Status of the FERMI@Elettra Project

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OUTLINE

- FERMI@Elettra Overview
- Facility Performance
- Recent Progress
- Outlook and Conclusions
FERMI@Elettra
OVERVIEW
FERMI@Elettra

FERMI FEL:
80 – 4 nm SEEDED HGHG

Elettra Synchrotron Light Source, Trieste, ITALY:
up to 2.4 GeV, top-up mode

FERMI buildings and infrastructure construction:
2008-2010
Scientific Case

The three Scientific Programs are:

- **Low Density Matter (LDM)**
  - Structure of nano-clusters: brightness
  - High resolution spectroscopy: narrow bw, $\lambda$-tunability
  - Ionization dynamics: circular polarization
  - Catalysis in nano-materials: fs pulse and stability

- **Elastic and Inelastic Scattering (EIS)**
  - Transient Grating Spectroscopy (collective dynamics at the nano-scale): Transform Limited Bandwidth
  - Pump & Probe Spectroscopy (including ultra-fast magnetization dynamics): brightness, $\lambda$-tunability

- **Diffraction and Projection Imaging (DiProl)**
  - Single-shot Coherent Diffraction Imaging (bio and solid state structures)
  - Resonant CDI (chemical and magnetic imaging)
  - Time-resolved CDI (morphology and internal structure at the nm scale): Brightness, $\lambda$-tunability, circular polarization
Fermi Concept

Seeded FEL user facility, designed to produce fundamental output wavelengths from 80 nm down to 4 nm with High Gain Harmonic Generation.

FEL photon beam
- high peak power (>GWs), short pulse length (<100 fs)
- full spatial and temporal coherence
- APPLE II-type undulators with variable gap, variable polarization and tunable wavelength (80-4 nm)

LINAC
1.5 GeV - 3 GHz
18 normal conducting accelerating sections

UV seed laser

bunch compression
<1 ps electron bunches

photo-cathode GUN
High Brightness electron beam
50 Hz repetition rate

electron beam dump

 Courtesy E. Allaria

Reference A. NELSON
Machine Layout

Linac Tunnel

- 100 MeV
- 300 MeV
- 800 MeV
- 1.2 GeV
- 1.5 GeV

Undulator Hall

- Spreader
- 1.2 GeV
- 1.5 GeV
- Delay Line
- FEL-1
- FEL-2
- Modulator Undulator
- Radiator Undulator
- Main Beam Dump
- To the Beamlines

Experimental Hall

- Slits
- I/O Monitors & Gas Cells
- PADReS
- Photon Analysis
- Delivery and Reduction System
- EIS
- DIPROI
- Diffraction and Projection Imaging
- LDM
- Low Density Matter

Commissioning started in 2012
# Machine Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FEL- 1*</th>
<th>FEL -2</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength</td>
<td>80-20</td>
<td>20-4</td>
<td>nm</td>
</tr>
<tr>
<td>Electron Beam Energy</td>
<td>1.2</td>
<td>1.5</td>
<td>GeV</td>
</tr>
<tr>
<td>Bunch Charge</td>
<td>0.5 – 0.8</td>
<td></td>
<td>nC</td>
</tr>
<tr>
<td>Peak Current</td>
<td>600 – 900</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Bunch Length (FWHM)</td>
<td>600</td>
<td></td>
<td>fs</td>
</tr>
<tr>
<td>Norm. Emittance (slice)</td>
<td>≤1.2</td>
<td>≤1.0</td>
<td>mm mrad</td>
</tr>
<tr>
<td>Energy Spread (slice)</td>
<td>≤250</td>
<td>≤150</td>
<td>keV</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>10 – 50 (2013)</td>
<td></td>
<td>Hz</td>
</tr>
<tr>
<td>Peak Power</td>
<td>1-5</td>
<td>&gt;0.3</td>
<td>GW</td>
</tr>
</tbody>
</table>

* achieved on FEL-1
FACILITY PERFORMANCE
FEL-1 Milestones 2010-2011

September 2010
Linac energy 1.2 GeV

December 2010
First FEL-1 Coherent Harmonic Generation

July 2011
FEL-1 Gaussian mode and exponential gain

FEL spectrum @ 43 nm
- Single narrow emission
- Width is few tens of meV
500 consecutive spectra acquired for FEL -1 operated at 52 nm (5\textsuperscript{th} harmonic of the seed laser)

- **Wavelength fluctuations** (black line): 0.006 nm (0.03 %) rms
- **Average bandwidth** (purple lines): 0.03 nm that is close to the Fourier limited for the expected FEL pulse length (<100fs)
- **FEL intensity fluctuation** (red line): about 15 % rms

_Courtesy of E. Allaria, C. Svetina_
With the **FEL optimized** for **on axis** operation exponential **gain** could be measured. The FEL gain has been measured both for **circular** and **planar polarization** showing the expected behavior ($l_g \sim 2.0$ m and 2.5 m).

Measured FEL behavior is in good agreement with FEL simulations using the expected electron beam parameters.
The fine FEL tuning around 52 nm has been achieved by changing the seed laser wavelength of ~1 nm (0.4%). After tuning of the seed laser wavelength, the undulator resonance is changed accordingly, in order to maximize the FEL power.

**LDM – Citius coollaboration**
Resonant absorption line of \( \text{He} \ 1s-4p \) transition around 52 nm. The experiment measures the dependence of the fluorescence signal on \( \lambda_{\text{FEL}} \).

