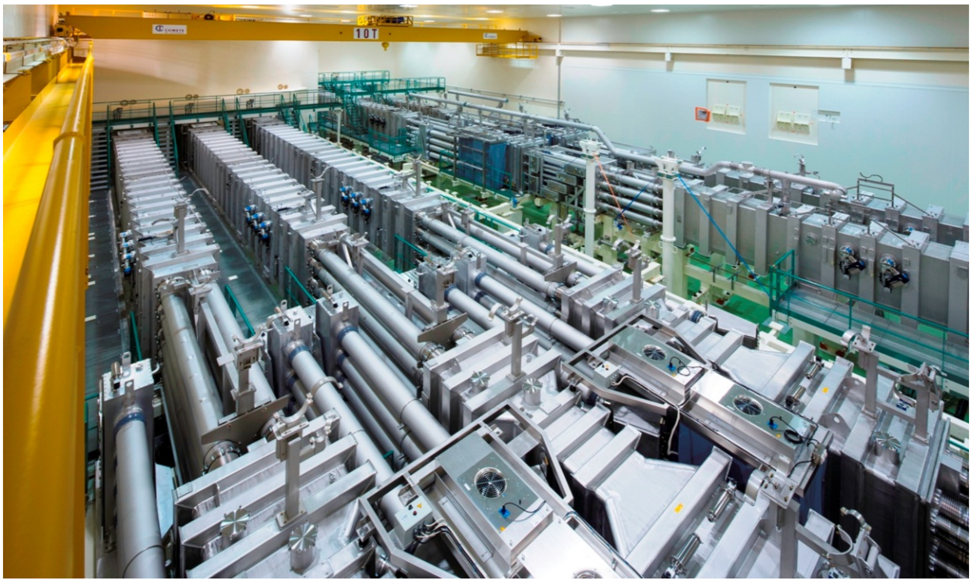


Figure V.3: South-West Laser Bay equipped with 5 amplification sections

In the amplification section, the beams are grouped in bundle of 8 beams and they are amplified 30 000 times to reach energy of 15-18 kJ per beam. The amplification section includes two 4-pass amplifiers, two spatial filters, a plasma electrode pockels cell, a polarizer and a deformable mirror for wavefront correction.

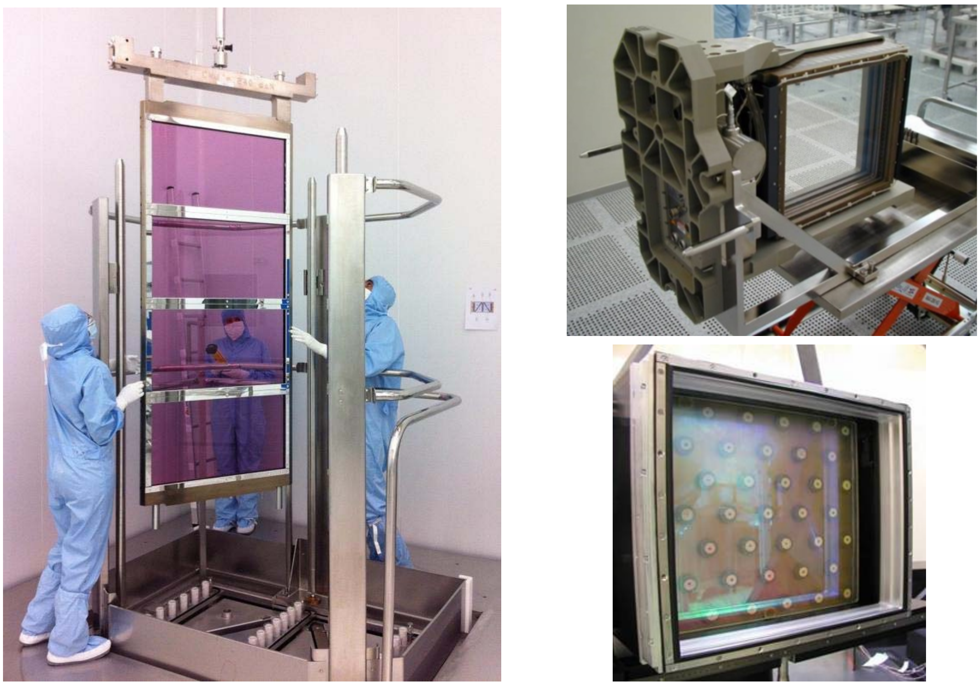


Figure V.4: Mounting of 4 laser slabs, plasma electrode pockels cell and deformable mirror

In the switchyards, each individual bundle is divided into two quads of 4 beams, which are directed to the upper and lower hemispheres of the chamber by the mean of 5, 6 or 7 transport mirrors. The quad is the basic independent unit for experiments.

The LMJ target chamber is arranged with a vertical axis. LMJ is configured to operate usually in the "indirect drive" scheme [41], which directs the laser beams into cones in the upper and lower hemispheres of the target chamber. Forty quads enter the target chamber through ports that are located on two cones at 33.2°

and 49° polar angles. There are 10 quads per cone on each hemisphere. Four other quads enter the target chamber at 59.5° polar angle, and will be dedicated to radiographic purpose (see Figure V.5).

The PETAL beam enters the experimental chamber in the equatorial plane.

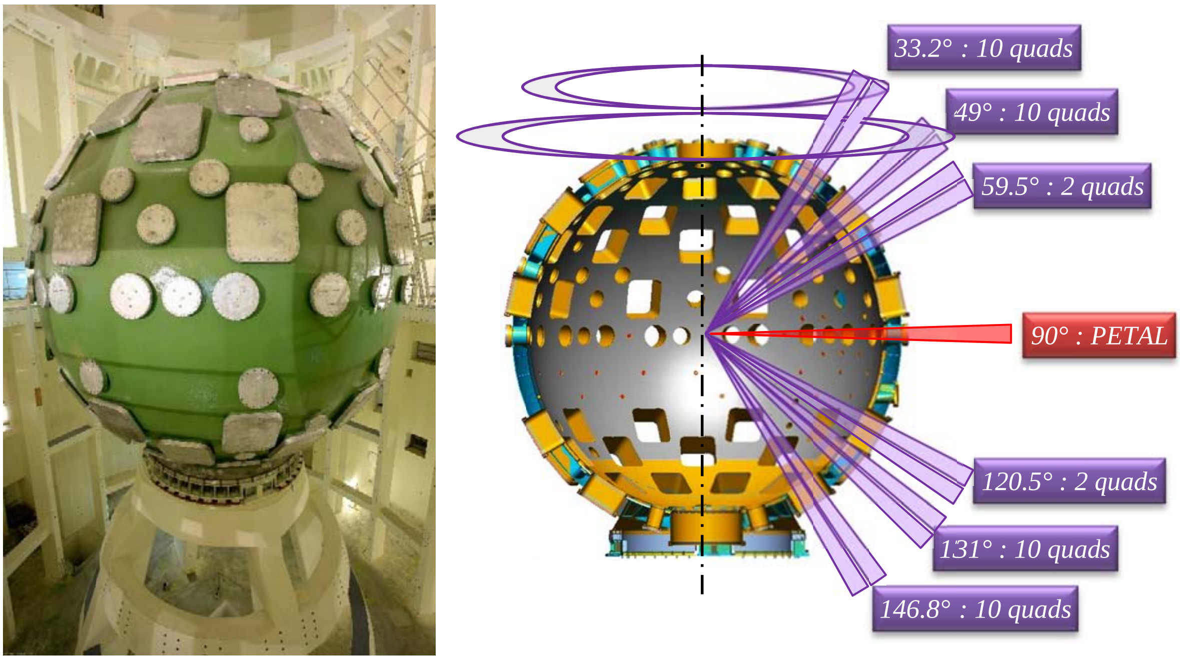


Figure V.5: Target chamber and geometry of the LMJ irradiation

A detailed configuration of irradiation geometry is given in Figure V.6 and the spherical coordinates of all beam ports are given in Table V.1.

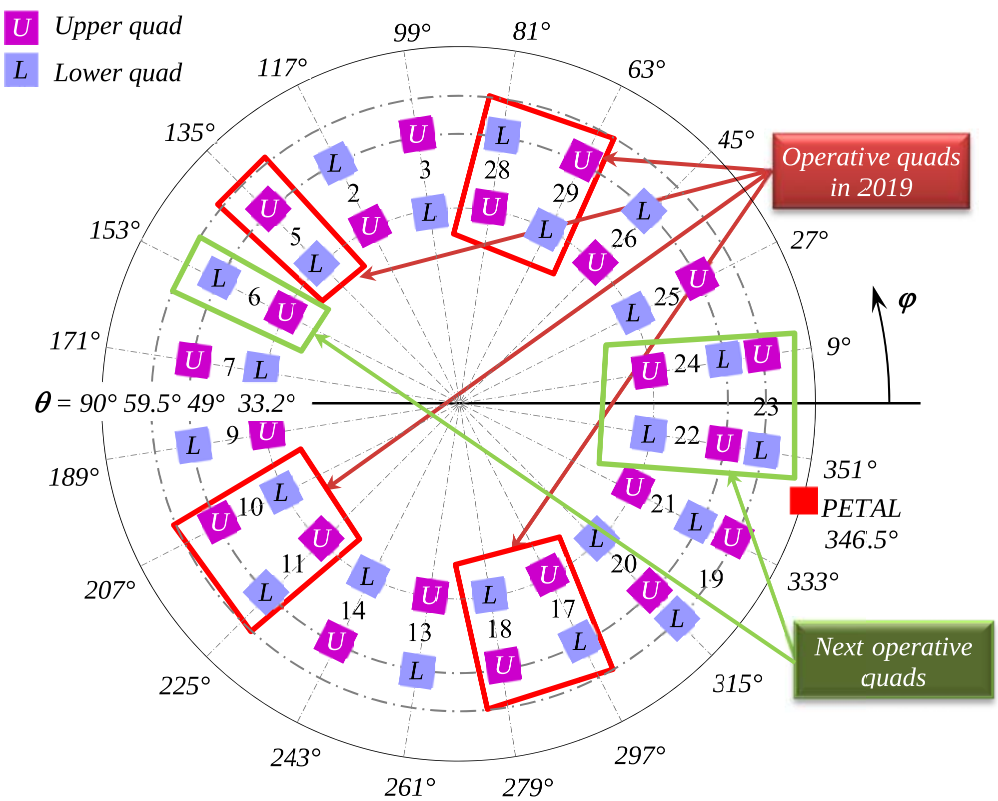


Figure V.6: Irradiation geometry of LMJ quads and PETAL beam.
The operative quads at the beginning of 2019 are indicated in red (Bundles # 5, 10, 11, 17, 18, 28 and 29).
The next operative quads are indicated in green (Bundles # 6, 22, 23 and 24)

Beam Port	θ	φ	Beam Port	θ	φ	Beam Port	θ	φ	Beam Port	θ	φ
Quads operative in 2019											
28U	33.2°	81°	28L	131°	81°	29U	49°	63°	29L	146.8°	63°
17U	33.2°	297°	17L	131°	297°	18U	49°	279°	18L	146.8°	279°
10U	49°	207°	10L	146.8°	207°	11U	33.2°	225°	11L	131°	225°
5U	49°	135°	5L	146.8°	135°	PETAL	90°	346.5°			
Next operative quads											
6U	33.2°	153°	6L	131°	153°	22U	49°	351°	22L	146.8°	351°
24U	33.2°	9°	24L	131°	9°	23U	59.5°	9°	23L	120.5	351°
Subsequent quads											
2U	33.2°	117°	2L	131°	117°	13U	33.2°	261°	13L	131°	261°
21U	33.2°	333°	21L	131°	333°	26U	33.2°	45°	26L	131°	45°
9U	33.2°	189°	9L	131°	189°	19U	59.5°	333°	19L	120.5°	315°
7U	49°	171°	7L	146.8°	171°	25U	49°	27°	25L	146.8°	27°
20U	49°	315°	20L	146.8°	315°	14U	49°	243°	14L	146.8°	243°
3U	49°	99°	3L	146.8°	99°						

Table V.1: Spherical coordinates of beam ports

V.2- LMJ Frequency Conversion and Focusing Scheme

The optics assembly for frequency conversion and focusing is composed of a 1ω grating, two KDP and DKDP crystals for Second and Third Harmonic Generation, and a 3ω focusing grating. The 1ω grating deflects by an angle of 50° the incoming 1ω beam. An angular dispersion of the spectrum is introduced by the grating which allows broadband frequency tripling. The frequency converters use a Type I-Type II third harmonic generation scheme. The 3ω grating deflects back the 3ω beam by an angle of 50°, while the unconverted light is stopped by absorbers. As a consequence no volume restrictions and additional shielding for unconverted light issues have to be taken into account in the making of the experiments.

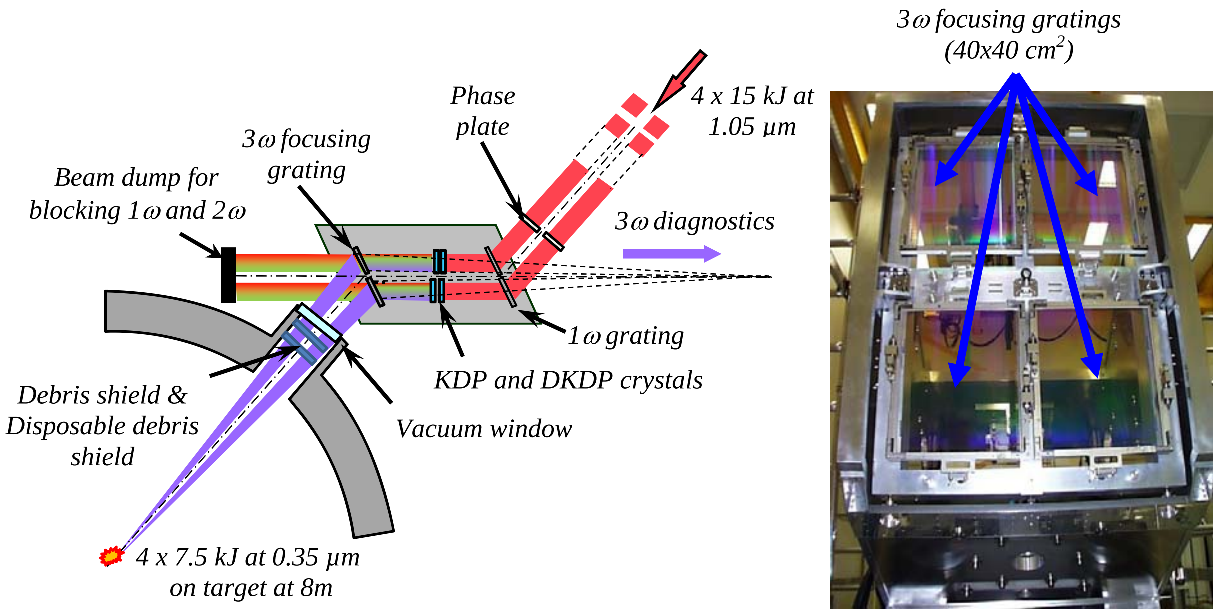


Figure V.7: LMJ frequency conversion and focusing by gratings

The pointing accuracy of LMJ quadruplets depends on the aim point. Two pointing volumes have been defined. The finest accuracy (50 µm rms) is achieved inside a 30 mm diameter x 30 mm high orthocylinder (see Figure V.8). Outside this first cylinder the pointing volume can be described by two other imbricated cylinders with a 75 to 100 µm pointing accuracy. These capabilities have to be considered for the positioning of X-ray backlighters for instance.

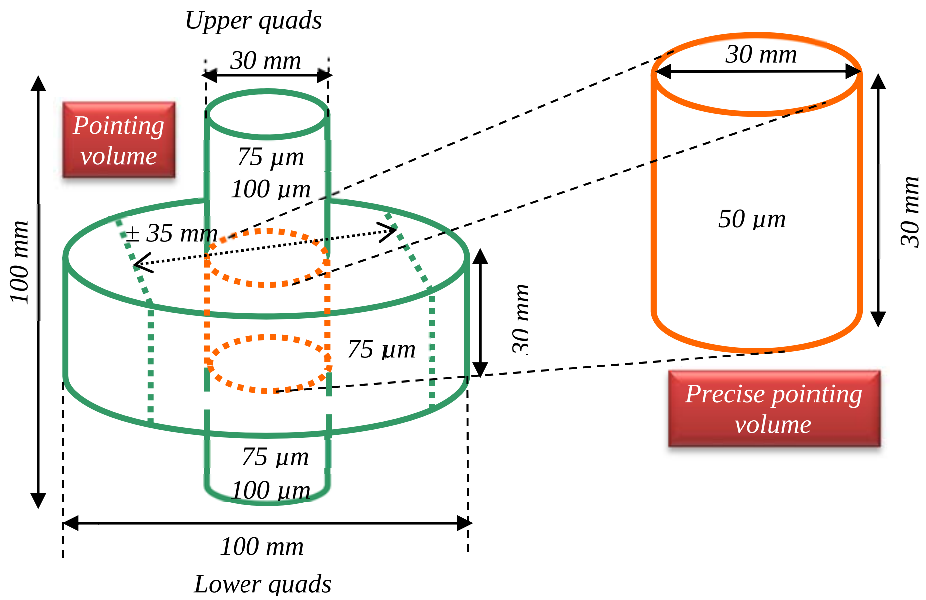


Figure V.8: LMJ pointing volume and expected pointing accuracy (rms)

V.3- Beam Smoothing

To reduce the peak intensity of the light on the target, several techniques are available on LMJ: continuous phase plate (see Section V.4) and smoothing by spectral dispersion.

Two phase modulations at 2 GHz and 14 GHz around the central wavelength are realized. The first one (2 GHz) is used to raise the threshold of appearance of the Brillouin effects in optics in the front-end and at the end of the laser chain. The second one (14 GHz) is dedicated to Smoothing by Spectral Dispersion (SSD). The full bandwidth available with both frequency modulations is 0.5 nm at 1ω in order to reduce the contrast in the speckles of the focal spot on the target down to 20% [44].

Due to the specific LMJ focusing system, the movement of speckles in the focal spot is along the laser axis (longitudinal SSD) instead of being perpendicular to this axis (transverse SSD) as in standard laser facilities. Another smoothing technique, polarization smoothing, will be installed later for ignition experiments.

V.4- Spot Sizes

Various Continuous Phase Plates (CPP) could be considered for the focal spot sizes. Four types have been defined, three for circular focal spots, called CPP Type D, Type E, Type F and one for elliptical focal spot called Type A.

The nominal phase plate is Type A, it is used for heating hohlraums which are positioned along the chamber axis. The Type D is for heating other kinds of target. The Type E provides a larger focal spot for uniform irradiation (direct drive EOS experiments or large backlighter). The Type F provides a smaller focal for radiography purposes.

Type A is available for all the beams, but the number of other types phase plates is limited. The number of phase plates available on the facility is indicated in chapter IX.1.

The peak intensity on target for a 5 TW pulse, the diameters of focal spots at 1/e and 3 % of the peak intensity and the order of the super-Gaussian describing the intensity profile are given in the Table V.2 below.

