Laser-based e-beam manipulation

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The Center for BRIGHTBEAMS
A National Science Foundation Science & Technology Center

Let's narrow the field …

Laser systems are ubiquitous is accelerators and are used to control the beam at different levels. Just a few examples:

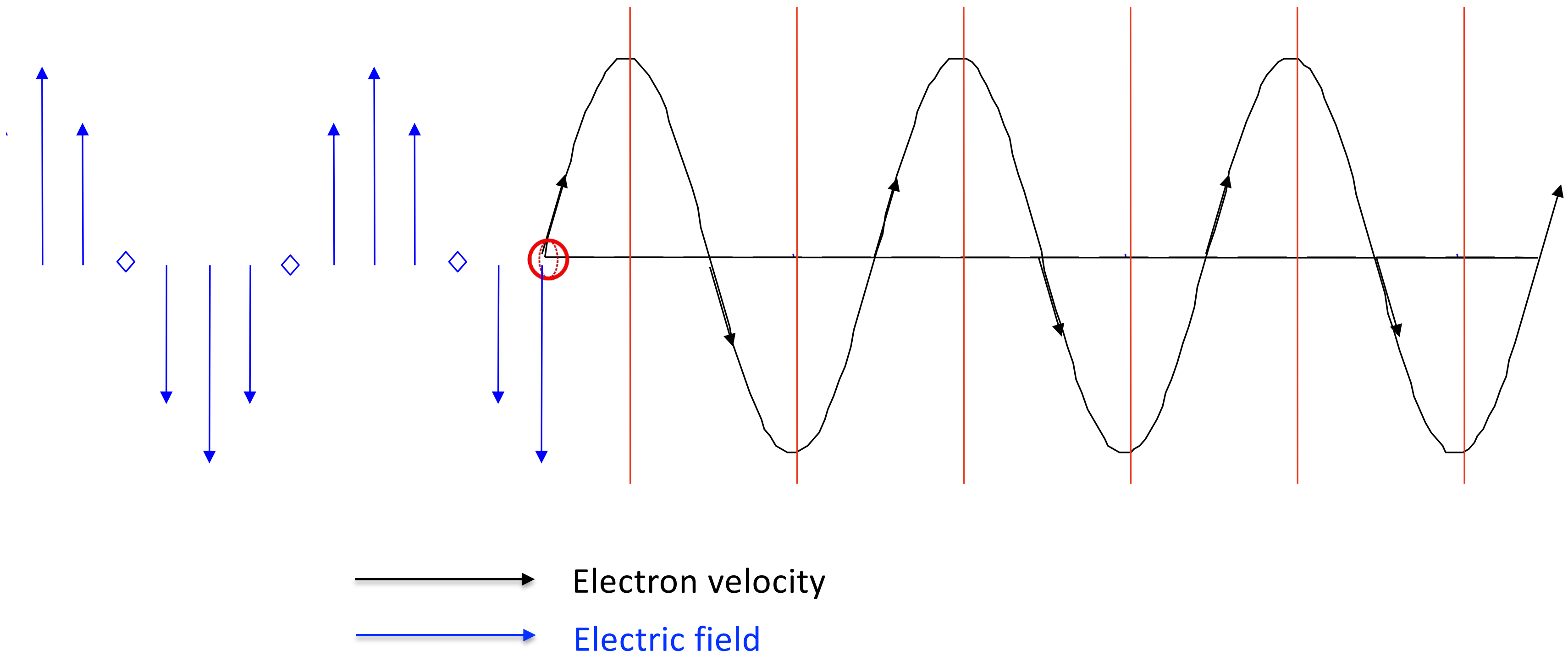
- Lasers allow the generation of high brightness beams by photemission in RF photoinjectors
- Lasers can be the "source" of the accelerating field:
  - Laser Plasma acceleration
  - Inverse FEL
- Lasers are used to manipulate the electron beam phase space:
  - Laser Heater
  - Enhanced-SASE
  - **Seed an FEL amplifier**

The ones in red have in common the resonant interaction of a laser field with the beam in magnetic undulator.

Electron motion in undulator with a co-propagating optical wave

At resonance ($\lambda=\lambda_0$) the radiation phase advances one period for every undulator period

$$\lambda_0 = \frac{1}{2\gamma^2}(1 + K_{rms}^2)$$

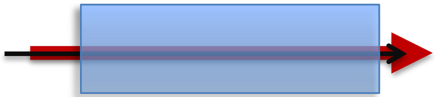


Energy exchange $\Delta\gamma \propto \beta_\perp \cdot E$ **depends on the phase**

