LMJ program
&
Diagnostics plan

J.L. MIQUEL Program leader, Laser-plasma experiments
CEA, DAM, F-91297 Arpajon, France
Laser MegaJoule main characteristics

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

Target bay
- Biological protection: 2 m thick concrete
- Target chamber $\varnothing 10$ m
- 200 ports for laser beams and diagnostics

Target chamber $\varnothing 10$ m, $H 38 m$, $\varnothing 60 m$
LMJ Schedule: the “3 thirds rule”

Three main activities are performed during the year

- Mounting of new bundles
- Activation / qualification of the previous mounted bundles
- Plasma experiments

Only one shift is dedicated to experiments => 1 shot/day during less than 4 months
- 50 Physics shots + 30 preparation shots (Diagnostic qualification, pointing, synchro, ...)

Other activities can impact the schedule:

- Preparation for maintenance of activated equipment
  - Due to high energy particles generated by PETAL shot in 2017
=> no experiments at the end of 2016
The 8 experimental topics of the Simulation Program

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

2. Fundamental data
   - EOS, Opacities...
   - Control of matter’s behavior under HP and HT

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

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

5. Hydrodynamics Instabilities
   - Instabilities growth, turbulence
   - Control of mixing

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

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

8. Applications
   - Coupling of an ignition target with another target
   - Control of complex powerful system
The 6 experimental configurations of Laser MegaJoule

1st configuration: 1 laser bundle
2 SID
4 diagnostics

Total Energy = 25 kJ

<table>
<thead>
<tr>
<th>X-ray Diagnostics</th>
<th>Optical Diagnostics</th>
<th>Particles Diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagers</td>
<td>Spectro.</td>
<td>DMX</td>
</tr>
<tr>
<td>GXI-1</td>
<td>GXI-2</td>
<td>miniDMX</td>
</tr>
</tbody>
</table>
Target bay: 1st configuration equipment (today)
The 6 experimental configurations of Laser MegaJoule

2nd configuration: 2 laser bundles (+ PETAL)
3 SID
9 diagnostics

Total Energy = 60 kJ

<table>
<thead>
<tr>
<th>X-ray Diagnostics</th>
<th>Optical Diagnostics</th>
<th>Particles Diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Imagers</td>
<td>Spectro.</td>
<td></td>
</tr>
<tr>
<td>GXI-1</td>
<td>DMX</td>
<td>SESAME</td>
</tr>
<tr>
<td>GXI-2</td>
<td>miniDMX</td>
<td>SEPAGE</td>
</tr>
<tr>
<td>SHXI</td>
<td>SPECTIX</td>
<td></td>
</tr>
<tr>
<td>SSXI</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Target bay: 2nd configuration equipment - 2017
### The 6 experimental configurations of Laser MegaJoule

#### 3rd configuration: 5 laser bundles (+ PETAL)
- 4 SID
- 13 Diagnostics

#### Total Energy = 150 kJ

<table>
<thead>
<tr>
<th>X-ray Diagnostics</th>
<th>Optical Diagnostics</th>
<th>Particles Diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>GXI-1</td>
<td>DMX</td>
<td>FABS1</td>
</tr>
<tr>
<td>GXI-2</td>
<td>miniDMX</td>
<td>EOS pack</td>
</tr>
<tr>
<td>SHXI</td>
<td>SPECTIX</td>
<td></td>
</tr>
<tr>
<td>SSXI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERHXI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPXI</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Target bay: 3rd configuration equipment - 2018
The 6 experimental configurations of Laser MegaJoule

4th configuration: 7 to 9 laser bundles (+ PETAL)
- 3rd order « symmetry » (then 4th) => First Implosion (D₂/Ar gas) and neutron production

