Implementation of Single-Stage Echo-Enabled Harmonic Generation on the FERMI@Elettra FEL

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Outline

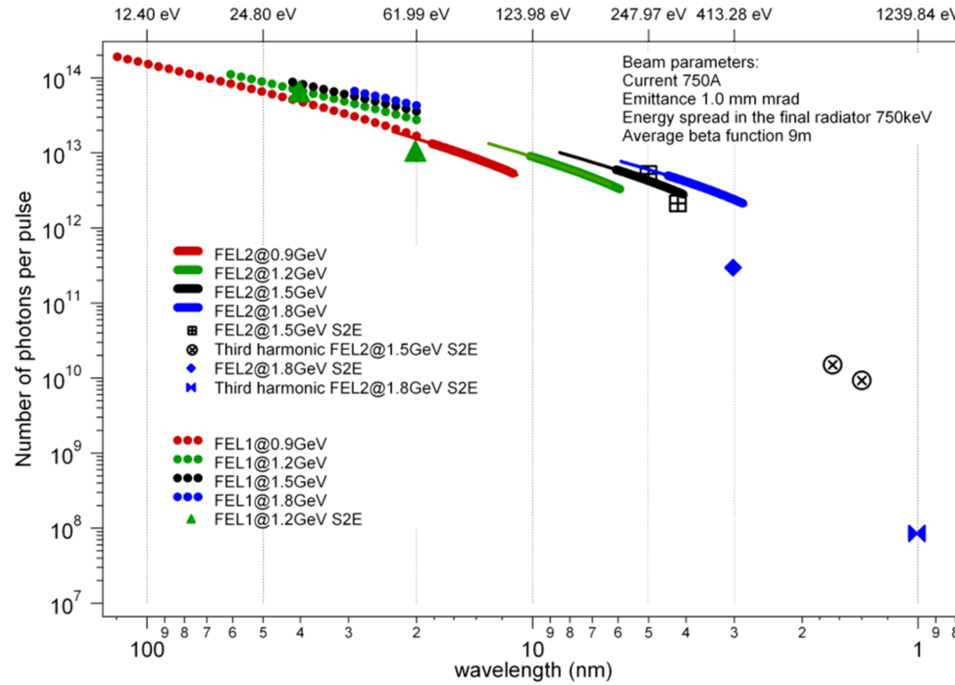
- FERMI FEL facility
  - FEL-1 and FEL-2
  - FERMI wavelength range
  - FEL-2 nominal layout
- EEHG in FERMI
  - Available hardware
  - Expected performance
  - Possible improvement

