Status of the FERMI@Elettra Project

Michele Svandrlik
Elettra, Trieste, Italy

IPAC 2012 – New Orleans
May 22nd, 2012

OUTLINE

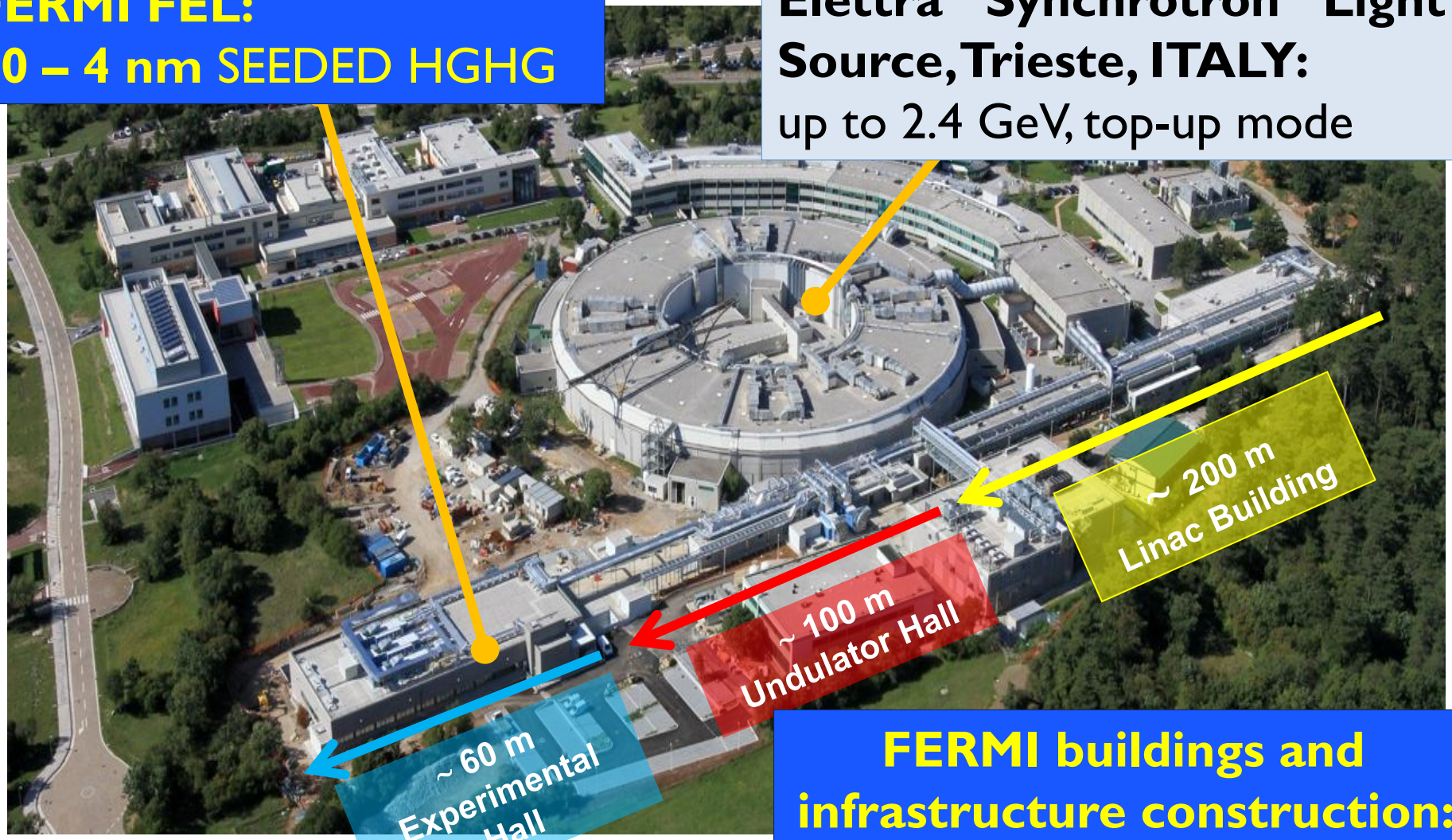
- **FERMI@Elettra Overview**
- **Facility Performance**
- **Recent Progress**
- **Outlook and Conclusions**

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, λ-tunability*
  - Ionization dynamics ..... *circular polarization*
  - Catalysis in nano-materials ..... *fs pulse and stability*

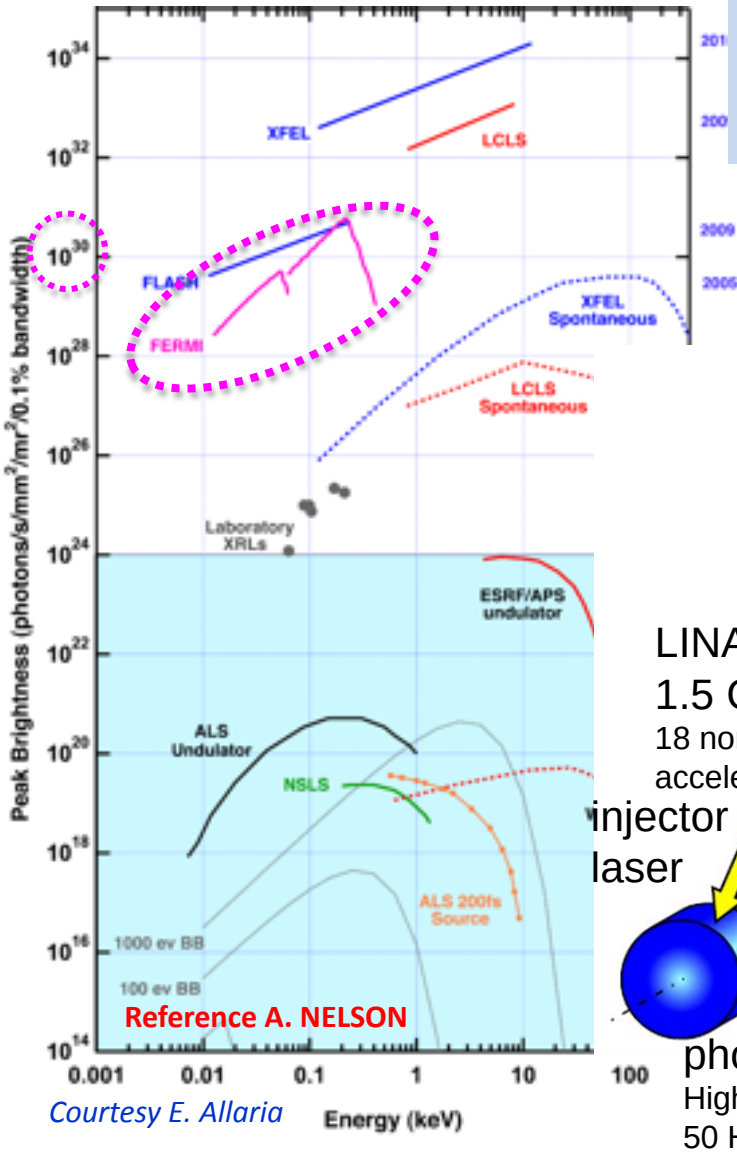
- **Elastic and Inelastic Scattering (EIS)**
  - Transient Grating Spectroscopy (collective dynamics at the nano-scale) ..... *Transform Limited Bandwidth*
  - Pump & Probe Spectroscopy (including ultra-fast magnetization dynamics) ..... *brightness, λ-tunability*