5 SID
19 Diagnostics

Total Energy = 250 to 320 kJ

<table>
<thead>
<tr>
<th>X-ray Diagnostics</th>
<th>Optical Diagnostics</th>
<th>Particles Diagnostics</th>
</tr>
</thead>
<tbody>
<tr>
<td>GXI-1 DMX</td>
<td>FABS1&amp;2</td>
<td>SESAME</td>
</tr>
<tr>
<td>GXI-2 miniDMX</td>
<td>NBI</td>
<td>SEPAGE</td>
</tr>
<tr>
<td>SHXI SPECTIX</td>
<td>EOS pack</td>
<td>Neutron pack</td>
</tr>
<tr>
<td>SSXI HRXS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ERHXI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>UPXI-LPXI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSXI</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The 6 experimental configurations of Laser MegaJoule

5th configuration: 11 to 21 laser bundles (+ PETAL)  
Total Energy = 530 kJ to 1 MJ

- Low Temp. target positioning system, 5th order axial symmetry => Ignition preparation
- 6 SID
- 26 Diagnostics

<table>
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<tr>
<th>X-ray Diagnostics</th>
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</tr>
<tr>
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<td>FABS1&amp;2</td>
</tr>
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<td>GXI-2</td>
<td>miniDMX</td>
<td>NBI</td>
</tr>
<tr>
<td>SHXI</td>
<td>SPECTIX</td>
<td>EOS pack</td>
</tr>
<tr>
<td>SSXI</td>
<td>HRXS</td>
<td>Thomson Scattering</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neutron pack</td>
</tr>
<tr>
<td>ERHXI</td>
<td>SRSXS</td>
<td></td>
</tr>
<tr>
<td>UPXI-LPIXI</td>
<td>miniDMX2</td>
<td></td>
</tr>
<tr>
<td>GSXI</td>
<td>SRHXS</td>
<td></td>
</tr>
<tr>
<td>SHXI-2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GXI-3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The 6 experimental configurations of Laser MegaJoule

6th configuration: 22 laser bundles (+ PETAL)
- Cryogenic target positioning system, Full axial symmetry => Ignition Milestone
- Up to 10 SID
- 26+ Diagnostics

Total Energy = 1,5 MJ

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</tr>
<tr>
<td>SHXI</td>
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</tr>
<tr>
<td>SSXI</td>
<td>HRXS</td>
<td>Thomson Scattering</td>
</tr>
<tr>
<td>ERHXI</td>
<td>SRSXS</td>
<td>...</td>
</tr>
<tr>
<td>UPXI-LPXI</td>
<td>miniDMX2</td>
<td>...</td>
</tr>
<tr>
<td>GSXI</td>
<td>SRHXS</td>
<td></td>
</tr>
<tr>
<td>SHXI-2</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>GXI-3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The experimental program on LMJ

- New diagnostics for Fundamental data
- Increased energy and precision
- Symmetry, implosion

Graph showing configurations 1 to 5 with categories:
- Fusion
- Hydrodynamics instabilities
- Implosion hydrodynamics
- Radiation transport
- Fundamental data
- Hohlraum energetics
October 2014: The first LMJ Campaign
Dynamics of slot closure

Demonstrate LMJ abilities to perform experiments for Simulation program
- Slot dynamics is diagnosed by auto-radiography
- First shot with Ta$_2$O$_5$ aerogel sample, 200 µm thickness

Details of the phenomena are well predicted by simulations
- Late phenomena of the closure dynamics

2D simulations

Upper Quad

Radiography

100 µm slot
75 µm slot

Stagnation area
(Plasmas collision)

Experiment

Closure dissymmetry

Lower Quad

2D simulations before shot

$t = t_1$
$t = t_2$
$t = t_3$
$t = t_4$
2015 - Asymmetrical implosion
Variations in capsule position and shield size

**GXI-2**: Beams pointing monitoring
- LEH Backlighter

**DMX**: Rad. Temp. measurement
- Tr drive 0-2keV

**GXI-1**: less convergent implosion with big shield

**DMX**: LEH time integrated picture

**DMX**: Rad. Temp. measurement
- Tr drive 0-2keV

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

- Ti or Sc backlighter
- Optimized pulse (11 kJ - 1+2 ns)

- Au shield
- Heating pulse 11 kJ - 3 ns

- CH capsule Ø 500 µm

- 23 Nov. - Ø bouclier = 1,2 mm
t=5,5 ns

- 24 Nov. - Ø bouclier = 1,4 mm
The egg shape, predicted by simulation, is due to the anisotropic distribution of the drive around the capsule.
Effect of a technological singularity present on a laser target

- Shock propagation in Ta₂O₅ disk (radiographic contrast) including the singularity.
- Shocks coalescence and inversion of the defect, which leads to a jet of material in a foam.
- Multi-time late radiography of the jet.

