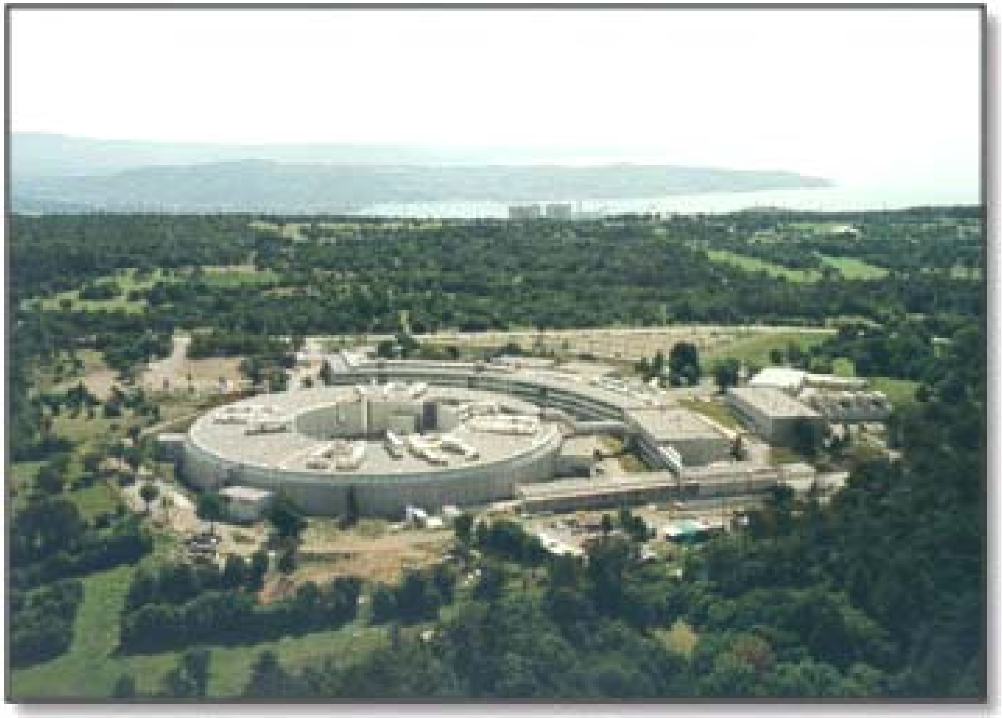
The European FEL at ELETTRA at 1.5 GeV: Towards Compatibility of Storage Ring Operation for FEL and Synchrotron Radiation

Mauro Trovò, Sincrotrone Trieste
on behalf of the Project Team

Outline

1. Elettra Storage Ring
2. European FEL Project
3. e-beam
4. Output Power
5. Laser stability
6. Compatibility
7. An example
8. Conclusions