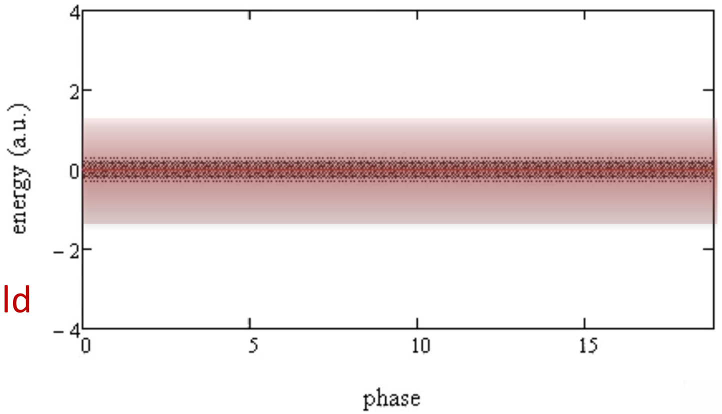
Phase space manipulation

Inducing energy modulation

Undulator

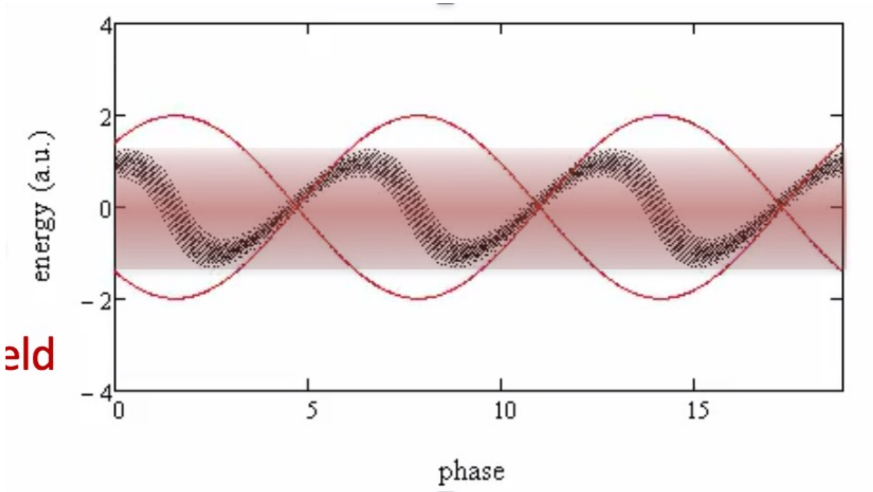


Increasing the laser field



Beam heating: to suppress microbunching instability, *Z. Huang et al. Phys. Rev. ST Accel. Beams 7, 074401*

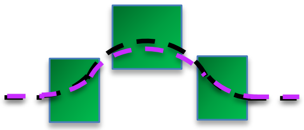
Shaped beam heating: to control pulse duration, *D. Cesar, et al. Phys. Rev. Accel. Beams* ***24****, 110703*



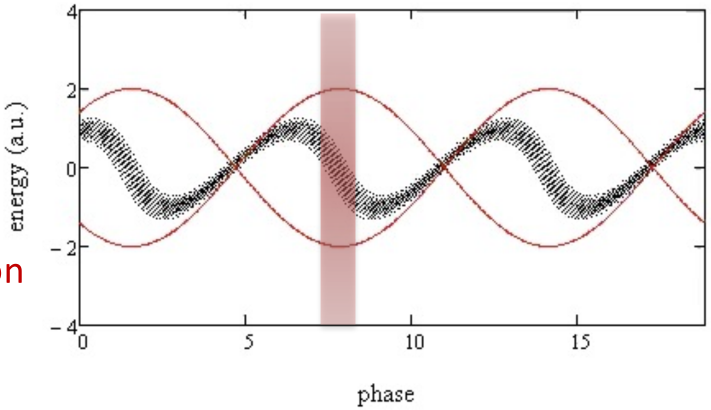
Phase space manipulation

Inducing density modulation

Dispersion



Increasing the dispersion



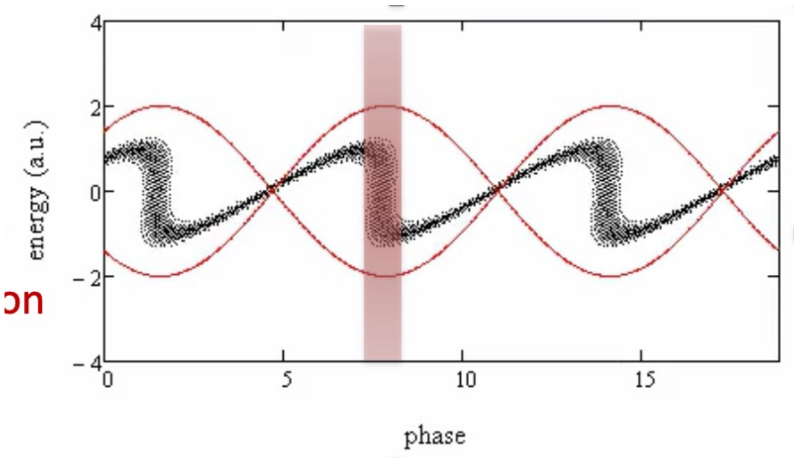
Enhanced SASE: - Generate current spike

A. Zholents, Phys. Rev. ST Accel. Beams ***8****, 040701 (2005)*

Seeding: Induce modulation with higher frequency components

I.Boscolo, V. Stagno, Il Nuovo Cimento 58, 271 (1980)

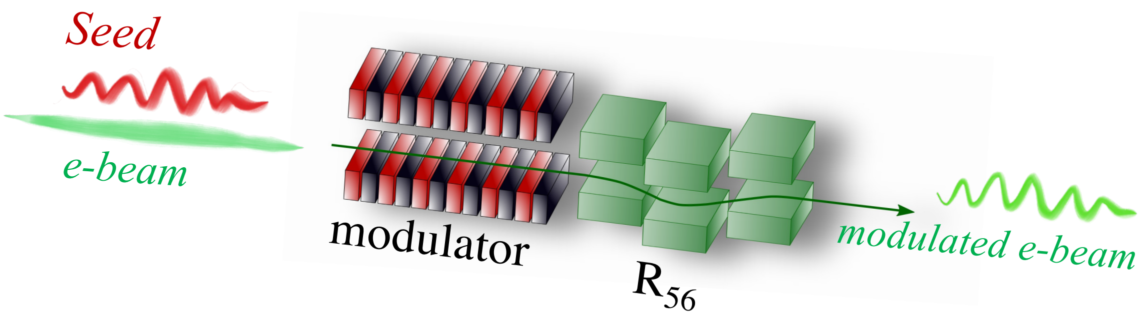
L.H. Yu, Phys. Rev. A 44, 5178 (1991)