Simulation:

- X-ray Radiography Simulation
  - Grid
  - X-ray Radiography
  - Jet

- Tube
- Grid (Spatial reference)

X Radiography of the jet (Hard X-ray Imager GXI-1)

Ta₂O₅ disk with central defect

Δt = 18 ns 21 ns 24 ns 27 ns

Position of the tip of the jet (mm)

- E laser ~ 11.5 kJ
- #1 11 kJ
- #2 10.5 kJ
- #3 9 kJ
- #4 8 kJ
- #5 6.5 kJ

Time (ns) 18 20 22 24 26 28 30 32

Points expérimentaux

Tube Grid Jet

CH Foam

Q28H

Q28B

J-L. Miquel CEA/DAM/DAN

Rochester | June, 29th 2016

2015 - Technological Singularity
Continuation of dynamics of slot closure, with quantification of losses through the slot.

- X-ray conversion in a gold hohlraum with shield
- Measurement of radiation temp. in hohlraum and losses through the slots
- Samples with empty slots or filled with CH (delayed closure)

High sensitivity to the sample characteristics (thickness, slot width, …)
Continuation of the program

**Radiation transport**
- Radiative balance in hohlraums - 2016
- Radiative propagation in a close sub-sonic regime – 2017
- Radiative propagation in inhomogeneous media -2017
- Rosseland opacities - 2017

**Hohlraum energetics**
- Characterization of magnetic fields – 2017 (Academic access)
- X-ray conversion on the rear face of target – 2018
- Laser-Plasma Interaction in gas hohlraum – 2019

**EoS**
- Reference materials (Quartz, Al, diamond) and low-Z materials (B, HLi) – 2019

**Implosion hydrodynamics**
- Corrected asymmetrical implosion - 2017
- 1D planar hydrodynamics – 2018
- D₂ capsule implosion (neutron production) - 2019

**Hydrodynamics Instabilities**
- Turbulence in shock tube - 2018
Access of the Academic Community to LMJ-PETAL

Opening policy
- The CEA-DAM has promoted for several decades collaboration with national and international scientific communities
- Between 2005 and 2014, access to the LIL facility has been given to the scientific community

With the LMJ and PETAL facilities, the CEA-DAM is once again in a position to welcome national and international teams.

- LMJ-PETAL User Guide (+ Diagnostic forms) provides the necessary technical references for the writing of Letter of Intent of experimental proposals to be performed on LMJ-PETAL.
- Regularly updated version of this User guide is available on LMJ website at: http://www-lmj.cea.fr/en/ForUsers
- Academic access and selection of the proposals are coordinated by Institut Laser & Plasmas (ILP) with the help of the International Scientific Advisory Committee of PETAL.

A direct access to LMJ-PETAL is also possible through NNSA-CEA collaboration
Academic experiments

First call for experiments:
- The first configuration (end 2016) includes 4 quads and the PETAL beam

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

Second call: launched on April 2016
- After this pre-selection, the deposit of the full proposals will be asked for December 2016.
  - The experiments will take place in 2019 and 2020, with 14 quads and 16 diagnostics.
## Plasma diagnostics installed on LMJ

