Facility Reports: FERMI@Elettra

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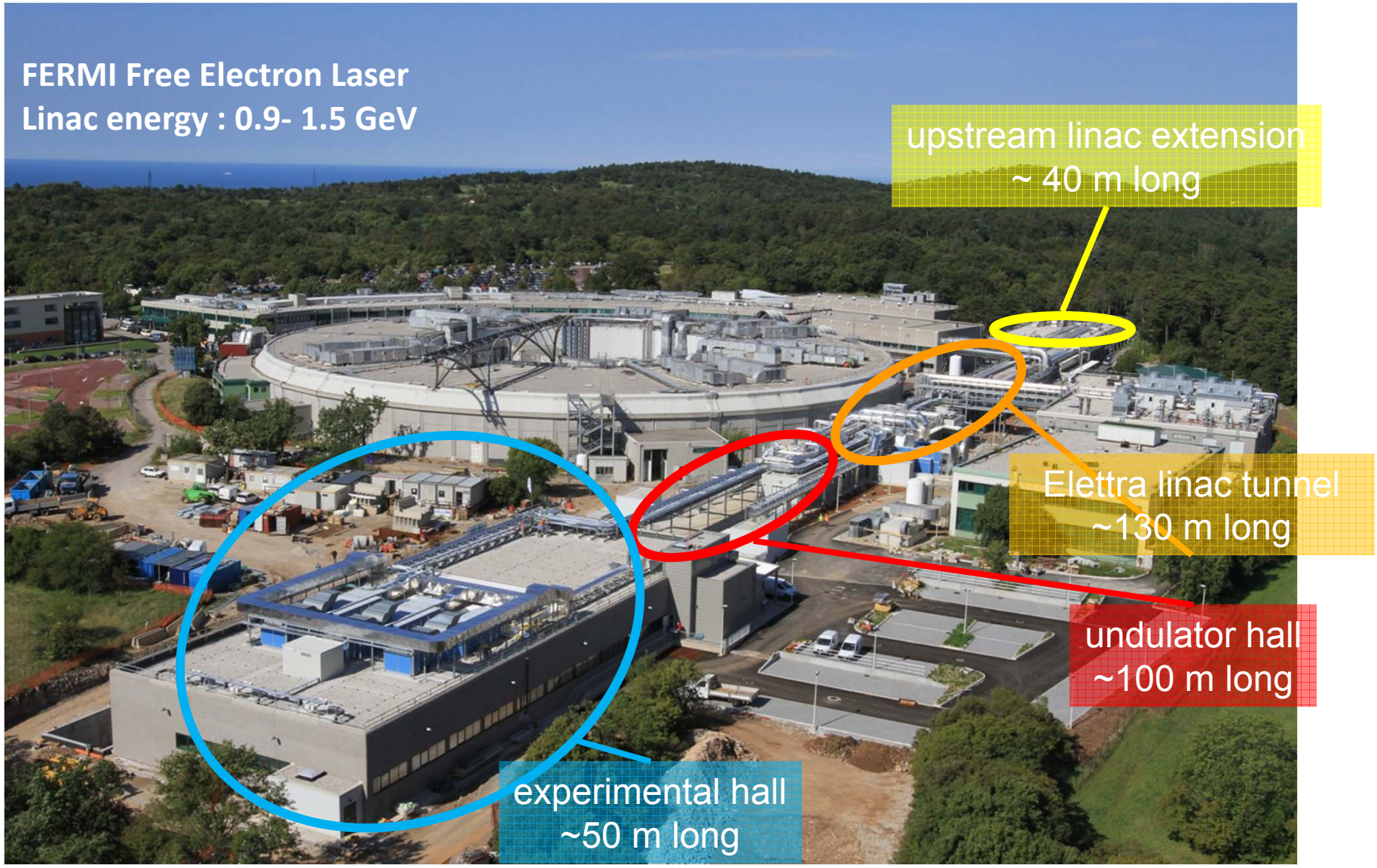
on behalf of the Fermi Team

Outline

- FERMI FEL project
  - Layout
  - Specifications
- Status of the commissioning
- Day-1 Expected FEL performance
- FEL evolution in 2011

FERMI@Elettra Laboratory



FERMI main features

- FERMI@Elettra single-pass seeded FEL user-facility.
- Two separate FEL amplifier will cover the spectral range from 100 nm (12eV) to 4 nm (320 eV).
- Based on the high gain harmonic generation scheme the two FEL will provide users with photon pulses with following characteristics:

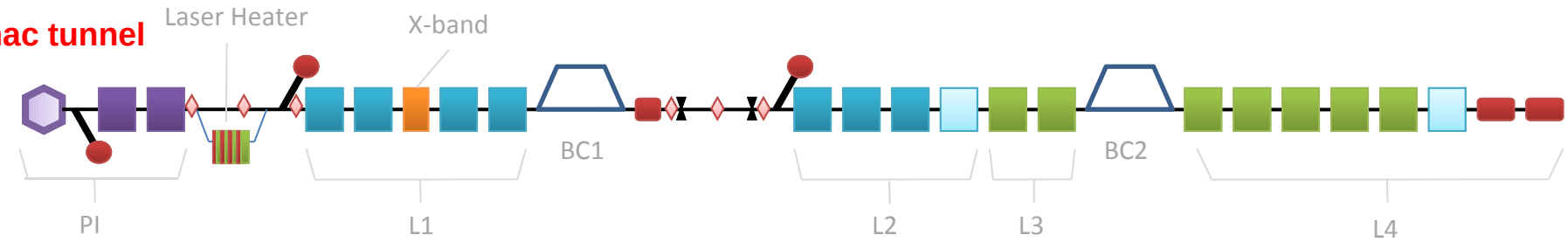
high peak power	0.3 – GW's range
short temporal structure	sub-ps to 10 fs time scale
tunable wavelength	APPLE II-type undulators
variable polarization	horizontal/circular/vertical
seeded harmonic cascade	strong longitud. and transv. coherence