- **Diffraction and Projection Imaging (DiProI)**
  - 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, λ-tunability, circular polarization

Fermi Concept

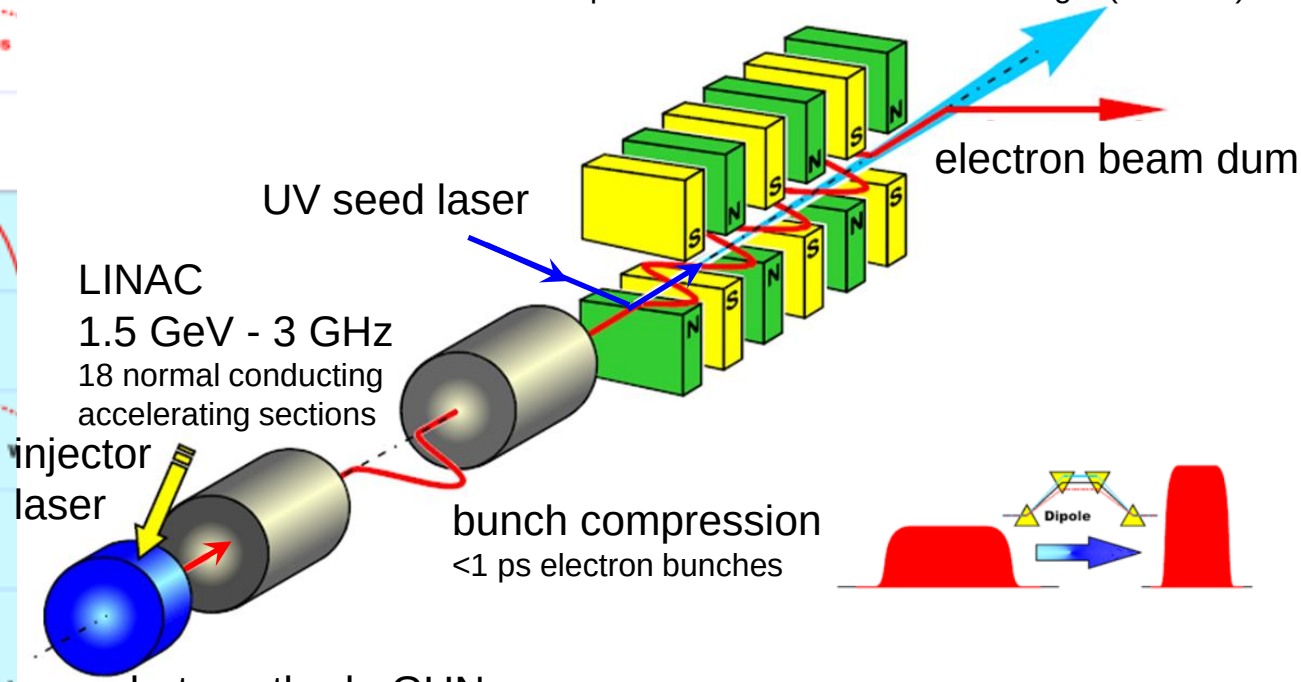
Seeded FEL user facility, designed to produce fundamental output wavelengths from **80 nm** down to **4 nm** with **High Gain Harmonic Generation**