<table>
<thead>
<tr>
<th>Name</th>
<th>Characteristics</th>
<th>Needs</th>
<th>Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>GXI-1</td>
<td>Gated hard X-ray imager, Space resolution = 35 µm</td>
<td>2D X-ray image</td>
<td>SID</td>
</tr>
<tr>
<td></td>
<td>Field of view: 3 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GXI-2 (GXI-1 like)</td>
<td>Gated hard X-ray imager, Space resol. = 150 or 50 µm</td>
<td>Beams pointing monitoring</td>
<td>SID</td>
</tr>
<tr>
<td></td>
<td>Field of view: 15 mm or 5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DMX</td>
<td>Broad-band X-ray spectrometer, temporally resolved</td>
<td>Primary hohlraum radiative temp.</td>
<td>MS D9 (D8 in 2018)</td>
</tr>
<tr>
<td>Mini-DMX</td>
<td>Mini Broad-band X-ray spectrometer, temporally resolved</td>
<td>Secondary hohlraum radiative temp.</td>
<td>SID</td>
</tr>
</tbody>
</table>
GXI-1 (and 2), Gated X-ray Imager 1 (and 2)

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range</th>
<th>Spatial resolution (µm) / Field of view (mm)</th>
<th>Time resolution (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnification = 4.3 (0.9)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2x4 time-resolved toroidal mirror channels</td>
<td>0.5 - 10 keV</td>
<td>35 / 3 (150/15)</td>
<td>110 - 130 / 20</td>
</tr>
<tr>
<td>4 pinhole (refractive lenses) channels</td>
<td>2 (6) - 15 keV</td>
<td>40 / 3 (150/15)</td>
<td>110 – 130 / 20</td>
</tr>
<tr>
<td>1 time-integrated mirror channel</td>
<td>0.5 - 10 keV</td>
<td>50 / 5 (140/20)</td>
<td>without</td>
</tr>
</tbody>
</table>

- Dedicated to X-ray radiography (Pointing monitoring)
- Microscope with large source-to-optic distance and a large size gated micro channel plate detector.
- Three-film protective holder to protect optical components from damages caused by target debris and UV radiation.
**DMX, Broad-band X-ray Spectrometer**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range (resol. E/ΔE)</th>
<th>Spatial resol. (µm) / Field of view (mm)</th>
<th>Time resol.(ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 time-resolved broad-band channels</td>
<td>0.03 - 20 keV (5)</td>
<td>/ 5</td>
<td>150 / 10⁵</td>
</tr>
<tr>
<td>Grating X-ray spectrometer Dl &lt; 1 Å</td>
<td>0.1 - 1.5 &amp; 1.5 - 4 keV</td>
<td>17 / 2 to 120 / 25</td>
<td></td>
</tr>
<tr>
<td>Laser Entrance Hole Imager</td>
<td>0.5 - 2 keV</td>
<td>100 / 5</td>
<td>500 / 20</td>
</tr>
<tr>
<td>X-ray Power</td>
<td>0.1-2 , 2-4 &amp; 4-6 keV</td>
<td>/ 5</td>
<td>150 / 10⁵</td>
</tr>
</tbody>
</table>

- a time resolved soft X-ray broad-band spectrometer (20 channels combining mirror, filters, X-ray diodes)
- a time resolved soft X-ray spectrometer (gratings and streak camera)
- a laser entrance hole imaging - time resolution planned
- a time resolved X-ray power measurement spectrally integrated.
### Mini-DMX, Mini-Broad-band X-ray Spectrometer

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range (resol. E/ΔE)</th>
<th>Spatial resol. (μm) / Field of view (mm)</th>
<th>Time resol. (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 time-resolved broad-band channels</td>
<td>0.03 – 7 keV (5)</td>
<td>- / 5</td>
<td>150 / 10^5</td>
</tr>
</tbody>
</table>

- Second hohlraum energetic performance measurements axis on the LMJ facility.
- Composed of 16 broadband channels combining filters, mirrors and coaxial detectors
- Positioned at its working distance (1000 mm or 3500 mm) by a SID,

This diagnostic, like DMX, is absolutely calibrated
## Plasma diagnostics in progress