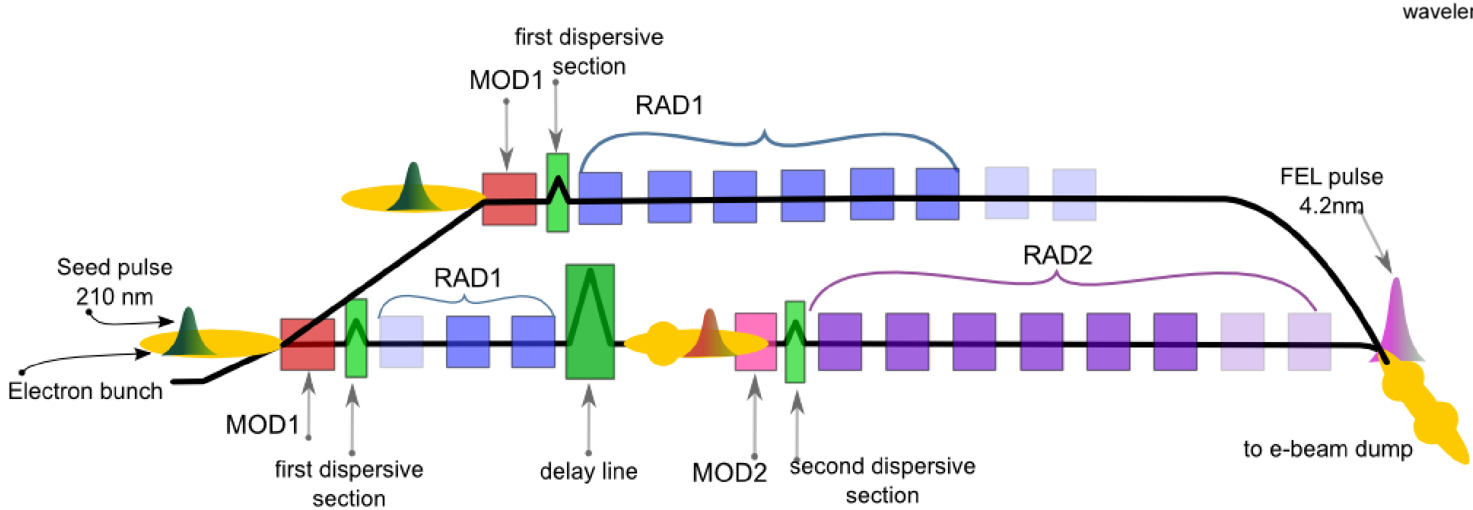
FERMI FELs: FEL-1 and FEL-2

FERMI is a FEL user facility based on a normal conducting LINAC.
Nominal parameters for the FERMI e-beam are:

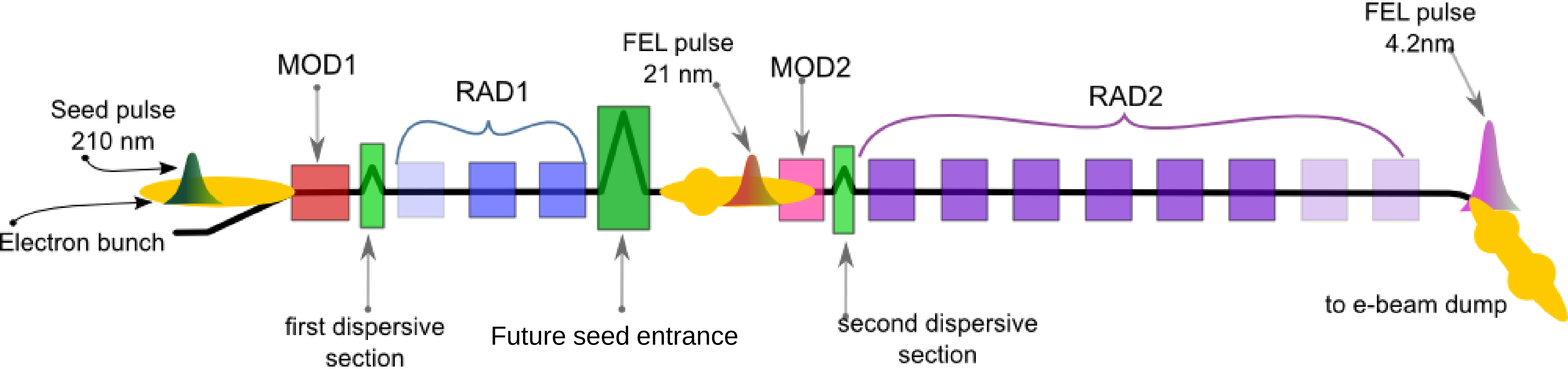
Parameter	*Value*	*Units*
Energy	**0.9-1.5**	**GeV**
Peak current	**800**	**A**
Emittance	**1.0**	**mm mrad**
Energy spread	**150**	**keV**

Using two seeded FEL lines FERMI will cover the spectral range from 100 to about 4 nm





FEL-2: the layout



- The nominal layout for FEL-2 is the double cascade High Gain Harmonic Generation scheme.
- This includes a first **modulator** followed by a **dispersive section** chicane and the **first radiator** where up to the tenth harmonic of the **seed laser** wavelength can be amplified.
- FEL-2 will use the **fresh bunch** technique, a **strong chicane** is used **to delay** the e-beam with respect to the FEL pulse generated into the first radiator.
- The FEL pulse produced in the first radiator seeds a fresh part of the e-beam in the **second modulator.** This is followed by a dispersive section and a **final long radiator** where the final harmonic is produced and amplified

The FERMI LINAC has been designed and optimized for such a scheme however, the layout has been designed to be flexible for future upgrades and possible different seeding schemes.

