Commissioning and Initial Operation of FERMI@Elettra FEL

S. Di Mitri, on behalf of the FERMI Team

BERKELEY LAB
LAWRENCE BERKELEY NATIONAL LABORATORY

LBNL, 17 April 2012
Outline

- Project Overview and Achievements
  - Photon Beamlines, Design Goals and Achievements

- e-Beam Commissioning
  - Extraction, Compression, Emittance, Wakefields

- FEL Commissioning
  - Seeding, Optimization, Coherence, Recent Studies

- Users Operation
  - Preliminary Results
FERMI Project Overview & Achievements

Science, Design and Achievements
SINCROTRONE TRIESTE is a nonprofit shareholder company of Italian national interest, established in 1987 to construct and manage synchrotron light sources as international facilities.

**FERMI@Elettra FEL:**
100 – 4 nm, fully funded

- **Sponsors:**
  - Italian Minister of University and Research (MIUR)
  - Regione Auton. Friuli Venezia Giulia
  - European Investment Bank (EIB)
  - European Research Council (ERC)
  - European Commission (EC)

- **Collaborations:**
  - INFN
  - ENEA
  - MIT
  - DESY
  - and many others...

**ELETTRA Synchrotron Light Source:**
up to 2.4 GeV, top-up mode,
768 proposals from 39 countries in 2010

- 200 m Linac Tunnel + Injector Extension
- ~100 m Undulator Hall

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Fermi Photon Beamlines

Elastic and Inelastic Scattering (coord. C. Masciovecchio)
- Transient grating spectroscopy .............. transform-limited bandwidth
- Pump & Probe Spectroscopy, including ultra-fast magnetization dynamics ........ brightness, λ-tunability

Diffraction and Projection Imaging (coord. M. Kiskinova)
- Single-shot CDI (bio and solid state structures)
- Resonant CDI (chemical and magnetic imaging)
- Time-resolved CDI (morphology and internal structure at the nm scale)

Low Density Matter (coord. C. Callegari)
- Structure of nano-clusters ............. brightness
- High resolution spectroscopy ........ narrow bw, λ-tunability
- Ionization Dynamics .................. circular polarization
- Catalysis in nano-materials .......... fs pulse and stability

Head of Science:
Prof. F. Parmigiani

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FERMI is a **single-pass, 10/50Hz, externally seeded FEL facility of soft X-rays**:

- high peak power: 0.3 to GW’s range
- short temporal structure: sub-ps to 10 fs time scale
- tunable wavelength: APPLE II-type undulators
- variable polarization: horizontal/circular/vertical

**peak brilliance**: \(10^{30} - 10^{31}\) ph/sec/mm\(^2\)/mrad\(^2\)/0.1\%bw

**flux**: \(10^{12} - 10^{14}\) ph/pulse

**bandwidth**: \(~\text{Fourier Transform Limit}\)

**FEL SCHEME**

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RF Photo-cathode Gun and Injector + up to 1.35 GeV Linac
- 2 Magnetic Bunch Length Compressors + 2 Bunch Length Monitors
- 2 RF Vertical Deflectors for time-resolved measurements
- 4 Diagnostic Stations + 5 Spectrometers
- 3 Collimation sections
- Planar/APPLE-type Undulators + RF BPMs + γ/e- Screens + EOS + Quad-movers
- Photon Diagnostics Hutch + X-ray Transport + 3 Beamlines
- Still NOT fully commissioned (but already in place): X-band & Laser Heater

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FACILITY ("real")
OTHER MACHINE SYSTEMS...

- **Controls** (news in M. Lonza’s, G. Gaio’s and L. Pivetta’s talk at ICALEPCS 2011)
  - Tango-based
  - Real-time framework
  - Elegant-based on-line optics control
  - MATLAB for Mach. Phys. Applications
  - Scientific Data Management

- **Diagnostics** (see R. De Monte’s talk and “Elettra” contributions at DIPAC 2011)
  - Electro-Optical Sampling
  - Bunch Length Monitor
  - Bunch Arrival Monitor
  - 2µm-res. RF Cavity BPMs
  - Intra-Undulator Screens

- **Timing & Synchronization** (see M. Ferianis’ talk at FEL Conf. 2011)
  - All-optical timing system
  - Synchronization with femtosecond precision

- **Machine Protection System** (see L. Froehlich’s talk at DIPAC 2011)
  - Cerenkov fiber beam loss posit. monitor
  - On-line dosimeter with MOSFETs
  - Ionization chamber beam loss monitor

- **Lasers** (see M. Danailov’ talk at FEL Conf. 2011)
MILESTONES

- PI Laser, Gun & Injector: 2009 – 2.5 months. (2008, first Gun tests at MAX-lab.)