<table>
<thead>
<tr>
<th>Name</th>
<th>Characteristics</th>
<th>Needs</th>
<th>Position</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSXI</td>
<td>Streaked soft X-ray Imager, Space resol. = 30 or 50 µm</td>
<td>Rosseland Opacities Radiative Transfer</td>
<td>SID</td>
<td>2017</td>
</tr>
<tr>
<td></td>
<td>Field of view : 5mm or 15mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHXI</td>
<td>Streaked hard X-ray imager</td>
<td>1D X-ray image</td>
<td>SID</td>
<td>2017</td>
</tr>
<tr>
<td></td>
<td>Space resol. = 150 µm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Field of view: 15 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOS Pack</td>
<td>VISAR, SBO, Pyrometer, Reflectivity</td>
<td>EOS Shocks propagation</td>
<td>SID + analysis table</td>
<td>2019</td>
</tr>
</tbody>
</table>
SSXI, Streaked Soft X-ray Imager

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range</th>
<th>Spatial resolution (µm) / Field of view (mm)</th>
<th>Time resolution (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnification = 1 or 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time-resolved bi-toroidal mirror channel</td>
<td>0.05 – 1.5 keV</td>
<td>30 / 5 or 50 / 15</td>
<td>17 / 2 to 120 / 25</td>
</tr>
<tr>
<td>1 time-integrated bi-toroidal mirror channel</td>
<td>0.05 – 1.5 keV</td>
<td>30 / 5 or 50 / 15</td>
<td>without</td>
</tr>
<tr>
<td>Spectral selection by grating</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Time-resolved 1D image or time / space-resolved spectra in the soft X-ray spectral region.
- Analysis of radiative waves and soft X-ray target emission.
- Association of an optics assembly and a spectral selection device (blast shield which large flat mirror, with grazing incidence, and an X-ray microscope with two channels).
- The spectral selection is provided by two low-pass mirrors combined with a reflective flat field grating.
**SXHI, Streaked Hard X-ray Imager**

<table>
<thead>
<tr>
<th>Characteristics</th>
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<th>Spatial resolution (µm) / Field of view (mm)</th>
<th>Time resolution (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnification = 1 or 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 time-resolved toroidal mirror channels</td>
<td>0.5 - 10 keV</td>
<td>150 / 15 or 50 / 5</td>
<td>17 / 2 to 120 / 25</td>
</tr>
<tr>
<td>1 time-integrated mirror channel</td>
<td>5 - 10 keV</td>
<td>130 / 20 or 50 / 6.5</td>
<td>without</td>
</tr>
</tbody>
</table>

- Time-resolved 1D image in the hard X-ray spectral region.
- X-ray radiography and hard X-ray target emission.
- Two X-ray channels per magnification (grazing angle-of-incidence toroidal mirrors and a filter).
- One image of them produced on the streak camera while the other formed on a time integrated detector (CID).
- A protective holder contains three films to protect optical components.
## EOS Pack, Diagnostics set for EOS experiments

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Measurement or Spectral range (nm)</th>
<th>Spatial resol. (µm) / Field of view (mm)</th>
<th>Time resol. (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 VISARs (1064 and 532 nm)</td>
<td>Velocity 0.5 - 200 km/s</td>
<td>30 / 1 to 50 / 5</td>
<td>50 / 5 to 500 / 100</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>R &gt; 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Shock Break Out (SBO)</td>
<td>490 - 750</td>
<td>30 / 1 to 100 / 10</td>
<td>50 / 5 to 500 / 100</td>
</tr>
<tr>
<td>Pyrometer</td>
<td>Temp. &gt; 0.1 eV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 x 2 D images</td>
<td>490 - 750</td>
<td></td>
<td>75 – 200 / 2 - 20</td>
</tr>
</tbody>
</table>

- Optical system, positioned close to the target (SID),
- Optical transport system
- Analysis table.
- Laser and optical analyzers will be hardened and protected against EMP inside Faraday cages.
## Plasma diagnostics under study