FEL-2 simulations

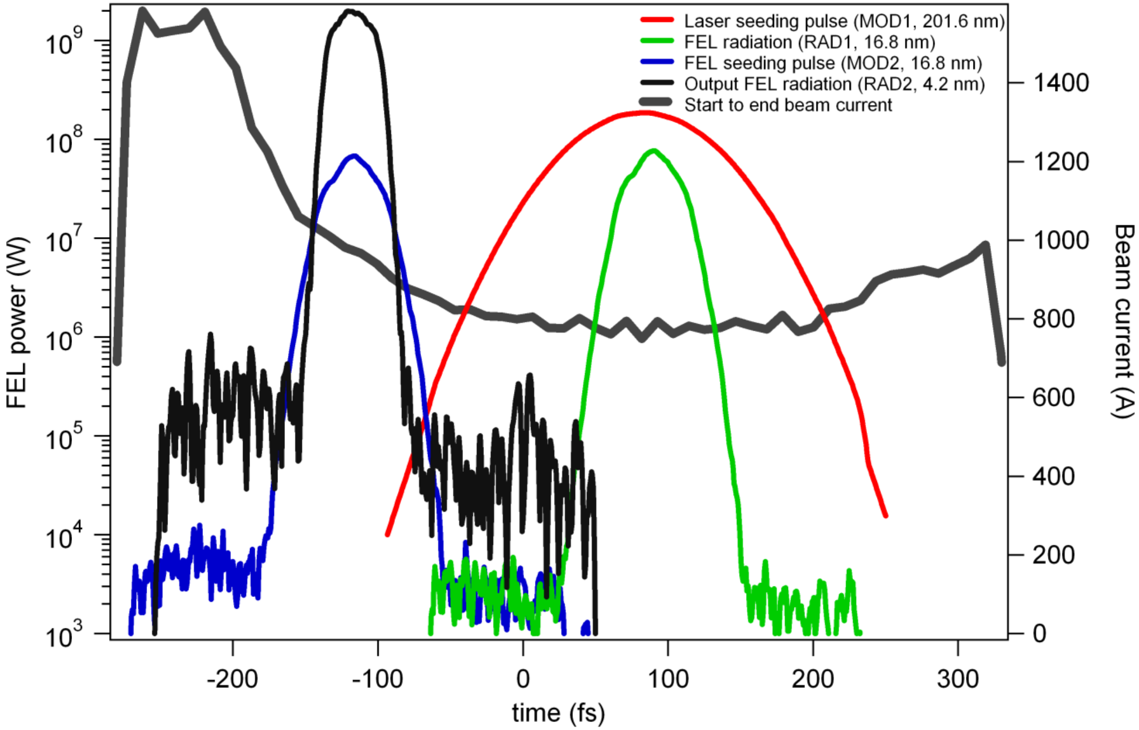
In order to accommodate the two FEL pulses of the fresh-bunch the FERMI e-beam has to have a relatively long (500fs) flat region where the two pulses can be accommodated.

Start to end studies at FERMI show the possibility of producing a beam with about 800A and with the required properties. The start to end files have been used to perform the FEL simulations.

Starting with a 100fs (FWHM) seed at ~200nm FEL pulses of about 40 fs FWHM and about 2GW of peak power are produced. The data here show the case for 4.2 nm which is the shortest fundamental wavelength for FERMI with the current design and is the most sensitive to beam properties.

The possibility to meet the FERMI goals with FEL-2 is strongly related to the possibility to operate the FERMI LINAC with 800pC beams that allow one to generate the needed electron bunches for the fresh bunch process.

