The diagnostics of the PETAL+ project

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June 29-30, 2016
PETAL and the PETAL+ project

- **Energy**: ~1kJ short term (3,5kJ long term)
- **Wavelength**: 1053 nm (526 nm option)
- **Pulse duration**: from 0.5 to 10 ps
- **Focal length**: 7.8 m (focal spot ~50 µm)
- **Intensity on target**: ~ $10^{20}$ W/cm²
- **Temporal contrast**: $10^{-7}$ at -7 ps
- **Energy contrast**: $10^{-3}$

A secondary source for:
- X-ray or proton radiography,
- Additional heating of the LMJ target
- Magnetic field characterization,
- Electronic transport experiments,
- …

**PETAL+ project goal**: Construction of 3 new diagnostics to characterize the particle source produced by the interaction of PETAL with a target

- A. Casner et al., HEDP, **17**, (2014)

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Expected particle beams with PETAL

Particle source simulations with PICLS (E. d’Humières)

<table>
<thead>
<tr>
<th></th>
<th>X-rays</th>
<th>Electrons</th>
<th>Protons (H⁺)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>7 – 100 keV</td>
<td>5 – 150 MeV</td>
<td>0.1 – 150 MeV</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>1/300*</td>
<td>1/20</td>
<td>1/10</td>
</tr>
</tbody>
</table>

*Kα₁ and Kα₂ lines must be separated

**Passive detectors** with a high dynamic range must be used!!!
e.g. Imaging Plates, RCF and CR39 (long term)
SPECTIX

a X-ray spectrometer
Physical concept of the X-ray spectrometer

Geometrical setup

Exemple of a raw spectrum obtained with LCS at LULI

A Cauchois-type hard X-ray spectrometer…

- … which is robust and easy to align
- … that covers a wide spectral range
- … with reduced background noise

X-ray dispersion according to the Bragg’s law:

\[ 2d \sin \theta = n\lambda \]
The SPECTIX design

SPECTIX : Spectromètre PEtal à Cristal en Transmission X

*(PEtal Spectrometer using a X-ray Transmission Crystal)*

**Distances:**
- Total length: 1600 mm
- TCC – crystal: 793 or 843 mm

Inserted in the LMJ chamber via a SID
Characteristics of the spectrometer module

**Spectrometer module**

- Crystal holder $R_c = 125\text{mm}$
- Crystal holder $R_c = 250\text{mm}$
- Filter holder

**Characteristics of the 3 crystals**

<table>
<thead>
<tr>
<th>Crystal type</th>
<th>2d [Å]</th>
<th>$R_c$[mm]</th>
<th>Dimensions [mm²]</th>
<th>Target-Crystal distance [mm]</th>
<th>Spectral range [keV]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz (10(\bar{1})0)</td>
<td>8.512</td>
<td>125</td>
<td>50 x 30</td>
<td>843</td>
<td>6.3 to 31</td>
</tr>
<tr>
<td>Quartz (10(\bar{1})1)</td>
<td>6.687</td>
<td>250</td>
<td>50 x 30</td>
<td>793</td>
<td>14.2 to 117</td>
</tr>
<tr>
<td>LiF (200)</td>
<td>4.027</td>
<td>250</td>
<td>50 x 30</td>
<td>793</td>
<td>23.5 to 190</td>
</tr>
</tbody>
</table>

- Enhanced spectral range thanks to a versatile detector positioning and the use of 3 different crystals
- Crystals’ reflectivities fully characterized
Remaining background noise removal using the magnet module

The magnet geometry

- Collimation plate
  - W, thick.: 20mm
- Magnet holder
  - Soft iron
- FeNdB magnets
  - 42mmx31mm
- Rear plate

Resulting magnetic field:
- 0.5T (front)
- 0.25T (rear)

3D modeling of the noise removal using Geant4 simulations

Without magnet

With magnet

Experimental validation at LULI2000


Geant4 simulations well reproduce the remaining background noise often observed experimentally.

This background noise is produced by the incoming charged particles that pass through the slit (especially electrons).