CPP	Spot Geometry	Size at 1/e (µm)	Size at 3 % (µm)	Intensity (5 TW) (W/cm²)	Super-Gaussian Order
Type A	Elliptical	Major axis: 870	Major axis: 1430	$1.7\ 10^{15}$	3
		Minor axis: 450	Minor axis: 790		2.4
Type D	Circular	Diameter: 690	Diameter: 1020	$1.6\ 10^{15}$	2.7
Type E	Circular	Diameter: 980	Diameter: 1460	$7.0\ 10^{14}$	3.7
Type F	Circular	Diameter: 375	Diameter: 680	$4.8\ 10^{15}$	2.1

Table V.2: Characteristics of available Continuous Phase Plates

V.5- Energy and Power

The available laser energy for user experiments is constrained by optical damages on gratings [45] and vacuum windows, and operating costs. Whereas LMJ nominal laser energy is designed for 30 kJ per quad for ignition experiments, a lot of CEA experiments will be performed at limited laser energy to reduce the optical damages on final optics. Experimental designs with 10 to 15 kJ per quad are to be considered.

The maximum sustainable laser energy for a given pulse shape will be refined with feedbacks from laser scientists [46, 47] during the preliminary design review of an experiment. Operational limits depend on the exact pulse shape and the type of CPP. The figure V.9 gives the maximum performance and the recommended setting as a function of pulse duration for square pulses.

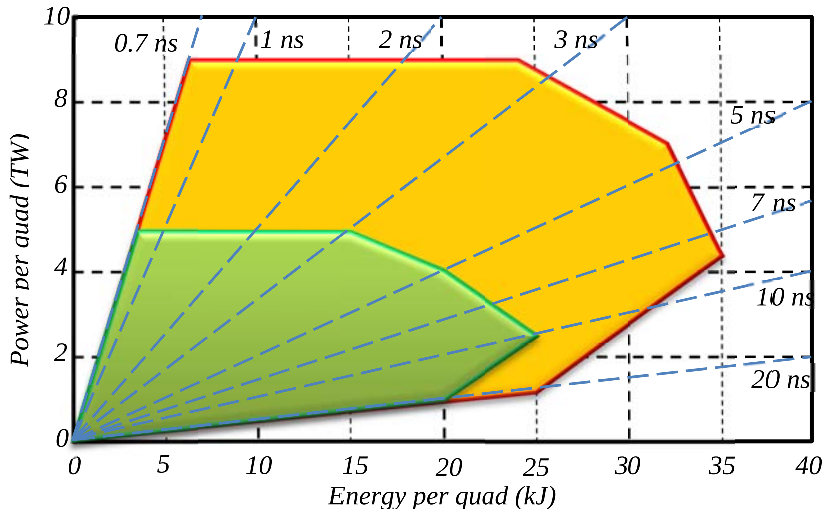


Figure V.9: LMJ sustainable operational energy and power limits. The red line is the maximum performance; the green line is the recommended setting in order to limit damage on optics.

V.6- Pulse Shaping Capabilities

The LMJ source (master oscillator) is designed to deliver complex ignition pulse. As a consequence, a wide variety of pulse shapes can be produced on LMJ, with a minimum duration of 0.7 ns and a maximum duration of 25 ns. Complex pulse shapes (rising pulse, decreasing pulse, multiple pulse, with pedestal, etc.) can be fashioned, but will required some test laser shots for a fine tuning [47]. Some examples of pulse shapes are given in figure V.10 and V.11.

The LMJ beams will be synchronized at the center of the target chamber within a standard deviation of 60 ps in 2019, and 40 ps later with all the 176 beams.

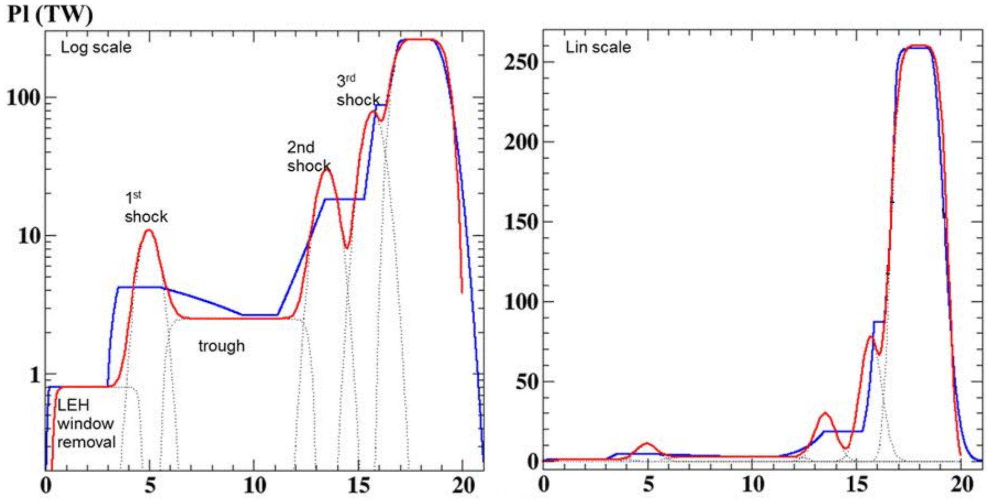


Figure V.10: Different envisioned pulses shapes for ignition target (in red and blue). The dashed black lines are supergaussian used to fit each specific part of the pulse

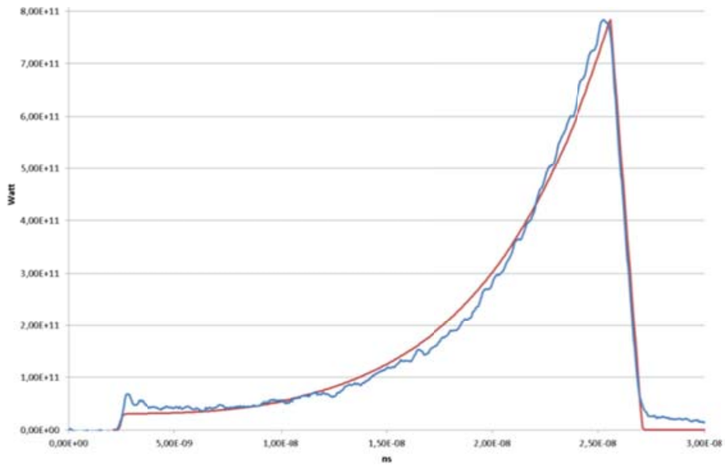


Figure V.11: Typical pulse shape realized on the LIL facility for isentropic compression experiments [37] (request in red)

On LMJ, the Pre-Amplifier Module (PAM) is common for two beams within one quadruplet. However as the two PAMs of a single quadruplet share the same master oscillator (see Figure V.12), only one pulse shape is available per quadruplet. This versatility in pulse shaping will be beneficial for Polar Direct Drive Shock Ignition [48]. Delays between quadruplets could be defined for example to use one quadruplet as the main driver and one quadruplet to irradiate an X-ray backlighter. The maximum available delays are currently limited to 100 ns.

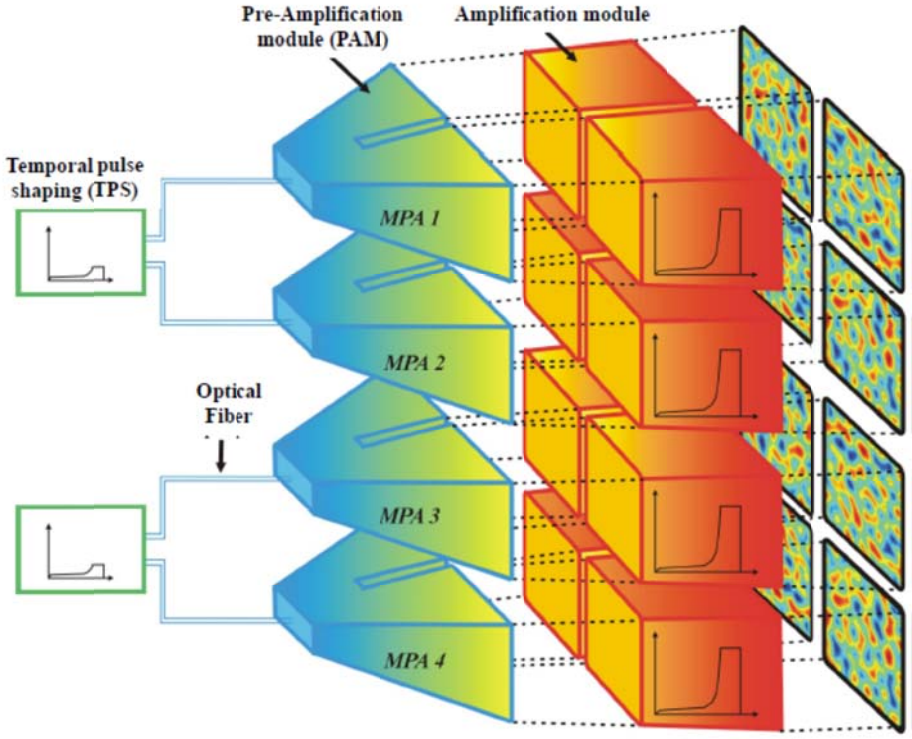


Figure V.12: Schematic of the pulse shaping capability within a LMJ bundle (2 quads, 8 beams)

V.7- LMJ Performance

The first LMJ experiments were carried out in October 2014, with the 8 initial beams (quads 28U and 28L). Until the end of 2016, 240 laser shots have been performed, and among them 90 were dedicated to plasma experiments. All revealed good performance of the whole system.

The mean pointing accuracy of the quads was 52 µm, and the beams synchronization was less than 50 ps for 84 % of the shots. The figure V.13 shows the history of energy and power delivered per quad on target. 87 % of the shots delivered the required energy with less than7 % discrepancy.

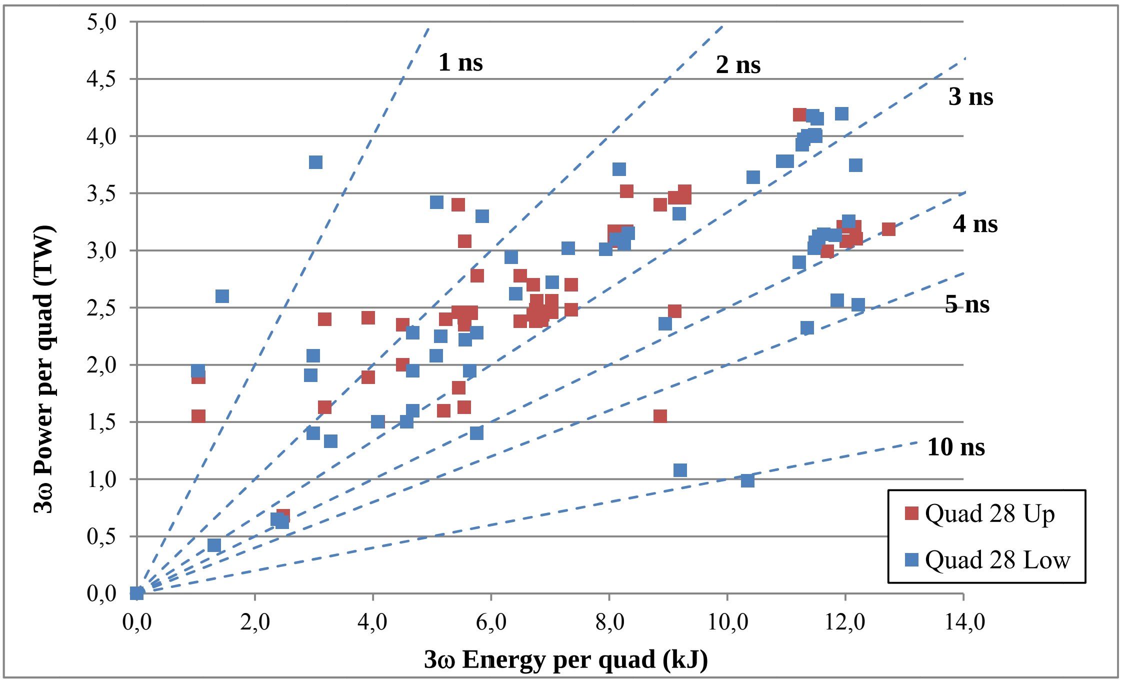


Figure V.13: Delivered pulse energy and power per quad on target.

For all the experiments, the achieved pulse shapes present a good reproducibility. The Figure V.14 shows some examples of pulse shape (radiography and heating pulse).

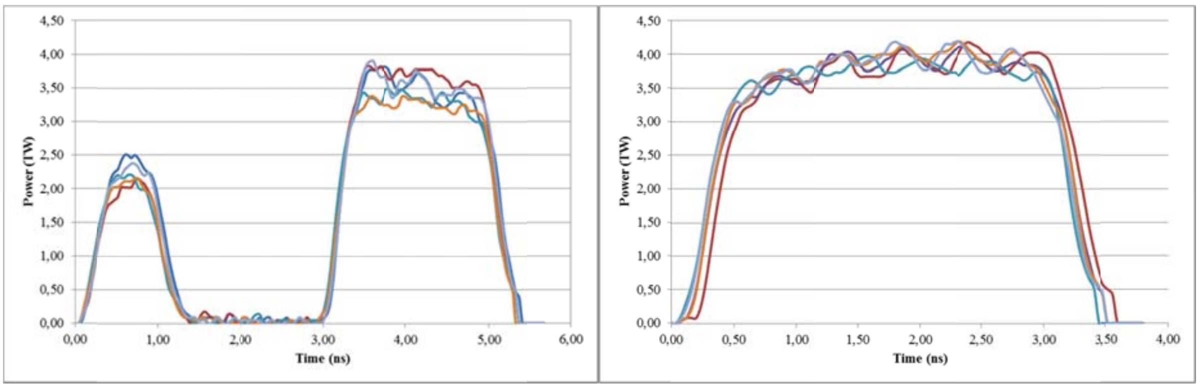


Figure V.14: Pulse shapes of physics campaign on LMJ
(Left: radiography pulse, Right: heating pulse)

VI- PETAL

VI.1- Laser System

The PETAL design is based on the Chirped Pulse Amplification (CPA) technique combined with Optical Parametric Amplification (OPA) [49-52]. Moreover, it takes the benefits of the laser developments made for the high-energy LMJ facility allowing it to reach the kilojoules level.

Figure VI.1 shows the implementation of PETAL in the LMJ facility. The PETAL beamline occupies the place of a LMJ bundle in the South-East laser bay. The compressor stages are situated at the bottom level of the target bay, and after a transport under vacuum, the beam is focused in the equatorial plane of the LMJ chamber via an off-axis parabolic mirror.

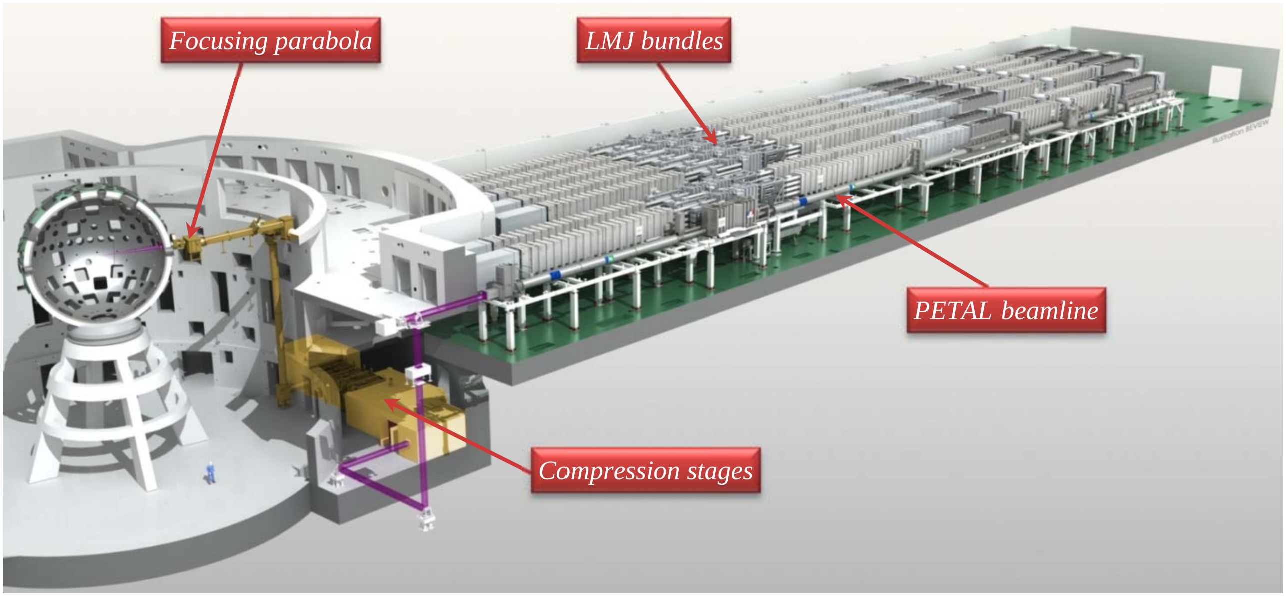


Fig. VI.1: Implementation of PETAL in the LMJ facility.
The PETAL beam is focused in the equatorial plane of the target chamber

The front end consists in a standard Ti:sapphire mode locked oscillator delivering 3 nJ /100 fs / 16 nm pulse at 77.76 MHz and 1053 nm wavelength. The pulse is stretched to 9 ns in an Öffner stretcher in eight passes. Then the pulse is sent to the Pre-Amplifier Module (PAM) including OPA stages and pump laser. The OPA scheme consists of two cascaded LBO crystals and a BBO crystal. A 150 mJ amplified signal pulse with a shot-to-shot stability of less than 2 % has been demonstrated on the LIL facility [50, 51].

The PETAL amplifier section has the same architecture as the LIL/LMJ amplifier section using a single 37 × 35.6 cm^2 beam. It is a four-pass-system with angular multiplexing and a Reverser. It uses 16 amplifier laser slabs arranged in two sets and delivering up to 6 kJ. At this stage, due to gain narrowing, the bandwidth is reduced to 3 nm and duration to 1.7 ns. The main differences with the LIL/LMJ power chain are the wavefront and chromatism corrections [52].

The compression scheme is a two-stage system (see Figure VI.2). The first compressor, in air atmosphere, reduces the pulse duration from 1.7 ns to 350 ps in an equivalent double pass configuration. The output mirror is segmented in order to divide the initial beam into 4 sub-apertures which are independently compressed and synchronized into the second compressor in a single pass configuration under vacuum [54]. These sub-apertures are coherently added using the segmented mirror with three interferometric displacements for each sub-aperture. The pulse duration is adjustable from 0.5 to 10 ps.

The focusing system consists in an off-axis parabolic mirror with a 90° deviation angle, followed by a pointing mirror (see Figure VI.3). The focal length is 7.8 meters, and the focal spot goal is a 50 µm diameter, this will result in intensities above 10^{20} W/cm^2 on target. The polarization of the PETAL beam on target is linear vertical. Due to the 4 sub-apertures of the beam [55], a multi-beam option could be available: a segmented pointing mirror could redirect the beams towards up to 4 separate focuses. This option will be studied in detail if required.