Different schemes have been studied for possible alternative solutions



Pulse:2GW, 40fs FWHM, 60μJ, 3.7e^{12} ph/pulse

Photons: 4.2nm, 295eV

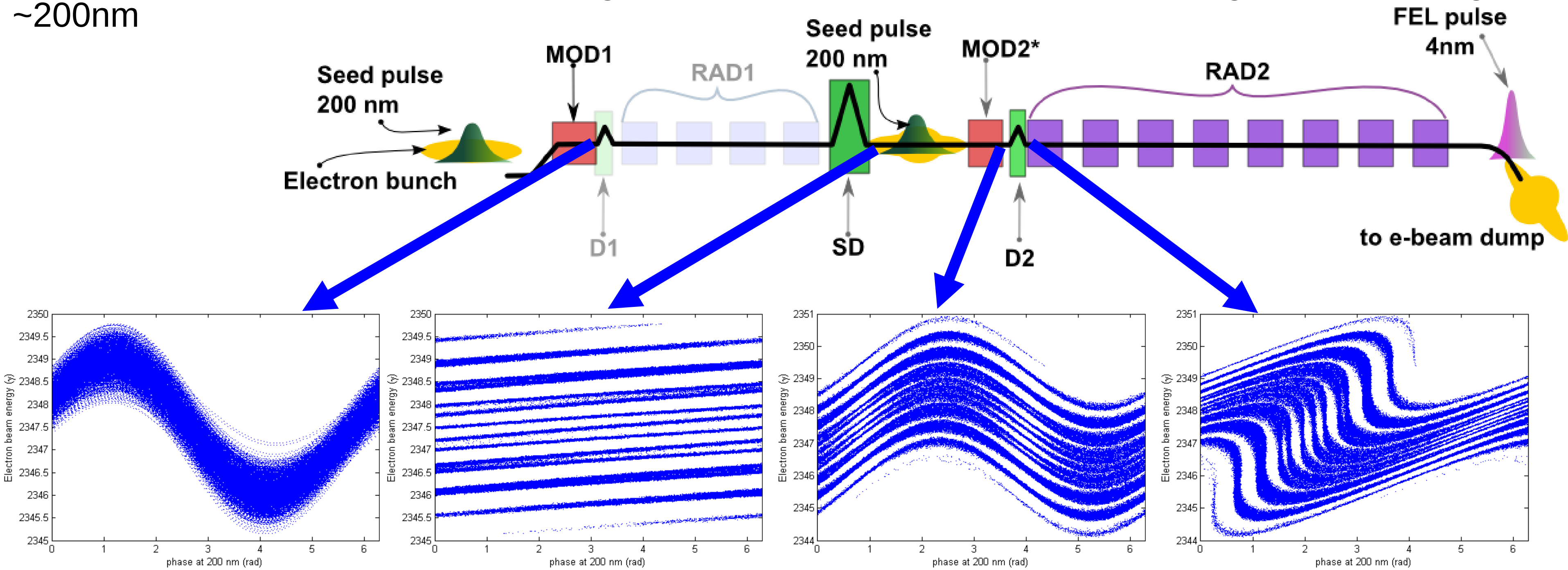
Bandwidth: 4e-4, ~100meV

Possible other schemes, EEHG

The possibility to implement the EEHG scheme with the FEL-2 layout with small modification has been studied*.

The strong dispersive section (R56~mm) can be obtained from the standard delay line of the current scheme.

The second modulator has to be changed to allow the resonance at the seeding laser wavelength ~200nm



Additional schemes like using short wavelength seeding sources (HHG) are under investigations.