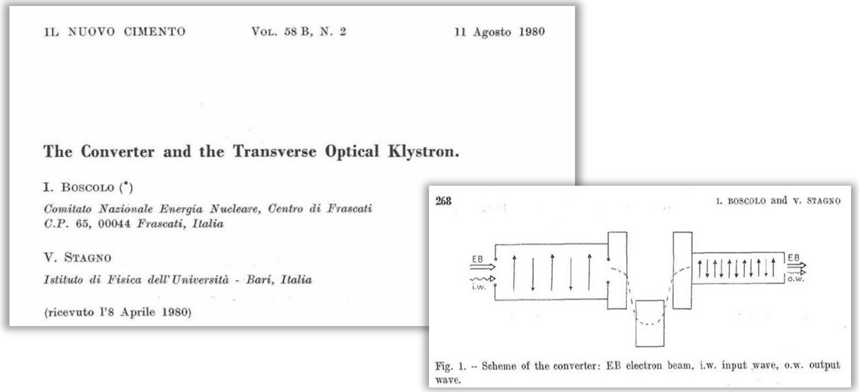


The «converter» concept

A FEL «modulator» encodes **phase and amplitude** of a laser field on the phase-space of an electron beam.

The concept of harmonic conversion traces back to the early days of the FEL history
I.Boscolo, V. Stagno, Il Nuovo Cimento 58, 271 (1980)




IL NUOVO CIMENTO VOL. 58 B, N. 2 11 Agosto 1980

The Converter and the Transverse Optical Klystron.

I. BOSCOLO (*)

Comitato Nazionale Energia Nucleare, Centro di Frascati
C.P. 65, 00044 Frascati, Italia

V. STAGNO

Istituto di Fisica dell'Università - Bari, Italia

(ricevuto l'8 Aprile 1980)

268 I. BOSCOLO and V. STAGNO

Fig. 1. – Scheme of the converter: EB electron beam, i.w. input wave, o.w. output wave.

Seed amplitude and phase

Bunching factor = Fourier transform of the electron density at n-th harmonic.

In HGHG after modulator and dispersive section:

$$b_n(\zeta) = \frac{1}{\lambda_0}\int_{\zeta}^{\zeta+\lambda_0} \rho_e(\zeta')\, e^{-ink_0\zeta'} d\zeta' = \exp\left[-\frac{1}{2}\left(nk_0 R_{56}\frac{\sigma_\gamma}{\gamma}\right)^2\right] J_n\left(nk_0 R_{56}\frac{|a(\zeta)|}{4\pi N}\right) e^{in\Phi(\zeta)}$$

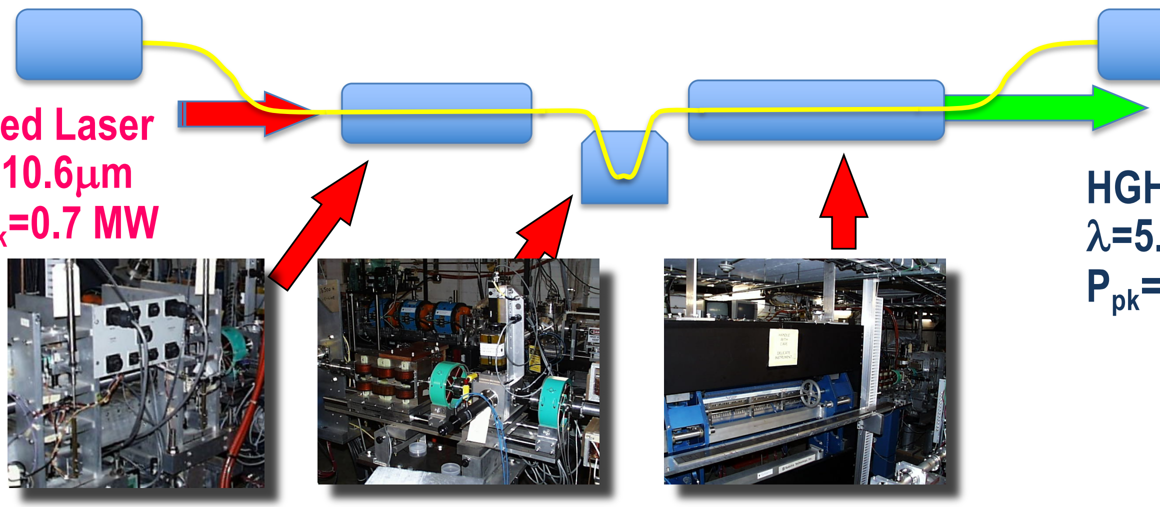
In the amplifier:

$$E_n(\zeta, z) \propto z\, b_n(\zeta)$$

While retaining of the coherence of the original laser, the encoded phase-space can be manipulated in different ways to induce emission of light with different properties, in terms of **wavelength, field amplitude & phase, and polarization**