Specifications

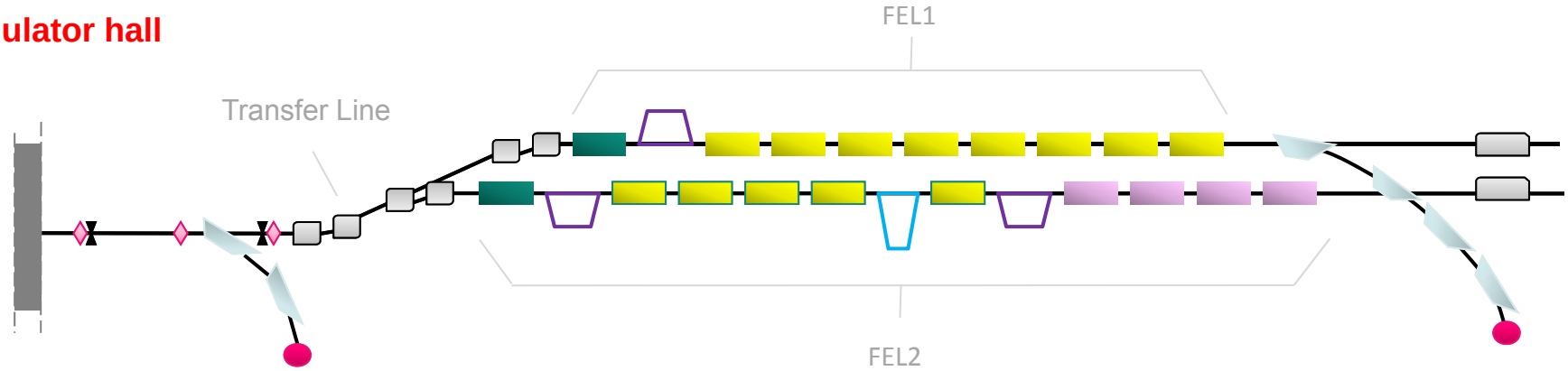
	Parameter	FEL1	FEL2	Units
photons	Output Wavelength (fundam.)	**100 – 20**	**20 – 4**	**nm**
	Output Pulse Length, rms	≤50	≤50	fs
	Peak Power	**1 – 5**	**> 0.3**	**GW**
	Photons per Pulse	> 10^{13}	> 10^{12}	
	Power Stability	<30	<50	%
	Transverse Stability	<10%		e-size
	Repetition Rate	**10**	**50**	**Hz**
electrons	Energy	**1.2**	**1.5**	**GeV**
	Charge	0.8		nC
	Slice Norm. Emittance, rms	**1.0**		**mm mrad**
	Slice Energy Spread, rms	**<0.20**	**<0.15**	**MeV**
	Total Energy Spread, rms	<1.2	<1.5	MeV
	Peak Current, flat region	**800**		**A**
	Bunch Length, fwhm	0.7		ps
	Energy Jitter, rms	0.1		%
	Timing Jitter, rms	<150		fs