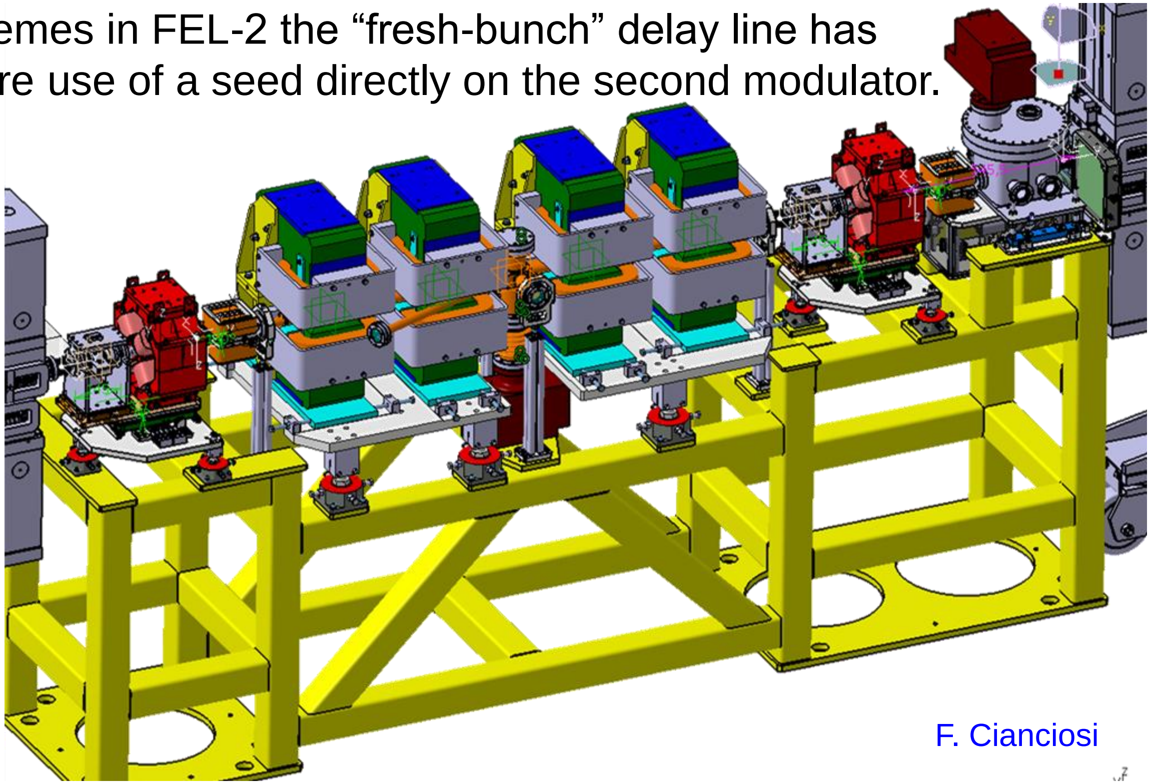
*D.Xiang et al. **MOPC02**, FEL09

The FERMI delay line

With the aim of allowing future new schemes in FEL-2 the “fresh-bunch” delay line has been designed in order to allow the future use of a seed directly on the second modulator.

Two input ports for future seed sources are available in the middle of the chicane.

The present design of the chicane magnets can provide an R56 larger than 1 mm for energies up to 1.2GeV. Although the allowed dispersion is not as strong as that required by the optimal EEHG scheme the available strength is enough to implement the EEHG up to about the 30th harmonic.



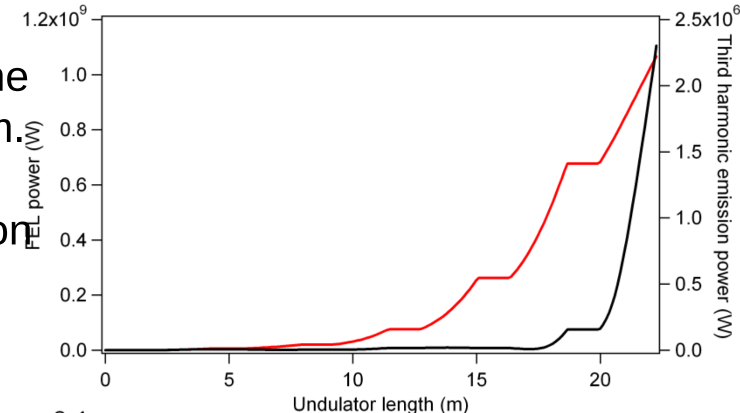
F. Cianciosi

FERMI Bending Delay Line:		[illegible]	*0.9GeV*	*1.2GeV*	*1.5GeV*	*1.8 GeV*	*residual*	unit
# of Dipoles	N		4	4	4	4	4	
Curvature angle 0	α		6.40536E-02	4.80489E-02	3.84322E-02	3.20268E-02	3.14159E-04	rad
Curvature angle 1			3.670	2.753	2.202	1.835	0.018	°
Beam energy of reference	E_0		0.9	1.2	1.5	1.8	0.9	GeV
Magnetic straight length	L_{mag}		181.3	181.3	181.3	181.3	181.3	mm
Drift between the magnets center 2 center	L_{drift}		360	360	360	360	360	mm
R56	R		2461.15	1384.16	885.32	614.73	0.06	um
Chicane transversal drift	dX		23.08	17.31	13.84	11.53	0.11	mm
Integrated magnetic field at E_0	IY_0		0.1922	0.1922	0.1922	0.1922	0.0009	T·m
Magnetic field at magnet centre at E_0	BY_0		1.0599	1.0601	1.0599	1.0599	0.0052	T