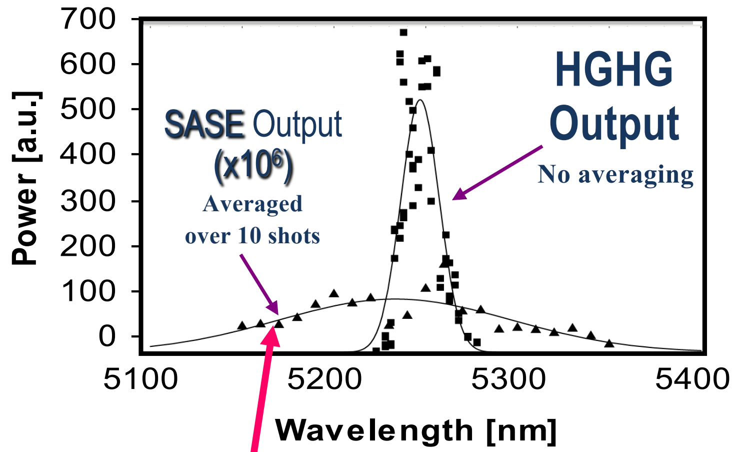
Courtesy of I. Ben Zvi

The HGHG Experiment at BROOKHAVEN NATIONAL LABORATORY

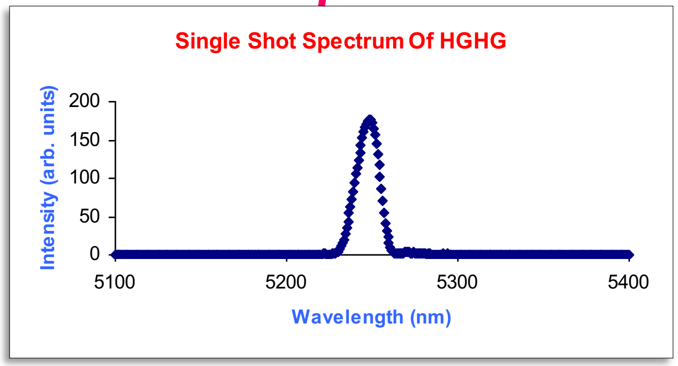


Seed Laser
λ=10.6μm
P_{pk}=0.7 MW

HGHG FEL
λ=5.3 μm
P_{pk}=35 MW



Modulator Section	Dispersion Section	Radiator Section
B_w=0.16T l_w=8cm L=0.76 m	L=0.3 m	B_w=0.47 l_w=3.3cm L=2 m