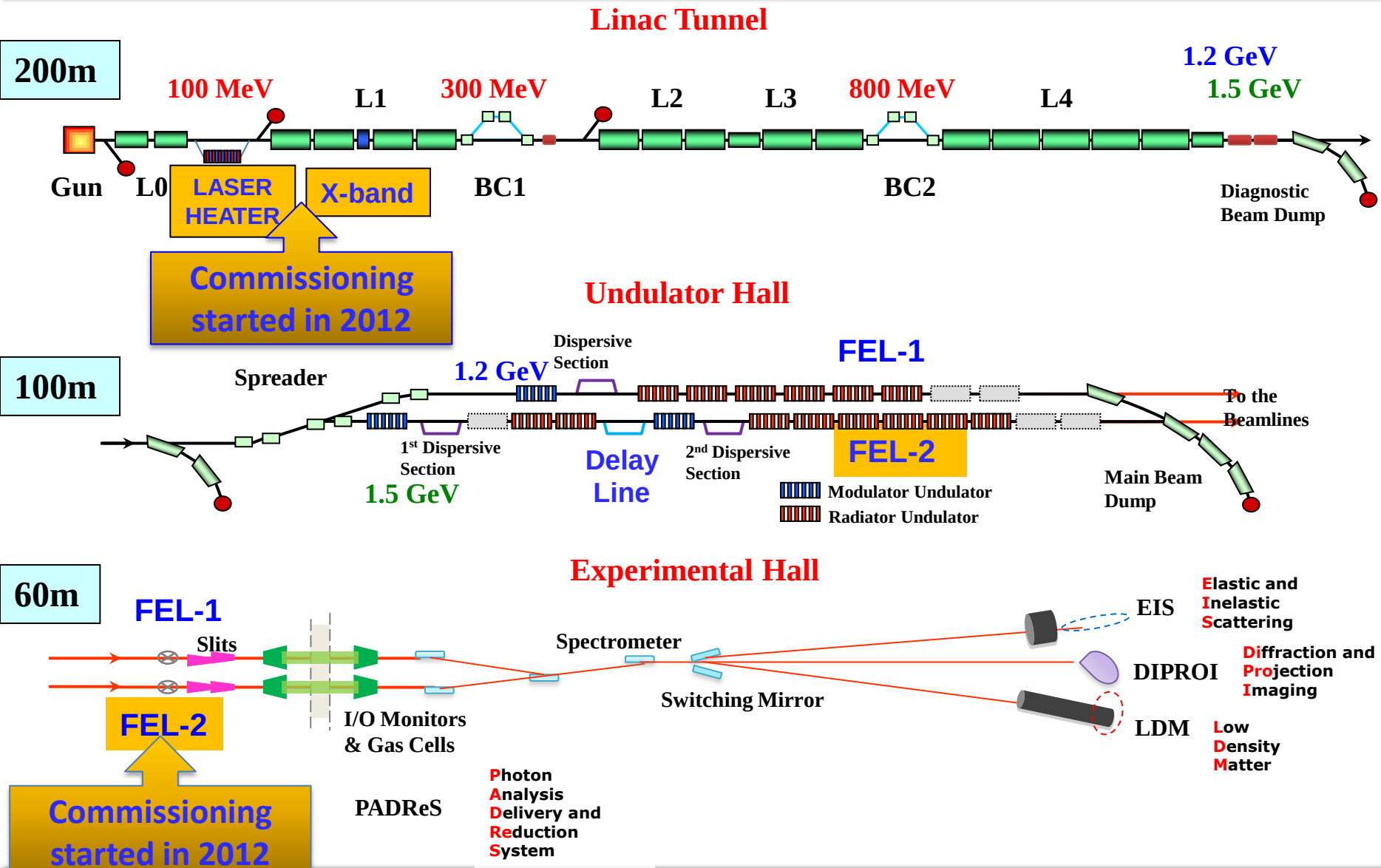
Courtesy E. Allaria

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)



Machine Layout



Machine Parameters

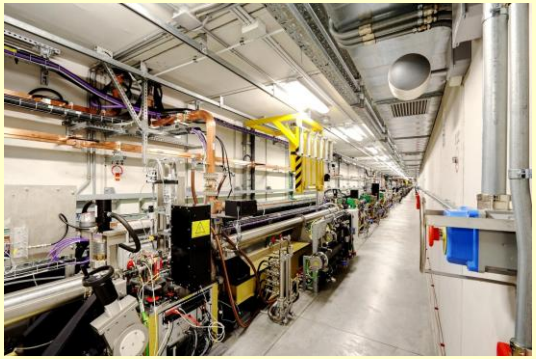
Parameter	FEL- 1*	FEL -2	Units
Wavelength	**80-20**	20-4	nm
Electron Beam Energy	**1.2**	1.5	GeV
Bunch Charge	**0.5** – 0.8		nC
Peak Current	600 – 900		A
Bunch Length (FWHM)	600		fs
Norm. Emittance (slice)	**≤1.2**	≤1.0	mm mrad
Energy Spread (slice)	**≤250**	≤150	keV
Repetition rate	**10** – 50 (*2013*)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

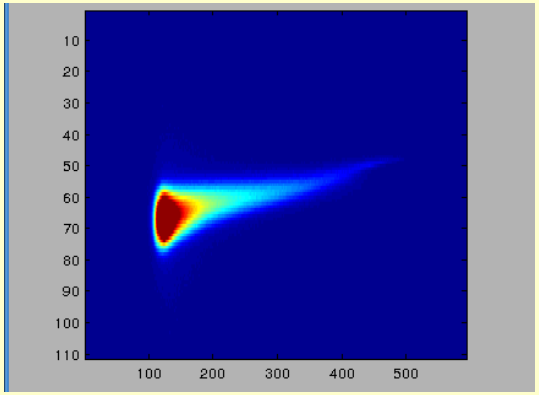
**** achieved on FEL-1***

FACILITY PERFORMANCE

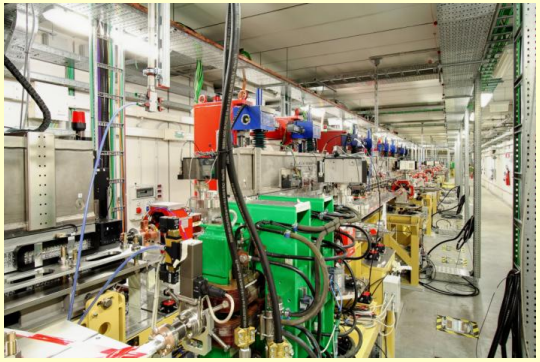
FEL-1 Milestones 2010-2011

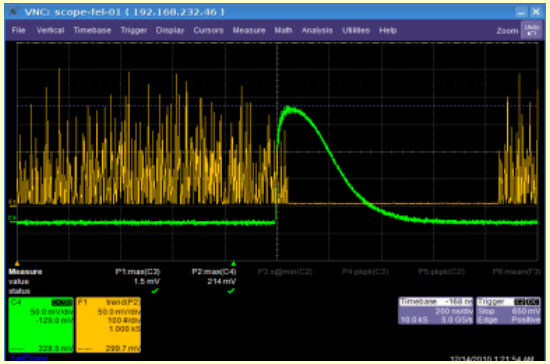
September 2010
Linac energy
1.2 GeV





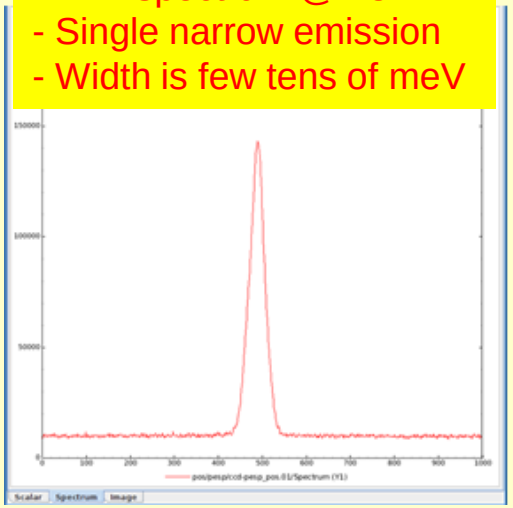
December 2010
First FEL-1 Coherent
Harmonic Generation