Results (Simulations + experiment) show that the use of a magnet in front of the spectrometer allows to considerably reduce this noise.
The SPECTIX performances

<table>
<thead>
<tr>
<th>REQUIRED</th>
<th>SPECTIX</th>
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<tr>
<td>Spectral range</td>
<td>7 – 100 keV</td>
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<tr>
<td>Spectral resolution</td>
<td>1/300*</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>$10^{10} – 10^{13}$ ph/sr (over the whole spectral range)</td>
</tr>
</tbody>
</table>

*Kα₁ and Kα₂ lines must be separated

**Available in 2017 for experiments**
SESAME
the electron spectrometer
Physical concept of the SESAME spectrometer

Lorentz force: $F_L = q(\vec{v} \times \vec{B})$

![Diagram showing the physical concept of the SESAME spectrometer.](image)

### Dispersion equation

$E_{kin} = \frac{q^2 e^2 L_m^2 B^2 (D_m + \frac{L_m}{2})^2}{2mX^2}$

- $L_m$: Magnets length
- $D_m$: Drift distance between magnets and detector
- $m$: Particle mass
The SESAME design

SESAME: Spectromètre ElectronS Angulaire Moyennes Energies

Directly mounted on the LMJ wall chamber

Adaptation, collimation and W shielding

Spectrometer module

Detector module

Side IP holders

Rear IP holder

Magnetic dipole + shielding

Slit adjustment system

Adjustable slit (0.5, 2 or 5 mm)

W shielding (10 plates of 10 mm thick, spaced by 1 mm)

Adaptation flange (DN500)

~1 m
to the TCC

B. Vauzour | CEA - NNSA Joint Diagnostic Meeting | June 28-29, 2016
Characteristics of the spectrometer module

B field modelling with OPERA 3D

Magnetic dipole characteristics

<table>
<thead>
<tr>
<th>B field [T]</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnet material</td>
<td>NdFeB (N45)</td>
</tr>
<tr>
<td>Magnet holder material</td>
<td>Soft iron</td>
</tr>
</tbody>
</table>

Geant4 simulation of a typical electron trace obtained with SESAME (side IP)
## The SESAME performances

<table>
<thead>
<tr>
<th>REQUIRED</th>
<th>SESAME</th>
</tr>
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<tbody>
<tr>
<td>Spectral range</td>
<td>5 – 150 MeV</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>1/20 (5%)</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>$10^8 – 10^{15}$ e⁻/MeV/sr (over the whole spectral range)</td>
</tr>
</tbody>
</table>

Available in 2017 for experiments
SEPAGE

the proton and electron spectrometer
Physical concept of the Thomson Parabola (TP)

Lorentz force: \( \vec{F}_L = q(\vec{E} + \vec{v} \times \vec{B}) \)

Due to the Lorentz force:
- Energy dispersion along the X-axis due to \( \vec{B} \)
- q/m dispersion along the Y-axis due to \( \vec{E} \)

Example of TP raw spectra

\[
Y = \frac{A m L_e E \left(D_e + \frac{L_e}{2}\right)}{q e L_m^2 B^2 \left(D_m + \frac{L_m}{2}\right)} X^2
\]

- \( L_e \): Electrodes length
- \( L_m \): Magnets length
- \( m \): Particle mass
- \( A \): Atomic weight
- \( D_e \): Drift distance between electrodes and detector
- \( D_m \): Drift distance between magnets and detector
The SEPAGE design

SEPAGE: Spectromètre Electrons Protons À Grandes Energies
(High Energy Electrons and Protons Spectrometer)

Total length of SEPAGE
(Radiography cassette stretched out)
2,88m

Inserted in the LMJ chamber via a SID
Characteristics of the two Thomson Parabola

<table>
<thead>
<tr>
<th>TP</th>
<th>High energy</th>
<th>Low energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>B field [T]</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Magnet dimensions [mm³]</td>
<td>6x52x100</td>
<td>3x40x104</td>
</tr>
<tr>
<td>E field [kV/mm]</td>
<td>5</td>
<td>2.6</td>
</tr>
<tr>
<td>Electrode dimensions [mm³]</td>
<td>2x100x240</td>
<td>2x30x40</td>
</tr>
<tr>
<td>Pinhole dimensions</td>
<td>500 µm x 40 mm</td>
<td>200 µm x 4 mm</td>
</tr>
<tr>
<td>Proton range [MeV]</td>
<td>10 – 200</td>
<td>0.1 – 20</td>
</tr>
<tr>
<td>Electron range [MeV]</td>
<td>8 – 150</td>
<td>0.1 – 20</td>
</tr>
<tr>
<td>Dynamic [MeV⁻¹sr⁻¹]</td>
<td>10⁸ – 10¹⁴</td>
<td>10⁸ – 10¹⁶</td>
</tr>
<tr>
<td>Field of view</td>
<td>~10 mm (4,2mrad)</td>
<td>~2,3 mm (1,25mrad)</td>
</tr>
</tbody>
</table>