FERMI Layout

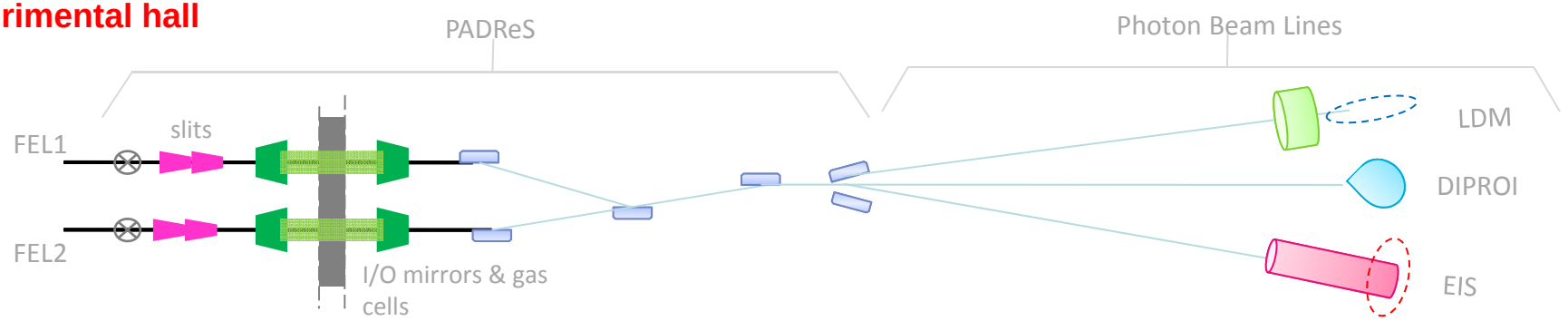
linac tunnel



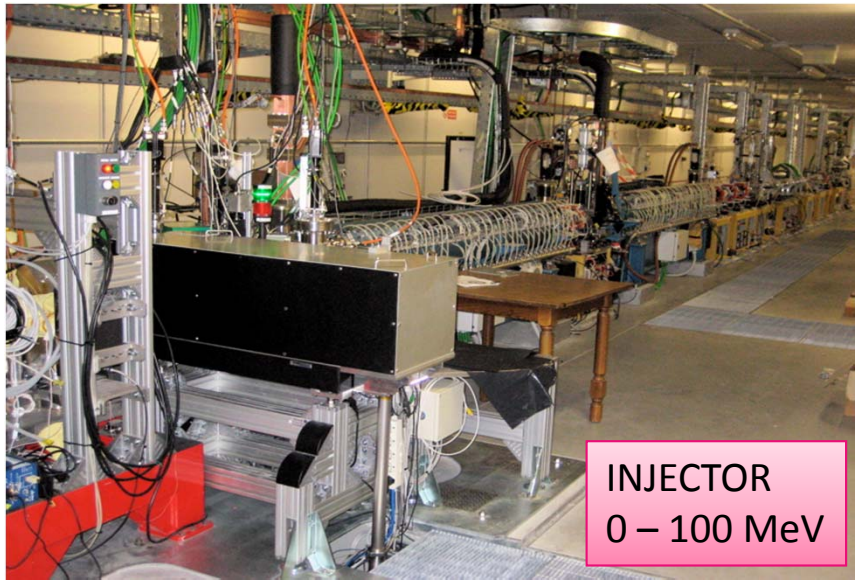
undulator hall

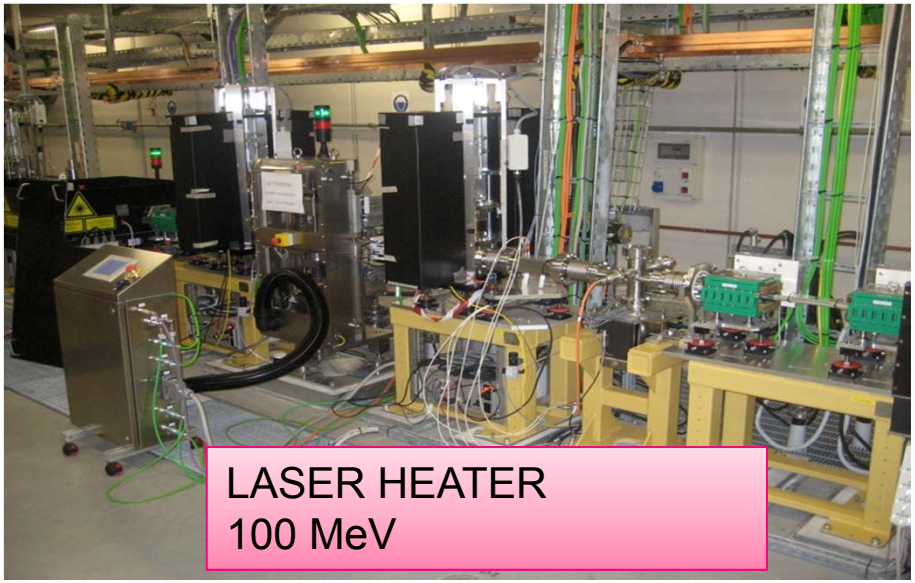


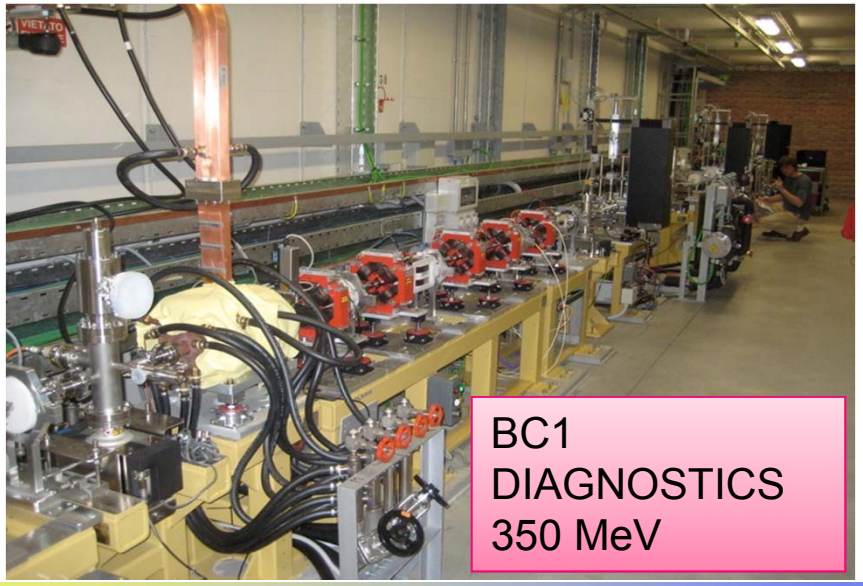
experimental hall

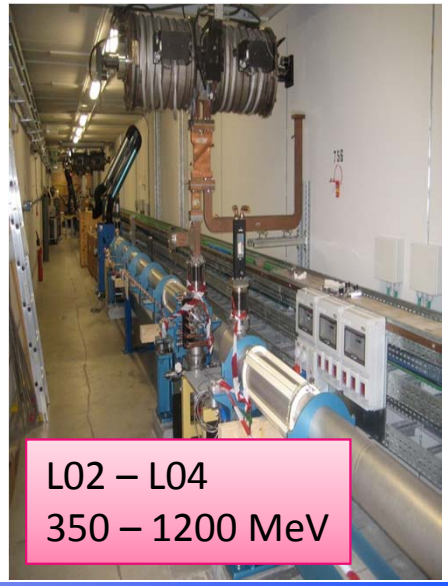


Linac Tunnel

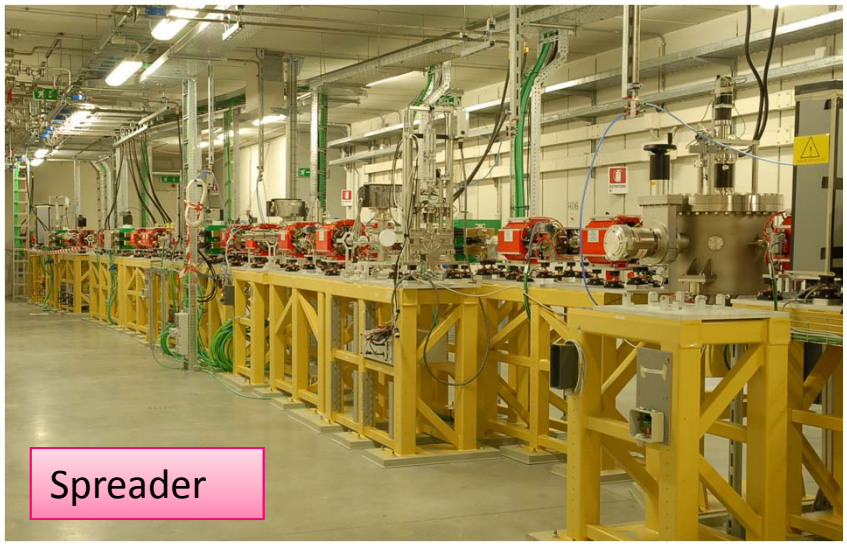


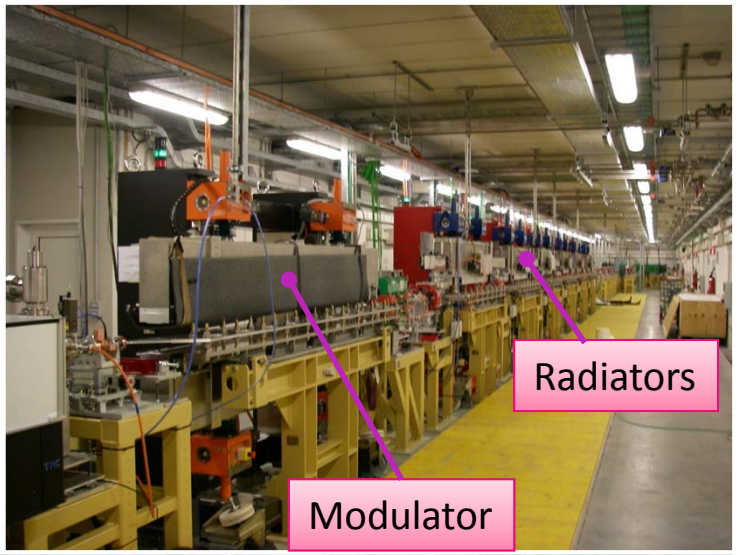


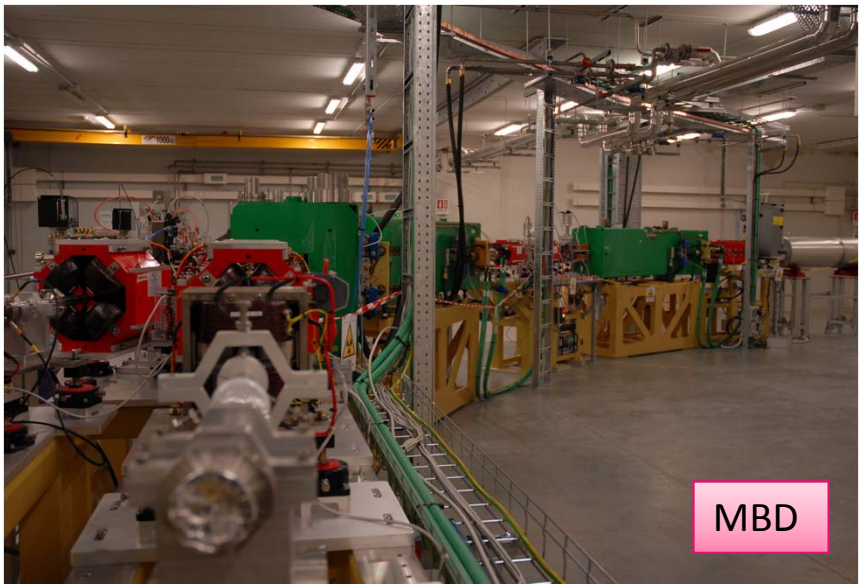