ELETTRA, Sincrotrone Trieste



Europe's first "third generation" VUV/Soft Xray synchrotron light source

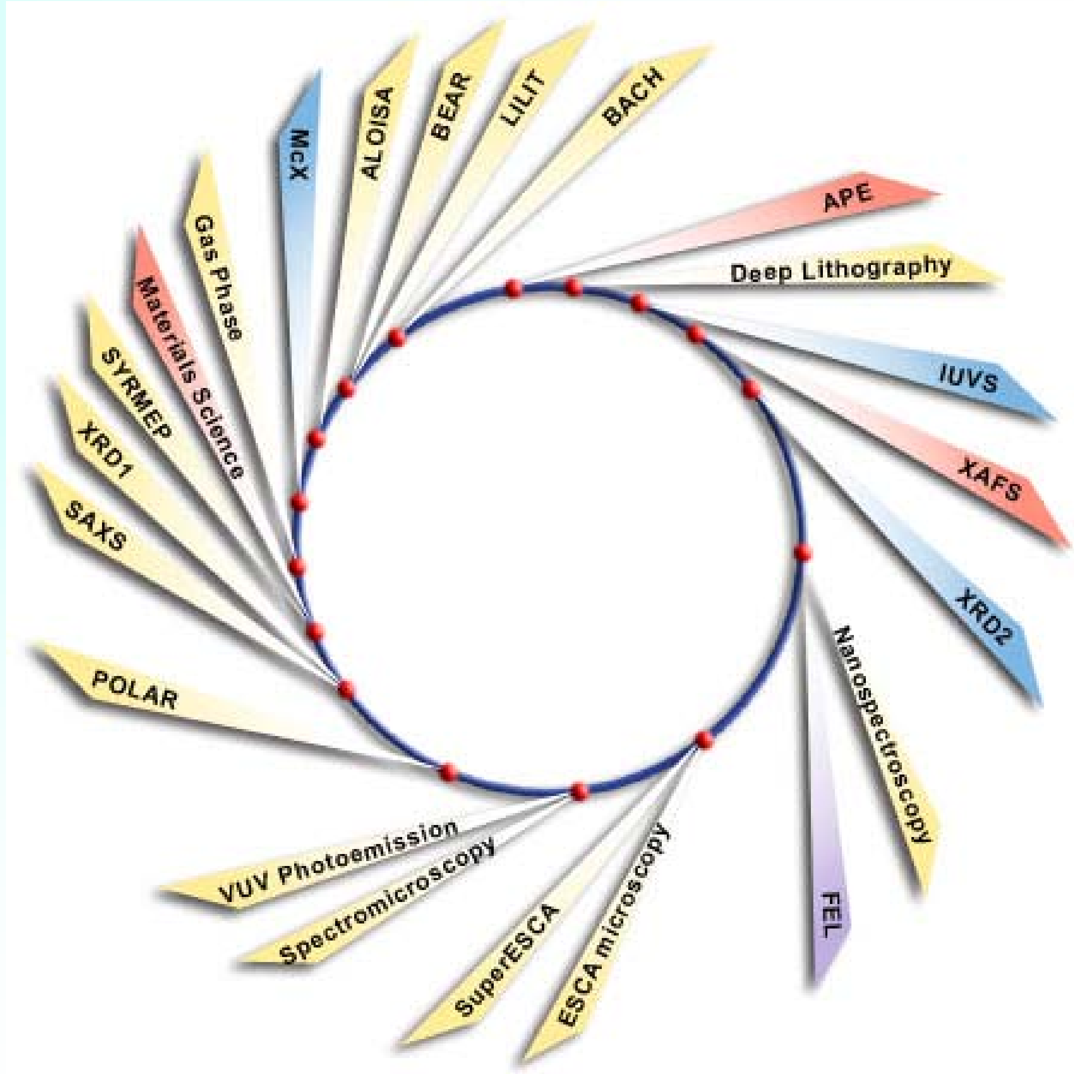
Operational since 1993

Energy: 0.9 ÷ 2.4 GeV

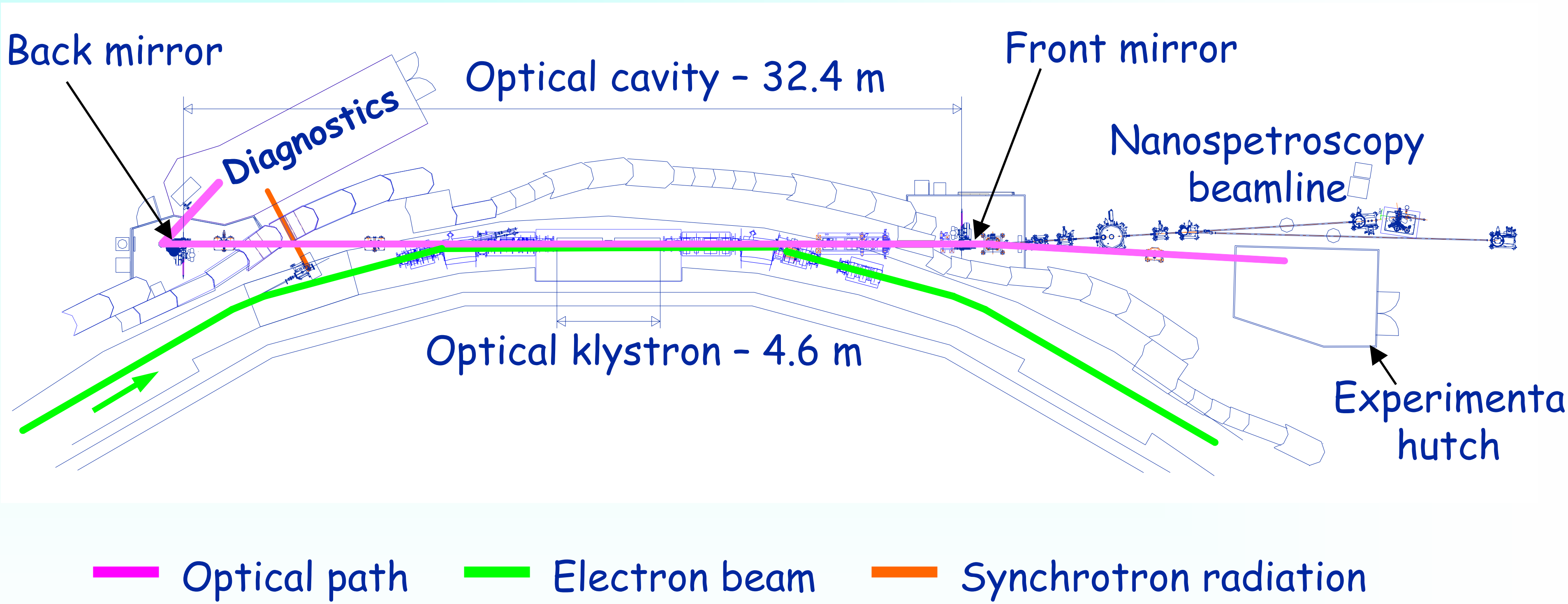
Circumference: 259 m

ELETTRA, Sincrotrone Trieste

- 20 beamlines (used for investigations in materials science, life sciences, physics, chemistry and geology)
- Light range from eV to tens of keV
- Total operating time about 5000 h/year



FEL at Elettra: operational since 2000



Activity milestones

- Oct. 1998: FEL parameters definition
- Aug. 1999: Start of installation
- Feb. 2000: Completion of hardware installation
- Feb. 2000: **First lasing** at 350 nm
- May 2000: Lasing at **220 nm**
- Feb. 2001: Lasing at **190 nm**
- July 2001: **330 mW** extracted power at 250 nm and 0.9 GeV
- Nov. 2001: First operation at **1.3 GeV**
- Mar. 2002: Surface Magnetometry experiment [Herve Cruguel, WS-O-08]
- June 2002: e-beam energy up to **1.5 GeV**
- Aug. 2002: **520 mW** extracted power at 1.3 GeV

EC Project - EUFELE

Partially funded now under EC FP5 contract (No. HPRI-CT-2001-50025):

"Development of the European Free-Electron Laser at ELETTRA as a VUV Research Facility"

Start date: 01/12/01 End date: 30/11/04

	Partners
Sincrotrone Trieste	Italy (coordinator)
CEA/DSM	France
CLRC-Daresbury Lab.	England
CNRS-LURE	France
ENEA-Frascati	Italy
Fraunhofer Institute, Jena	Germany
Laser Zentrum Hannover	Germany

Main Goals

- Develop suitable mirrors in order to reach VUV wavelengths
- Improve FEL beam stability
- Realize a VUV compatible beamline and diagnostics
- Develop experimental equipment and perform initial set of experiments

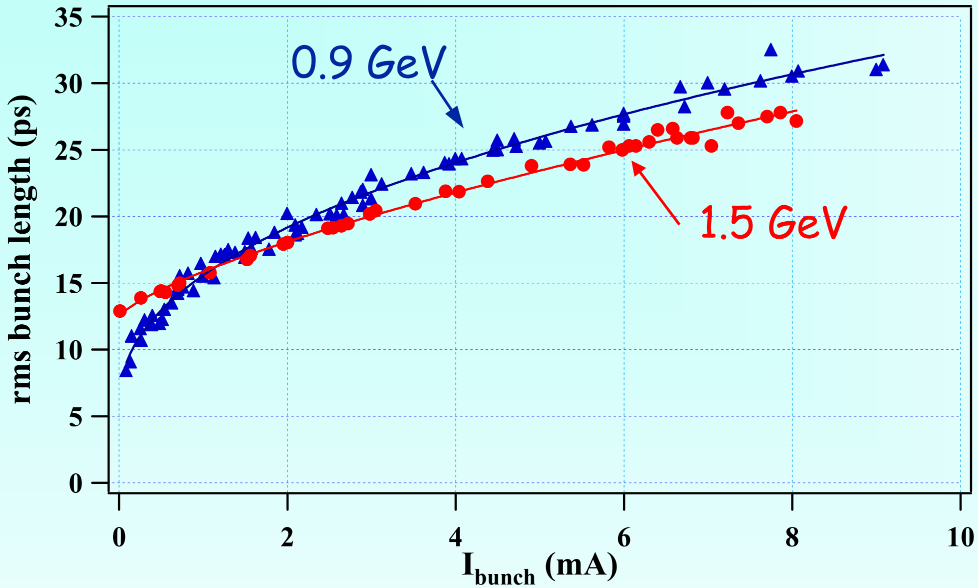
Higher e-beam energy

The **high gain** (up to 20%) and the **robustness** of oxide **mirrors** (400 mAh of dose without degradation effects) allow to increase the operation energy above the 0.9 GeV injection energy