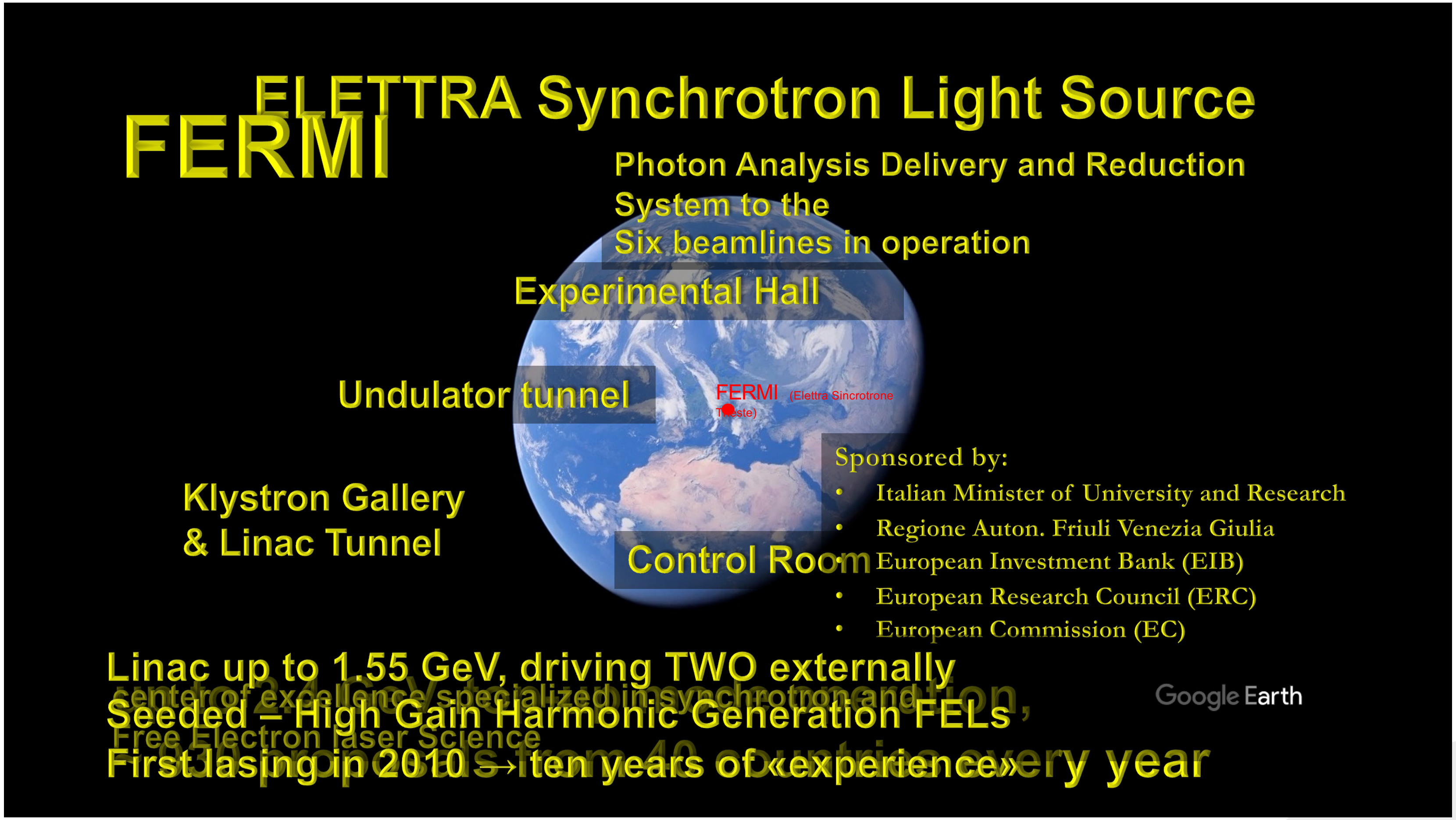


Electron Beam Input Param.:
E= 40 MeV
ε_n= 4π mm-mrad - dγ/γ=0.043%
I = 110A - τ_e= 4 ps

L. H. Yu et al. Science **289** (2000) 932

In 2003 extended to UV L. H. *Yu et al, PRL 91,* 074801 *(2003)*

Bird's eye view of Elettra Sincrotrone Trieste



Elettra Sincrotrone Trieste

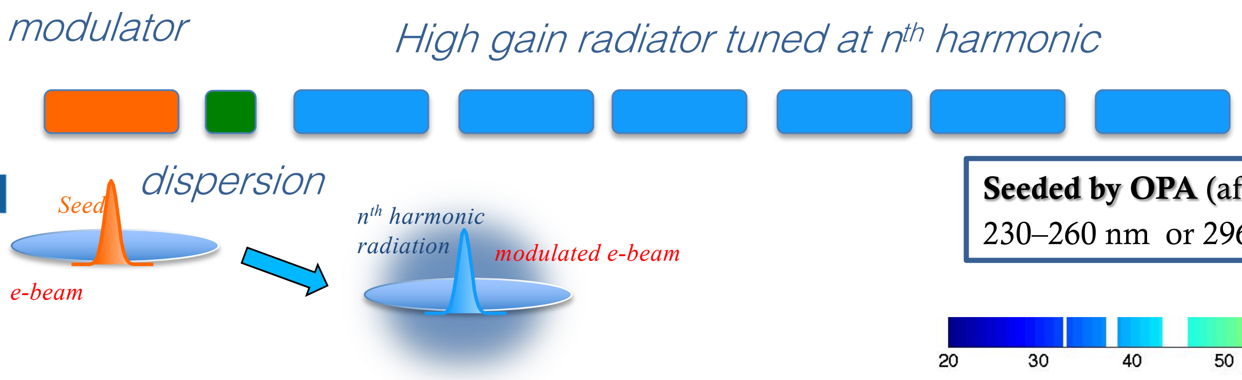
FERMI FELs: FEL-1 & FEL-2

FERMI FEL-1

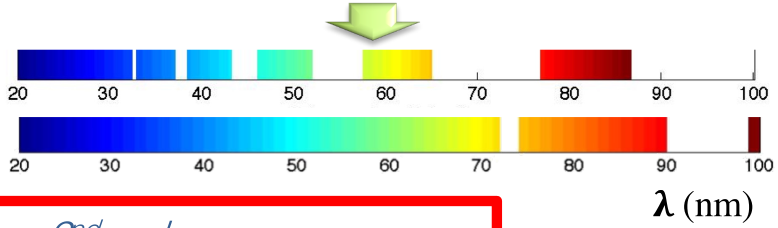
nature photonics | ARTICLES
PUBLISHED ONLINE: 23 SEPTEMBER 2012 | DOI: 10.1038/NPHOTON.2012.233

Highly coherent and stable pulses from the FERMI seeded free-electron laser in the extreme ultraviolet