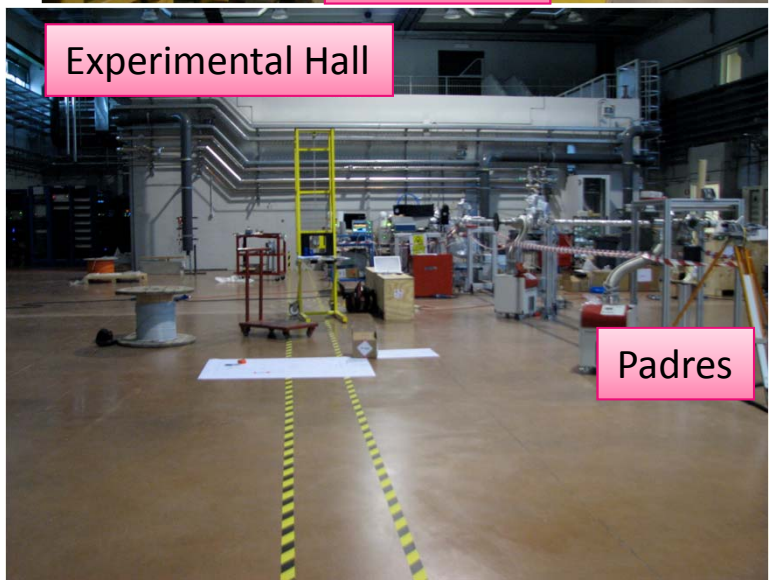


Spreader - Fel 1 – MBD – Exp.

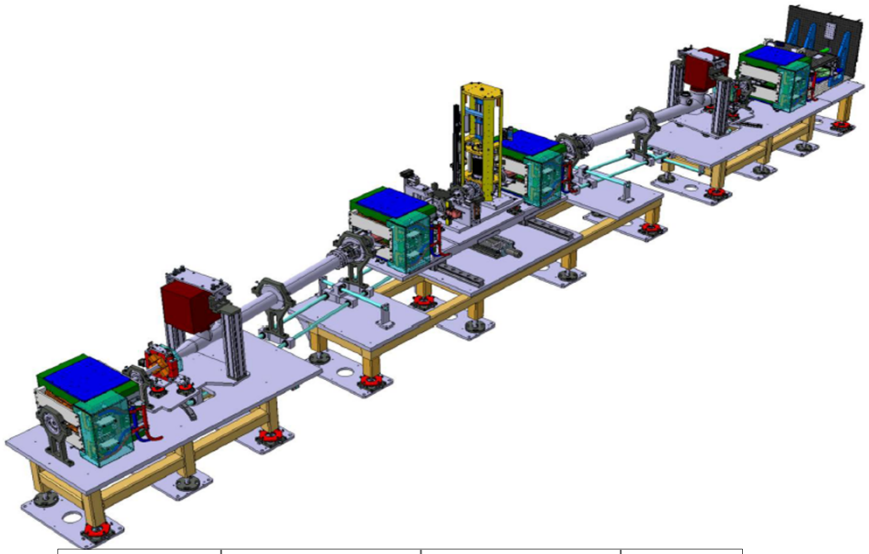




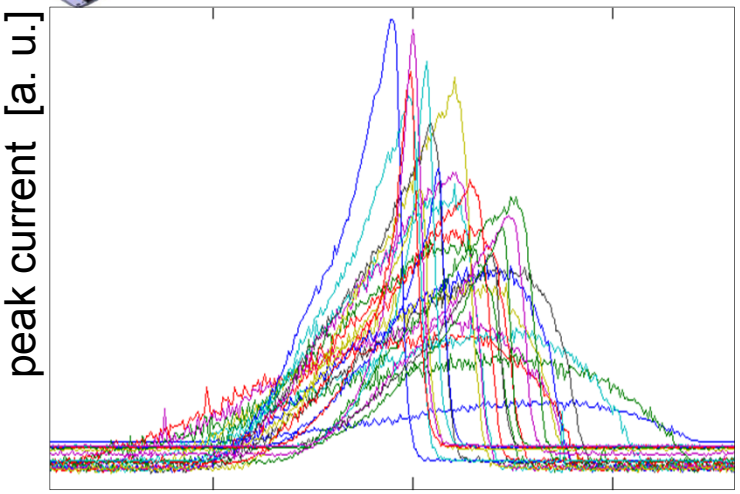




Magnetic Bunch Length Compressor



MAGNETIC COMPRESSOR ~ 300 MeV

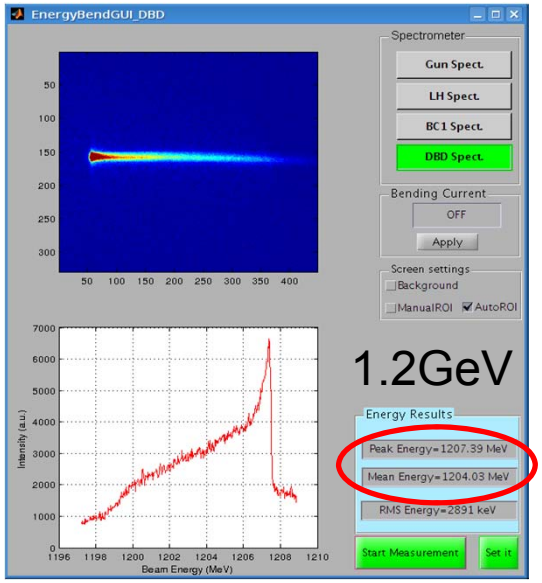


bunch duration (~0.7 – 6 ps fwhm) during compression

a **high peak current** (500 A over 0.7 ps FWHM) is generated by compressing the bunch length.