Raw TP spectra expected with SEPAGE (Rear IP)
The radiography cassette

Radiography cassette setup

Stack composed of RCF and filters of various thicknesses and materials

Geant4 simulations of dose deposition inside a stack of 20 RCF

- Proton range: 3 – 200 MeV
- Film diameter: 95 mm
- Adjustable distance to TCC (min 100 mm)
- Various type of RCF to cover the whole dynamic range
- Stack design adaptable to experiments
The SEPAGE performances

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<tr>
<td>Dynamic range</td>
<td>$10^6 – 10^{15}$ p$^+$/MeV/sr (over the whole spectral range)</td>
</tr>
</tbody>
</table>

Radiography cassette (CRACC) available in 2017 for experiments
Spectrometer (TP) available in 2018
Overview of the PETAL+ diagnostics

Two Electron spectrometers
SESAME

PETAL axis

PETAL target

Normal to the target

Electron emission: ± 40° from PETAL axis

Proton emission: ± 20° from the normal to the target

Hard X-ray spectrometer
SPECTIX

Charged particle spectrometer: protons-ions-electrons
SEPAGE

LMJ chamber equatorial plane
Calibration of the detectors
Absolute X-ray calibration of the Imaging Plate

3 different types of IP

- SR
- MS
- TR

X-ray source $^{55}$Fe + fit

$f(t) = A_1 e^{-t/B_1} + A_2 e^{-t/B_2}$

Exp + Geant4 simulations

Fading correction

Normalized fading functions versus time


IP response as a function of the X-ray energy

Absolute calibration of the 3 different IP for X-rays in the 1-100keV range

Good agreement between Geant4 simulations and experimental results

The present model allows to extend the calibration up to MeV energies

Absolute calibration for protons and electrons have also been realized

Absolute calibration of the RCF

Experimental setup on the 4MV accelerator (CEA/DIF Van de Graaff)

RCF response to protons versus exposure time

Optical density

Dose [Gy]

HD-V2

EBT-3

EBT-XD

Canal Rouge
Canal Vert
Canal Bleu
Fit Canal Rouge
Fit Canal Vert
Fit Canal Bleu

Dose [Gy]

Dose [Gy]

Dose [Gy]
Summary

- The PETAL+ project ⇒ construction of 3 new diagnostics to detect and characterize the particle produced by PETAL
  - An X-ray spectrometer: SPECTIX
  - An Electrons spectrometer: SESAME
  - An Electrons/Protons/Ions spectrometer: SEPAGE + Radiography cassette (CRACC)

- **SPECTIX, SESAME** and **CRACC** are under construction and will be available in **2017**
- **SEPAGE** will be available in **2018**
- Absolute calibration of the new RCF generation (HD-V2, EBT3, EBT-XD and MD-V3) is in progress
Collaborators


**CEA-DAM-CESTA**: F. Granet, S. Noailles


**LULI**: S. Bastiani-Ceccotti, E. Brambrink J. Fuchs, M. Koenig, J.R. Marquès

**LKB**: C. Szabo

**CEA-DSM-IRAMIS**: T. Ceccotti, S. Dobosz-Dufrénoy

**CELIA**: D. Batani, G. Boutoux, J.E. Ducret, S. Hulin, E. D’Humières, K. Jakubowska, N. Rabhi

**CENBG**: L. Sérani
Thank you!!!
Crystal reflectivities and spectrometer resolution

Integrated reflectivities

Spectrometer resolving power (with IP SR)

\[ E^{K\alpha_1}/(E^{K\alpha_1} - E^{K\alpha_2}) \]
The detector holders
Geant4 simulations of electron deviation in the presence of the front magnet

Magnetic field: 0.5 T parallel to the X-axis (horizontal), length: 50 mm.

All the electrons with E<100 MeV are deviated before the crystal.
How to get back detectors which are under confinement?

**Needs:** get back/replace films between two shots.

**Constrains:**
- maintain the continuity of the confinement
- vacuum limit of the LMJ chamber
- being able to see what we are doing
- resist to the nuclear ventilation system
- adapted to the arm length

**Solution:**
- Use of the DPTE (Vacuum proof double doors transfer system)
- The solid part is vacuum compatible
- Flexible transparent film
- Deformable structure

Prototype is under construction (CESTA/DLP) and will be implemented on the front window of the SID+ for SPECTIX and SEPAGE, and at the rear of SESAME.