Motivations:

- Enhancement of the extracted power
- Improvement of the beam stability
- Compatibility with other synchrotron radiation users

Electron beam characterization

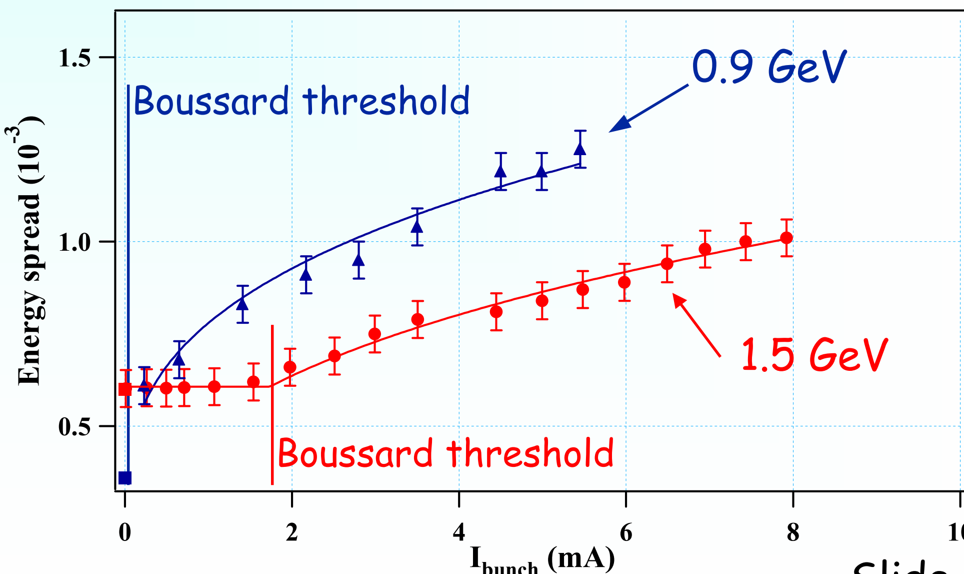


Energy (GeV)	0.9	1.5
$\sigma_\tau^{natural}$ (ps)	5.45	11.5
σ_τ^{max} (ps)	33	28

Microwave instabilities are less important at high energy

Energy (GeV)	0.9	1.5
$\sigma_\gamma^{natural}$ 10^{-3}	0.36	0.6
σ_γ^{max} 10^{-3}	1.3	1.0
$I_{Boussard}$ (mA)	0.16	1.8

At 1.5 GeV the Boussard threshold becomes close to the laser threshold



Output power

- Renieri Limit

$$P_{FEL} = 8\pi \cdot \underbrace{T/\Gamma}_{Mirrors} \underbrace{(N+N_d)\, f \cdot \left[\left(\sigma_\gamma{}^{on}\right)^2 - \left(\sigma_\gamma{}^{off}\right)^2 \right]}_{Fel\ equilibrium} \cdot \underbrace{P_{SR}}_{Ring}$$

T = transmission

Γ = total losses

$N + N_d$ = effective number of periods

f = modulation rate

σ_γ = normalized energy spread

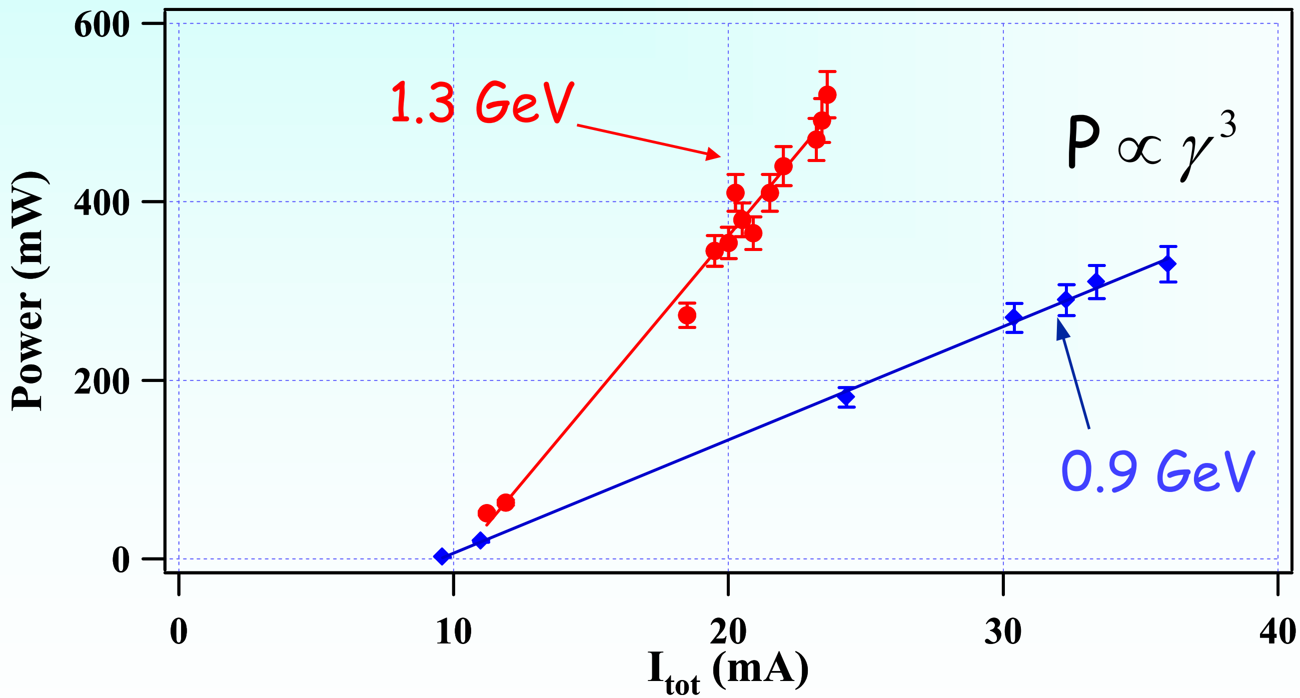
$P_{SR} \propto I \cdot \gamma_e^4$ synchrotron power