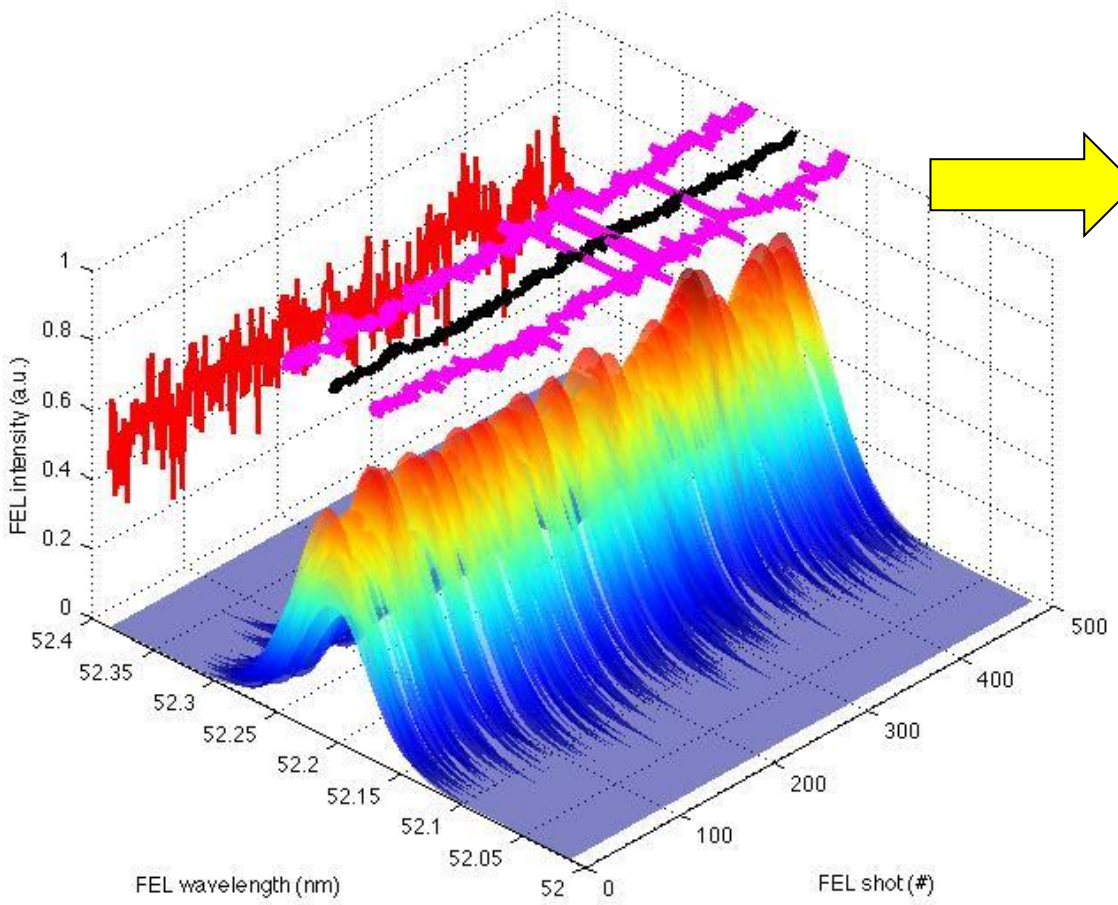
July 2011
FEL-1 Gaussian mode and
exponential gain

FEL spectrum @ 43 nm
- Single narrow emission
- Width is few tens of meV



FEL Spectrum Stability

500 consecutive spectra acquired for **FEL -1** operated at **52 nm** (5^{th} harmonic of the seed laser)