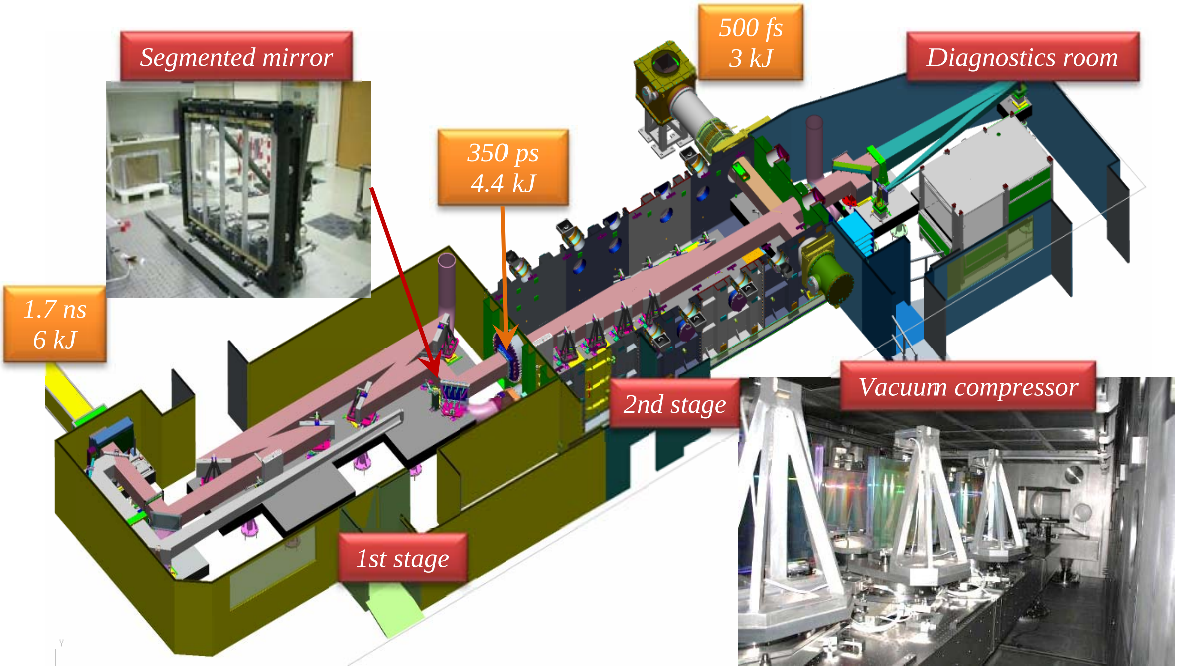


Figure VI.2: Compressor stages with a subaperture compression scheme: first stage in air and second stage in vacuum with 4 independent compressors

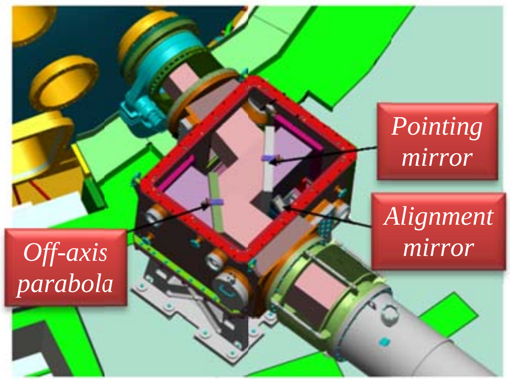


Figure VI.3: PETAL beam and LMJ bundles in the South-East laser bay, and PETAL focusing scheme

The PETAL performance depends on the damage threshold of optics. Great efforts have been made on gratings in order to improve their strength. The effect of electric field on damages has been demonstrated [56], and the groove profile of PETAL multilayer dielectric gratings has been optimized in order to obtain a damage threshold above 4 J/cm² in the ps range. But in fact, the transport mirrors may not sustain more than 2 J/cm² compared to the 4 J/cm² specified value required for a 3 kJ output level. **Therefore, the current mirrors will first limit the available energy on target at a ~1 kJ level**. New technologies are required to increase this value and the intensity on target. Several ways of improvement are identified and are being explored.

VI.2- PETAL Performance

The commissioning of PETAL with broadband spectrum pulses began in 2015. The amplification at 1.4 kJ energy of a stretched pulse (2 ns, 3.5 nm) in the amplification section was validated.

The Petawatt capacity was demonstrated with several shots in 2015 with the diagnostics located just after the compressor. Several shots at 1.05 kJ energy and 1ps duration were obtained, and on May 29th 2015, PETAL delivered 846 J in 0.7 ps corresponding to a peak power of 1.2 PW. PETAL became the most powerful laser beam in the world, in the high energy lasers category.

Next step aimed at transporting and focusing the PETAL beam into LMJ target chamber. Five PETAL laser shots were carried out in the target chamber on a calorimeter and achieved 635 J at 0.7 ps (0.9 PW) on December 2015. In parallel, the first associated LMJ and PETAL laser shot in the LMJ target chamber was performed.

In 2016, the next steps of the laser commissioning concerned a more comprehensive characterization of the laser performances. Thanks to the activation of spectral phase measurements, the pulse duration was improved till 570 fs (with a 220 J energy shot) which corresponds to a potential power of 1.85 PW for a full energy shot. The temporal contrast was also characterized ; on a long time scale (10 ns) the energy contrast (ratio between ps-pulse energy and pedestal energy) is 10^{-3}, measured by a silicon integrator, and on a short time scale (250 ps) the power contrast is around 10^{-6}, measured with a single shot 3rd order cross-correlator.

In 2017 the focal spot will be characterized, and an upgrade of the beam spatial profile, in order to increase the energy on target, will be implemented.

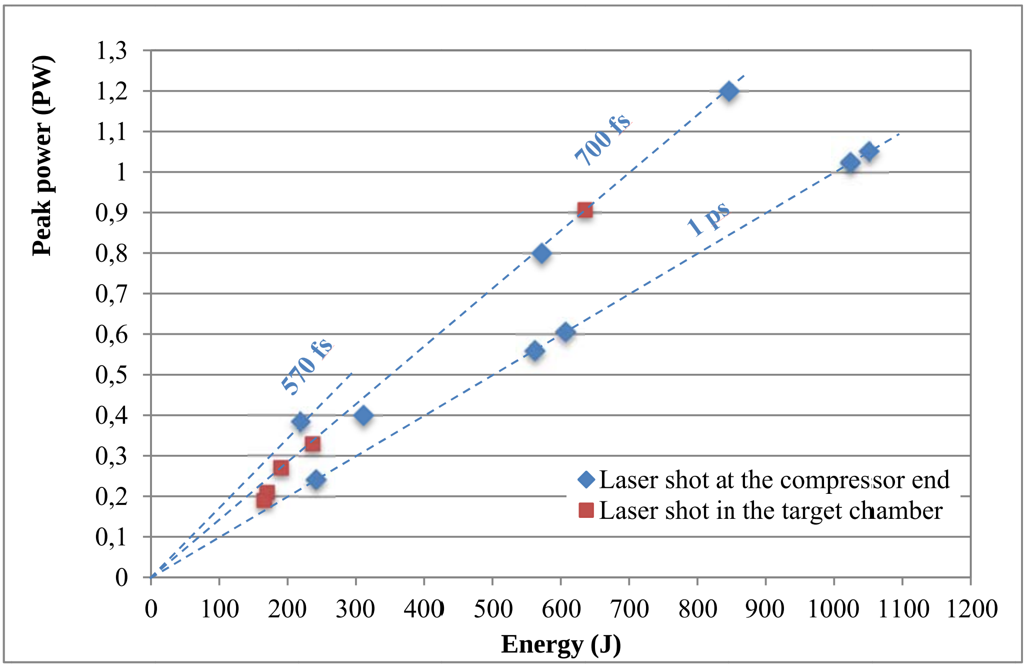


Figure VI-4: Main PETAL laser shots.

VII- Target Area and Associated Equipment

As shown previously in Figure IV.1, the target bay area occupies the central part of the building. There are 8 floors. A detailed CAD of the target chamber with the major target bay equipment is shown in Figure VII.1.

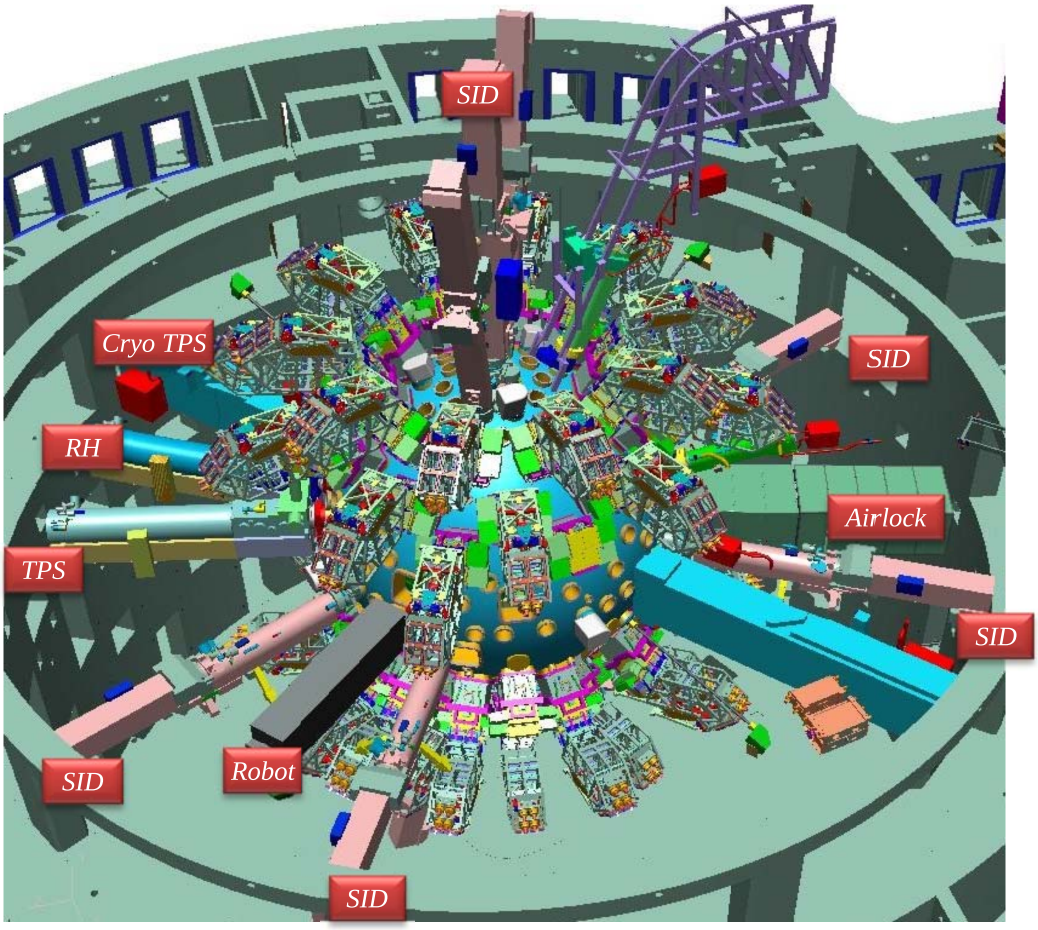


Figure VII.1: CAD of the final stage of target area

The radius of LMJ target chamber is 5 meters. Beam and diagnostic ports cover the full surface. Most part of the plasma diagnostics are positioned inside the target chamber with the help of a manipulator called SID (System for Insertion of Diagnostics). A SID is a two-stage telescoping system that provides a precise positioning of a diagnostic close to the center of target chamber. It positions 150-kg diagnostic with a 50-µm precision. SIDs are provided on several different port locations. Two kinds of SIDs are available: the LMJ SIDs are designed for ignition experiments, they provide the best positioning accuracy for imaging system, can be positioned on polar axis, and use only electronic detectors; the PETAL SIDs are dedicated to PETAL diagnostics which use passive detectors due to electromagnetic perturbations induced by PETAL shots, and cannot be positioned on polar axis. Nevertheless, PETAL SIDs are compatible with LMJ diagnostics and can be used also with electronic detectors. About 10 SIDs are envisioned for the LMJ.

Diagnostics are inserted in the SID with the help of a diagnostic transfer box (BTDP, see figure VII.5.b). This box is used to transfer diagnostics from and to the maintenance laboratory. All heavy devices connected to the target chamber (Diagnostics, SID, BTDP, TPS, etc.) are moved with the help of a dedicated means of transportation named intervention vehicle (see figure VII.5b).

The port locations of the target chamber equipment (Reference Holder (RH), Target Positioning System (TPS) and cryogenic TPS, SOPAC viewing stations) and the possible port locations for the different SID are listed in the Table VII.1. Three Specific Mechanisms ports are also available, 2 of them (MS8 and MS9) being reserved for DMX Broadband time-resolved spectrometer.

The diagnostics manipulators locations are schematically drawn in Figure VII.3. Additional target chamber ports for fixed diagnostics exist and may be considered for future diagnostics developments.

Port	θ	φ	Remark
Target chamber equipment			
RH	90°	238.5°	Reference holder
TPS	90°	255.5°	Target Positioning System
Cryo TPS	90°	220.5°	Cryogenic TPS, unavailable
SOPAC	16°	9°	Target viewing station
SOPAC	24°	243°	Target viewing and lighting station
SOPAC	90°	13.5°	Target viewing station
SOPAC	90°	103.5°	Target viewing station
SOPAC	90°	193.5°	Target viewing station
SOPAC	90°	283.5°	Target viewing station
SOPAC	164°	9°	Target viewing and lighting station
SOPAC	164°	189°	Target viewing station
Diagnostics manipulators			
S1	16°	333°	Close to polar axis, dedicated to UPXI diagnostic
S2	164°	279°	Close to polar axis, dedicated to LPXI diagnostic
S3	16°	153°	Close to polar axis, unavailable
S5	90°	112.5°	Unavailable
S7	164°	99°	Close to polar axis, laser injection and collection for EOS Pack
S12	90°	148.5°	
S16	90°	58.5°	
S17	0°	0°	Polar axis
S20	90°	292.5°	Optical system of EOS pack
S22	90°	328.5°	SPECTIX diagnostic, Opposite S12
S26	90°	180°	SEPAGE diagnostic
Specific mechanisms			
MS 8	24°	99°	DMX position 1
MS 9	70°	72°	DMX position 2
MS 18	90°	222°	Activation diagnostic, unavailable
SESAME 1	90°	166.5°	SESAME diagnostic position 1
SESAME 2	90°	121.5°	SESAME diagnostic position 2

Table VII.1: Spherical coordinate of target chamber equipment and diagnostics manipulators. The unavailable locations for experiments in 2019 are indicated

Figure VII.2 : Reference holder and Target positioning system

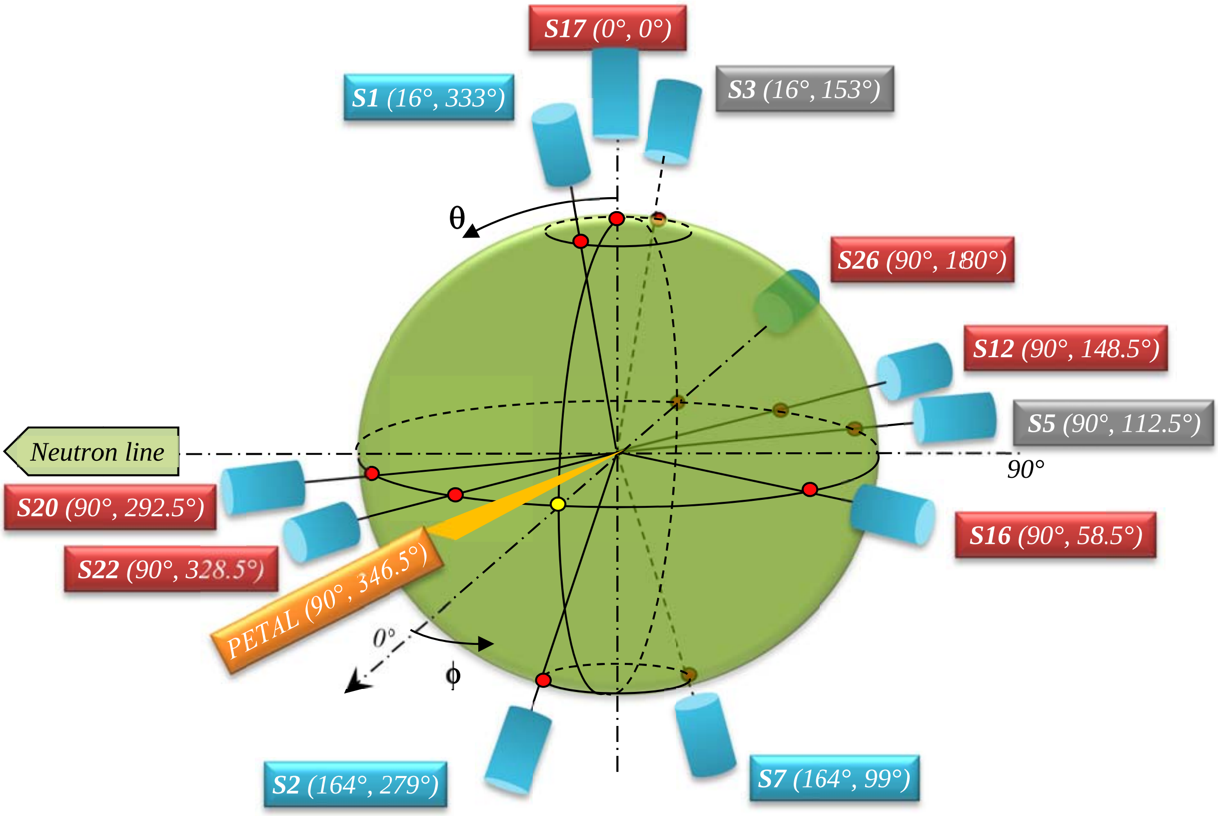
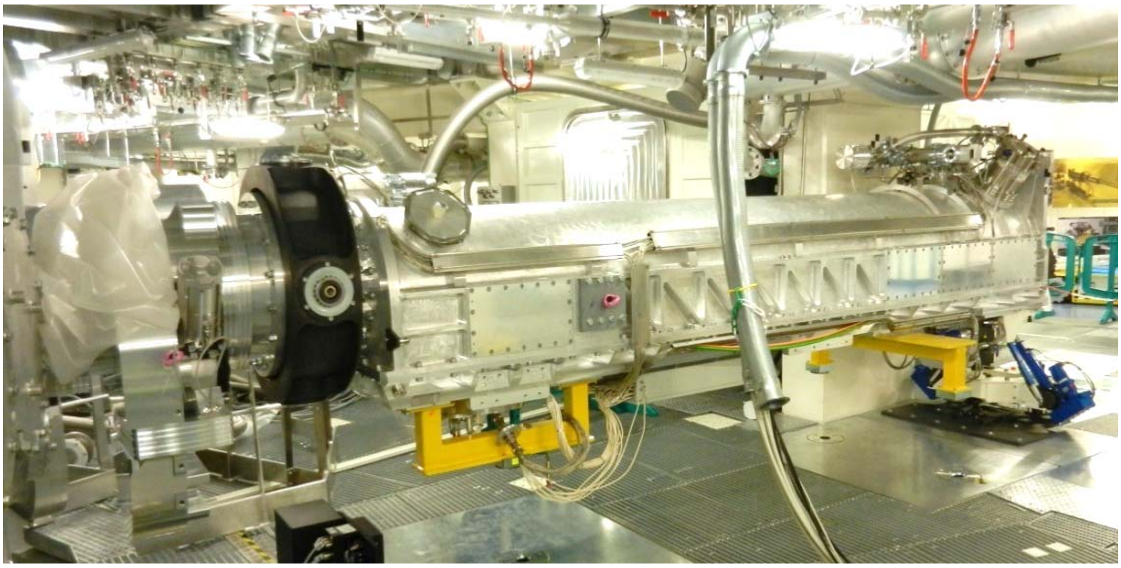
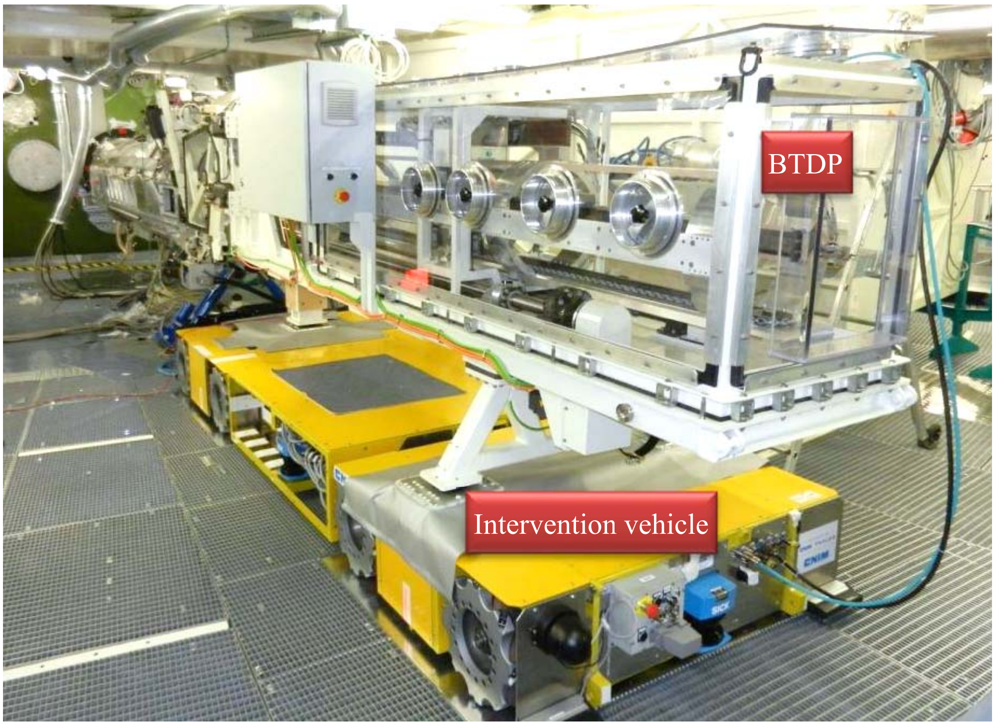