Ref. La Civita, Di Mitri, Castronovo, Scafuri

Main Linac & Undulator

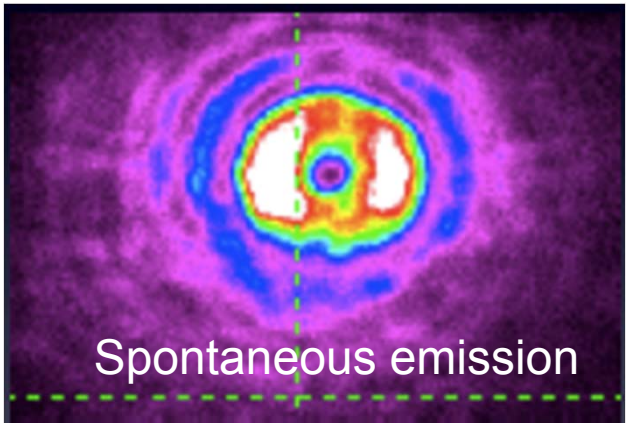


LINAC

- Trajectory control and RF phasing are used to maximize the transport efficiency and compensate for the energy loss induced by the linac wake fields
- An emittance growth is measured from BC1 to LINAC end. Probably due to residual dispersion in LINAC the problem is under investigation
- Both energy spread and energy fluctuations in diagnostic beam dump are good (<0.1%).

Undulators

- Before Installing Undulators we had to define a reliable trajectory in the FEL beam-line
- The beam trajectory is kept under control to transport the electron beam core to the MBD with minimal losses (≤ 1%)
- A machine protection system is monitoring the beam losses to prevent damages to the undulators



Day-1 expected FEL performance

We agreed with FERMI users on a reasonable set of FEL parameters as a GOAL for the first period of commissioning that could also be used for first user experiments.
Based on expected :

- e-beam parameters (1.2GeV, 200A, ε_N<2 mm mrad, time jitter<200fs, energy jitter<0.5%)
- available hardware
- commissioning time

- **Wavelength**: initially at ~65 nm and then at ~52nm
- **Polarization**: initially horizontal polarization.
- **Power**: hundreds of MW
- **Pulse length**: In the range between 70 fs and 200 fs (rms)
- **Energy**: ~100 μJ per pulse (~10^{13} photons/pulse)
- **Stability**: no control on the shot to shot FEL power fluctuations
- **Bandwidth**: significantly smaller than SASE, fully longitudinal coherence can not be assured
- **SASE**: The SASE signal is expected to be a few percent of the seeded signal

FEL evolution in 2011

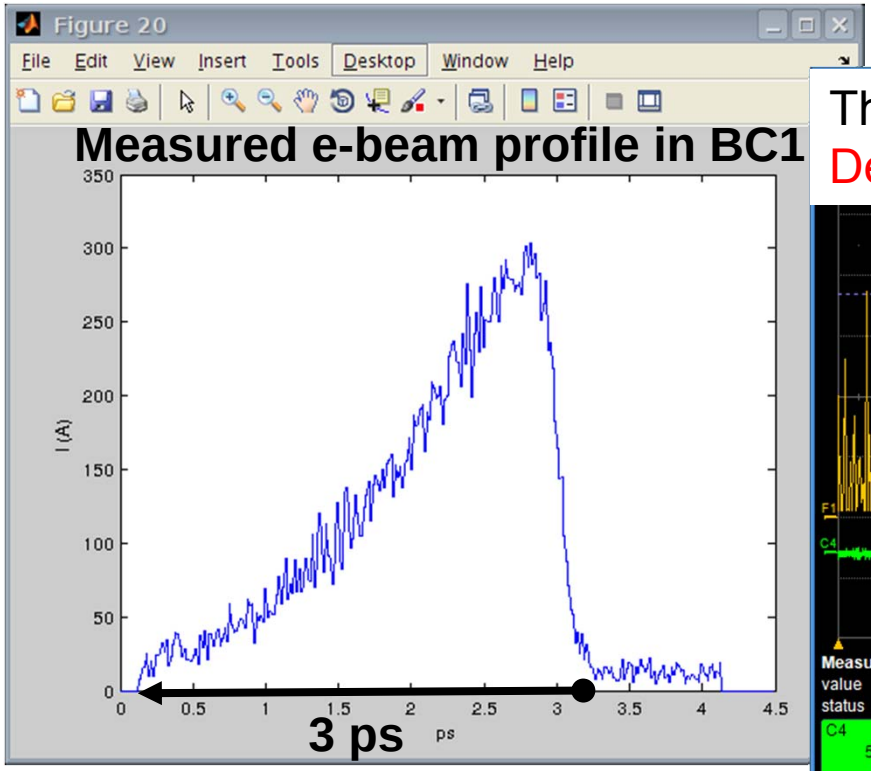
The plans for FEL commissioning have been planned according to the commissioning for the LINAC