- Linac & First Bunch Length Compressor: 2010 – 3.5 months.

- Transfer Line to Main Beam Dump: 2010 – 1.5 month.

- 1st Coherent Emission at 43 nm: 2010 – 1.5 months. (13 Dec. 2010)

  Coherent X-rays within 9 months after warm-up


- FEL Exponential Gain, Polarization & Tunability: 2011 – 1.5 months.

- 65 – 32.5 nm to LDM, TIMEX & DIPROI Lines: 2011 – 1.5 months.

  First user tests 5 months after 1st coherent output

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DESIGN GOALS & ACHIEVEMENTS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>FEL-1</th>
<th>FEL-2</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output Wavelength (fund.)</td>
<td>80 (65) – 20</td>
<td>20 – 4</td>
<td>nm</td>
</tr>
<tr>
<td>Peak Power</td>
<td>1 – 5</td>
<td>&gt; 0.3</td>
<td>GW</td>
</tr>
<tr>
<td>Energy</td>
<td>1.2 (1.35)</td>
<td>1.5</td>
<td>GeV</td>
</tr>
<tr>
<td>Charge</td>
<td>250 – 800 (500)</td>
<td>800</td>
<td>A</td>
</tr>
<tr>
<td>Peak Current (core)</td>
<td>200 – 800 (350)</td>
<td>800</td>
<td>A</td>
</tr>
<tr>
<td>Slice Norm. Emittance</td>
<td>1.5 – 3.0</td>
<td>1.0</td>
<td>mm mrad</td>
</tr>
<tr>
<td>Slice Energy Spread</td>
<td>~0.20</td>
<td>0.15</td>
<td>MeV</td>
</tr>
</tbody>
</table>

$\Delta t \Delta \nu \approx 1.5 \cdot 0.44 \ (FWHM)$

$\frac{\Delta I}{I} \leq 10\%$

$\frac{\Delta \lambda_0}{\lambda_0} \leq 5 \cdot 10^{-5}$

$\frac{\Delta b_w}{b_w} \leq 3\%$

FEL on YAG

FEL TEM$_{00}$ Gaussian mode.
Up to $10^{13}$ photons per pulse at 43 nm.

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e-Beam Commissioning

Extraction, Compression, Emittance, Wakefields
After UV/Ozone cleaning* routinely implemented at machine start-up: **QE restored.**

**After 2 months operation:** **QE depletion**

The Cu cathode surface is sampled by a 200 μm, 10 μJ laser.

Gaussian spot (r=0.53mm) is the best compromise between cathode surface stress and emittance performance.

* see M. Trovo’ et al., *Workshop on PC for RF Guns*, Lecce, Italy (March 2011).
"CSR"-induced $\varepsilon_x$ growth is minimized by shrinking $\beta_x$ in the 2$^{nd}$ half of BC1. Optics matching is done at each step of RF phasing.*

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* S. Di Mitri et al., PRST-AB 15, 020701 (2012).
The linac transverse wakefields are minimized with scans of beam size vs. trajectory offsets, possibly at different screens.

Modeling of the linac longitudinal wakefields was experimentally benchmarked with 1 MeV accuracy.
Final proj. $\varepsilon_{x,y}$ is important for matching into the undulator, finally for a higher FEL gain. Source of degradation: **CSR, transverse wakefield**. Knob for restore: **optics**.

This has been preserved through Spreader and FEL1 with -l transport matrix*

350pC, 6.5ps BC1 and BC2 at 5°

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SPECIAL DIAGNOSTICS

Cavity BPMs
Res. 1.2 µm • Range ±1.5 mm

Electro-Optical Sampling
Measured jitter 80 fs

Fiber Beam Loss Monitor
Resolution 50 cm

Bunch Arrival Time Mon.
Resolution <20 fs

RADFET Online Dosimetry
Integrating solid-state sensors

Res. 1.2 µm • Range ±1.5 mm

Measured jitter 80 fs

500 pC

F. Rossi, G. Penco

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Courtesy of L. Froehlich, R. De Monte,
M. Veronese, F. Rossi, G. Penco et al.