Figure VII.3:3D view of the SIDs location on the target chamber. S3 and S5 are unavailable in 2019.
S1 and S2 are dedicated to Polar X-ray imagers,
S7 is dedicated to laser injection and collection for EOS Pack

Figure VII.4: View of the upper part of the target bay


(a)



(b)

Figure VII.5: Photographs of first LMJ SID (a)
and Diagnostic transfer box (BTDP) on intervention vehicle connected to the SID (b)

VIII- LMJ Diagnostics

Over 30 diagnostics are considered on LMJ with high spatial, temporal and spectral resolution in the optical, X-ray, and nuclear domains. Development plan for LMJ diagnostics began with LIL laser facility and rely on decades of expertise in the design, fabrication and commissioning of advanced plasma diagnostics. The OMEGA laser facility has also been used and will continue to be the test bed for the development of CEA nuclear diagnostics. The early diagnostics, designed using the feedback of LIL's diagnostics, consist of:

• seven hard and soft X-ray imaging systems (30 eV to 15 keV range) with a 15 to 150 µm spatial resolution and a 30 to 120 ps time resolution, providing over 40 imaging channels,

• a diagnostic set for hohlraum temperature measurements including an absolutely calibrated broadband X-ray spectrometer (30 eV - 20 keV), a grating spectrometer, an imaging system of the emitting area,

• an absolutely calibrated broadband X-ray spectrometer (30 eV - 7 keV),

• a time resolved high resolution X-ray spectrometer (1 - 15 keV) coupled to a framing camera,

• a time integrated hard X-ray spectrometer (6 - 100 keV),

• an optical diagnostic set dedicated to EOS measurements including 2 VISAR (Velocity Interferometer System for Any Reflector), 2 SBO (Shock Break Out), a pyrometer and a reflectivity measurement,

• a Full Aperture Backscatter System, and a Near Backscatter Imager to measure the power, spectrum, and angular distribution of backscattered light to determine the laser energy balance,

• two electron spectrometers (5 - 150 MeV),

• a charged particles spectrometer for electrons (0.1 - 150 MeV) and ions (0.1 - 200 MeV) including an imaging module for proton radiography,

• a neutron pack, to measure neutron yield, ion temperature and neutron bang time.

Companion Table-top laser facilities [57] or X-ray sources [58] are used to perform metrology of the X-ray diagnostics before any plasma experiment.

Diagnostics development takes into account the harsh environment [28, 59] which will be encountered on LMJ, as well as the electromagnetic perturbations induced by PETAL [60].

VIII.1- X-ray Imagers

The development of grazing-incidence X-ray microscopes is one of the skills of CEA diagnostics development laboratory. On LMJ, debris [61] and X-ray production [28] impose to place any imager as far away from the source as possible, which would degrade the spatial resolution. Grazing incidence X-ray microscopes allow overpassing this limitation. Compared to standard pinhole imagers, they offer also the best solution in terms of resolution versus signal to noise ratio. The design of LMJ X-ray imagers benefits from years of expertise either on OMEGA [62] or LIL X-ray imagers [63, 64].

Four of these imagers, either gated (GXI-1 and GXI-2) or streaked (SHXI and SSXI), share a common mechanical structure (see Figure VIII.1) with the X-ray optical assembly itself, a telescopic extension and the optical analyzer (X-ray framing camera or streak camera) working inside an air box mechanical structure (see Figure VIII.2) [65].

Two others (UPXI and LPXI) are dedicated to the observation of the LEHs from the upper and lower poles of the chamber. A last one (ERHXI) offers an enhanced spatial resolution with the help of channels including two toroidal mirrors.

The main characteristics of the first seven X-ray Imagers are described in Table VIII.1.

X-ray Imagers				
Diagnostics & Setting	*Characteristics*	*Spectral range*	*Spatial resol. (µm) / Field of view (mm)*	*Time resol. (ps) / Dynamic (ns)*
GXI-1 *Gated X-ray Imager (high resolution)* *SID*	*Magnification = 4.3*			
	2x4 time-resolved toroidal mirror channels	*0.5 - 10 keV*	*35 / 3*	*110 - 130 / 20*
	4 pinhole channels	*2 - 15 keV*	*40 / 3*	*110 - 130 / 20*
	1 time-integrated mirror channel	*0.5 - 10 keV*	*50 / 5*	*without*
GXI-2 *Gated X-ray Imager (medium resolution)* *SID*	*Magnification = 0.9*			
	2x4 time-resolved toroidal mirror channels	*0.5 - 10 keV*	*150 / 15*	*110 - 130 / 20*
	4 X-ray refractive lenses channels	*6 - 15 keV*	*150 / 15*	*110 - 130 / 20*
	1 time-integrated mirror channel	*0.5 - 10 keV*	*140 / 20*	*without*
SHXI *Streaked Hard X-ray Imager (medium resol.)* *SID*	*Magnification = 1 or 3*			
	1 time-resolved toroidal mirror channels	*0.5 - 10 keV*	*150 / 15 or 50 / 5*	*17 / 2 to 120 / 25*
	1 time-integrated mirror channel	*5 - 10 keV*	*130 / 20 or 50 / 6.5*	*without*
SSXI *Streaked Soft X-ray Imager (high resolution)* *SID*	*Magnification = 3*			
	1 time-resolved bi-toroidal mirror channel	*0.1 - 0.8 keV*	*30 / 5*	*17 / 2 to 120 / 25*
	1 time-integrated bi-toroidal mirror channel	*0.05 - 1.5 keV*	*30 / 5*	*without*
	Spectral selection by grating			
UPXI *Upper Pole X-ray Imager* ***LPXI*** *Lower Pole X-ray Imager* *Specific mechanics*	*1 pinhole channel*	*> 3 keV*		
	Passive detector Magnif. = 2 to 5 – *CID detector*		*80 / 12 to 65 / 5*	*without*
	Passive detector Magnif. = 2 to 5 – *Image Plate*		*80 / 50 to 65 / 25*	*without*
	Optional camera Magnif. = 6 – *Streak camera*		*65 / 2*	*17/2 to 120 / 25*
	Optional camera Magnif. = 6 – *Framing camera*		*65 / 2*	*110 - 130 / 20*
ERHXI *Enhanced Resolution Hard X-ray Imager* *SID*	*Magnification = 8*			
	8 time-resolved bi-toroidal mirror channels	*0.5 - 13 keV*	*In 2019: 10 / 1.5* *In 2020: 5 / 0.6*	*110 - 130 / 20* *In 2020: 50 / 20*

Table VIII.1: LMJ X-ray Imagers acronyms and their main characteristics

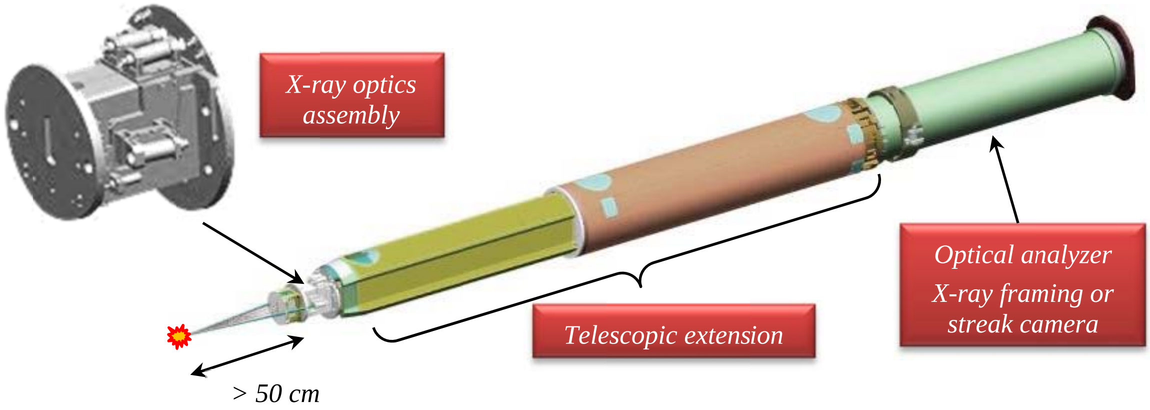


Figure VIII.1: Common mechanical structure of some LMJ X-ray imagers

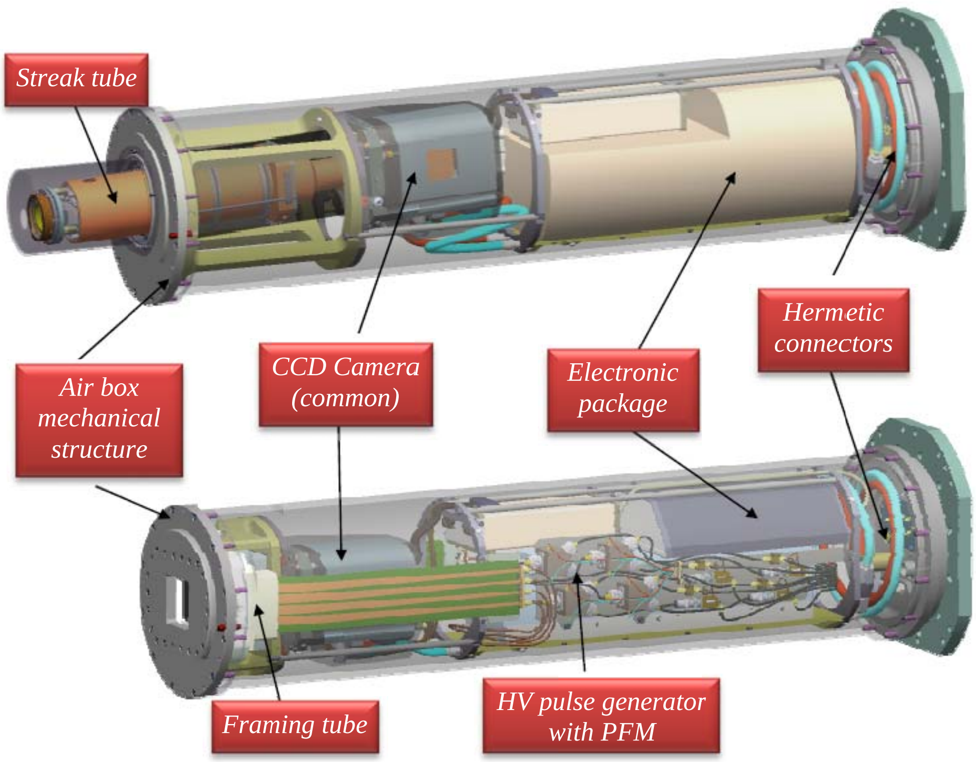


Figure VIII.2: Current design of LMJ optical analyzers [65]

VIII.1.1 - GXI-1, Gated X-ray Imager (high resolution)

The first LMJ X-ray imager GXI-1 records time-resolved 2D image in the hard X-ray spectral region. It is dedicated to X-ray radiography of target motion and to hard X-ray target emission [53].

The GXI-1 incorporates a microscope with large source-to-optic distance (61 cm) and a large size gated micro channel plate detector.The microscope includes twelve X-ray channels: eight consisting of grazing angle-of-incidence mirrors [66-69] and a filter, and four straight-through channels consisting of pinholes with a filter. Each image of the twelve X-ray channels is produced along four micro channel striplines (ARGOS detector) [80].

GXI-1 also includes a three-film protective holder to protect optical components from damages caused by target debris and UV radiation. A filter holder is dedicated to select a broad band energy range on each column of four images on the detector. A CID camera, implemented close to the main detector, monitors X-ray emission with time integration and also controls internal alignment of the diagnostic. A photoconductive detector with a fast time response is mounted close to the framing camera to provide a fiducial.

GXI-1 is set up in the target chamber by a SID (System for Insertion of Diagnostics, see VII. Target area and associated equipment).

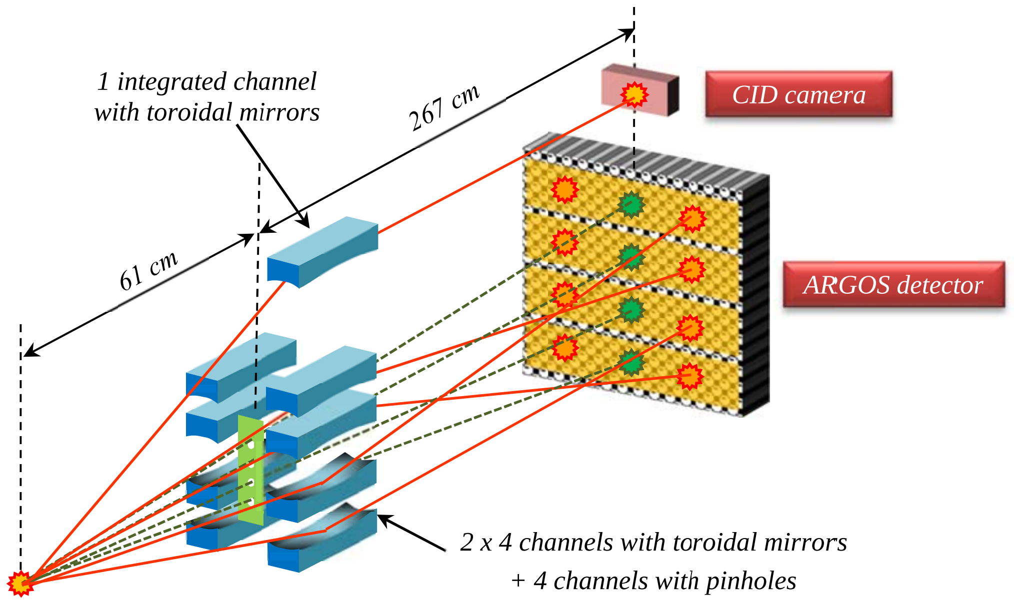


Figure VIII.3: Details of the acquisition channels of GXI-1.

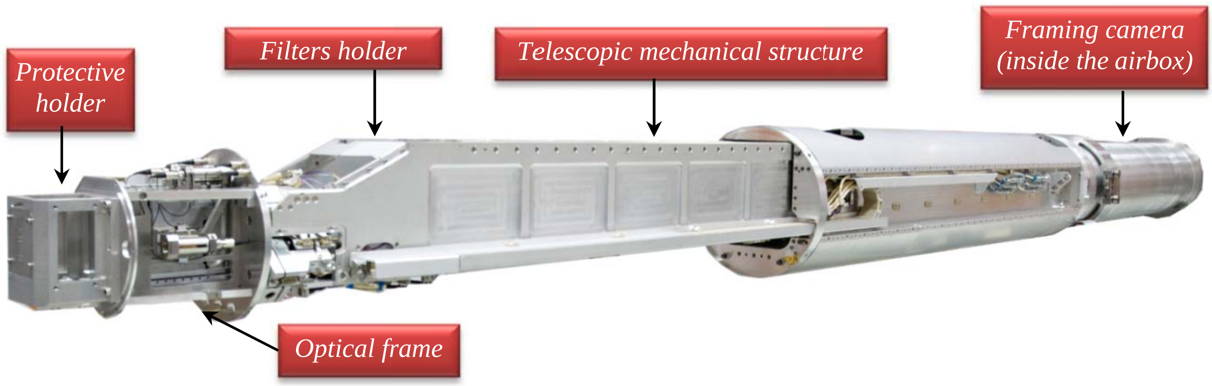


Figure VIII.4: Photograph of GXI-1.

VIII.1.2 - GXI-2, Gated X-ray Imager (medium resolution)

The second X-ray imager, GXI-2, records time-resolved 2D image in the hard X-ray spectral region, on a large field of view. It is mainly dedicated to the control of laser beams pointing [53].

The GXI-2 incorporates a microscope with a very large source-to-optic distance (303 cm) and a large size gated micro channel plate detector. Like GXI-1, the microscope includes twelve X-ray channels: eight consisting of grazing angle-of-incidence mirrors and a filter, and four straight-through channels consisting of refractive lenses with a filter. Each image of the twelve X-ray channels is produced along four micro channel striplines (ARGOS detector) [80].

GXI-2 also includes a three-film protective holder to protect optical components from damages caused by target debris and UV radiation. A filter holder is dedicated to select a broad band energy range on each column of four images on the detector. A CID camera, implemented close to the main detector, monitors X-ray emission with time integration and also controls internal alignment of the diagnostic. A photoconductive detector with a fast time response is mounted close to the framing camera to provide a fiducial.

GXI-2 is set up in the target chamber by a SID (see VII. Target area and associated equipment).