<table>
<thead>
<tr>
<th>Name</th>
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<th>Position</th>
<th>Planned</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UPXI - LPXI</strong></td>
<td>Hard X-ray imagers, upper and lower polar</td>
<td>LEH images in polar irradiation</td>
<td>Specif. Mechanics</td>
<td>2018-2019</td>
</tr>
<tr>
<td><strong>FABS</strong></td>
<td>Full aperture backscattering system (Raman-Brillouin spectrometer), Q28H</td>
<td>Energy Balance Interaction</td>
<td>Focusing system</td>
<td>2019</td>
</tr>
<tr>
<td><strong>NBI</strong></td>
<td>Near Backscatter Imager (analysis of backscattered light outside Q28H &amp; Q29H)</td>
<td>Energy Balance Interaction</td>
<td>Chamber</td>
<td>2019</td>
</tr>
<tr>
<td><strong>ERHXI</strong></td>
<td>Enhanced Resolution Hard X-ray Imager, Spatial resolution: 7 to 20 µm Field of view 0.5 or 1.5 mm</td>
<td>Imploded core image</td>
<td>SID</td>
<td>2019</td>
</tr>
<tr>
<td><strong>HRXS</strong></td>
<td>High Resolution X-ray Spectrometer, Spatial resolution: 10 or 100 µm Field of view 0.5 or 5 mm</td>
<td>NLTE spectroscopy Spectral opacities</td>
<td>SID</td>
<td>2019</td>
</tr>
<tr>
<td><strong>Neutron Pack</strong></td>
<td>Neutron Counting, flying time for Ti, bang time</td>
<td>First fusion reactions</td>
<td>Chamber</td>
<td>2019</td>
</tr>
</tbody>
</table>
## UPXI – LPXI, Upper – Lower Polar X-ray Imagers

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range</th>
<th>Spatial resolution (µm) / Field of view (mm)</th>
<th>Time resolution (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 pinhole channel</td>
<td>&gt; 3 keV</td>
<td>80 / 12 to 65 / 5</td>
<td>without</td>
</tr>
<tr>
<td>Passive detector Magnif. = 2 to 5</td>
<td>CID detector</td>
<td>80 / 50 to 65 / 25</td>
<td></td>
</tr>
<tr>
<td>Image Plate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optional camera Magnif. = 6</td>
<td>Streak camera</td>
<td>65 / 2</td>
<td></td>
</tr>
<tr>
<td>Framing camera</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Time-integrated 2D image, or optionally time-resolved 2D or 1D image, in the hard X-ray spectral region.
- Dedicated to pointing precision of LMJ laser beams
- 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).
- Available with time-integrated detectors and time-resolved detectors (X-ray streak camera operating with a temporal resolution of 50 ps or ARGOS framing camera).
### Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Measurement or Spectral range (nm)</th>
<th>Spatial resol. / Field of view</th>
<th>Time resol. (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brillouin spectrometer Δλ &lt; 0.05 nm</strong></td>
<td>346 - 356</td>
<td></td>
<td>50 / 5 to 250 / 25</td>
</tr>
<tr>
<td><strong>Raman spectrometer Δλ &lt; 5 nm</strong></td>
<td>375 - 750</td>
<td>without</td>
<td>Without / 5 to 25</td>
</tr>
<tr>
<td><strong>Time integrated calibration spectrom.</strong></td>
<td>350 - 700, 375 - 750</td>
<td></td>
<td>250 / 25</td>
</tr>
<tr>
<td><strong>3 Brillouin power channels</strong></td>
<td>&lt; 360</td>
<td></td>
<td>500 / 25</td>
</tr>
<tr>
<td><strong>2 Raman power channels</strong></td>
<td>350 - 750</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1, 2, 3w power channels</strong></td>
<td>1053, 526, 351</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- 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 sent to the Raman-Brillouin spectrometer.
NBI, Near Backscatter Imager

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range (nm)</th>
<th>Spatial resol. (µm) / Field of view (mm)</th>
<th>Time resol. (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Brillouin power channels</td>
<td>346 - 356</td>
<td>without</td>
<td>250 / 25</td>
</tr>
<tr>
<td>2 Raman power channels</td>
<td>375 - 750</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brillouin image</td>
<td>346 - 356</td>
<td>Angle: 2° / 16°</td>
<td></td>
</tr>
<tr>
<td>Raman image</td>
<td>375 - 750</td>
<td>Angle: 2° / 16°</td>
<td></td>
</tr>
</tbody>
</table>