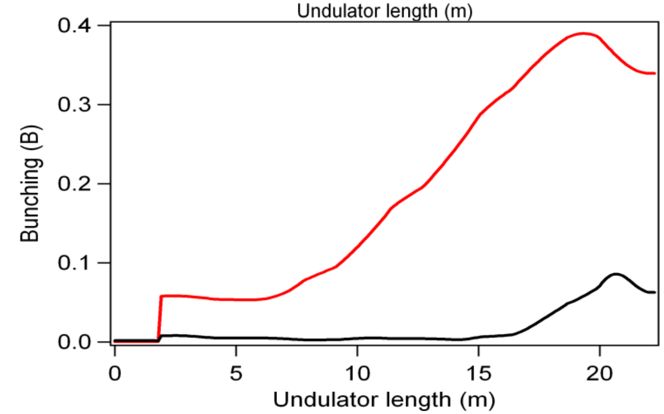
D. Castronovo

EEHG time steady results

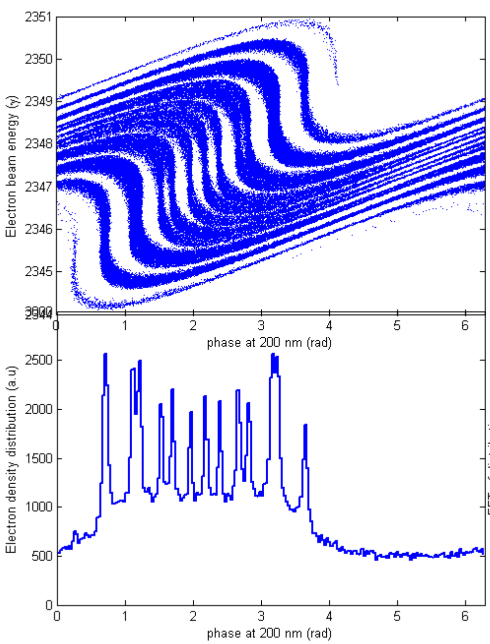
Results of FEL simulations with GINGER.
Using the nominal parameters for the e-beam we simulated the FEL using EEHG at 6.6 nm and starting from a seed at 200nm. Significant bunching (~0.1) can be produced at the exit of the second chicane and would allow the system to reach saturation within the six available undulators.

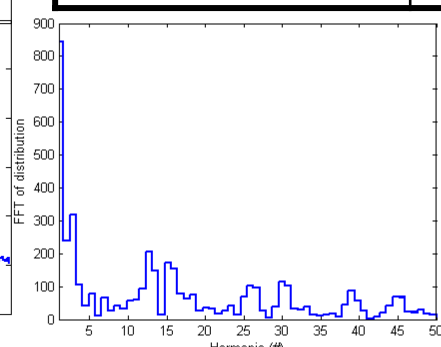


We can also predict a significant signal at the third harmonic



Parameter	*Value*	*Units*
E-beam energy	**1.2**	**GeV**
Seed lasers wavelength	**200**	**nm**
Seed laser 1 power	**20**	**MW**
Seed laser 2 power	**120**	**MW**
R56 first chicane	**0.9**	**mm**
R56 second chicane	**60**	**μm**

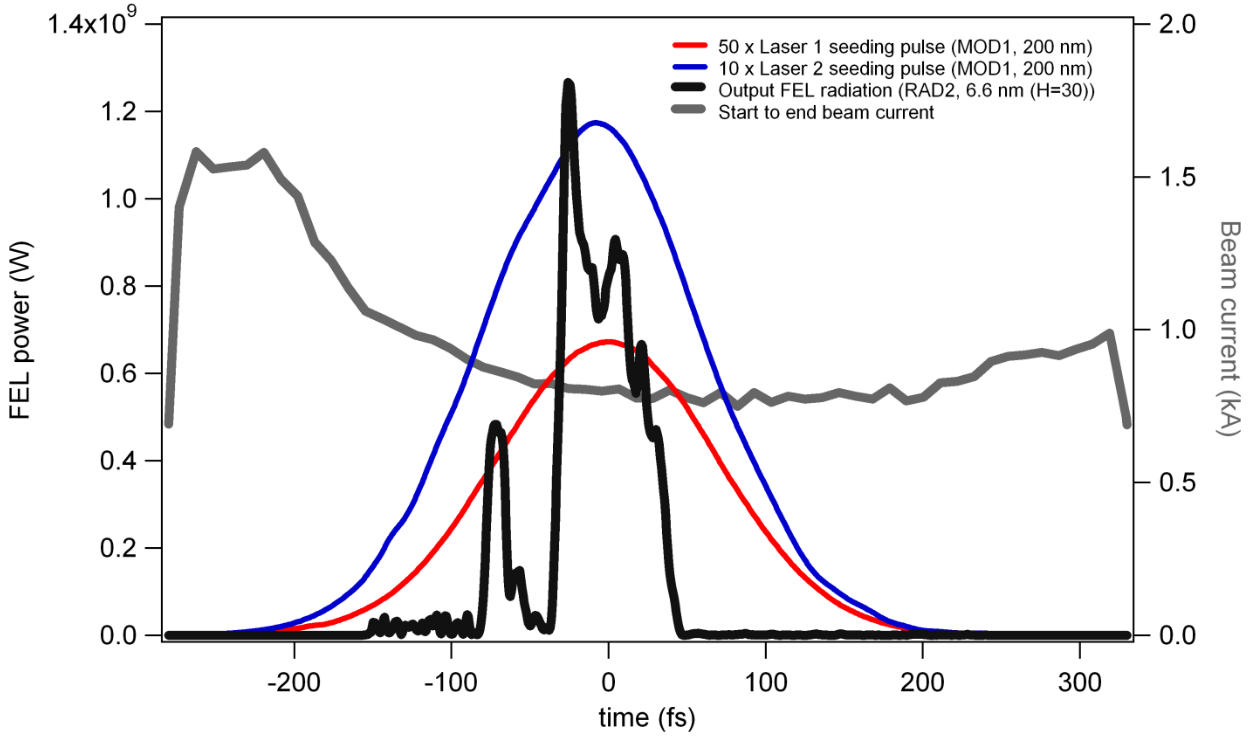




The Fourier analysis on the e-beam phase space at the entrance of the last radiator show that some bunching is also present at ~40th harmonic.