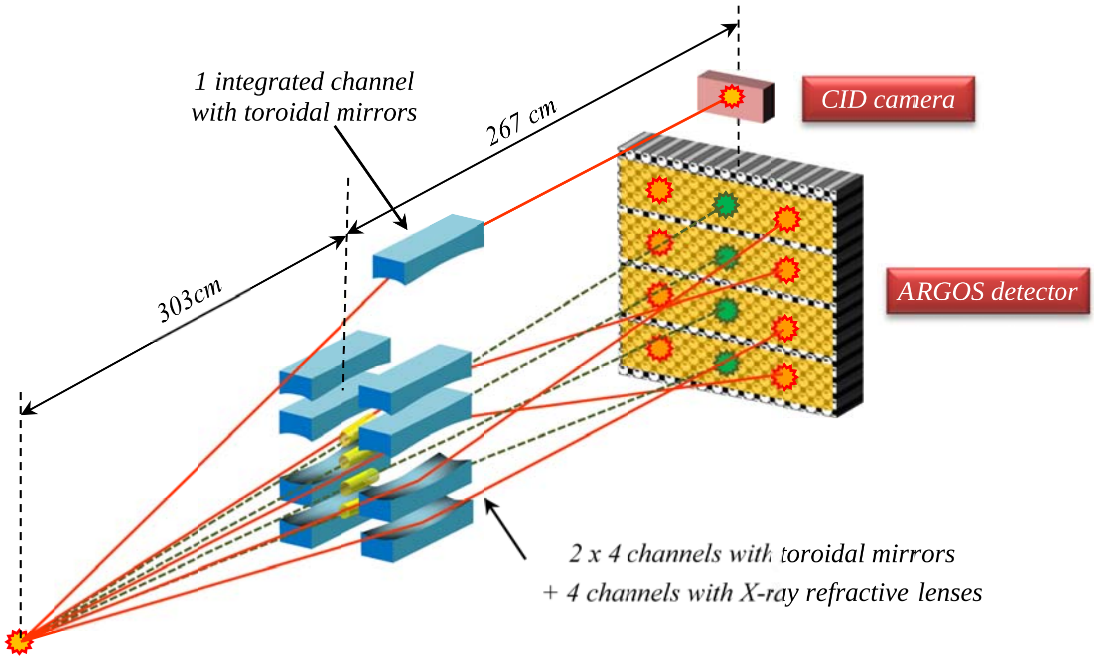


Figure VIII.5: Details of the acquisition channels of GXI-2.

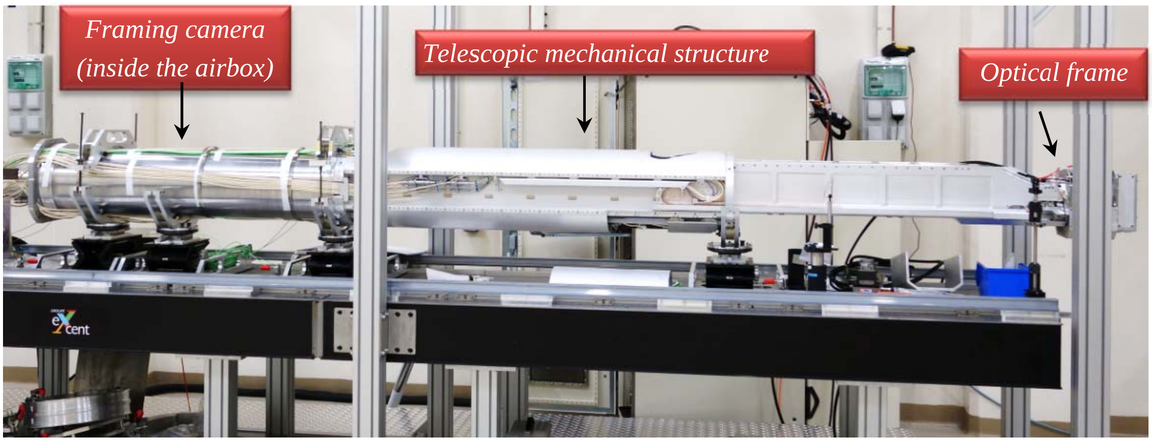


Figure VIII.6: GXI-2 during qualification test.

VIII.1.3 - SHXI, Streaked Hard X-ray Imager (medium resolution)

The streaked X-ray imager, SHXI, records time-resolved 1D image in the hard X-ray spectral region. It is dedicated to X-ray radiography of target motion and to hard X-ray target emission.

The SHXI has two X-ray channels per magnification, all of them consisting of grazing angle-of-incidence toroidal mirrors and a filter. One image of the two X-ray channels is produced on the streak camera while the other image is formed on a time integrated detector (CID).

As GXI-1 and GXI-2, a protective holder contains three films to protect optical components from damages caused by target debris and UV radiation.

SHXI is set up in the target chamber by a SID (see VII. Target area and associated equipment).

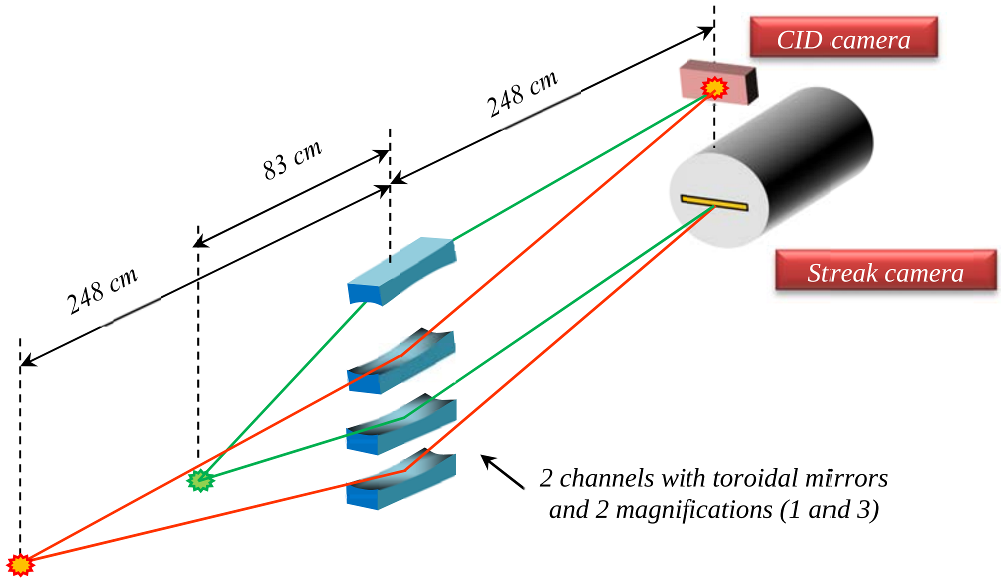


Figure VIII.7: Details of the acquisition channels of SHXI.

VIII.1.4 – SSXI, Streaked Soft X-ray Imager (high resolution)

The streaked soft X-ray imager, SSXI, records time-resolved 1D image or time/space-resolved spectra in the soft X-ray spectral region. It is dedicated to analysis of radiative waves (propagation, burn-through, etc.) and soft X-ray target emission.

It consists of the association of an optics assembly and a spectral selection device. As no filter can be used due to soft X-ray bandwidth, the optical scheme of the diagnostic is entirely based on grazing incidence optics. The optics assembly is composed of a blast shield which is a large flat mirror, with grazing incidence, that can be shifted shot after shot, and an X-ray microscope with two channels made of two toroidal mirrors for improving spatial resolution.

The spectral selection is provided by two low-pass mirrors combined with a reflective flat field grating. Depending on the orientation of the streak camera on the central channel, 1 temporally and spectrally resolved X-ray image or 1 temporally and spatially resolved X-ray spectra will be acquired, together with 1 time integrated image (for the second channel).

SSXI is set up in the target chamber by a SID (see VII. Target area and associated equipment).

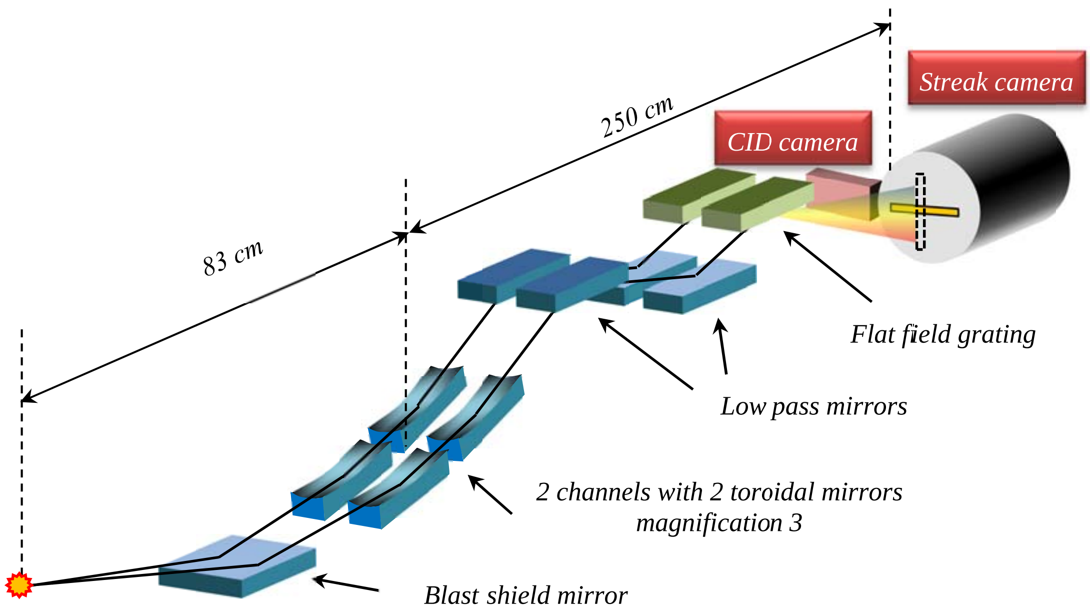


Figure VIII.8: Details of the acquisition channels of SSXI. The streak camera can be rotated in order to commute between a spectrally resolved imager and a spatially resolved spectrometer

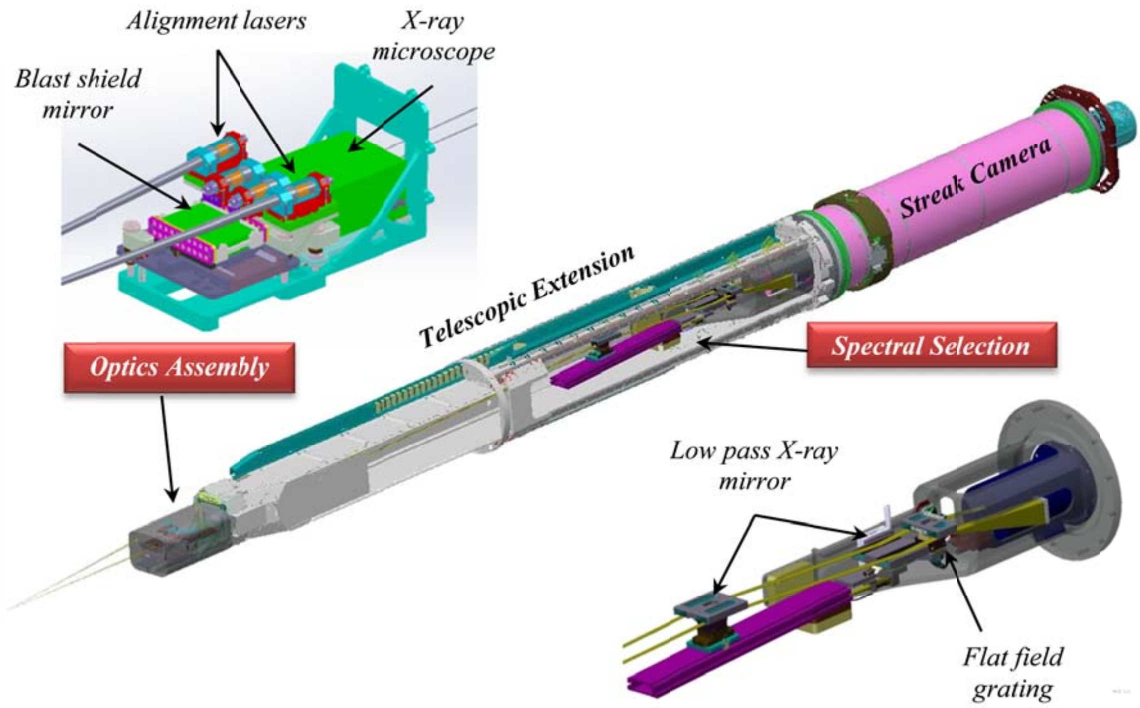


Figure VIII.9: Details of SSXI diagnostic structure

VIII.1.5 - UPXI and LPXI, Upper and Lower Polar X-ray imagers

The UPXI and LPXI diagnostics record time-integrated 2D image, or optionally time-resolved 2D or 1D image, in the hard X-ray spectral region. They are dedicated to precision pointing of LMJ laser beams: position and characterization of the laser spots, verification of main-target and backlighter-target positions, and time-resolved size measurement of the Laser Entrance Holes (LEH).

The image is accomplished with a single 50 µm diameter pinhole laser drilled into a tantalum foil. The maximum target to pinhole distance is 250 cm (minimum is 150 cm) for a magnification of 2 (5 or 6).

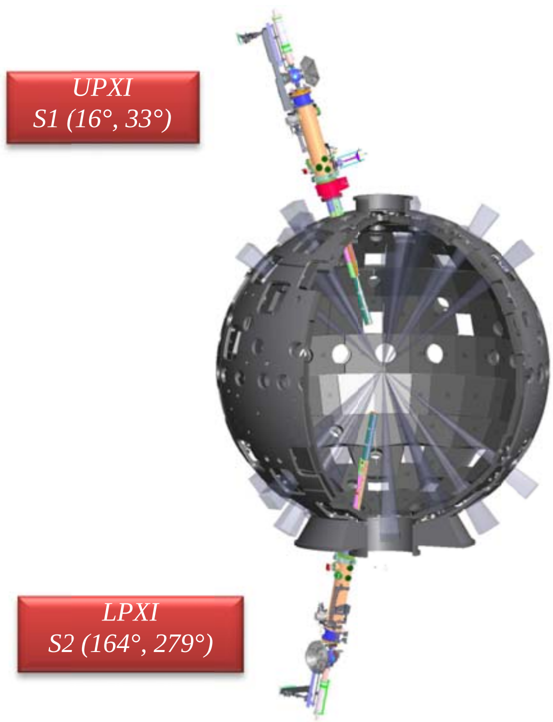


Figure VIII.10: Positions of the UPXI and LPXI diagnostics

These diagnostics are available with time-integrated detectors (CID camera or Image plate (IP) for PETAL experiments) and time-resolved detectors (X-ray streak camera operating with a temporal resolution of 50 ps or ARGOS framing camera).

These diagnostics are set up in the target chamber at fixed place with specific mechanics.

VIII.1.6 – ERHXI, Enhanced Resolution Hard X-ray Imager

The enhanced resolution hard X-ray imager, ERHXI, records time-resolved 2D image in the hard X-ray spectral region with a high spatial resolution. It is dedicated to X-ray radiography or hard X-ray emission of small size target (e.g. compressed ICF target).

It incorporates a microscope with large source-to-optic distance and a large size gated micro channel plate detector. The first version (2019) uses the existing ARGOS optical analyzer and a microscope. The second one (in 2020) will bring an improvement of the spatial and temporal performances ; it differs by minor modifications of the optical block, and a new analyzer with an advanced tube (ARGOS CELER tube type).

The microscope includes eight X-ray channels, each consisting of 0.6° grazing angle-of-incidence bi-toroidal mirrors and a filter. Each image of the eight X-ray channels is produced along four micro channel striplines. The bi-mirrors are mounted in a Wolter-like configuration. They are coated with platinum graded multilayers to have a good reflectivity till 13 keV [81, 82].

This imager also must include a film protective holder to protect optical components from damages caused by target debris and UV radiation.

ERHXI is set up in the target chamber by a SID (see VII. Target area and associated equipment).

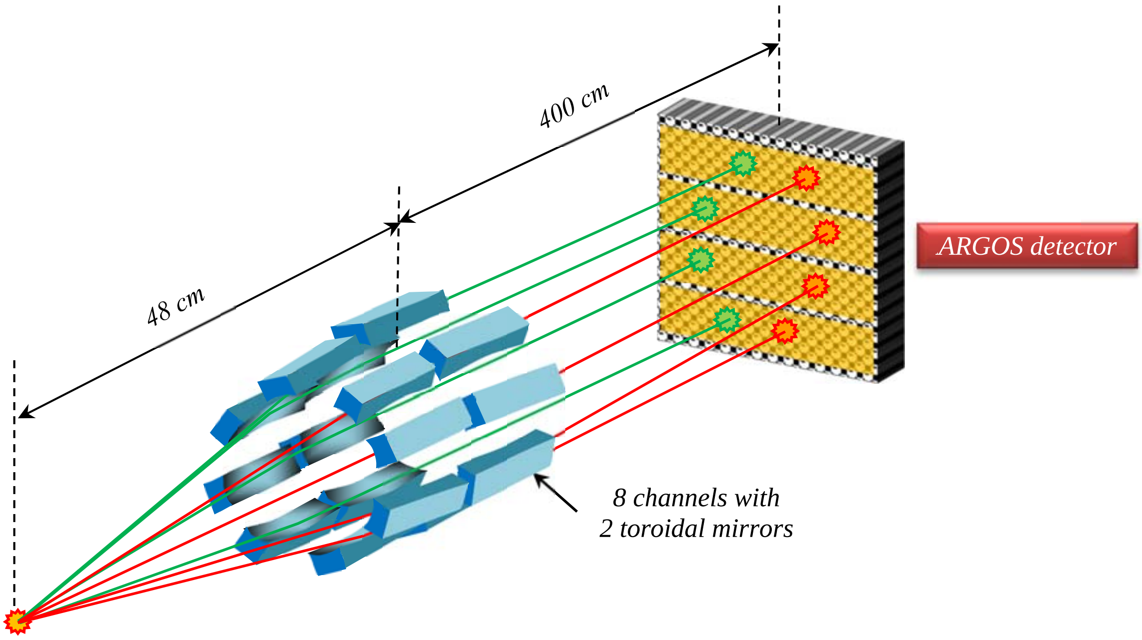


Figure VIII.11: Details of the acquisition channels of ERHXI

VIII.2- X-ray Spectrometers

Four X-ray spectrometers are available on the LMJ; two of them are constituted of 16 or 20 broadband channels, and the other ones use crystals for high spectral resolution.

The main characteristics of the first four X-ray Spectrometers are described in Table VIII.2.

X-ray Spectrometers				
Diagnostics & Setting	*Characteristics*	*Spectral range (resol. E/ΔE)*	*Spatial resol. (µm) / Field of view (mm)*	*Time resol. (ps) / Dynamic (ns)*
DMX *Broad-band X-ray spectrometer* *Specific mechanics*	*20 time-resolved broad-band channels*	*0.03 - 20 keV (5)*	*- / 5*	*150 / 10^5*
	Grating X-ray spectrometer Δλ<1Å	*0.1 - 1.5 keV 1.5 - 4 keV*		*17 / 2 to 120 / 25*
	Laser Entrance Hole Imager	*0.5 - 2 keV*	*100 / 5*	*Time integrated (time resolved in 2018)*
	X-ray Power	*0.1 - 2 keV 2.0 - 4.0 keV 4.0 - 6.0 keV*	*- / 5*	*150 / 10^5*
Mini-DMX *Broad-band X-ray spectrometer* *SID*	*16 time-resolved broad-band channels*	*0.03 - 7 keV (5)*	*- / 5*	*150 / 10^5*
HRXS *High Resolution X-ray Spectrometer* *SID*	*Slit magnification = 3*	*1 - 15 keV (~500)*	*70 (1D) / 5*	
	4 time-resolved crystal channels			*110 – 130 / 20*
	2x3 time-integrated crystal channels (CID)			*without*
SPECTIX *Hard X-ray spectrometer* *SID*	*1 time-integrated channel Transmission crystals*	*7 - 150 keV (>100)*	*without*	*without*

Table VIII.2: LMJ X-ray Spectrometers acronyms and their main characteristics

VIII.2.1 – DMX, Broad-band X-ray Spectrometer

DMX is a primordial diagnostic for hohlraum energetic performance measurements [28]. It is composed of a set of four diagnostics:

- a time resolved soft X-ray large band spectrometer made of 20 measurement channels combining mirror, filters and X-ray diodes,
- a time resolved soft X-ray spectrometer with gratings and streak camera,
- a time integrated soft X-ray laser entrance hole imaging with CID (a time-resolved version will be implemented in 2018),
- a time resolved X-ray power measurement spectrally integrated.