E. Allaria *et al.**



Seeded by OPA (after frequency up-conversion):
230–260 nm or 296–360 nm

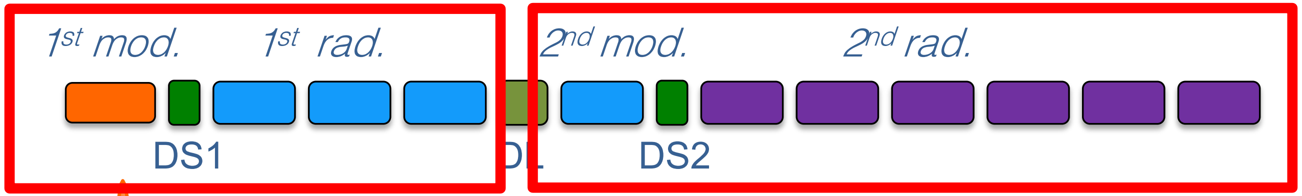


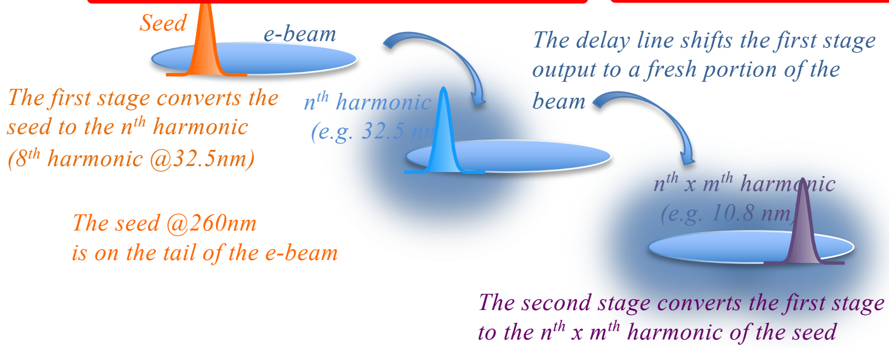
FERMI FEL-2

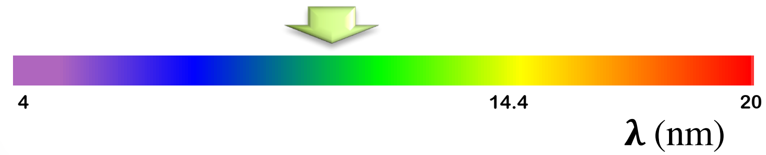
nature photonics | ARTICLES
PUBLISHED ONLINE: 20 OCTOBER 2013 | DOI: 10.1038/NPHOTON.2013.277

Two-stage seeded soft-X-ray free-electron laser

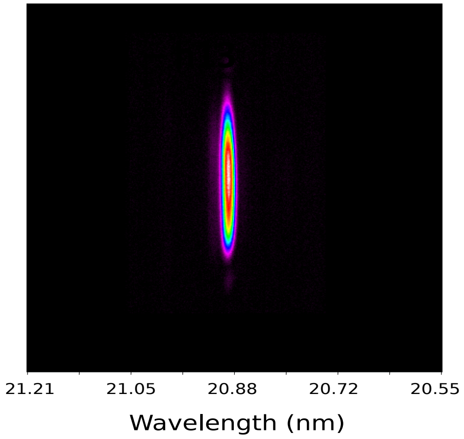
E. Allaria[1], D. Castronovo[1], P. Cinquegrana[1], P. Craievich[1†], M. Dal Forno[1,2], M. B. Danailov[1], G. D'Auria[1], A. Demidovich[1], G. De Ninno[1,3], S. Di Mitri[1], B. Diviacco[1], W. M. Fawley[1*], M. Ferianis[1], E. Ferrari[1], L. Froehlich[1], G. Gaio[1], D. Gauthier[1,3], L. Giannessi[1,4*], R. Ivanov[1], B. Mahieu[1,5], N. Mahne[1], I. Nikolov[1], F. Parmigiani[1,2], G. Penco[1], L. Raimondi[1], C. Scafuri[1], C. Serpico[1], P. Sigalotti[1], S. Spampinati[1,3], C. Spezzani[1], M. Svandrlik[1], C. Svetina[1,2], M. Trovo[1], M. Veronese[1], D. Zangrando[1] and M. Zangrando[1,6]