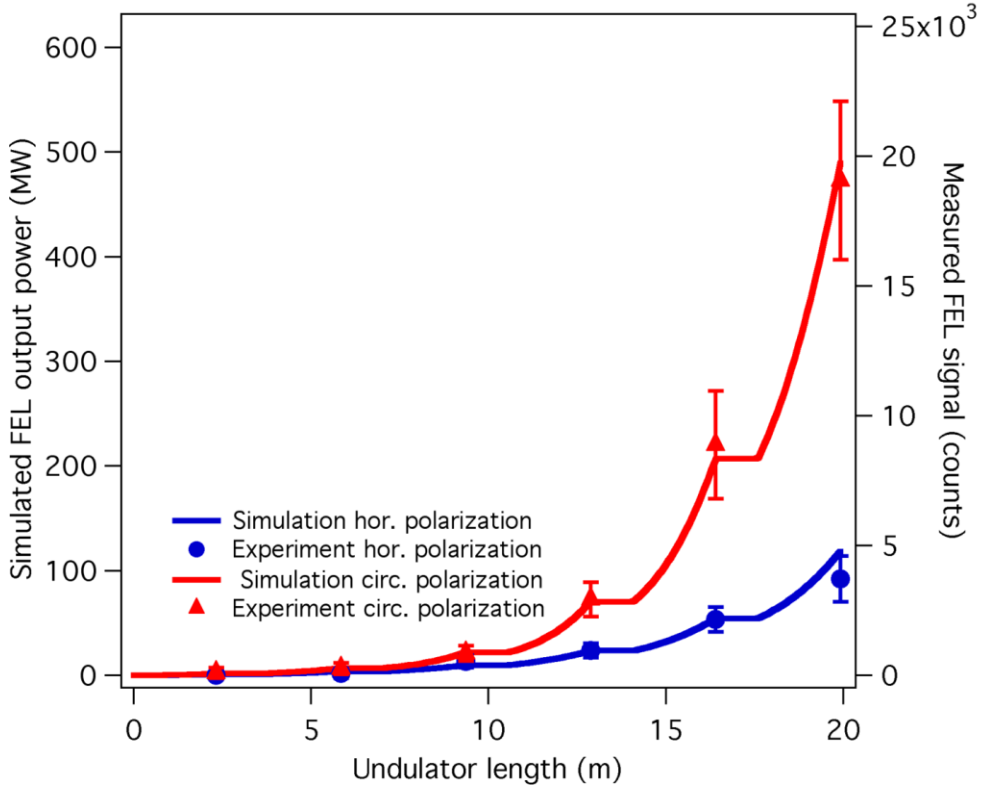


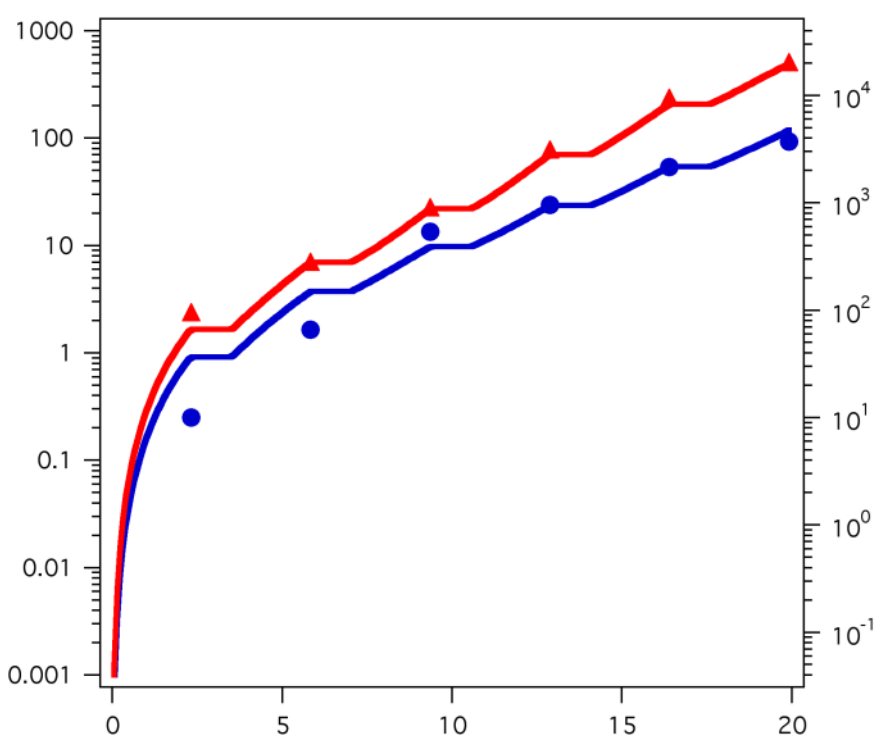
- **Wavelength fluctuations** (*black line*): **0.006 nm (0.03 %)** rms
- **Average bandwidth** (*purple lines*): **0.03 nm** *that is close to the Fourier limited for the expected FEL pulse length (<100fs)*
- **FEL intensity fluctuation** (*red line*): about **15 %** rms

Courtesy of E. Allaria, C. Svetina

Exponential gain

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~ 2.0 m and 2.5 m).

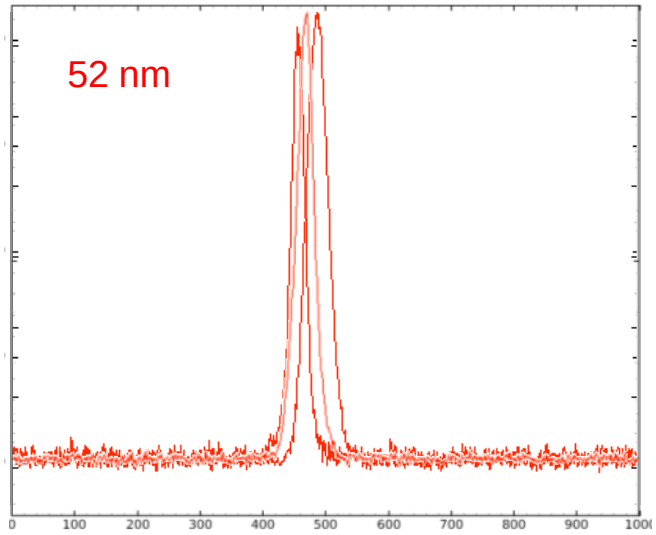




Measured FEL behavior is in good agreement with FEL simulations using the expected electron beam parameters.

FEL tuning

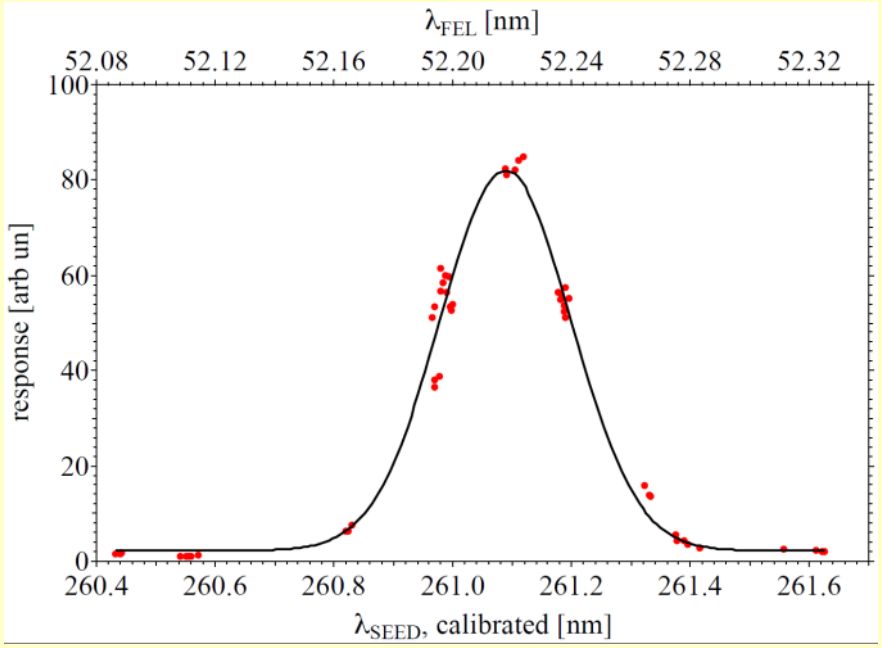
The fine FEL tuning around 52 nm has been achieved by changing the seed laser wavelength of ~1 nm (0.4%).
After tuning of the seed laser wavelength, the undulator resonance is changed accordingly, in order to maximize the FEL power.



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.