Beside standard soft X-ray measurements devoted to hohlraum energetics, the filtration of the channels could be adapted for specific purpose, such as conversion efficiency characterization of backlighters [70-72]. However, as those measurements may require additional filters metrology on synchrotron beam lines (synchrotron SOLEIL at Saint Aubin), the request should be done well in advance.

Multilayer mirrors with adjusted spectral bandwidth are included for flat-response X-ray channels [73].

DMX is set up in the target chamber at fixed place, with specific mechanics.

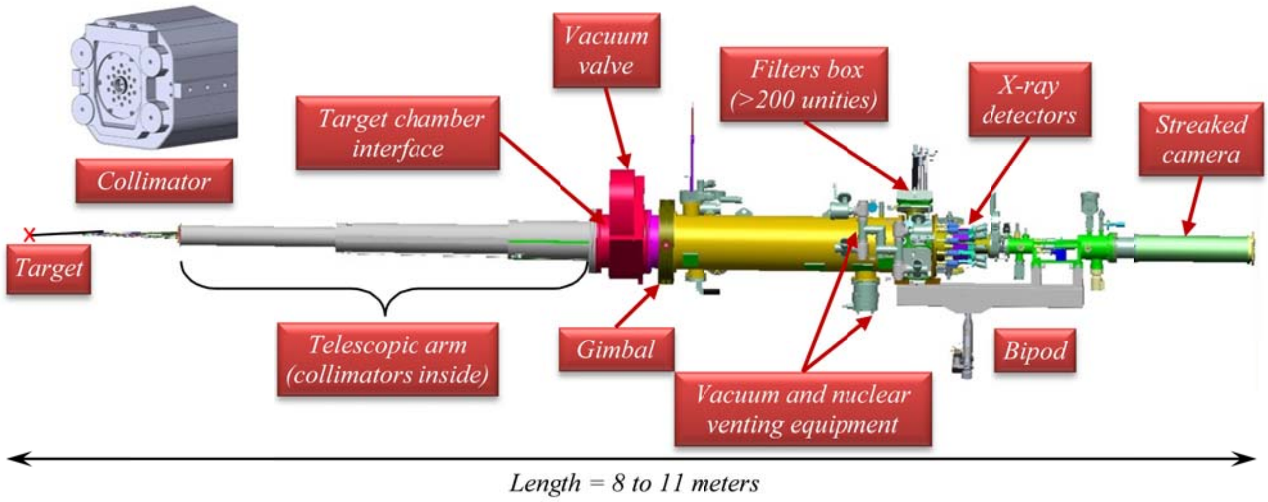


Figure VIII.12: Details of DMX diagnostic structure

Figure VIII.13: DMX implantation on LMJ

VIII.2.2 - Mini-DMX, Broad-band X-ray Spectrometer

Mini-DMX is a second hohlraum energetic performance measurements axis on the LMJ facility.

This diagnostic is composed of 16 broadband channels combining filters, mirrors and coaxial detectors. It is positioned at its working distance (1000 mm or 3500 mm) by a SID (see VII. Target area and associated equipment). This diagnostic, like DMX, is absolutely calibrated.

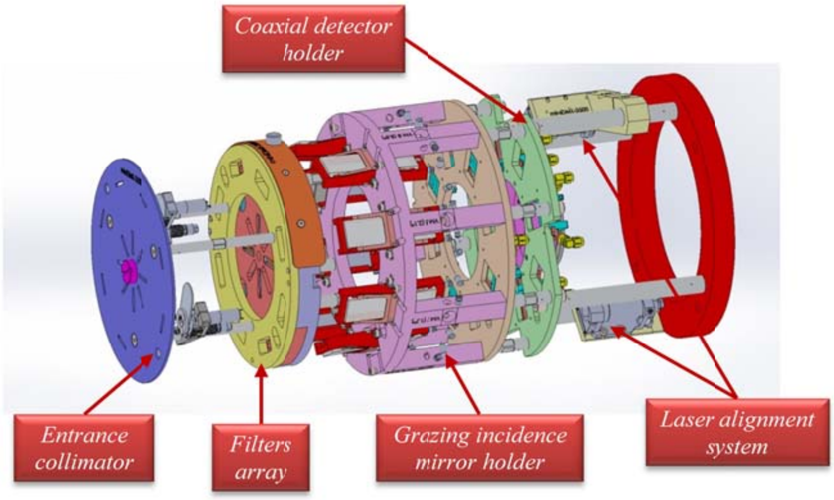


Figure VIII.14: Details of mini-DMX

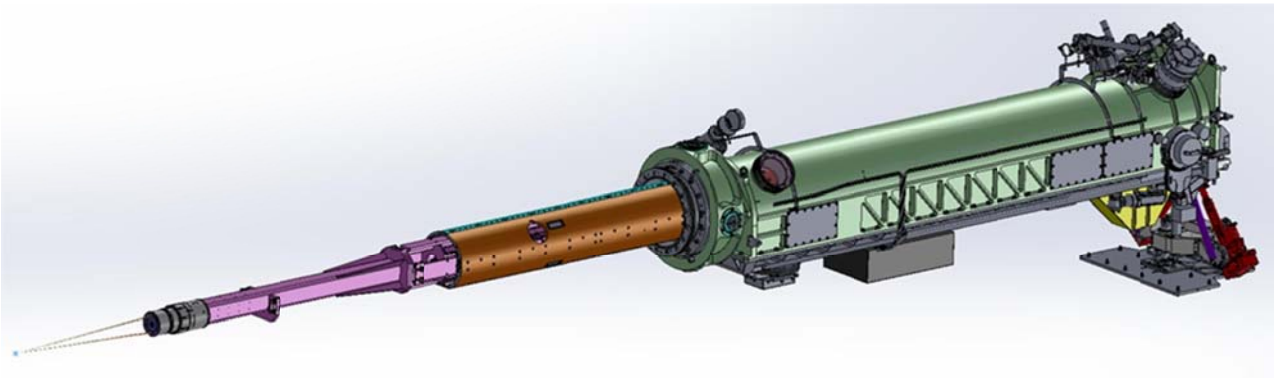


Figure VIII.15: Mini-DMX diagnostic positioned at working distance with SID

VIII.2.3 – HRXS, High Resolution X-ray Spectrometer

The High Resolution X-ray Spectrometer is dedicated to atomic physics (NLTE spectroscopy and opacity measurements). The central body is associated with a CEA framing camera ARGOS (4 channels).

It can be outfitted with one broad cylindrical concave crystal in order to get four frames at 4 different times in one spectral range or with two crystals in order to get 2 frames on each crystal and two different spectral ranges. On each side, there is a lateral spectrometer body with a CID detector and with three cylindrical concave crystals. The front end of the spectrometers includes a snout with collimation slits and a debris shield made of three filter rolls.

Two alignment modules are included in the setup. This diagnostic is inserted by a SID inside the target chamber. Distance of target to front end is 320 mm, distance of target to detectors is about 1400 mm.

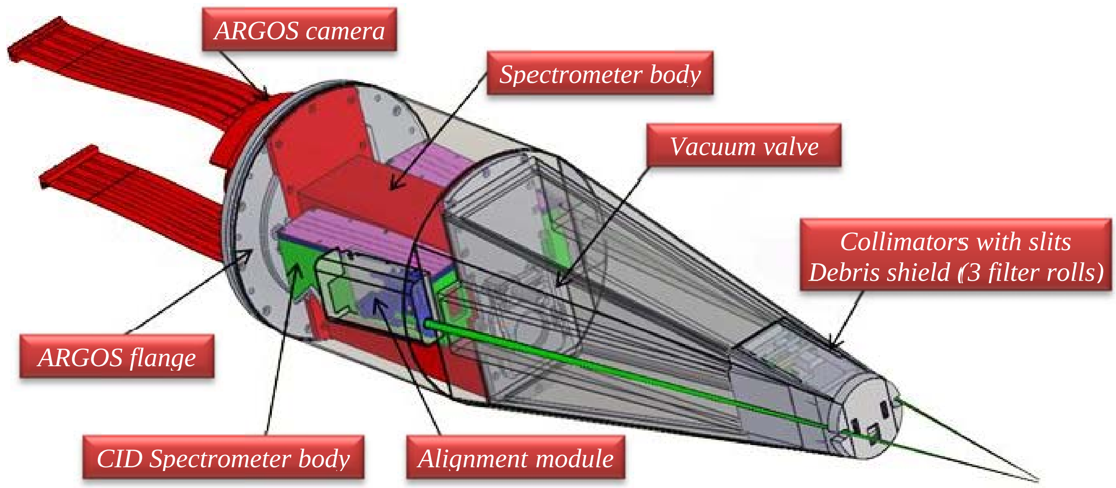


Figure VIII.16: Details of HRXS diagnostic

VIII.2.4 – SPECTIX, Hard X-ray Spectrometer

SPECTIX is a hard X-ray spectrometer dedicated to K-shell spectroscopy of a large number of materials. This diagnostic is developed in the framework of the PETAL+ project [42, 43, 83].

The concept is based on diffraction by transmission cylindrical crystals (Cauchois type) associated to a cross-over absorbing non diffracted x-rays [74, 75]. In this scheme, the diffraction plane is perpendicular to the surface of the crystal and diffracted x-rays are focused at the distance where the cross-over is located. Detection is performed with Image Plates (IP), which are insensitive to electro-magnetic pulses [84, 85].

The wide spectral range 7 – 150 keV is achieved by two different crystals, a quartz crystal (10-10) with a radius of 125 mm for low energies and a LiF crystal (200) with a radius of 250 mm for high energies.

The resolving power of SPECTIX is related to the size of the x-ray source, the distance of the IP to the Rowland circle (distance to crystal = crystal radius) and to the spatial resolution of the IP. The IP can be positioned on the Rowland circle (where spectral resolution is independent on x-ray source size) or farther. A resolving power of ~100 can be achieved on all the spectral range.

Identification of contributors to the background noise and shielding optimization were performed with the help of Monte-Carlo simulations [76]. A part of the noise induced by electrons emitted by the target is suppressed by a set of magnets located at the front end of the collimation. The noise created by hard x-ray photons is limited by the use of Densimeter@ DM176 in the cross-over and in all parts contributing to the frontal collimation.

SPECTIX is set up in the target chamber by a SID (see VII. Target area and associated equipment).

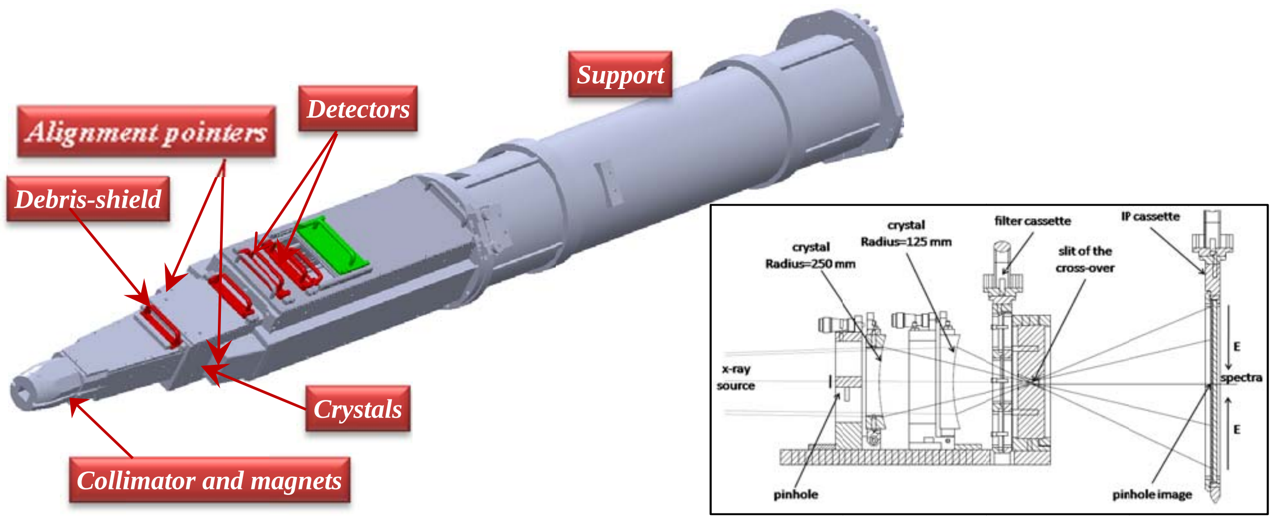


Figure VIII.17: Current design and principle of SPECTIX diagnostic

VIII.3- Optical Diagnostics

The optical diagnostics of the LMJ are composed of a diagnostic set for EOS measurements and two diagnostics for laser energy balance.

The main characteristics of the three optical diagnostics are described in Table VIII.3.

Optical Diagnostics				
Diagnostics & Setting	*Characteristics*	*Measurement or Spectral range (nm)*	*Spatial resol. (µm) / Field of view (mm)*	*Time resol. (ps) / Dynamic (ns)*
EOS Pack *Diagnostics set for EOS experiments* *SID*	*2 VISARs (1064 and 532 nm)*	*Velocity 0.5 - 200 km/s*	*30 / 1 to 50 / 5*	*50 / 5 to 500 / 100*
	Reflectivity	*R > 0.1*		
	2 Shock Break Out (SBO)	*490 - 750*	*30 / 1 to 100 / 10*	*50 / 5 to 500 / 100*
	Pyrometer	*Temperature > 0.1 eV*		
	2 x 2D images	*490 - 750*		*75 - 200 / 5 - 20*
FABS *Full Aperture Backscattering System* *Focusing system quad 28U*	*Brillouin spectrometer Δλ < 0.05 nm*	*346 - 356*	*without*	*25 / 5 to 250 / 50*
	Raman spectrometer Δλ < 5 nm	*375 - 750*		
	Time integrated calibration spectrometer	*350 - 700* *375 - 750*		*without*
	3 Brillouin power channels	*< 360*		*150 / 5 to 50*
	2 Raman power channels	*350 - 750*		
	1,2,3ω power channels	*1053, 526, 351*		*500 / 25*
NBI *Near Backscatter Imager* *Chamber wall quads 28U & 29U*	*2 Brillouin power channels*	*346 - 356*	*without*	*150 / 5 to 150*
	2 Raman power channels	*375 - 750*		
	Brillouin image	*346 - 356*	*Angle : 2°/16°*	
	Raman image	*375 - 750*	*Angle : 2°/16°*	

Table VIII.3: LMJ Optical diagnostics acronyms and their main characteristics

VIII.3.1 - EOS Pack

The development of the EOS Pack takes into account the feedback of the same kind of diagnostic that was in operation on the LIL facility [77]. This diagnostic combines an optical system, positioned close to the target with the help of a SID, an optical transport system and an analysis table.

The use of the EOS Pack requests the S20 location for the insertion of the optical system inside the chamber and the S7 location for laser injection, laser and self-emission collection.

The diagnostic (laser and optical analyzers) will be hardened and protected against EMP inside a Faraday cage. The goal is to be fully operational with PETAL so that simultaneous EOS measurements and side-on shock radiography may be possible.

The different acquisition channels are listed in the Table VIII.3: two VISAR at 532 nm and/or 1064 nm, two SBO/Pyrometer in the 490-750 nm range combined with 2 two-dimensional Gated Optical Imager (GOI).

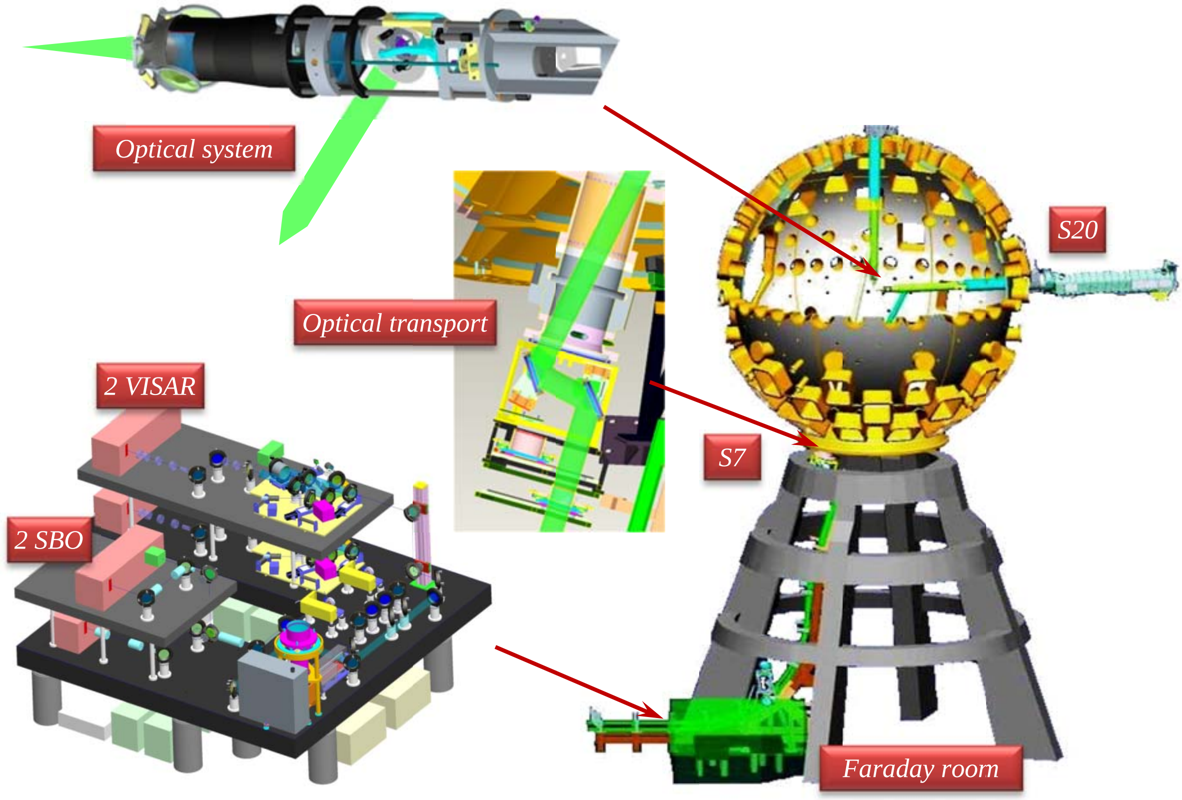


Figure VIII.18: EOS Pack location and closer view on the analysis Table

VIII.3.2 – FABS, Full Aperture Backscatter System

The FABS is dedicated to analysis of backscattered light in the focusing cone of quadruplet 28U (and later 29U). The backscattered energy is collected with an ellipsoidal spectralon® scattering panel and send to the Raman-Brillouin spectrometer.

The ellipsoidal scattering panel is located behind the 3ω gratings that are used on LMJ to deviate, to filter, and to focus the laser quadruplet on target. It is positioned so that the first focus of the ellipsoid is the TCC. The detection module is positioned at the second focus of the ellipsoid. It includes power detection and optical fibers which transport signal to spectrometers.