	RUN 6		RUN 7		RUN 8			RUN 9
	Feb	March	June	Luly	Sept	Oct	Nov	Dic
λ (nm)	65	65	60-70	60-70	80-60	80-60	80-60	80-60
P (GW)	0.3	0.3	1.5	1.5	2	2	2	2
Energy per pulse (μJ)	100	100	150	150	200	200	200	250
Photons per pulse	3.E+13	3.E+13	4.E+13	4.E+13	8.E+13	8.E+13	8.E+13	8.E+13
Pulse length FWHM (fs)	200	200	100	100	100	100	100	100
Spot size a the source (μm)	600	600	400	400	350	350	350	350
Polarization	Planar	Planar	Planar	Planar-Circular	Planar-Circular	Planar-Circular	Planar-Circular	Planar-Circular
Power fluctuation	50%	50%	50%	50%	50%	50%	50%	50%
Tunability	no	no	yes	yes	yes	scan	scan	scan
λ (nm)	-	32	30-35	30-35	60-40	60-40	60-40	60-40
P (MW)	-	50	100	1.00E+03	1.00E+03	1.50E+03	1.50E+03	1.50E+03
Energy per pulse (μJ)	-	10	10	100	100	150	150	150
Photons per pulse	-	1.E+12	1.E+12	1.E+13	2.E+13	3.E+13	4.E+13	4.E+13
Pulse length FWHM (fs)	-	180	100	100	100	100	100	100
Spot size a the source (μm)	-	400	400	350	350	300	300	300
Polarization	-	Planar	Planar	Planar-Circular	Planar-Circular	Planar-Circular	Planar-Circular	Planar-Circular
Power fluctuation	-	50%	50%	50%	50%	50%	50%	50%
Tunability	-	no	no	yes	yes	yes	scan	scan
λ (nm)	-	-	-	-	30-20	30-20	30-20	30-20
P (MW)	-	-	-	-	400	400	1.00E+03	1.00E+03
Energy per pulse (μJ)	-	-	-	-	50	50	100	100
Photons per pulse	-	-	-	-	6.E+12	6.E+12	1.E+13	1.E+13
Pulse length FWHM (fs)	-	-	-	-	100	100	100	100
Spot size a the source (μm)	-	-	-	-	300	300	200	200
Polarization	-	-	-	-	Planar-Circular	Planar-Circular	Planar-Circular	Planar-Circular
Power fluctuation	-	-	-	-	50%	50%	50%	50%
Tunability	-	-	-	-	yes	yes	scan	scan

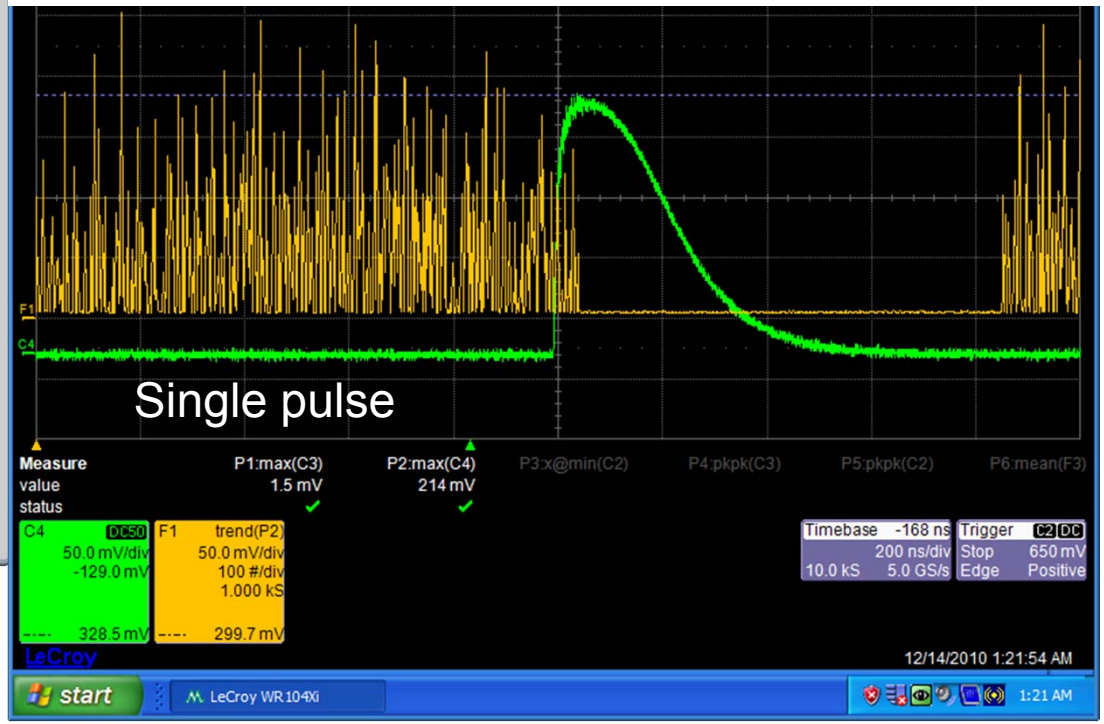
Courtesy E. Allaria

FERMI, first seeding signals

- Seed laser at 260nm (~100MW)
- 6 radiators tuned at 6th harmonic (43nm)



The 1st seeded FEL was observed on the 13th of Dec. 2010



Photodiode looking at undulator emission

1 Year Look ahead

- First experiment in March
- BC2 installation in April
- X-band linearizer installation in August
- FEL2 beamline in August
- Undulator for FEL 2 in October
- 2 RF deflector at linac end in October
- A new RF gun operating at 50Hz

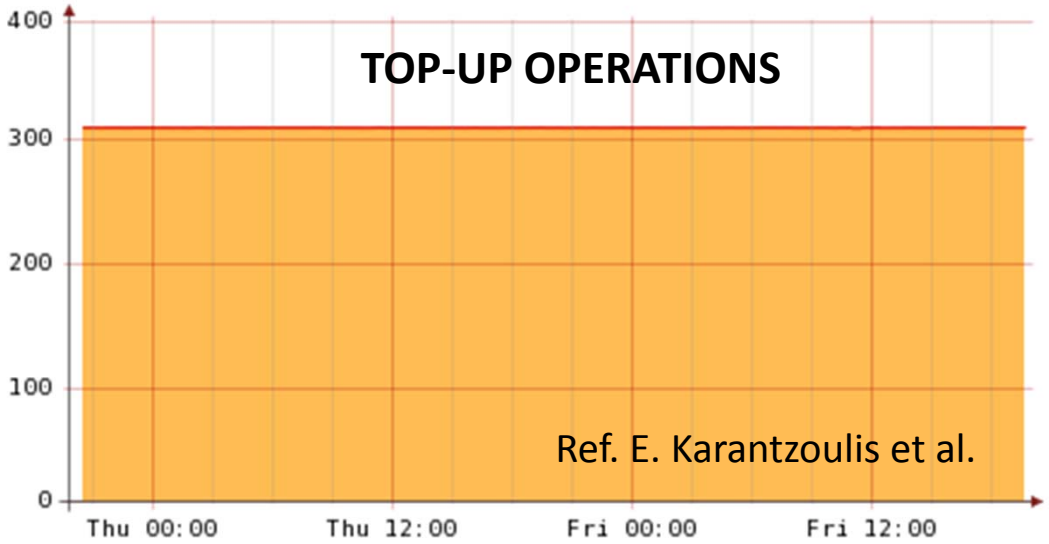
Acknowledgements

FERMI Commissioning Team, Engineers, Laser group, Diagnostic group, Control group, ELETTRA Operators, Linac Group, FERMI Commissioning Guests.