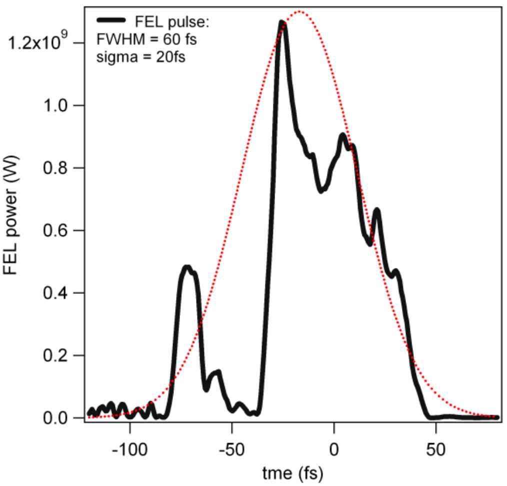
EEHG: S2E simulations (1/2)

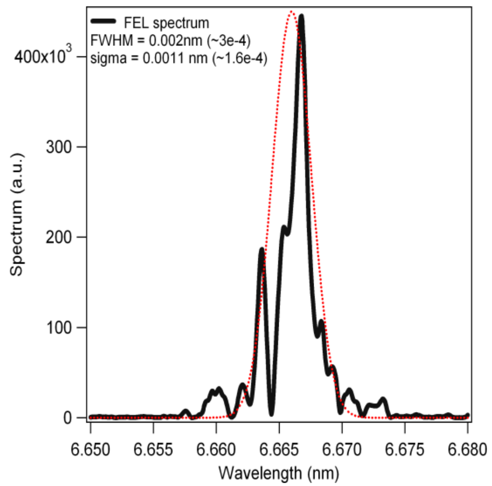
The simulations done using the present S2E electron beam of FERMI, which is not optimized for EEHG, show that FEL performance is very similar to that of the double cascade with the fresh bunch technique.

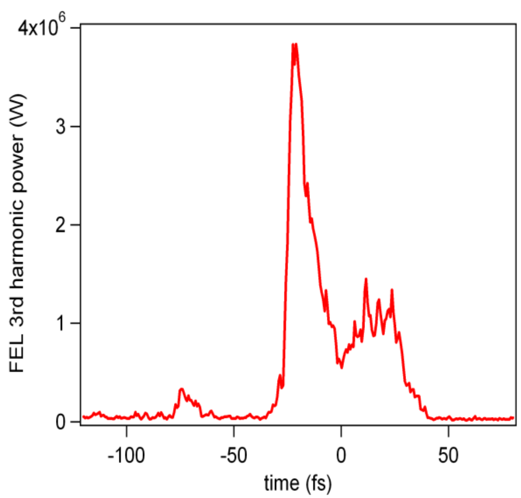


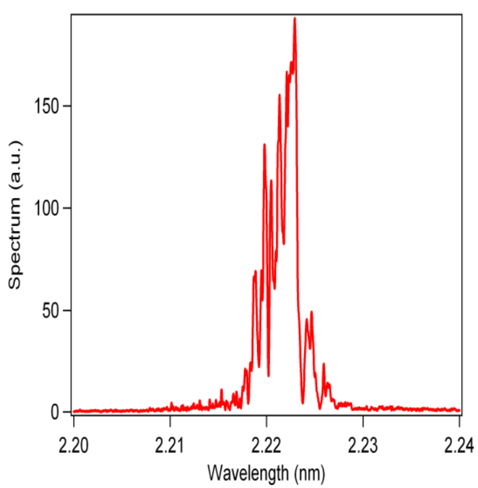
The GW level can be reached with pulses of about 50fs FWHM pulse length.