The Brillouin (346.5 - 355.5 nm) and Raman (375 - 750 nm) backscatter is measured with a 100 ps temporal resolution. *In situ* calibration of the diagnostic is possible with a xenon calibrated lamp located outside the chamber, behind a chamber vacuum window at the opposite of the conversion and focusing mechanical assembly.

Spectral and temporal characteristics are given in Table VIII.3.

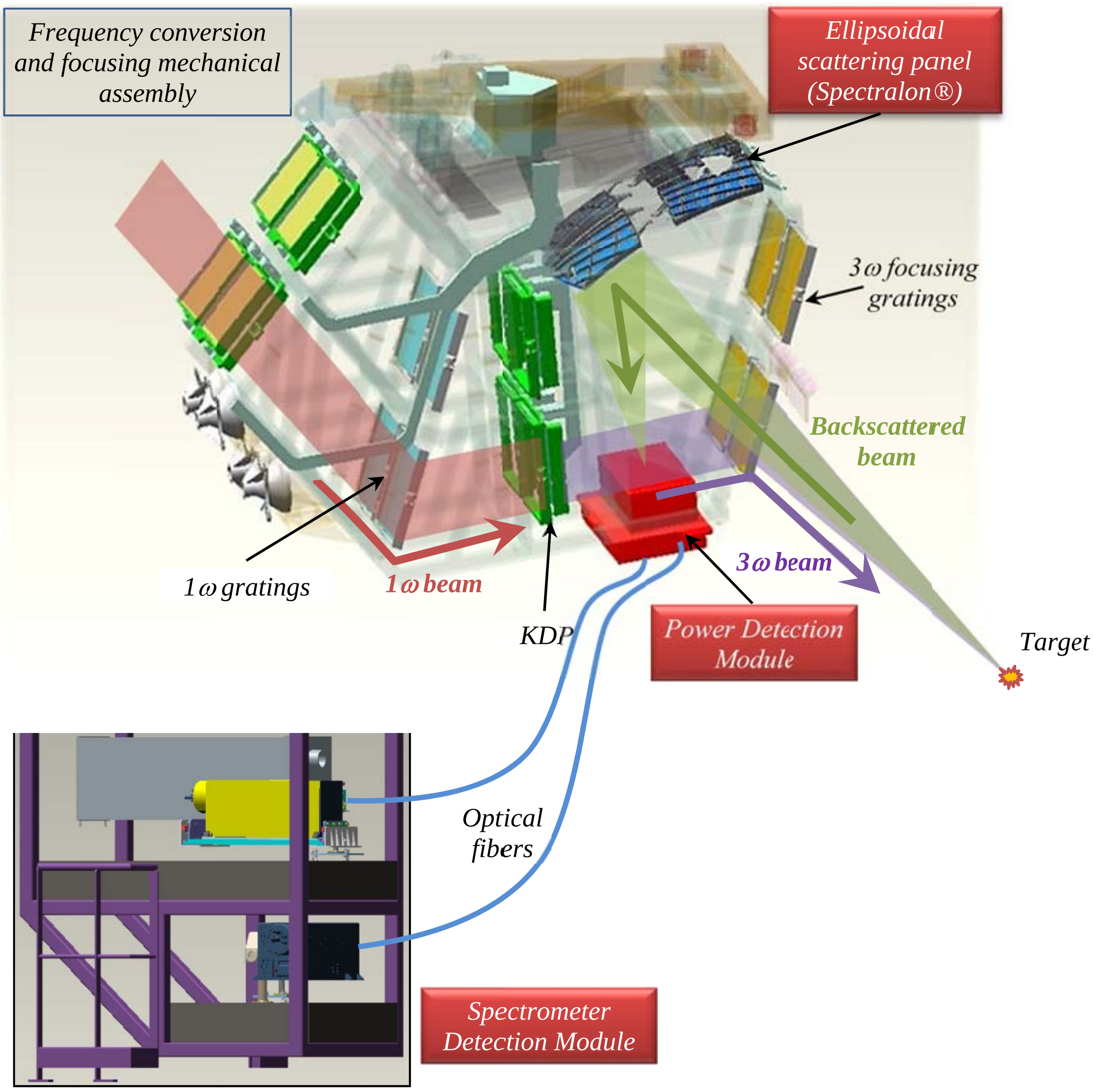


Figure VIII.19: Principle of the FABS

VIII.3.4 – NBI, Near Backscatter Imager

The Near Backscatter Imager (NBI) is dedicated to analysis of backscattered light outside the focusing cones of quadruplet 28U and 29U. The backscattered energy is collected by an optical system looking at Spectralon® scattering panels inside the chamber, and send to an optical table where Raman and Brillouin ranges are analyzed.

The NBI is made of:

- 9 flat scattering panels (Spectralon®, 7.1 m²) inside the target chamber, located around the beam ports of quads 28U (33.2° irradiation cone) and 29U (49° irradiation cone);
- an Optical system inserted in a diagnostic port (θ = 70°, φ = 306°) made of 4 lenses to collect light and send images to the optical analysis table via 4 bundles of 15 m long optical fibers;
- an Optical analysis table inserted in a Faraday cage, with 4 phototubes (power & energy), 2 ICCD (integrated images), 40 fast photodiodes and digitizers (time measurements).

A calibration system is used to control the plates’ reflectivity and to determine the sensitivity of the diagnostic with two modules: a lamp illuminating the surface of the plates and a pulsed laser associated to a mirror steering the laser beam onto numerous positions on the scatter plates with cm-size spots.

This diagnostic completes the FABS measurements.

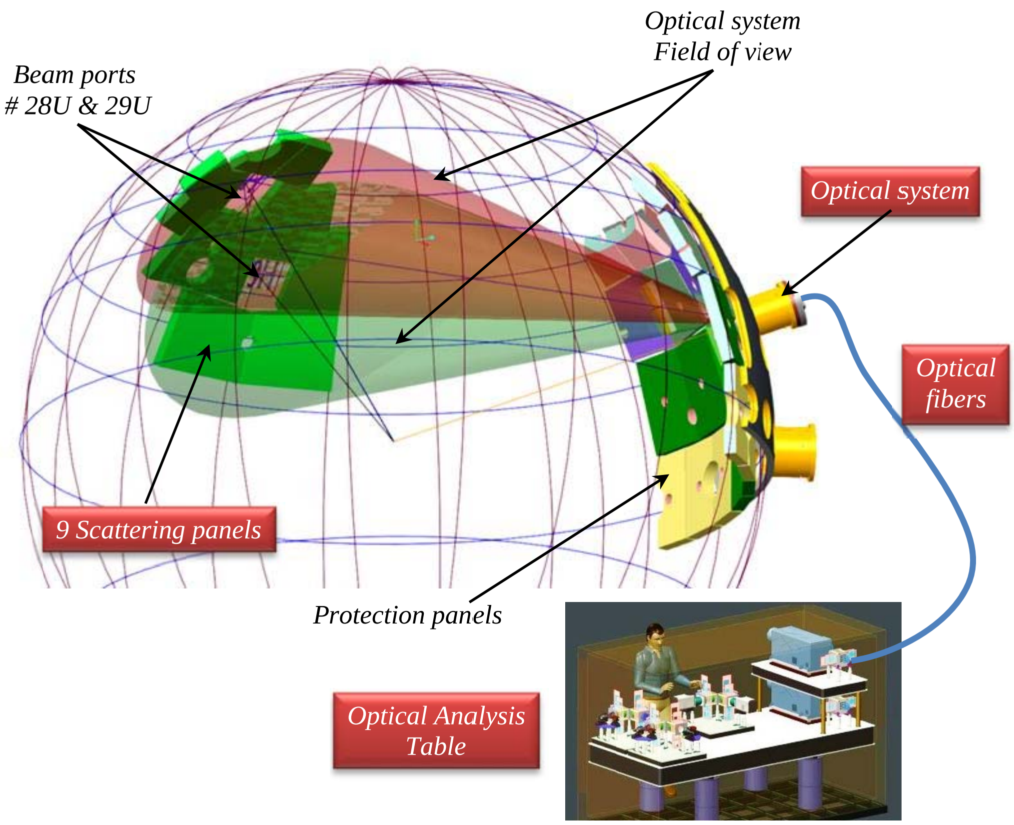


Figure VIII.20 : Principle of the LMJ NBI

VIII.4- Particles Diagnostics

The Particles diagnostics of the LMJ include a diagnostic set for neutron emission, and two types of spectrometers for electron and proton/ion emission.

The main characteristics of the first three Particles diagnostics are described in Table VIII.4.

Particles Diagnostics				
Diagnostic & Setting	*Characteristics*	*Yield / Spectral range*	*Spatial resol.(µm) / Field of view(mm)*	*Time resol. (ps)*
Neutron Pack *Activation and nTOF diagnostics* *Inside and outside the target chamber*	*Activation*	*D_2 : 10^9 to 10^{15} neutrons* *DT : 10^9 to 5.10^{18} neutrons*	-	*without*
	Gated PMT + scintillator			*50 (Timing accuracy)*
	Photodiode			
	CVD diamonds			
SEPAGE *Electron and proton spectrometer*	*Low energy Thomson parabola ΔE/E<0.5 % for e-, <6.5 % for p*	*e- : 0.1 - 20 MeV* *p : 0.1 - 20 MeV*	*- / 9*	*without*
	High energy Thomson parabola ΔE/E<1 % for e-, <6 % for p	*e- : 8 - 150 MeV* *p : 10 - 200 MeV*	*- / 2.3*	
SID	*Imaging module (proton Radiography) - Radiochromic film*	*3 - 200 MeV*	-	
SESAME1 & 2 *Electron (& proton) spectrometer* *Chamber wall*	*Magnetic spectrometer ΔE/E < 5 %*	*Electrons : 5 - 150 MeV* *Protons: 1 – 15 MeV*	*- / 15*	*without*

Table VIII.4: LMJ Particles diagnostics names and main characteristics

VIII.4.1 - Neutron Pack

The Neutron Pack is a set of several diagnostics to measure neutron yield, ion temperature, neutron bang time and the ratio of secondary to primary neutron reactions during D_2 and DT implosions [78, 79].

This set of diagnostics consists of several neutron Time of Flight detectors (nTOF: Gated photomultiplier tubes and scintillators, photodiodes, CVD diamonds) and activation (indium, copper, zirconium, etc.). All these diagnostics will be installed in several stages:

- In 2019, a first set of 6 nTOF detectors will be placed to describe two perpendicular equator axis and a near polar axis at 16°. All nTOF detectors will be installed in the target chamber at 3.6 meters from TCC using re-entrant tubes.

- Later, the activation diagnostic will complete the Neutron Pack and 5 more nTOF detectors will complete the nTOF diagnostic to be able to measure neutron yield and ion temperature anisotropy. Some other nTOF detectors will be placed on long LMJ equator lines of sight (East and West) and on the south low noise line of sight at 16° form the polar axis.

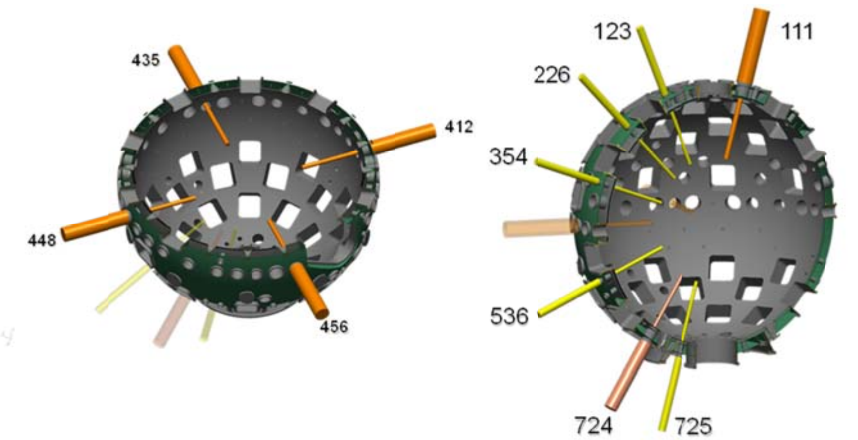


Figure VIII.21: Equator (left) and meridian (right) locations of nTOF detectors

VIII.4.2 – SEPAGE, Electron and Proton Spectrometer

The SEPAGE diagnostic records electron and ion/proton spectra on Image Plates (IP), and proton radiographies on radiochromic films (RCF). It is dedicated to high energy particles beams generated by PETAL. SEPAGE was developed by CEA/DRF/IRFU in the framework of the PETAL+ project [42, 43, 83].

It is composed of three parts:

- an ion spectrometer for energy from 100 keV to 200 MeV,
- an electron spectrometer for energy from 100 keV to 150 MeV,
- an imaging module for proton-radiography.

The spectrometer is composed of a set of two Thomson Parabolas (TP) for low (0.1 – 20 MeV) and high (8 – 200 MeV) energy particles. The standard imaging module is composed of a stack of RCF filters for protons in the 3 to 200 MeV energy range. The front film can be as close as 100 mm from the target.

A CAD drawing of the diagnostic is shown in Figure VIII.22. The preferred working location of SEPAGE is in SID position S26, opposite to the PETAL beam with an angle of 13.5°.

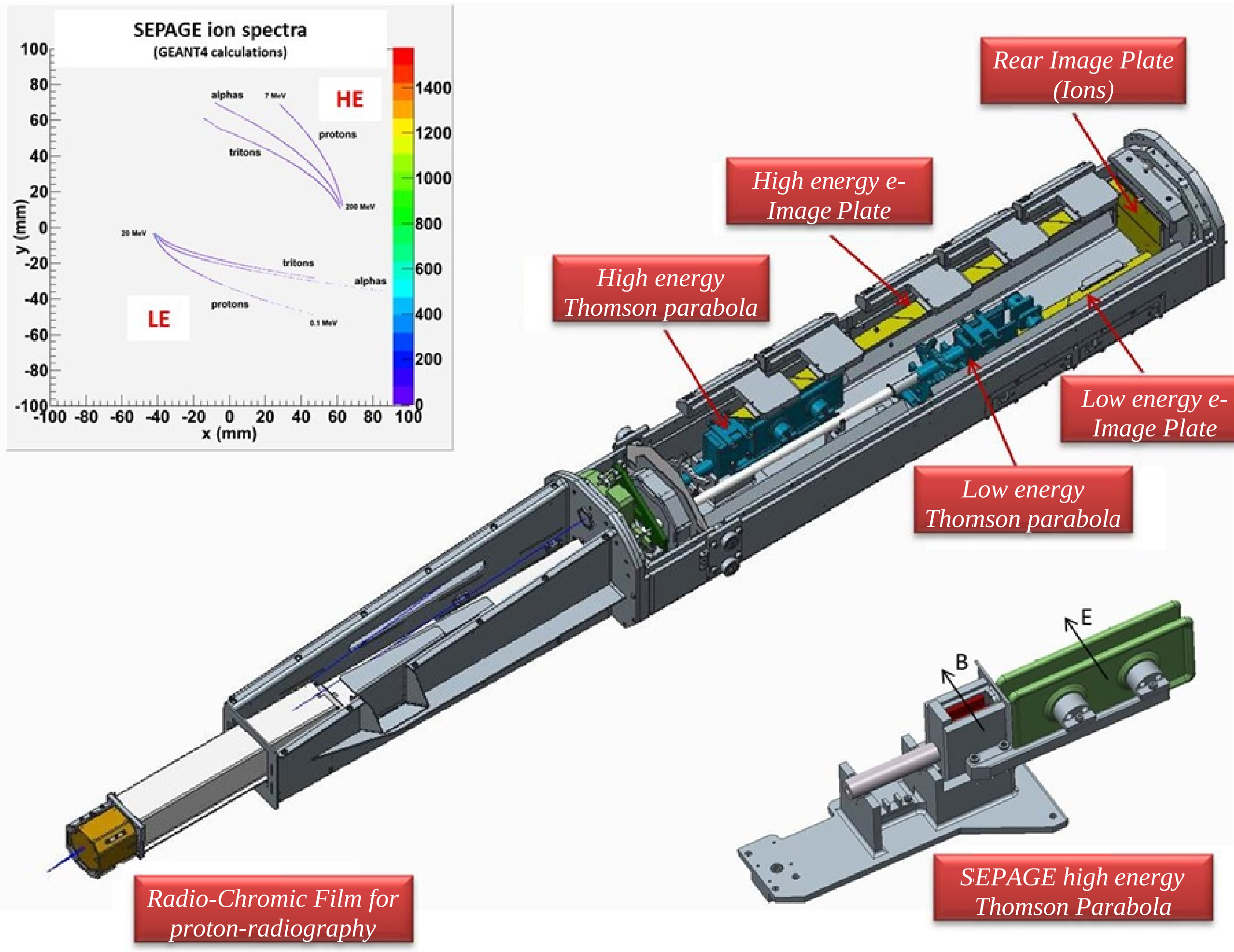


Figure VIII.22 : Current design of SEPAGE diagnostic

VIII.4.3 – SESAME, Electron Spectrometer

Complementary to the SEPAGE spectrometer, two additional electron spectrometers are installed at fixed location on the target chamber (see Table VII.1). SESAME 1 will allow electrons spectra measurements at 0° of PETAL axis whereas SESAME 2 will work at 45° of PETAL axis.

Both sides of the permanent magnets that deflect particles toward Imaging Plates Detectors (IPs) are used ; so positive and negative particles are analyzed.

The range for electrons is 5 to 150 MeV; the range for protons is 1 to 15 MeV.

These spectrometers are developed in the framework of PETAL+ project [42, 43, 83].

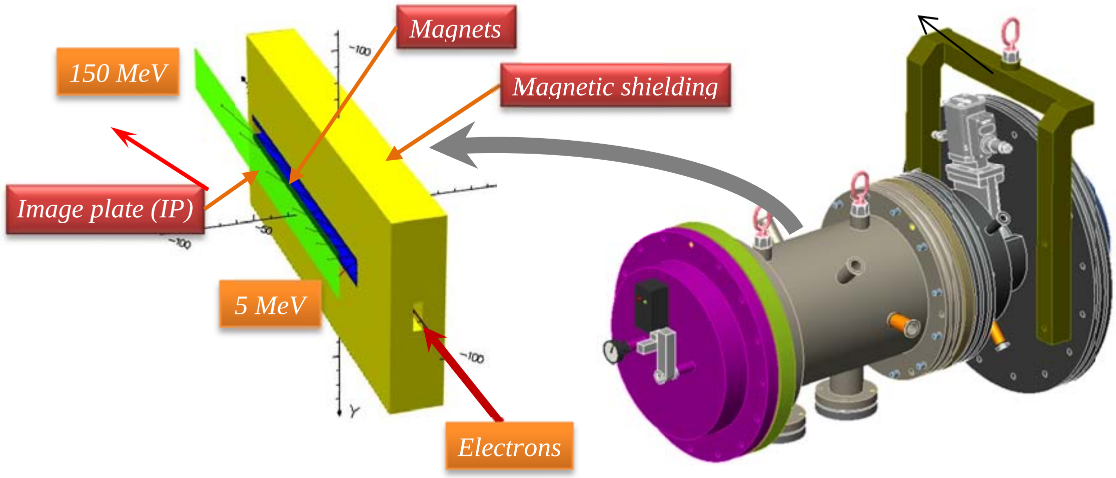


Figure VIII.23: Principle and current design of SESAME diagnostic

VIII.5- Diagnostics in Conceptual Design Phase

Beside the eighteen diagnostics described in the previous sections, eight other diagnostics have been identified for the next years and are under design.