- 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.
**ERHXI, Enhanced Resolution Hard X-ray Imager**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range</th>
<th>Spatial resolution (µm) / Field of view (mm)</th>
<th>Time resol. (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnification = 12</td>
<td>0.5 - 11 keV</td>
<td>7 / 0.7</td>
<td>50 / 20</td>
</tr>
<tr>
<td>8 time-resolved bi-toroidal mirror channels</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Time-resolved 2D image in the hard X-ray spectral region with a high spatial resolution.
- Microscope with large source-to-optic distance and a new gated MCP (new ARGOS detector).
- The microscope includes eight X-ray channels, each consisting of 0.6° grazing angle-of-incidence bi-toroidal mirrors and a filter.
- This imager must include a film protective holder to protect optical components from damages.
### HRXS, High Resolution X-ray Spectrometer

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Spectral range (resol. E/ΔE)</th>
<th>Spatial resol. (μm) / Field of view (mm)</th>
<th>Time resolution (ps) / Dynamic (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slit magnification = 3</td>
<td>1 – 15 keV (~ 500)</td>
<td>70 (1D) / 5</td>
<td>110 - 130 / 20 without</td>
</tr>
<tr>
<td>4 time-resolved crystal channels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 x 3 time-integrated crystal channels (CID)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Atomic physics (NLTE spectroscopy and opacity measurements). The central body is associated with the framing camera ARGOS (4 channels).
- 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.
- The front end of the spectrometers includes a snout with collimation slits and a debris shield made of three filter rolls.
Neutron Pack, Activation and nTOF diagnostics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Yield (neutrons)</th>
<th>Spatial resolution / Field of view</th>
<th>Time resolution (ps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activation</td>
<td></td>
<td></td>
<td>without</td>
</tr>
<tr>
<td>Gated PMT + scintillator</td>
<td>$D_2 : 10^9$ to $10^{15}$</td>
<td>without</td>
<td>without</td>
</tr>
<tr>
<td>Photodiode</td>
<td>$DT : 10^9$ to $5.10^{18}$</td>
<td>without</td>
<td>50</td>
</tr>
<tr>
<td>CVD diamonds</td>
<td></td>
<td></td>
<td>(Timing accuracy)</td>
</tr>
</tbody>
</table>

- Neutron yield, ion temperature, neutron bang time and ratio of secondary to primary neutron reactions during $D_2$ and $DT$ implosions.
- Several neutron Time of Flight detectors (nTOF: Gated photomultiplier tubes and scintillators, photodiodes, CVD diamonds) and activation (indium, copper, zirconium, etc.).
- These diagnostics will be installed in several stages.
## Plasma diagnostics planned after 2019

<table>
<thead>
<tr>
<th>Name</th>
<th>Characteristics</th>
<th>Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSXI</td>
<td>Gated Soft X-ray imager, medium field</td>
<td>Radiation transport</td>
</tr>
<tr>
<td>SRSXS</td>
<td>Spatially Resolved Soft X-ray spectrometer</td>
<td>Spectral opacities</td>
</tr>
<tr>
<td>2nd miniDMX</td>
<td>2nd MiniDMX adapted to measures of secondary cavities in nuclear environment</td>
<td>Tr secondary cavity Radiation transport:</td>
</tr>
<tr>
<td>FABS Q29H</td>
<td>Full Aperture Backscatter System on Quad29</td>
<td>Energy balance Interaction</td>
</tr>
<tr>
<td>SHXI-2</td>
<td>Streaked Hard X-ray Imager 2</td>
<td>Implosion dynamics</td>
</tr>
<tr>
<td>Thomson scattering</td>
<td>4 or 5ω probe beam</td>
<td>Characterization of plasma conditions in a cavity</td>
</tr>
<tr>
<td>GXI-3</td>
<td>Gated X-ray Imager 3 High resolution, improved temporal resolution</td>
<td>Implosions final phase</td>
</tr>
<tr>
<td>SRHXS</td>
<td>Spatially Resolved Hard X-ray Spectrometer Improved temporal resolution</td>
<td>Final implosion conditions analysis Mixing effects</td>
</tr>
<tr>
<td>Neutrons Pack 2</td>
<td>Neutron production history Directional measures</td>
<td>Neutron measurements enrichment rho-r / n(t) asymmetry</td>
</tr>
</tbody>
</table>
PETAL+ Project: Plasma Diagnostics for PETAL experiments