EEHG: S2E simulations (2/2)







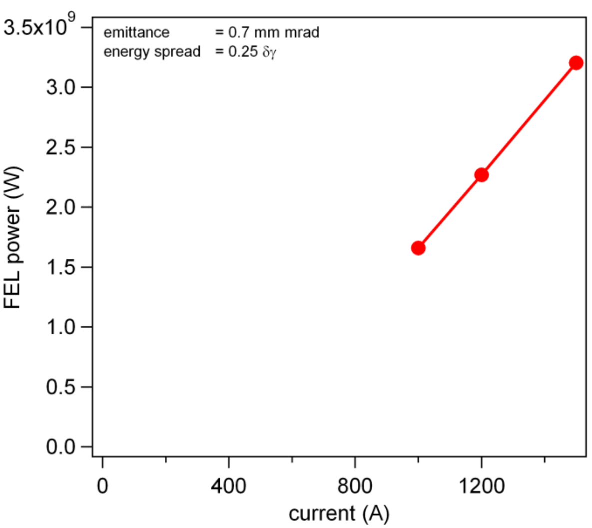


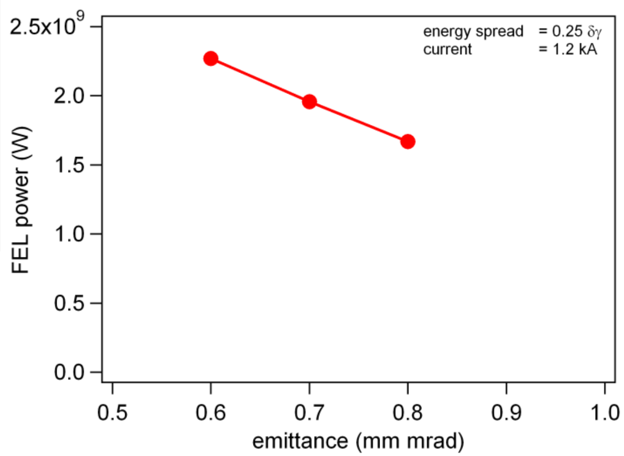
Parameter	*Value*	*Units*
Seed pulses (FWHM)	**150**	**fs**
FEL pulse (FWHM)	**60**	**fs**
FEL pulse energy	**60**	**μJ**
Photons per pulse	**$2*10^{12}$**	
FEL pulse bandwidth (FWHM)	**$3*10^{-4}$**	
FEL pulse bandwidth (FWHM)	**20**	**meV**
3th harmonic energy	**100**	**nJ**
3th ph/pulse	**10^9**	

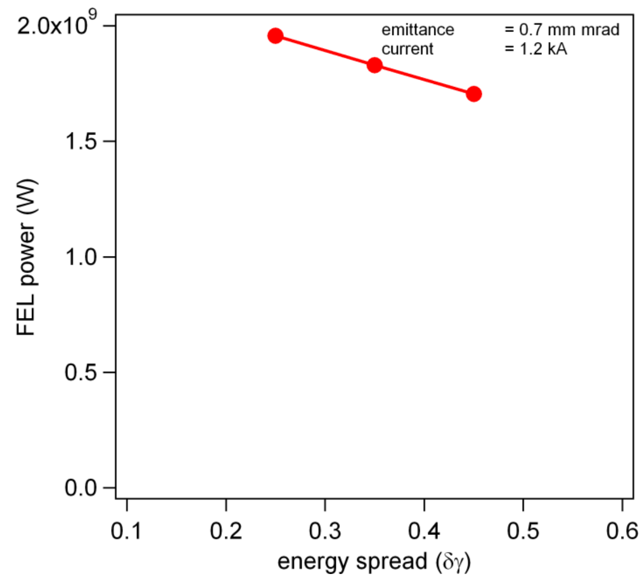
EEHG: e-beam parameters sensitivity

More time independent studies have been done to estimate the sensitivity of the EEHG scheme on electron beam parameters and the possible advantages of using different electron beams with respect to the nominal beam of FERMI.

The study focused on the 4nm FEL wavelength case with a 1.5 GeV electron beam.







Results show how the EEHG performance could be increased by having a beam with a higher peak current and also shows that the scheme is not particularly sensitive to the emittance and the energy spread for the cases studied here.

Acknowledgement

Initial discussions about the possibility of implementing an EEHG experiment at FERMI involved G. Stupakov, W. Fawley, S. Milton.

First numerical studies for EEHG in FERMI have been done in collaboration with D. Xiang.

We thank W. Fawley for the support in using Ginger and for the continuous effort in extending the code capabilities.

We thank the whole FERMI team.

Thank you for your attention