The future LMJ diagnostics in conceptual design phase include:

- two spatially resolved spectrometers (soft and hard X-ray);
- a gated soft X-ray imager;
- a broad band spectrometer (second miniDMX);
- a second FABS on Q29U;
- two high resolution hard X-ray imagers;
- a Thomson scattering diagnostic.

IX- Experimental Configuration for 2019

IX.1- Laser Beams Characteristics

At the beginning of 2019, the experimental configuration of the LMJ facility will include 7 bundles (14 quads) and the PETAL beam. The spherical coordinate of these beams and the angles between the quads and PETAL are given in Table X.1.

Beam Port	θ	φ	Angle vs. PETAL
5U	49°	135°	130.1°
5L	146.8°	135°	117.8°
10U	49°	207°	125.0°
10L	146.8°	207°	114.6°
11U	33.2°	225°	106.6°
11L	131°	225°	113.2°
17U	33.2°	297°	69.2°
17L	131°	297°	60.6°
18U	49°	279°	73.2°
18L	146.8°	279°	77.9°
28U	33.2°	81°	92.5°
28L	131°	81°	93.4°
29U	49°	63°	79.9°
29L	146.8°	63°	82.7°
PETAL	90°	346.5°	

Table IX.1: Angle of the LMJ quads and PETAL beam in 2019

The CPP Type A (see section V.4) will be available for all quads, the CPP Type D will be available for 4 quads, and the CPP Type E and F will be available for 3 quads.

Concerning the Smoothing by Spectral Dispersion, the 2 GHz modulation will be activated for all shots, and the 14 GHZ modulation will be activated if required.

IX.2- Target Bay Equipment

About 10 SIDs are envisioned for LMJ but at the beginning of 2019, only 4 of them will be available: 1 LMJ SID and 3 PETAL SIDs.

According to the first LMJ-PETAL configuration, the ILP has chosen in 2012 the preferred SID locations for the PETAL diagnostics. As a consequence and for sake of minimizing the number of Facility reconfiguration, the operational positions available in the 2019-2020 timeframe will be:

- S12, S16, S20, S22, S26 in the equatorial plane for the 3 PETAL SIDs,
- S17 close to the polar axis for LMJ SID.

The proposed experimental configurations should take these constraints into account.

The available LMJ diagnostics at the beginning of 2019 will be: GXI-1, GXI-2, SHXI, SSXI, UPXI, ULXI, ERHXI, DMX, Mini-DMX, HRXS, SPECTIX, EOS Pack, FABS, NBI, Neutron Pack, SEPAGE, SESAME 1&2.

X- Targets

X.1- Assembly and Metrology Process

According to the experimental process (see III.6.), the final target technological design is fixed during the Design Review (twelve months before the experimental shots), the metrology process definition begins. During this review, the list of all targets' materials and their respective mass is established. These data are used to check target compatibility with LMJ-PETAL laser facility safety rules. The MOE ensures that target design is approved according to these rules. Some other topics have also to be validated, such as target debris generation assessment, specific storage requirements, if necessary (External global target volume which should be less than 40x40x40 mm^3), etc.

CEA/CESTA Target Laboratory is in charge of target assembly and final target metrology. The final target structure study starts one year before the shots. This study requires:

- target CAD file with "Step" like file extension;
- laser and diagnostics experimental configuration.

CAD final target structure will be validated by PI and MOE between 4 and 8 months before the shots, depending on the target complexity. CEA/CESTA Target Laboratory has to receive the target between 1 and 3 months before the first shot, depending on the complexity. At that time, each target must be identified and described in a dimensional characterization document.

CEA/CESTA Target Laboratory supplies target positioner interface (alignment fiducial) used by the target alignment process and manufactures each subset assembling to obtain the final target structure. Then, it carries out metrology on the target structure (angular and dimensional controls), essential to generate target positioning data used by LMJ-PETAL target alignment system.

Targets redundancy should be sufficient to allow fulfilling the shot plan (1 to 6 shots).

X.2- LMJ-PETAL Target Alignment Process

LMJ-PETAL target alignment process is based on the visualization of four spheres set around the target. Metrology, performed as described above, associates the spheres location with the strategic target areas. So, with the LMJ target viewing station of four spheres and with the target metrology file, LMJ target alignment system can put the target at the expected location.

The LMJ target alignment process is summarized below. First step is the preliminary insertion of target by LMJ target positioner, as seen on the three pictures given by the target viewing station (Figure X.2.1.).

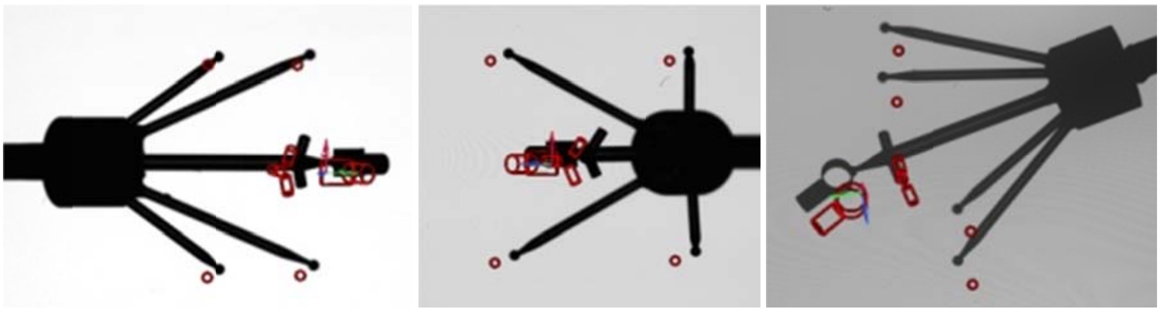


Figure X.2.1: LMJ target alignment process first step

Second step consists in a manual approach between target and final location represented by reticles (red circles and cylinder). When a partial superposition between spheres and red circles is reached this step is over.

Last step is the final automatic positioning, which provides the best alignment accuracy.

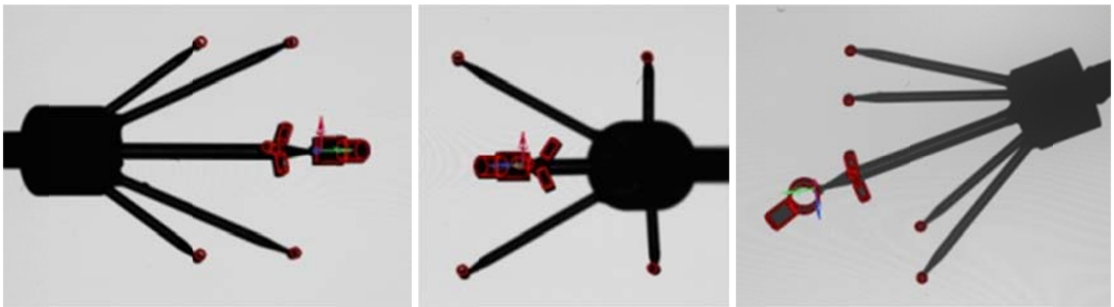


Figure X.2.2.: LMJ alignment process last step

XI- References

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XII- Acknowledgements

LMJ is a CEA project funded by the French Ministry of Defense

PETAL is a project of the Aquitaine Region funded by Europe, the French Ministry of Research and the Aquitaine Region.

PETAL+ is an Equipex project of the University of Bordeaux funded through the PIA by the ANR (French National Research Agency).

XIII- Glossary

ANR: French Agency for National Research
APS DPP: Meeting of the Division of Plasma Physics of the American Physical Society
BTDP: Transfer Box for Plasma Diagnostic
CAD: Computer Assisted Design
CEA-DAM: Military Applications Division of CEA
CPA: Chirped Pulse Amplification
CPP: Continuous Phase Plates
DMX: Broad-band X-ray spectrometer
ECLIM: European Conference on Laser Interaction with Matter
EOS: Equation of State
EOS Pack: Diagnostics set for EOS experiments
EPS: Conference on Plasma Physics of the European Physical Society
ERC: European Research Council
ERHXI: Enhanced Resolution Hard X-ray Imager
FABS: Full Aperture Backscattering System
GOI: Gated Optical Imager
GXI-1&2: Gated X-ray Imager
HEDLA: Conference on High Energy Density Laboratory Astrophysics
HEDP: High Energy Density Physics
HRXS: High Resolution X-ray Spectrometer
HTPD: Conference on High Temperature Plasma Diagnostics
ICF: Inertial Confinement Fusion
ICHED: International Conference in High Energy Densities
IFSA: Conference on Inertial Fusion Sciences and Applications
ILP: Institut Lasers & Plasmas
IP: Imaging Plate
ISAC-P: International Scientific Advisory Committee of PETAL
LEH: Laser Enhance Holes
LIL: Laser Integration Line
LMJ: Laser Megajoule
LOI: Letter of Intent
LPI: Laser Plasma Interaction
LPXI: Lower Pole X-ray Imager
Mini-DMX: Mini Broad-band X-ray spectrometer
MOE: CEA Experiment Manager
NBI: Near Backscattered Imager
NLTE: Non Local Thermodynamic Equilibrium
OPA: Optical Parametric Amplification
PAM: Pre-Amplifier Module
PETAL: Petawatt Aquitaine Laser
PETAL+: PETAL diagnostics Project funded by ANR (Equipex Projects)
PFM: Pulse Forming Module
PI: Principal Investigator
PIA: Programme d'Investissement d'Avenir (French National program for promising investment)
RCE: CEA Experiment Coordinator

RCF: Radio Chromic Film
RH: Reference Holder
RMS: Root mean square
SBO: Shock Break Out
SEPAGE: Electrons and protons spectrometer
SESAME: Electrons spectrometer
SHXI: Streaked Hard X-ray Imager
SID: System for Insertion of Diagnostics
SOLEIL: French Synchrotron facility located at L’orme des Merisiers, 91190 Saint Aubin
SOP: Streaked Optical Pyrometer
SOPAC: System for Optical Positioning and Alignment inside Chamber
SPECTIX: Hard X-ray spectrometer
SSD: Smoothing by Spectral Dispersion
SSXI: Streaked Soft X-ray Imager
TBD: To be determined
TCC: Target chamber center
TP: Thomson Parabola
TPS: Target Positioning System
UPXI: Upper Pole X-ray Imager
VISAR: Velocity Interferometer System for Any Reflector

XIV- Appendix

GPS coordinates:

- CEA-CESTA : 44° 39’ 30’’ N / 0° 48’ 29.8’’ W
- LMJ : 44° 38’ 08.8 ‘’ N / 0° 47’ 12’’ W
- ILP building : 44° 38’ 13’’ N / 0° 47’ 54.1’’ W

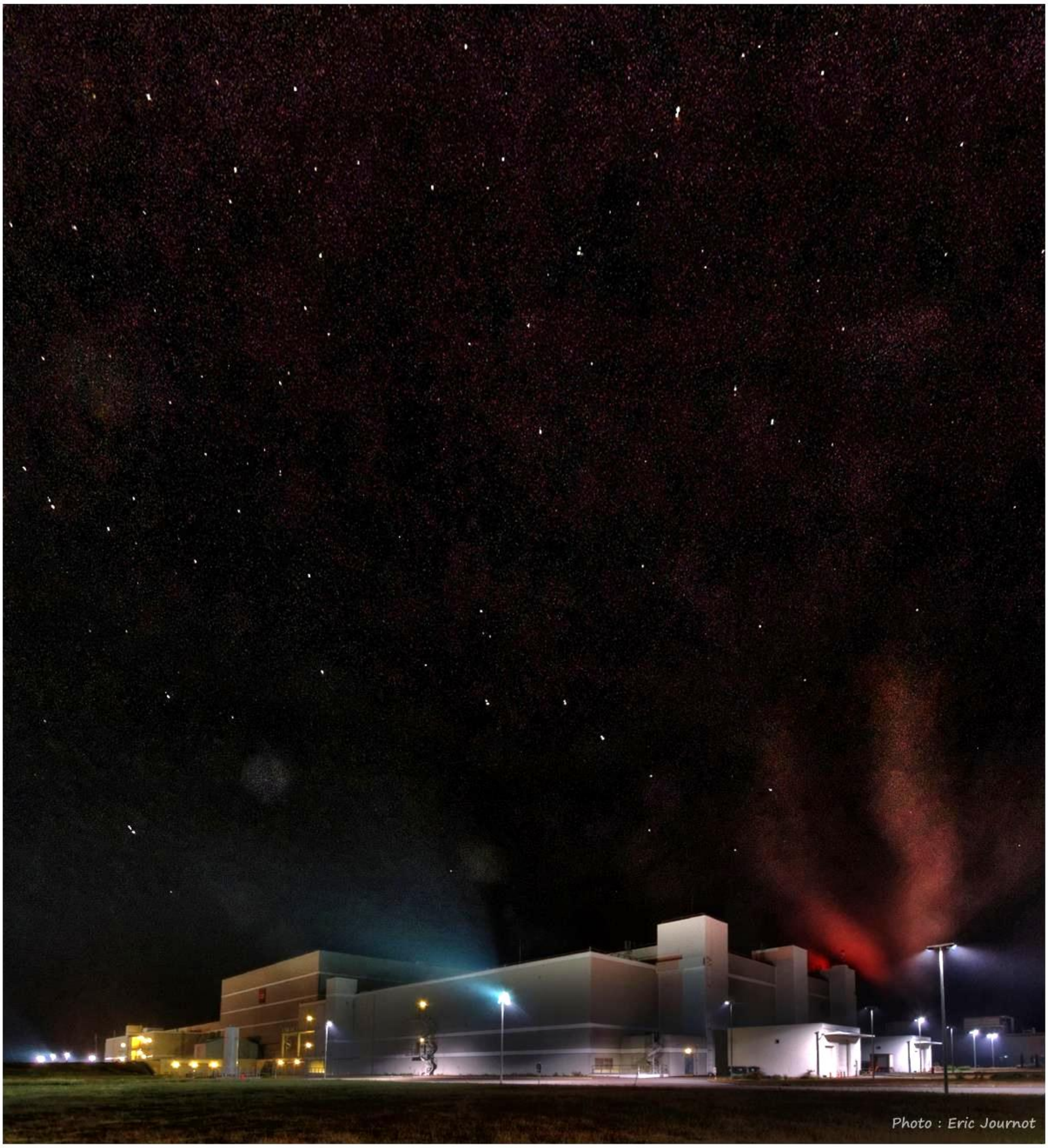
List of hotels close to CEA-CESTA, in Bordeaux and Arcachon.

Close to CEA-CESTA	Bordeaux
Hôtel-Restaurant LE RÉSINIER 68, av. des Pyrénées – RN10 33114 LE BARP Tel. : +33 5 56 88 60 07 Fax : +33 5 56 88 67 37	Hôtel Quality Suites Bordeaux aéroport 4* 83 avenue JF Kennedy 33700 MERIGNAC Tel : +33 5 57 53 21 22 reservation@qualitybordeaux.com
Domaine du Pont de l’Eyre 2 route de Minoy 33770 Salles **Tel : +33 5 56 88 35 00** **Fax : +33 5 56 88 35 99** **dom.pont.de.leyre@wanadoo.fr**	Hôtel Best Western « Bayonne Etche-Ona » 3* 15 cours de l’Intendance 33000 BORDEAUX Tel : +33 5 56 48 00 88 Fax : +33 5 56 48 41 60 bayetche@bordeaux-hotel.com
B&B MIOS 6 avenue ZAC 2000 Parc d’activités MIOS Entreprises 33380 MIOS Tél : +33 8 92 70 20 70 or +33 5 56 77 33 11 bb_4527@hotelbb.com	Hôtel TENEO gare Saint Jean 4 cours Barbey 33800 BORDEAUX Tel : +33 5 56 33 22 00 bordeaux@teneo.fr
Hôtel CAMPANILE A63 – aire de repos de CESTAS Tel : +33 5 57 97 87 00	
Arcachon	
Hôtel LE DAUPHIN 7 avenue Gounod 33120 ARCACHON Tel : +33 5 56 83 02 89 Fax : +33 5 56 54 84 90	Hôtel Park Inn 4 rue du Professeur JOLYET 33120 ARCACHON Tel : +33 5 56 83 99 91 Fax : +33 5 56 83 87 92 info.arcachon@rezidorparkinn.com
Hôtel AQUAMARINA 82 boulevard de la Plage 33120 ARCACHON Tel. : +33 5 56 83 67 70 Fax : +33 5 57 52 08 26	Hôtel Quality Suite Arcachon 4* 960 avenue de l’Europe 33260 LA TESTE DE BUCH Tel : +33 5 57 15 22 22 reservation@qualityarcachon-spa.fr
Hôtel LES VAGUES 9 boulevard de l’Océan 33120 ARCACHON Tel. : +33 5 56 83 03 75 Fax : +33 5 56 83 77 16	

XV- Revision Log

Rev No	Date	Main modifications	Brief description
1.0	12 Sept 2014	-	Initial release (Jean-Luc Miquel, Alexis Casner, Emmanuelle Volant)
1.1	28 April 2015	p6: III.4- Confidentiality rules p7-8: III.5- Selection process p8: III.6- Experimental process p16: V.4- Spot sizes - Table V.2. p19: V.7- Laser performance p26: VIII- LMJ Diagnostics - Table VIII.1 p30-31: VIII.3- Mini-DMX	Rearrangement of section III (precisions on Selection process, addition of Experimental process). Modification of spot sizes. Addition of Laser performance. Addition of Mini-DMX. (JLM, EV)
1.2	6 April 2016	P3 : table II.1 : History P6: III.5 – Selection process P7: III.6 – Experimental process p10: III.11 – Calls for proposals p14: V.1 – Laser architecture – Figure V.6 and Table V.1. p16: V.4- Spot sizes - Table V.2. p19: V.7- Laser performance p22: VI.2 – PETAL performance p24: VII- Target area and associated equipment – Table VII.1 – Figure VII.5 p27 to 45 : VIII- LMJ Diagnostics p46: IX.1 - Laser beams characteristics IX.2 – Target bay equipment p47:X.1 - Assembly & metrology process X.2 – LMJ-PETAL Alignment process p49:XI – References p52:XIII - Glossary	Update. Precisions on Selection process and Experimental process, addition of Calls for proposals. Modification of the operative quads in 2019. Modification of spot sizes. Update of laser performance. Addition of PETAL performance. Update of the 2019 locations of equipment and new Figure VII.5. Rearrangement of section VIII (description of all operative diag.). Update of Table IX.1. Modification of SID locations and available diagnostics. Precisions on assembly /metrology. Addition of alignment process. Update. Update. (JLM, EV)
1.2b	2 May 2016	p3: PETAL+ project p6 : III.5 Selection process	Roles of academic community and University of Bordeaux. LOI = preliminary proposal.
1.3	24 March 2017	p10 : III.11 Calls for Proposal History p15 : Table V.1 Figure V.7 p16 : V.4 Spot sizes and table V.2 p17 : Figure V.9 and V.6 Pulse shapes p20 : V.7 LMJ performances & figure V.13 p23 : VI.2 Petal performances p28 to 46 : VIII- LMJ Diagnostics p51 : XI- References	Update Quads order Addition of disposable debris shield Modification of spot sizes, addition of 1/e size Pulse duration limited at 20 ns. Update of laser performances. Update of PETAL performances. Update of diagnostics performances Update. (JLM, EV)

All Photos: @CEA



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