Inserters:
- Derived from LMJ SID (diagnostics compatibility)
- The first one is qualified

Electron spectrometer
- Magnetic spectrometer: 5 - 150 MeV
- Two modules on the chamber wall (0° and 45°/PETAL)
- Delivery: 2016

Hard X-ray spectrometer
- Transmission crystals (x2: Quartz, LiF): 15 – 100 keV
- Shielding: high energy X-ray and particles (magnets)
- Delivery: 2016

Charged particles diagnostic
- Proton spectroscopy & Imaging (proton-radiography)
  - 100 keV-200 MeV
- Electron spectroscopy
  - 100 keV – 150 MeV
- Two Thomson parabolas + Image Plate
- Delivery: 2017
2nd European Conference on Plasma Diagnostics
Bordeaux, France
18th – 21st April 2017

ECPD-conference aims at promoting cross-fertilisation between scientist experts in diagnostics from all fields in plasma physics. This is the 2nd conference in the series. ECPD is organised in alternate years with respect to the HTPD-conference in USA.

Topics and Scientific Committee

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

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

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

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

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

EPS endorsement pending

More information available at:
https://ecpd2017.sciencesconf.org
PETAL is a part of the opening policy of CEA
- It will be dedicated to the scientific community

PETAL was supported by

The coupling of PETAL with LMJ is an opportunity to study a wider field of physics

PETAL goals
- Energy: up to 3 kJ *
- Wavelength: **1053 nm** (526 nm option)
- Pulse duration: from 0,5 to 10 ps
- Intensity on target: \ (~ 10^{20} \text{ W/cm}^2
- Power contrast: \ 10^{-7} \text{ at -7 ps}
- Energy contrast: \ 10^{-3}

LMJ (1 beam)
- Energy: up to 7.5 kJ (x 176 = 1,3 MJ)
- Wavelength: 351 nm
- Pulse duration: from 0,3 to 25 ns
- Intensity on target: \ (~ 10^{15} \text{ W/cm}^2

* limited at the beginning to 1 kJ due to the limited damage threshold of the transport mirrors
First high energy shots in May 2015:
1,2 PW - 846 J / 700 fs

Experimental results May 29th

- PAM output profile
- Amplifier output
- Compressor output

20.3 mJ  
1,24 kJ  
846 J

Spatio-temporal profiles at compressor output

700 fs
(synchronization ~ 100 fs)

deep

Qualification is going on:

- Compression optimization: 570 fs 😊
- New diagnostics installed:
  - Contrast, focal spot, phase, ...
  - First contrast measurements: $10^{-6}$ @ -200 ps 😊 => 2w option to be considered
- Wave front correction (toroidal mirror) => better focal spot
- Spatial uniformity will be upgraded
- The filling of sub-aperture will be improved

=> 1.2 PW record
The LMJ beamlines: most of the components have been qualified on the LIL prototype

- Square shape 37 cm x 35 cm
- 4 pass amplification
- Converted to 351 nm (3w)
- Focusing by gratings

Amplification Section
- 4 pass amplifiers
- Spatial Filters
- Angular multiplexing

Transport, Frequency conversion and focusing
- Frequency conversion & focusing system
- Phase plate
- Transport mirrors

Target Chamber
- 1 & 2w beam dump
- Window + debris shield

Regenerative Section
- 1 nJ
- 10 mJ
- 500 mJ

Amplifier
- 15 kJ

Front end
- Source
- Regenerative cavity
- Deformable mirror
- PEPC (plasma electrode Pockels Cell)

M1
- 125 m

SCF
- 7.5 kJ UV
- 50 µm
- 15 ps