LDM – Citius coollaboration

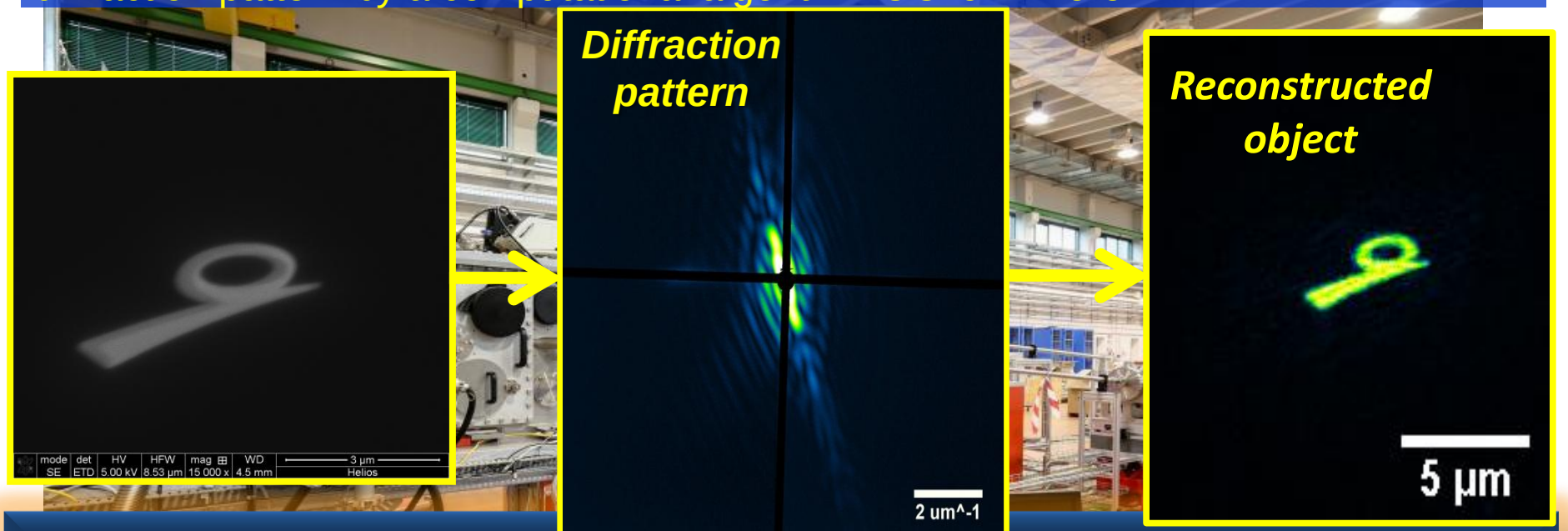
Resonant absorption line of *He 1s-4p* transition around 52 nm. The experiment measures the dependence of the fluorescence signal on λ_{FEL}.



Courtesy of E. Allaria, C. Callegari

Scientific Programs: Single Shot Imaging @ DiProI

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.



Courtesy of F. Capotondi, M. Kiskinova

First call for proposals

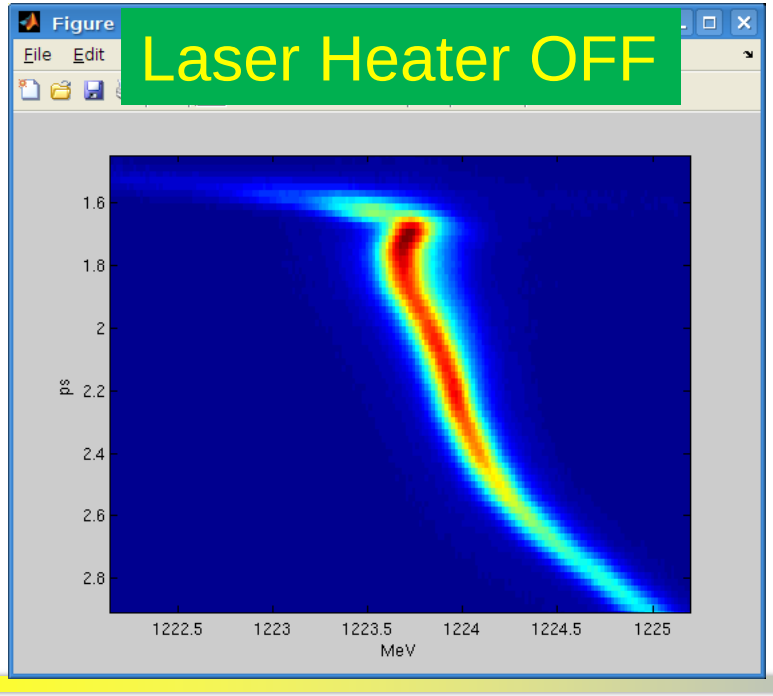
Based on the current performance, a call for proposal has been issued end of 2011, for beamtime in the second semester of 2012.

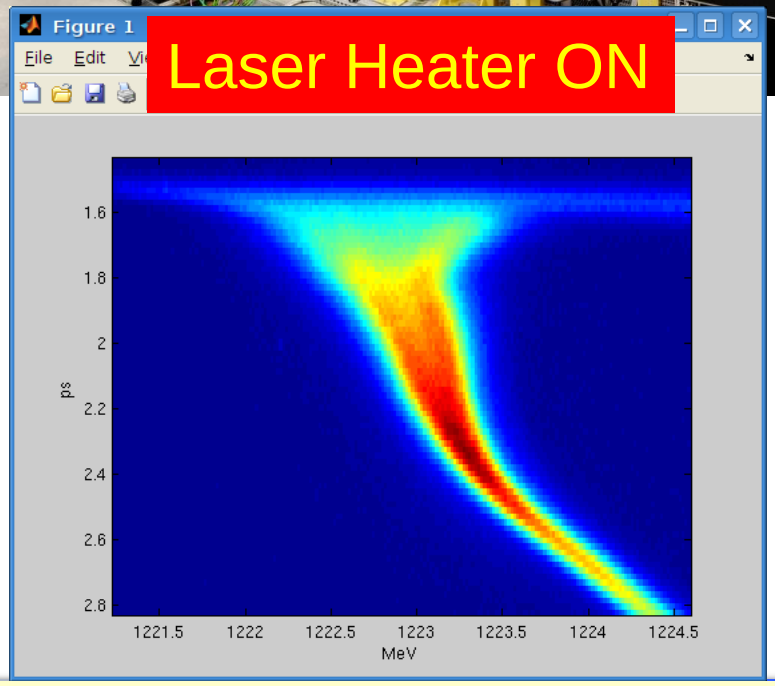
At the deadline *(April, 27th)* **34 proposals** were presented.