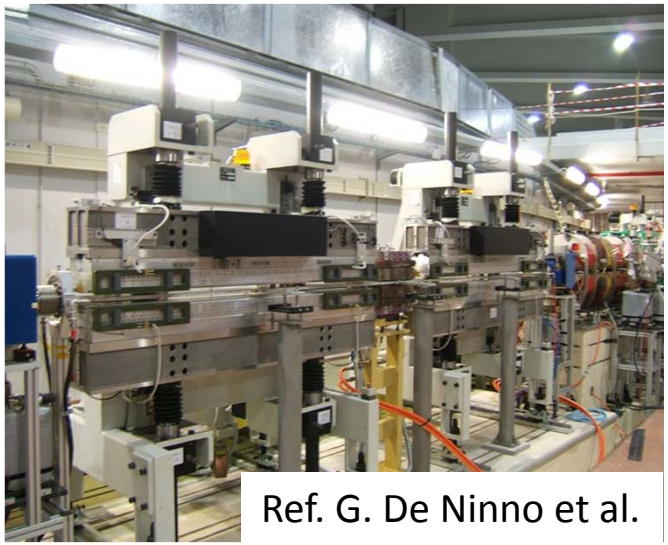
Thank you for your attention

BACK SLIDES

ELETTRA SR Status



- Full energy injection since 2008
- Top-up operation since May 2010
- 2 GeV@310 mA & 2.4 GeV@150 mA



Ref. G. De Ninno et al.

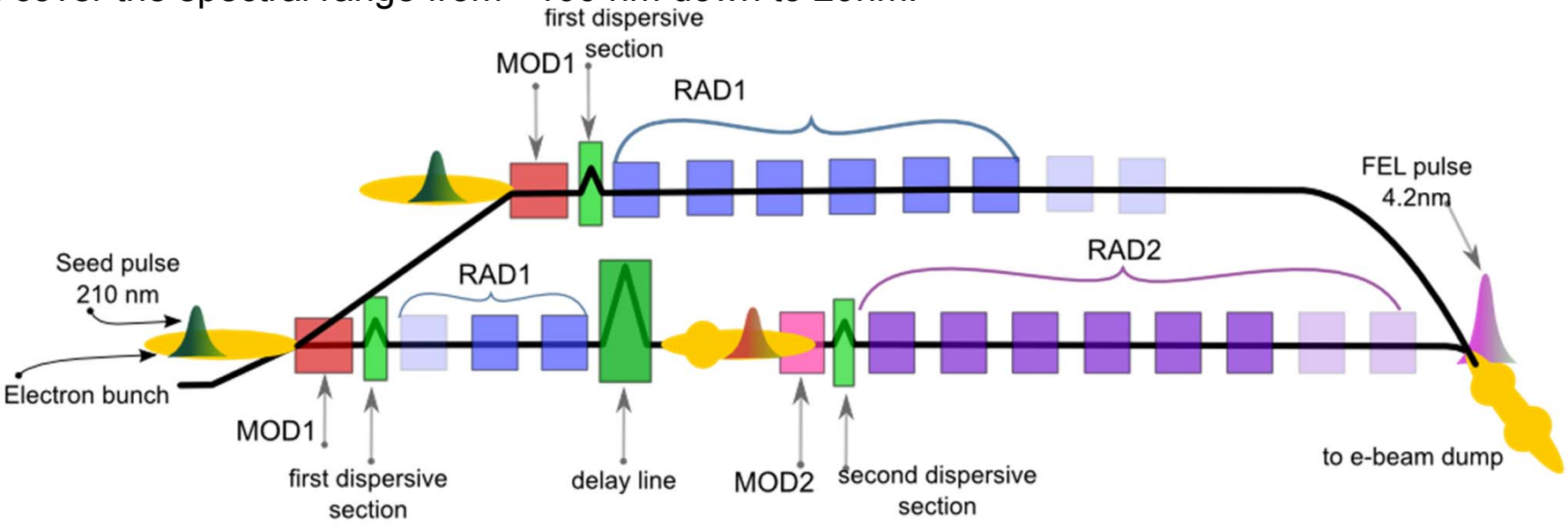
ELETTRA SR FEL

- Optical Klystron
- 2 Apple Undulators (10cm, 2 meters long)
- Dispersive section
- Seed Laser (Ti:Sapphire)
  - 780,390,260nm – 1-20GW, 0.12-1ps

FEL-1 and FEL-2

Two FELs will cover different spectral regions.

FEL-1, based on a single stage high gain harmonic generations scheme initialized by a UV laser will cover the spectral range from ~100 nm down to 20nm.