**Tuning the FEL** in a larger spectral range (30-60nm) is done using the Optical Parametric Amplifier on the seed laser. Typical **time needed** for wavelength tuning is about **10 minutes**, much shorter for fine tuning.

\[ \text{Response [arb. u.]} \]

\[ \lambda_{\text{FEL}} [\text{nm}] \]

\[ \lambda_{\text{SEED}, \text{calibrated}} [\text{nm}] \]

*Courtesy of E. Allaria, C. Callegari*
Single shot Coherent Diffraction Imaging experiment performed at DiProI. The reconstruction of a nanolitographic sample of the FERMI@Elettra logo from the diffraction pattern by a computational algorithm is shown here.

First call for proposals

Based on the current performance, a call for proposal has been issued end of 2011, for beamtime in the second semester of 2012. At the deadline (April, 27th) 34 proposals were presented.
RECENT PROGRESS
Commissioning started on 07.05.2012. After few hours, beam heating was observed: 100 keV induced energy spread with 160 MW laser power.

Courtesy of L. Giannessi, G. Penco, S. Spampinati
4th Harmonic system, X-band

- \( \geq 60 \text{ MW} \)
- \( \sim 1 \mu \text{s} @ 50 \text{ Hz} \)

**HV modulator**

**LLRF**

**RF Driver**

- \( P < 1.0 \text{ KW} \)
- \( \Delta \phi \leq 0.4^\circ X \)
- \( \Delta V \leq 0.5\% \)

*About 2 months activation time*

*See also G. D’Auria et al., TUPPP054 and THPPC054*
When X-band is **ON**, RF instabilities enhance the beam energy jitter: 380 keV (rms) when setting the phase at $-\pi/2$ (decelerating). This induces strong jitter in the compression factor. X-band LLRF set-up is not yet final, upgrade work in progress.
May 18th: FEL-2 1st CHG!

April 2012: FEL-2 undulators installation in the tunnel

February 2012: 100% e-beam transport to the Beam Dump

Friday May 18th, 2012: first Coherent Harmonic Generation from FEL-2 first stage, at 52 nm.

April 2012: FEL-2 undulators installation in the tunnel

May 18th: FEL-2 1st CHG!
OUTLOOK and CONCLUSIONS
Future Plans

**FEL-1**
- **2012**: attain **nominal performance** after the **X-band System**, the **Laser Heater** and the **Second Bunch Compressor** are operational.
- **2013**: upgrade **linac** to **50 Hz** and increase energy to **1.5 GeV**.
  - Stable and reliable operation for users established.

**FEL-2**
- **2012**: prove **double cascade HGHG** at **17 nm** (**1.2 GeV**), including FEL optimization using the fresh part of the bunch in the second stage.
- **2013**: complete the commissioning of FEL-2, down to **4 nm** (**1.5 GeV**).

**Experimental programs**
- **2012**: Provide part of the seed laser as **user laser** for **pump and probe** experiments. Expected relative jitter to FEL Pulses < 5 fs rms.
  - **Start the Users’ program** on **FEL-1** in autumn.
- **2013**: first test experiments with **FEL-2**.
  - Start-up **EIS-TIMER**, the fourth beamline now in construction.
CONCLUSIONS

- FEL-1 reached fairly intense photon fluxes, producing routinely 20-30 μJ, which corresponds to a factor 3 to 5 less than the final goal. However, this is achieved with reduced peak current.

- Good single shot spectra are obtained, showing single narrow emission of few tens of meV. Bandwidth and wavelength stability are very good. FEL tunability and variable polarization are routinely used.

- The above mentioned results have been obtained with a still evolving machine. Commissioning of the X-band cavity and of the Laser Heater started only recently.

- 34 proposals received in answer to the first Call for Users’.

- The two main goals for 2012 are:
  - on FEL-1: to start operation for Users
  - on FEL-2: to demonstrate double cascade HGHG
Elettra is organizing a workshop on “Seeding and Self-Seeding at New FEL Sources”

Dates: 10-11 December 2012

Venue: Adriatico Hotel, Trieste

More soon

www.elettra.trieste.it
Acknowledgement

See also other two posters reporting on FERMI at IPAC 2012:

G. Penco et al., MOEPPB014
“Time Jitter Measurements in Presence of a Magnetic Chicane in the FERMI Linac”

E. Ferrari et al., TUPPP063
“Electron-beam Optimization Studies for the FERMI FEL”

E. Allaria, L. Badano, S. Bassanese, F. Bencivenga, E. Busetto, C. Callegari,
F. Capotondi, D. Castronovo, M. Coreno, P. Craievich, I. Cudin, M. Dal Forno,
M.B. Danailov, G. D’Auria, R. De Monte, A. Demidovich, G. De Ninno,
M. Di Fraia, S. Di Mitri, B. Diviacco, A. Fabris, R. Faris, W.M. Fawley,
M. Ferianis, E. Ferrari, L. Fröhlich, P. Furlan Radivo, G. Gaio, R. Gobessi,
C. Grazioli, E. Karantzoulis, M. Kiskinova, M. Lonza, B. Mahieu, C. Masciovecchio,
S. Noè, F. Parmigiani, G. Penco, E. Principi, F. Rossi, L. Rumiz, C. Scafuri,
S. Spampinati, C. Spezzani, C. Svetina, M. Trovò, A. Vascotto, M. Veronese,
R. Visintini, M. Zaccaria, D. Zangrando, M. Zangrando

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THANK YOU FOR YOUR ATTENTION