RECENT PROGRESS

May 2012: Laser Heater **ON**

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

≥ 60 MW
~ 1 μs @ 50 Hz

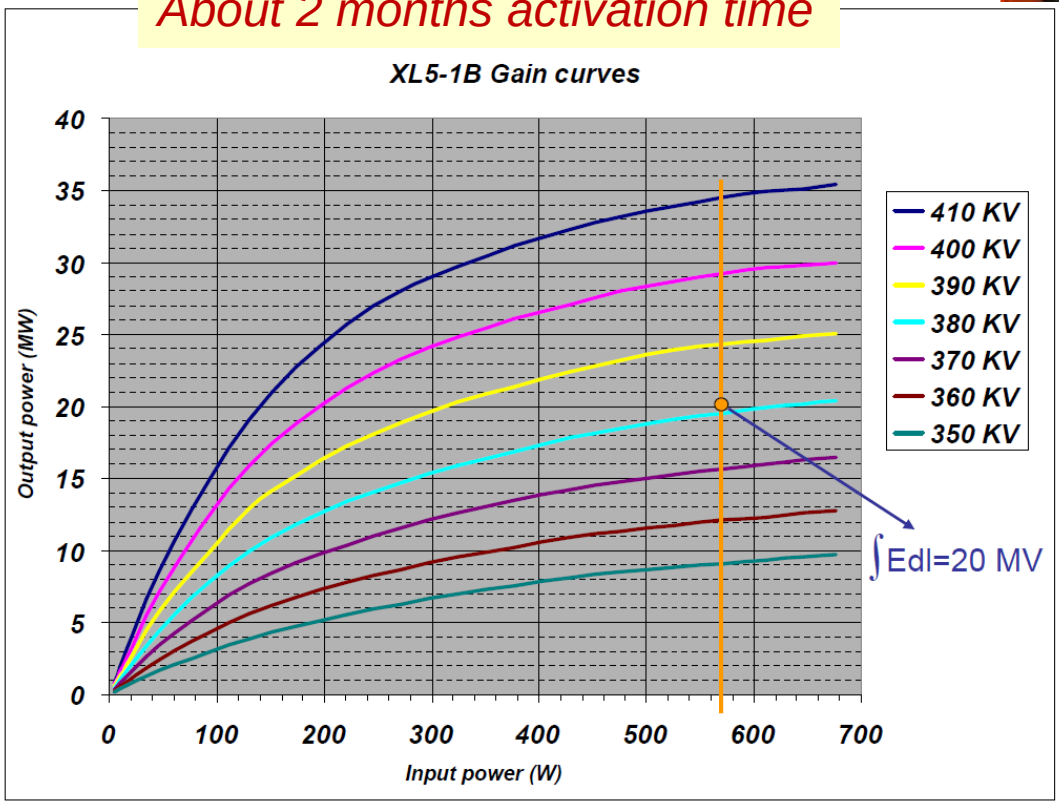
HV modulator

LLRF

RF Driver

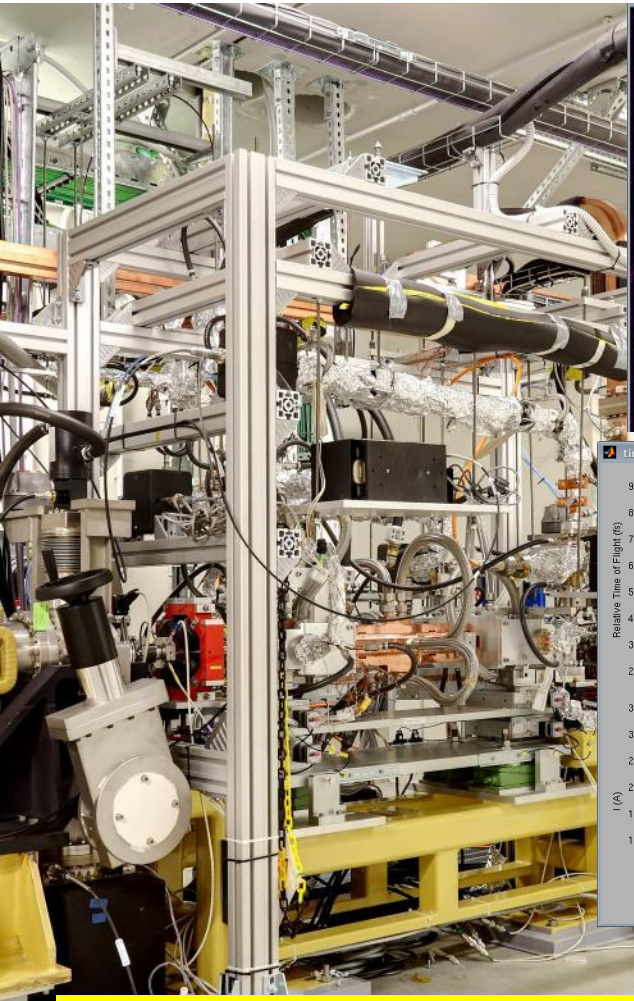
P < 1.0 KW
Δϕ ≤ 0.4°X
ΔV ≤ 0.5%

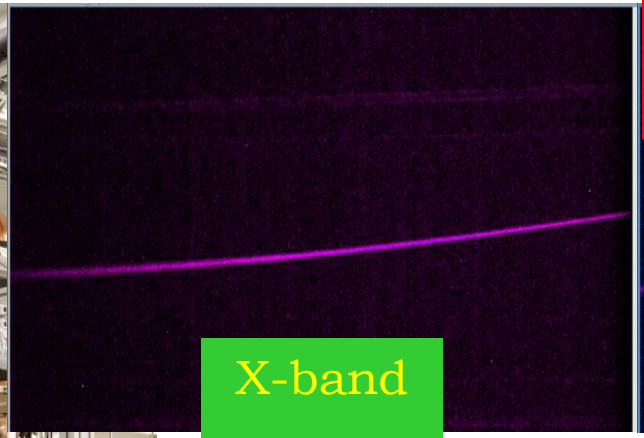
About 2 months activation time



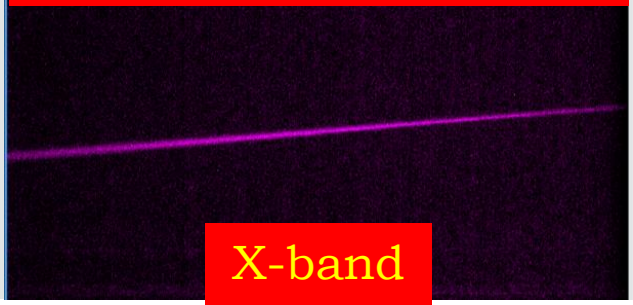
See also G. D'Auria et al., TUPPP054 and THPPC054