Output power

Power measurements @ 1.3 GeV and 900 MeV

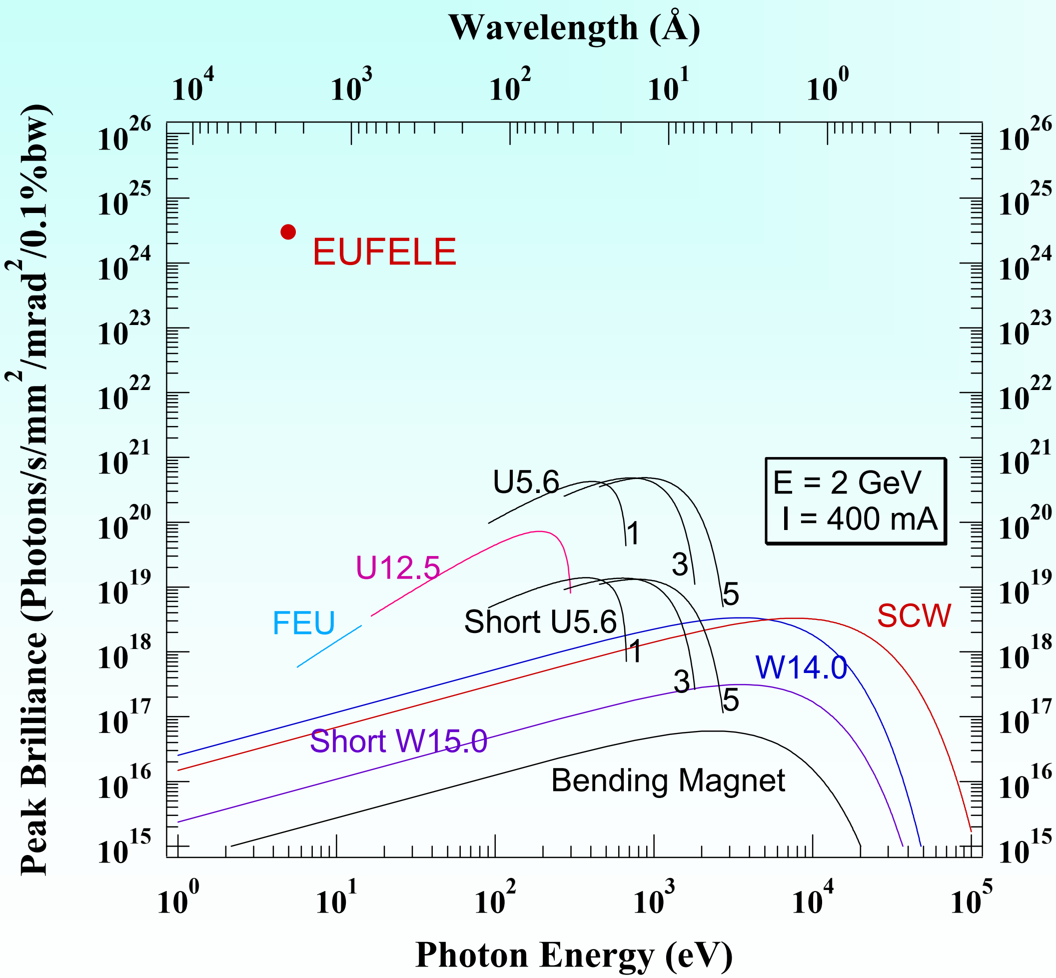
with mirrors at 250 nm ($\Gamma \cong 9$ %, $T \cong 5\%$)