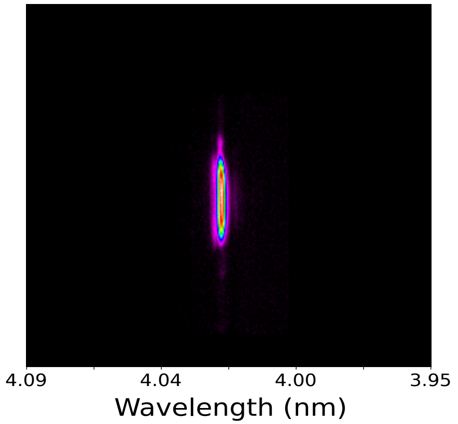




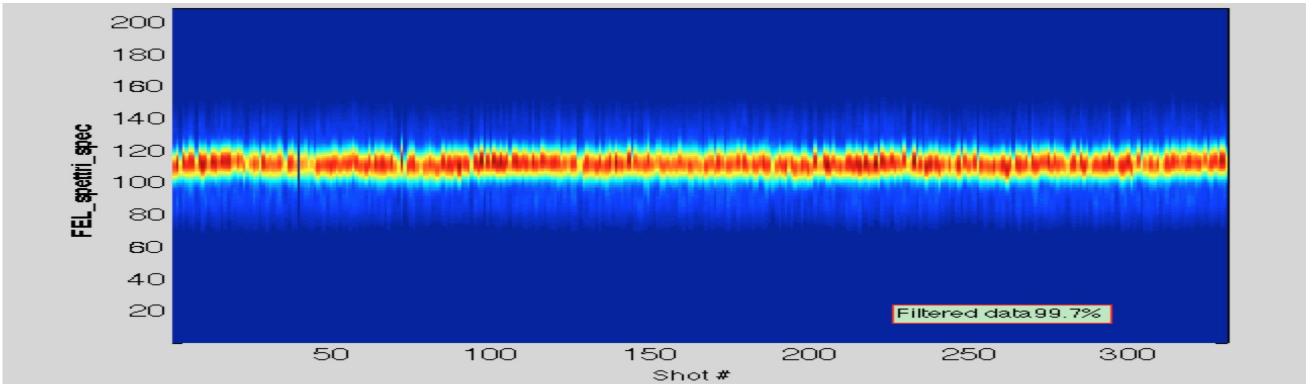


Spectral properties



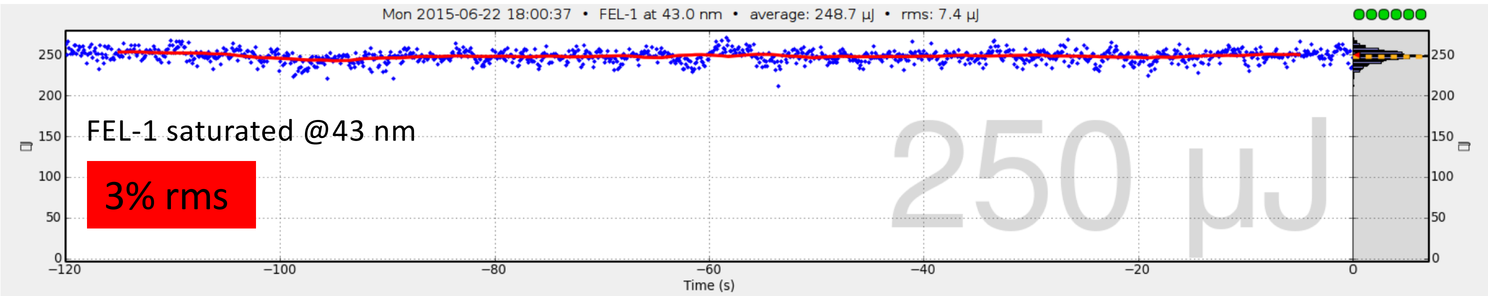


- The spectral properties can be preserved up to **h13-h15 on FEL1** and **h65 on FEL2** (***linewidth down to 2*** $\boldsymbol{10^{-4}}$ ***rms,*** *depending on wavelength & seed setting/duration*).
- Similar spectral quality with the OPA laser system.
- **High stability of central wavelength** set by the seed (**10^{-5} rms**)
- **FEL2** with the double stage is more sensitive to parameters fluctuations and to set-up & tune, but **similar spectral performances to the ones of FEL-1 are possible, even at h65 = 4 nm.**



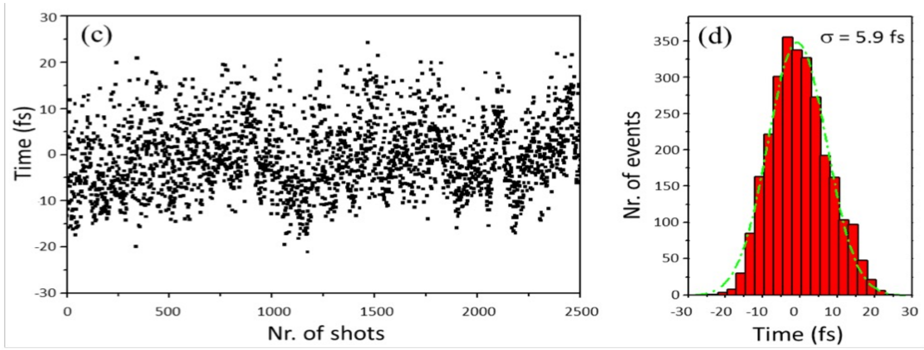
Energy stability and temporal jitter

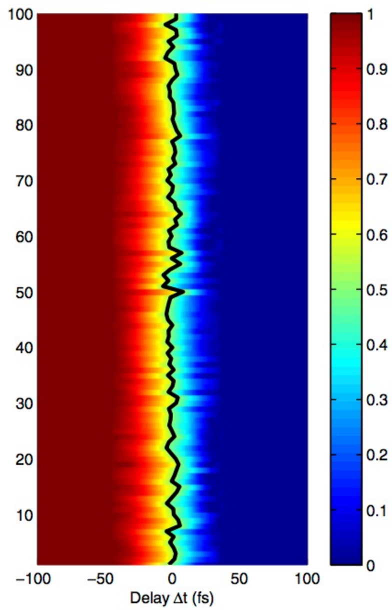
Not standard, typical 10-15% rms on FEL-1 ~ 1.3 – 1.5 × on FEL-2 (double stage cascade)



Temporal jitter < 6 fs

M. Danailov et al. Optics Express, Vol. 22, Issue 11, 12869 (2014)





Temporal jitter < 6 fs
2.2 fs
from *P. Finetti et al. Phys. Rev. X 7, 021043 (2017)*

Hanbury Brown and Twiss interferometry with spectral measurements

2°order correlation function

$$g^{(2)}(\mathbf{r}_1, \mathbf{r}_2) = \langle I(\mathbf{r}_1)I(\mathbf{r}_2)\rangle / \langle I(\mathbf{r}_1)\rangle\langle I(\mathbf{r}_2)\rangle,$$

Chaotic light

$$g^{(2)}(r_1, r_2) = 2$$

Ideal laser

$$g^{(2)}(r_1, r_2) = 1$$

FERMI (FEL-2 – 10.9 nm)