February 27th, X-band Cavity **ON**



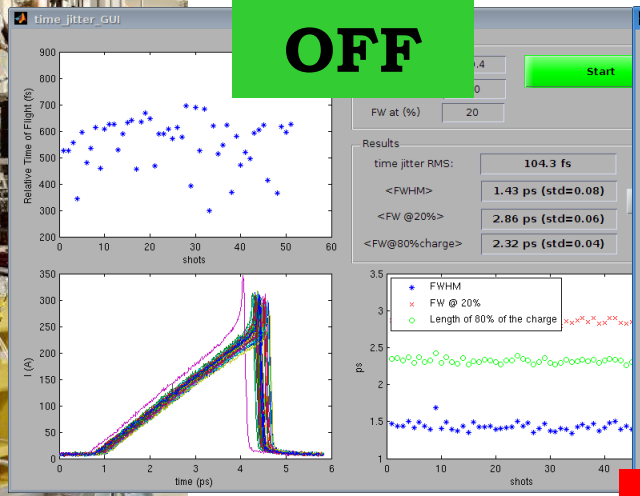


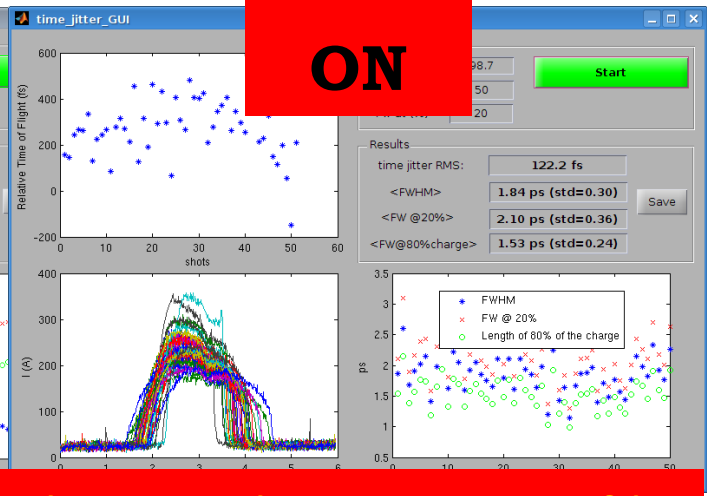
Longitudinal phase space is linearized



X-band **OFF**

X-band **ON**

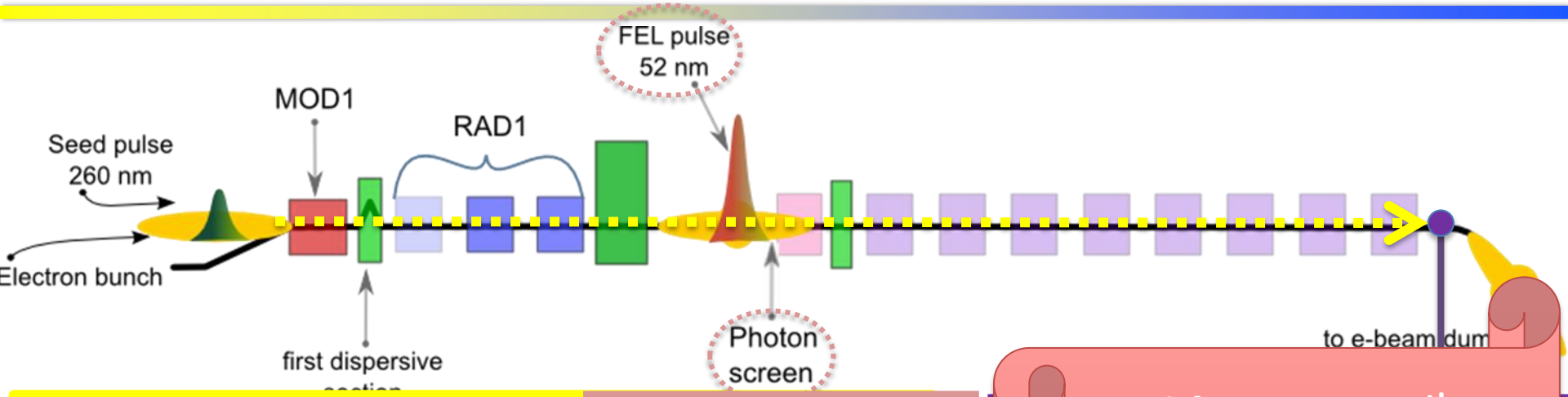


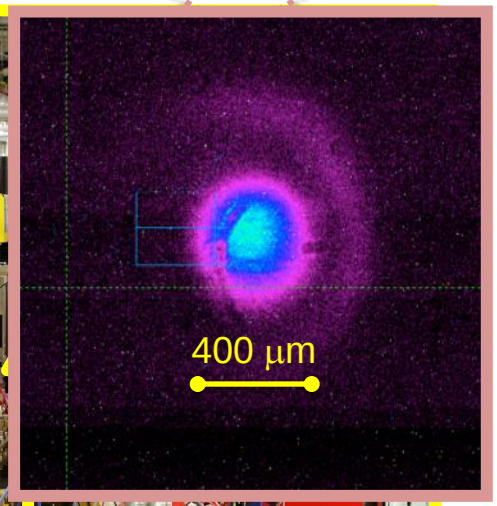


Flat Bunch current profile

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

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

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

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*

Announcement

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

ELETTRA Sincrotrone Trieste, 34149 Basovizza, Trieste, Italy

L. Giannessi, ELETTRA and ENEA C.R., Frascati, Italy

THANK YOU

FOR YOUR ATTENTION