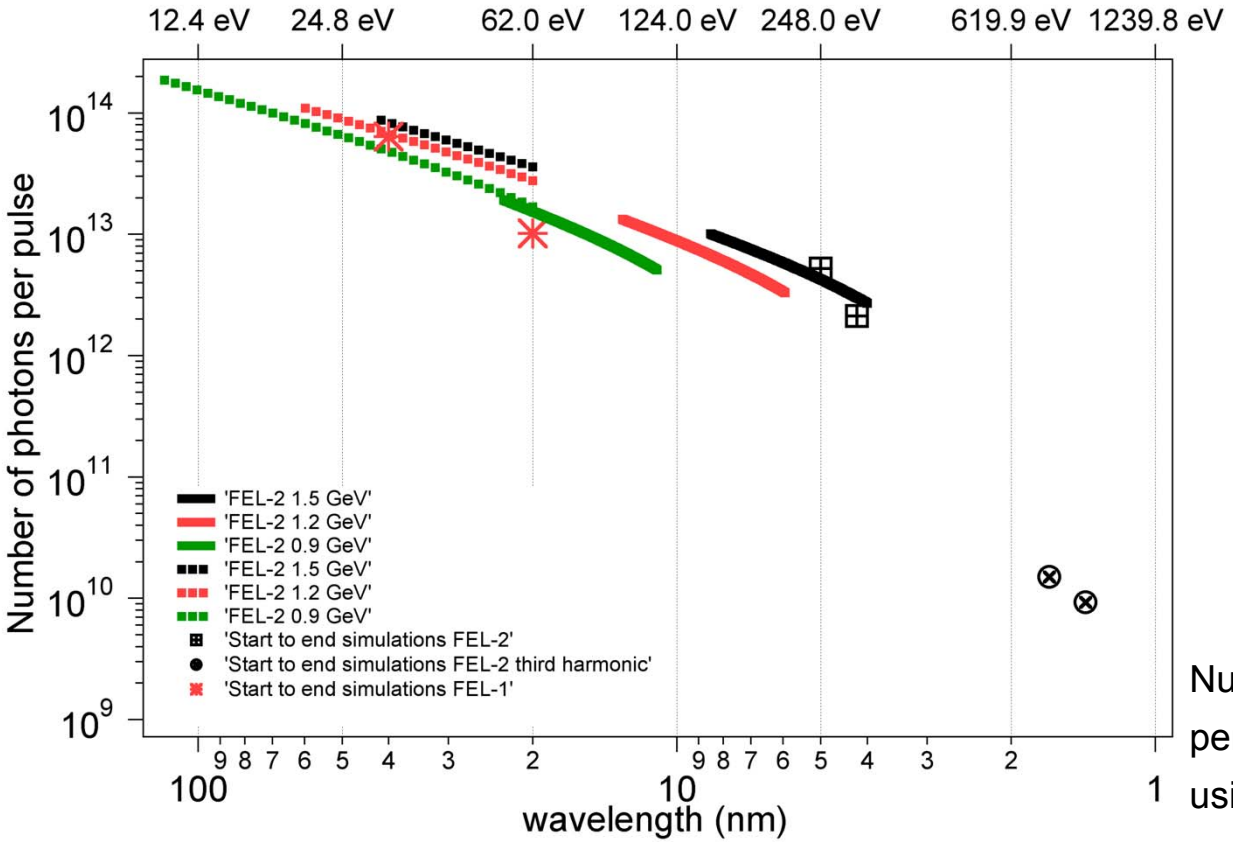


FEL-2, in order to be able to reach the wavelength range from 20 to ~4 nm starting from a seed laser in the UV, will be based on a double cascade of high gain harmonic generation. The nominal layout will use a magnetic electron delay line in order to improve the FEL performance by using the fresh bunch technique. Other FEL configurations are also possible.

FEL tunability

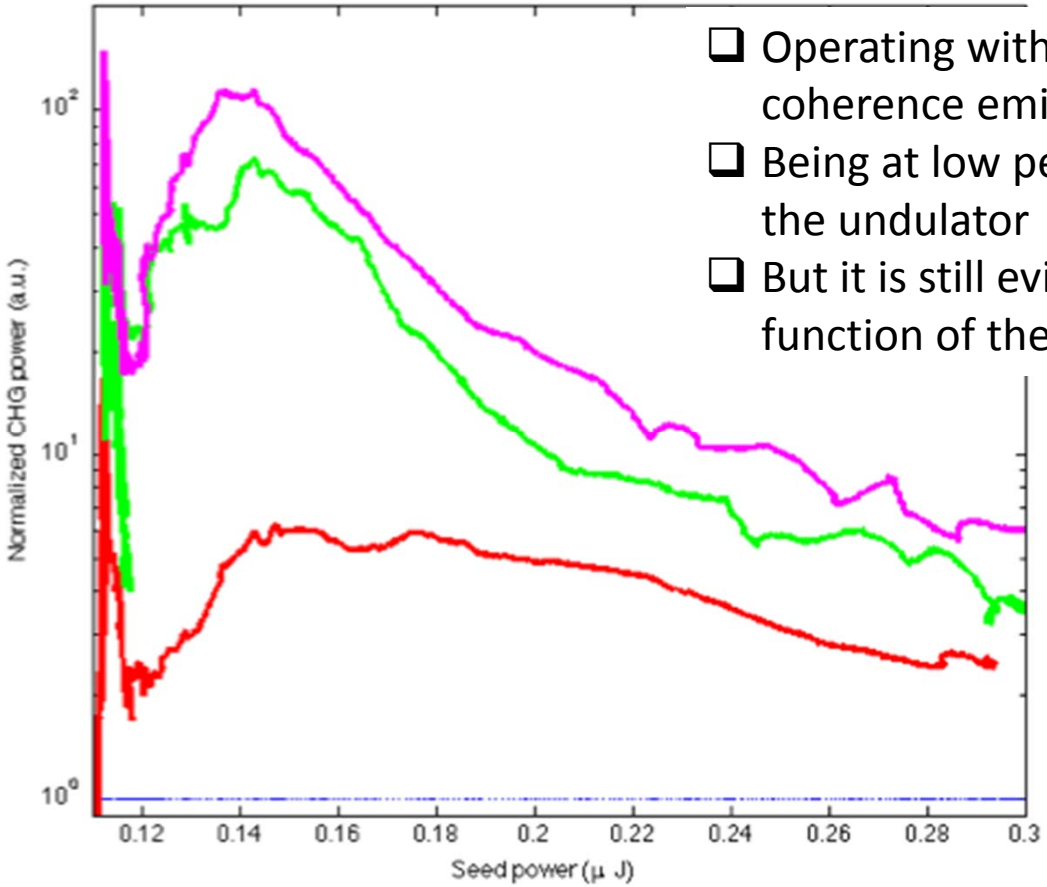
In the whole spectral range FERMI is expected to provide FEL pulses with about 10^{13} photons per pulse.

Using the emission at the harmonics of the resonance wavelength the spectral range can be extended toward about 1.5 nm.



Numerical predictions of the FEL performance based on M. Xie formulae using the FERMI parameters

Evidence of coherence emission



- Operating with an uncompressed beam we studied the coherence emission from the seeded bunch
- Being at low peak current we do not expect gain along the undulator
- But it is still evident an increase of CHG power as a function of the number of radiator used

→ Using 4 radiators allows to produce about 100 more signal than with one undulator in the same conditions

E. Allaria et al.

FERMI FEL commissioning goals

We agreed with FERMI users on a reasonable set of FEL parameters as a GOAL for the first period of commissioning that could also be used for first user experiments.

- **Wavelength**: in the range 50-60nm (tunability not required).
- **Polarization**: horizontal.
- **Power**: hundreds of MW (peak).
- **Energy**: ~100 μJ.
- **Coherence:** Transverse and longitudinal (long. not critical)

Startup of FEL-1 / HGHG

In the case of HGHG the success depend on the seeding process, putting stronger requirements on the available hardware.

Hardware requirements

- Seed laser available and aligned
  - Screens for spatial overlap;
  - Photodiode for coarse timing overlap.
- Dispersive section chicane and diagnostic available.
- The modulator available and aligned.
- Few undulators are sufficient.
- Timing jitter has to be smaller than 1ps (the smaller the better)

e-beam requirements

- Peak current should be of the order of 200 A
- Emittance should be of the order of 2 mm mrad
- Energy spread should be < 150keV (exp. 100keV)
- Energy fluctuation should be smaller than 0.5%

At the startup the fixed wavelength operation of the seed laser with more energy per pulse is required.