max power = ***520 mW*** *at 23.6 mA*



Peak Brilliance

520 mW at 250 nm => 3 10^{24} photons/s/0.1%bw/mm^2/mrad^2



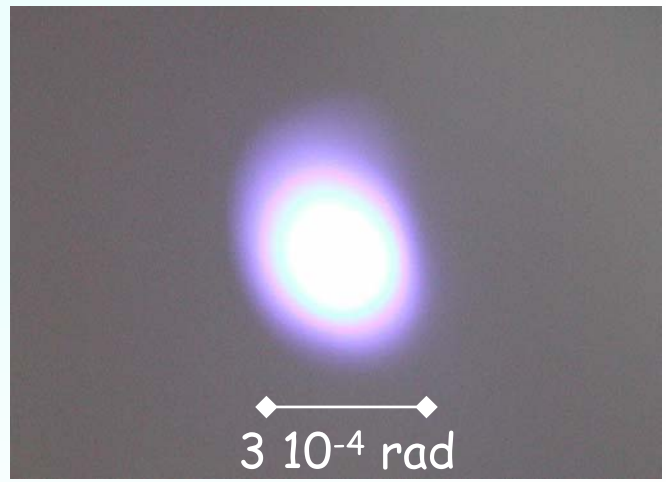


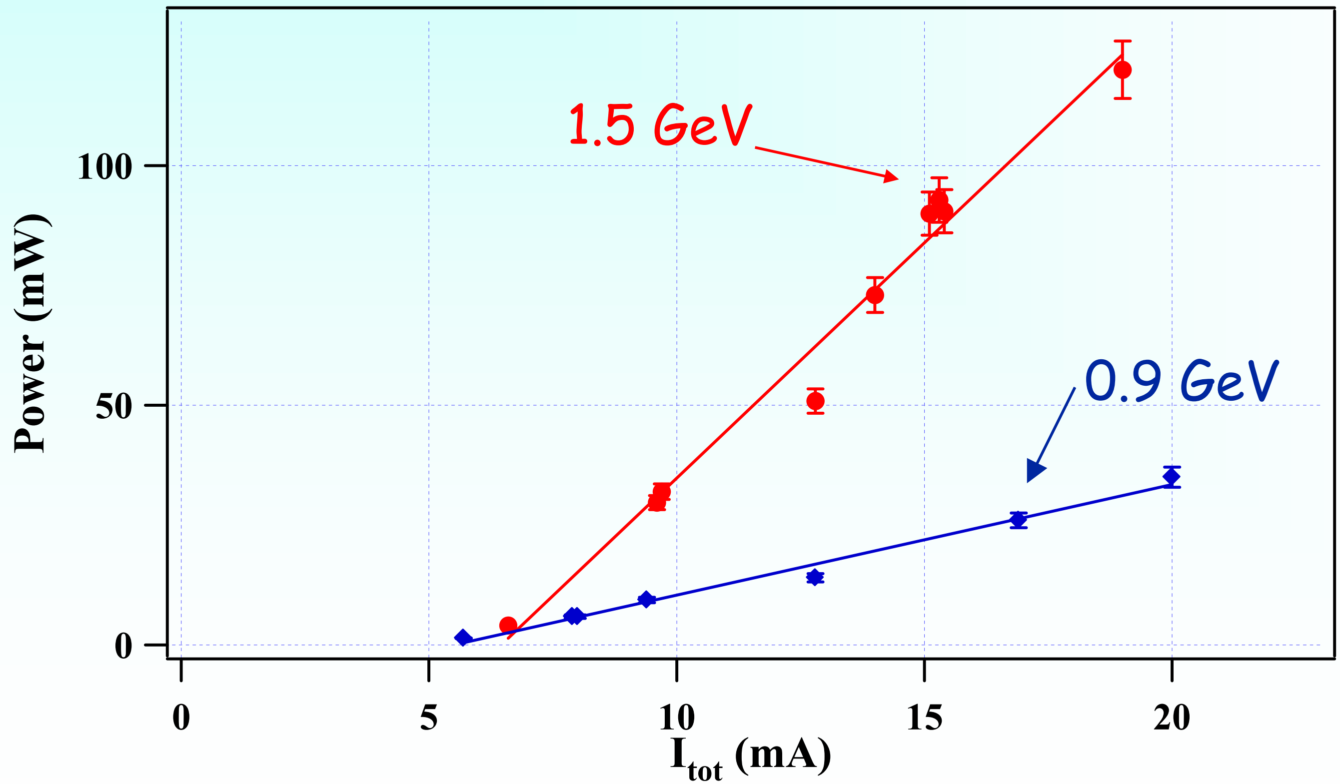
Photo of the laser spot

Output power

Power measurements @ 1.5 GeV and 900 MeV

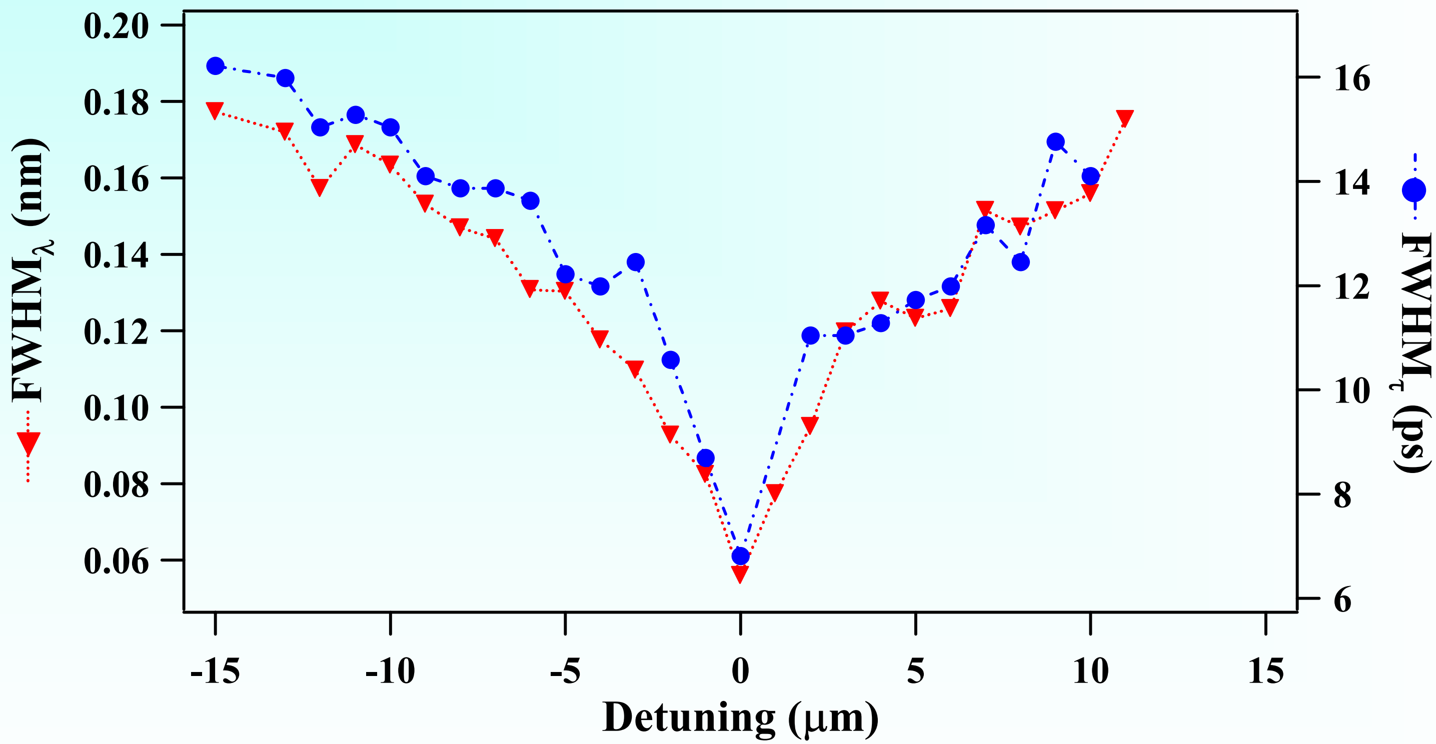
with mirrors at 208 nm ($\Gamma \cong 7$ %, $T \cong 1.2$ %)

max power = ***120 mW*** *at 19 mA*



Laser-electron beam detuning

Linewidth and Pulse length (@1.5 GeV and 208 nm) vs. optical cavity length:

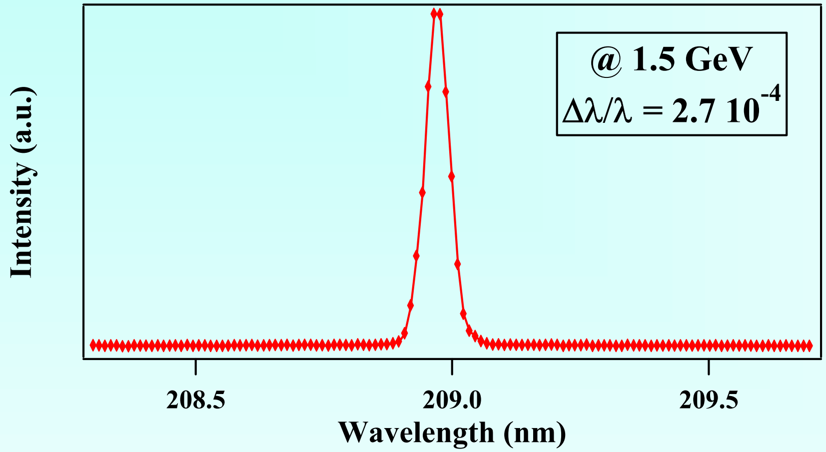


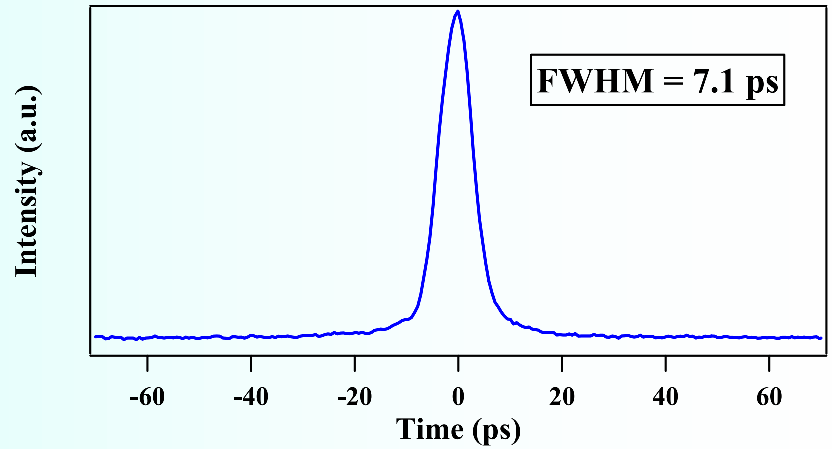
Minimum linewidth 0.06 nm - Minimum pulse length 7.1 ps

Linewidth and Pulse length

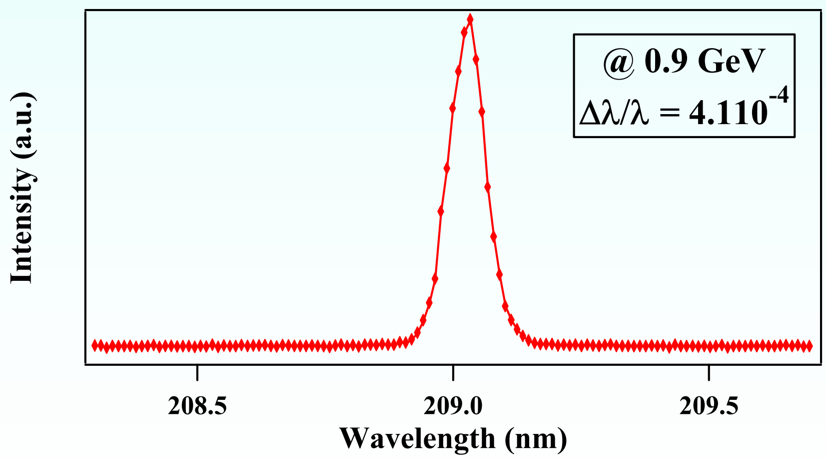
Narrower spectrum and shorter pulse are observed when energy increases:

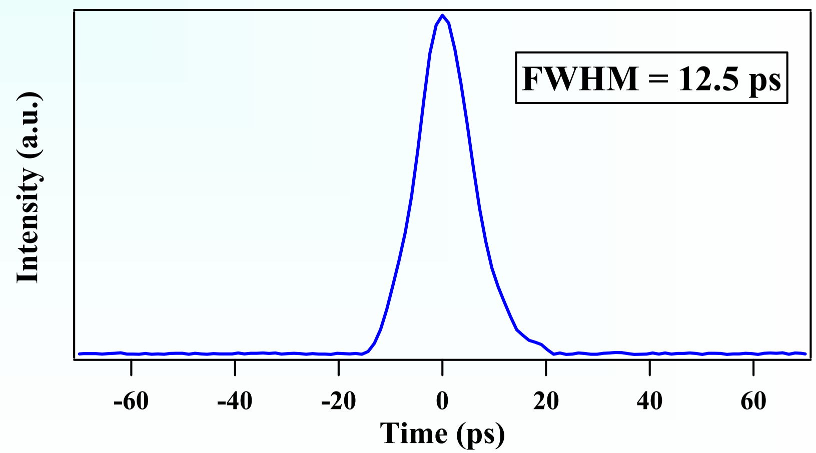
1.5 GeV





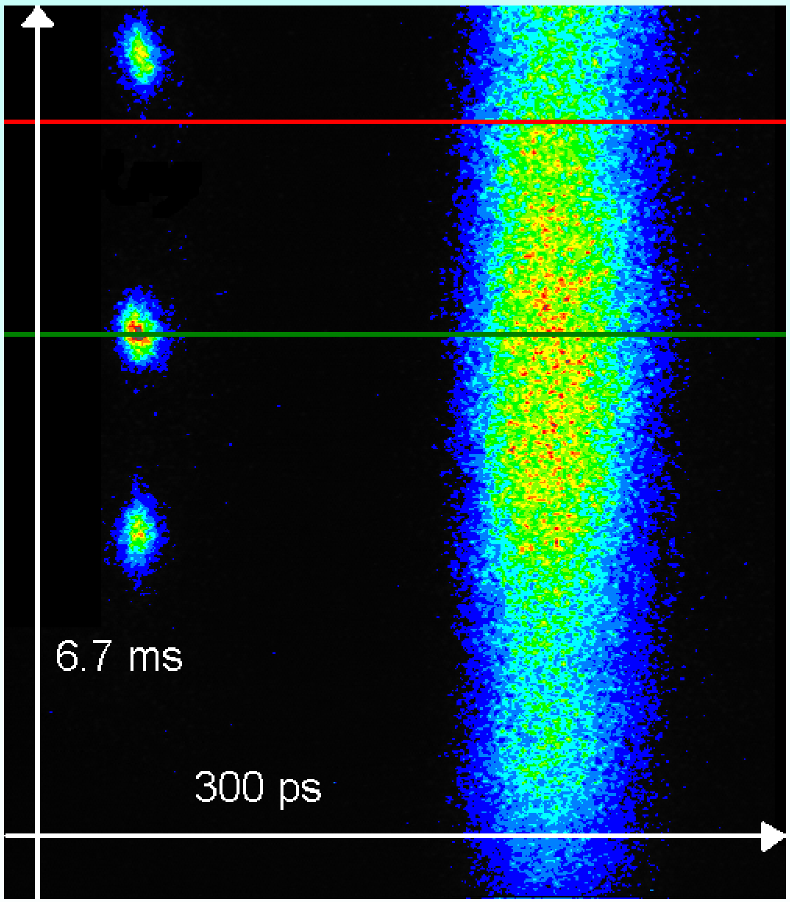
0.9 GeV

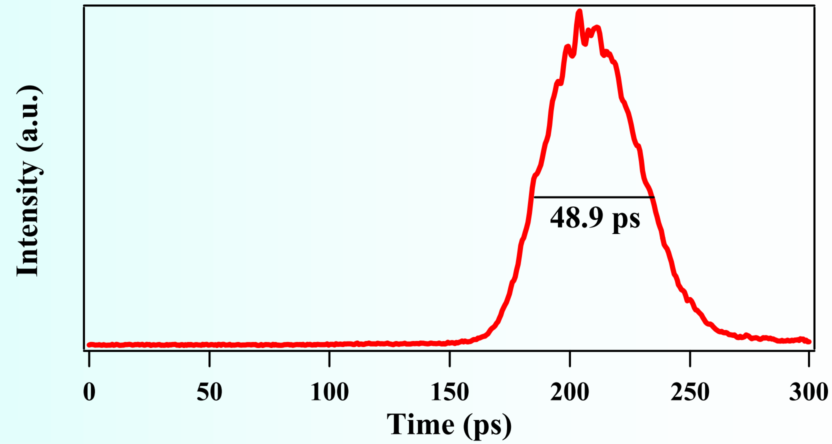


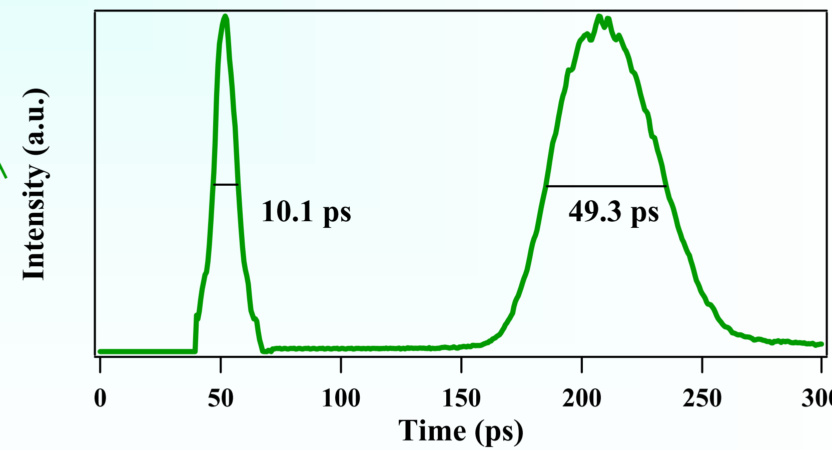


Electron beam behaviour

Measurements of the FEL and the e-beam with the Streak Camera:





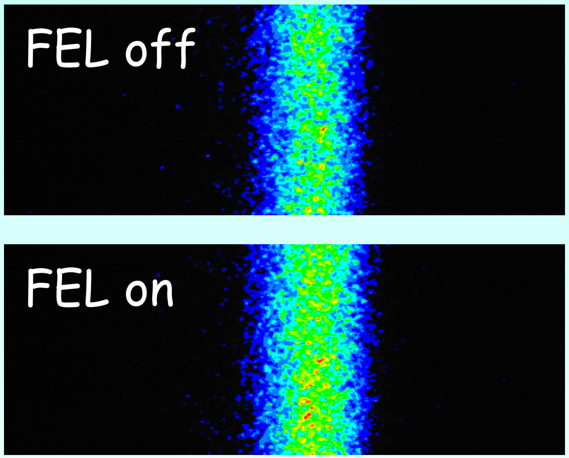


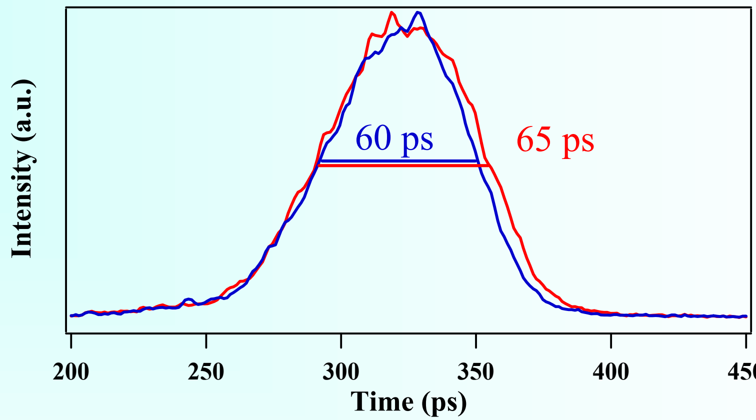
The bunch length stays almost constant

Electron beam heating

Measurements of the FEL induced bunch lengthening

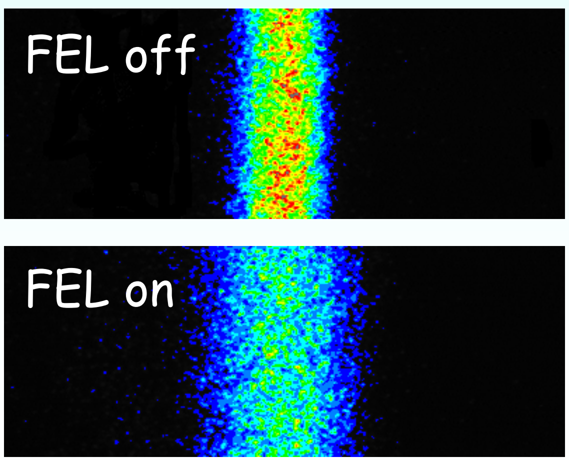
Γ = 7 %
0.9 GeV 15 mA

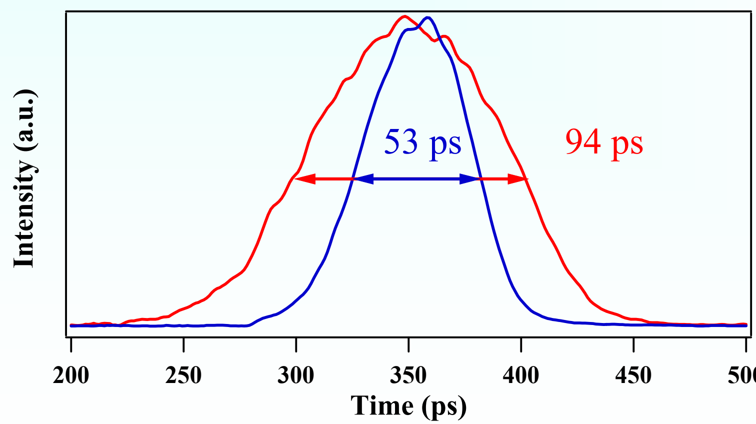




Lifetime
τ_{off} = 0.8 h
τ_{on} = 1 h

Γ = 4 %
0.9 GeV 11 mA





Lifetime
τ_{off} = 0.9 h
τ_{on} = 3 h

Towards Compatibility

The 4 bunch filling of Elettra is of interest for a number of experiments in various fields (chemistry, physics, biology).

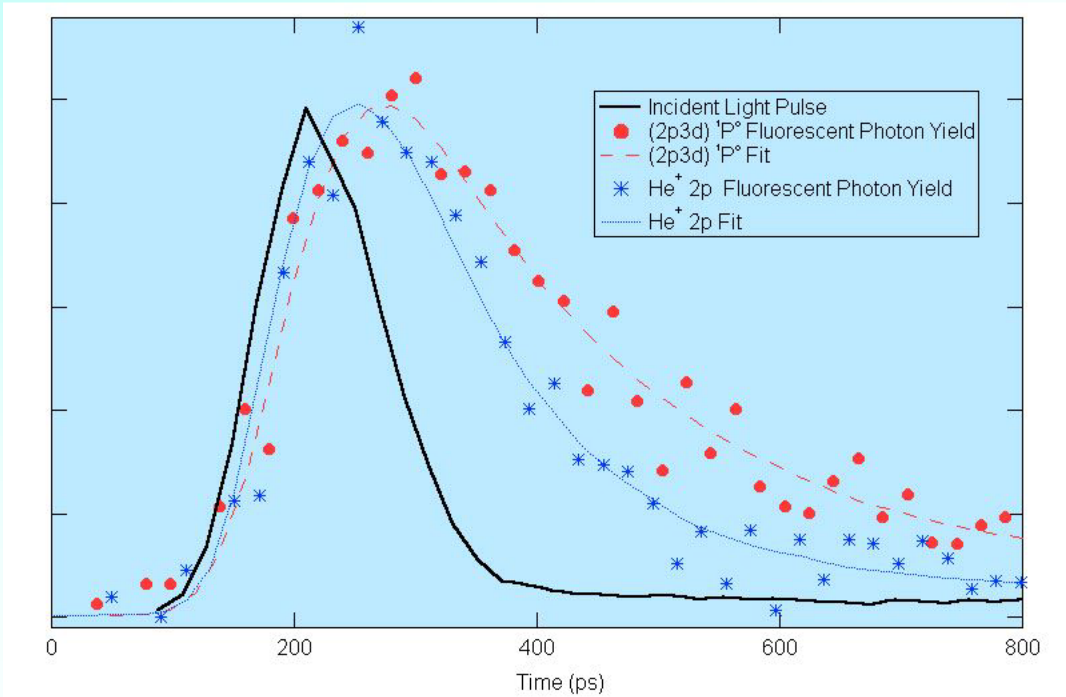
Energy lower than the usual one (2÷2.4 GeV), allows the beamlines to extend the useful photon energy range down to few eV

The short light pulses (less than 100 ps) with a repetition rate of 4.6 MHz and a good temporal stability (jitter less than few picoseconds) are suitable for many experiments like

- Time resolved fluorescence
- Coincidence spectroscopy with ions and electrons
- Time resolved magnetometry with photoelectrons

Gas Phase Experiment

During the FEL shifts the Gas phase beamline successfully performed doubly excited helium system exploration.



Measurements of the (2p3d) $^1P^o$ and of the He^+ 2p lifetime by detecting the fluorescent photons as a functions of time

[J.G. Lambourne, Elettra Highlights 2002 - to be published]

Conclusions

- Operation of the FEL at ELETTRA at different e-beam energies (900 MeV ÷ 1.5 GeV) has been successfully demonstrated
- In general, better beam stability is obtained at higher energies.
- Laser performance was improved at energies above 1 GeV in terms of power, spectral width and pulse duration.
- High extracted power operation reveals to be almost transparent for users applications.

Co-authors:

G. De Ninno, M. Danailov,
B. Diviacco, M. Marsi, E. Karantzoulis
(Sincrotrone Trieste, Trieste, Italy)

R.P. Walker
(Diamond Light Source, Oxford, U.K.)

M.E. Couprie
(CEA/SPAM and LURE, Orsay, France)

G. Dattoli, L. Giannessi,
R. Bartolini, L. Mezi
(ENEA, Frascati, Italy)

A. Gatto, N. Kaiser
(Fraunhofer Institut für Angewandte Optik und Feinmechanik, Jena, Germany)

S. Günster, D. Ristau
(Laser Zentrum Hannover, Hannover, Germany)

Acknowledgements :

F. Iazzourene, L. Tosi,
M. Ferianis, M. Coreno
(Sincrotrone Trieste)

R. Roux, D. Garzella
(CEA/SPAM and LURE)

R. Marl, I.D. Mullacrane, J.A. Clarke
(CLRC Daresbury Laboratory, U.K.)