SEEDED – FEL: laser light statistics

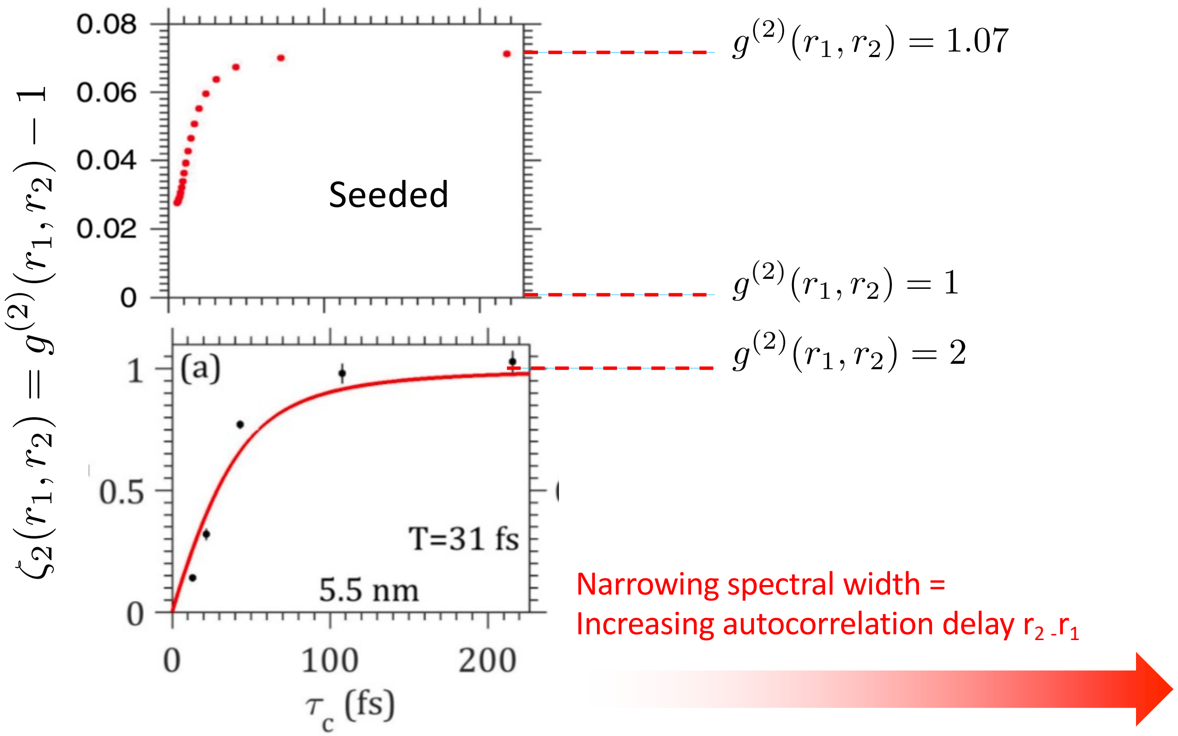
Second order coherence from the «seed» oscillator is preserved

O. Yu. Gorobtsov et al., Nat. Comm. (2018) 9:4498

FLASH in SASE

SASE – FEL: chaotic light statistics

O. Yu. Gorobtsov et al.,Phys. Rev. A 95, 023843 (2017)



Full control of the polarization

APPLE-II undulators in the final radiator ensure polarization control

Characterization of the FEL polarization produced by APPLE-2 undulators at 32nm, 26nm, 43nm, 53nm

- Horizontal/Vertical polarization.
- Circular polarization.

Three different setups for characterization of the FERMI FEL polarization:

- LOA optical UV polarimeter.
- DESY electron spectrometer polarimeter.
- LDM X-UV He fluorescence polarimeter.

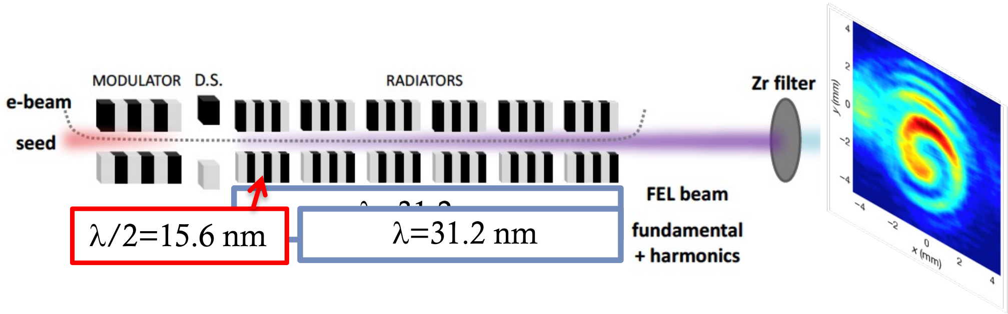
E. Allaria et al. Phys. Rev. X ***4****, 041040 (2014)*

Studies of cross-polarized schemes to control the polarization

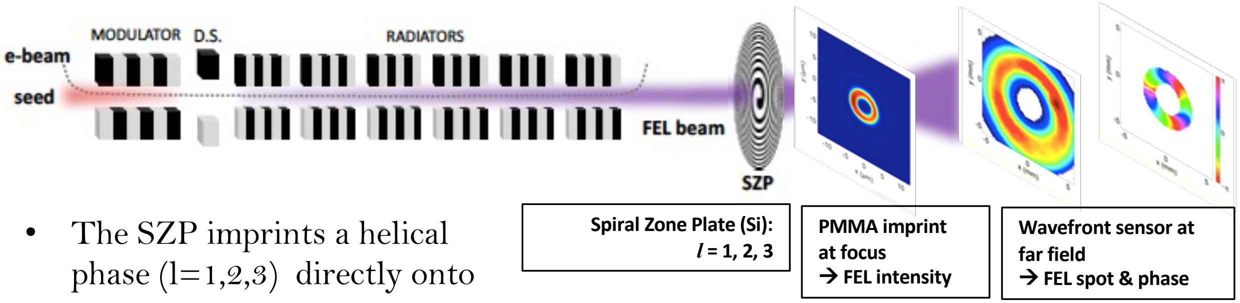
- Circular right and left for generating linear polarization.
- Linear vertical and horizontal for generating circular polarization.

E. Ferrari et al. Sci. Rep. ***5****:13531 (2015)*

Orbital Angular Momentum modes *TIMEX*



- **Zr filter blocks light at λ = 31.2 nm**
- FEL 2nd harmonic emerges from the helical-pol. radiator
- Interference of Gaussian (n=2) and OAM mode (2nd harm. of n=1) shows spiral intensity distribution.



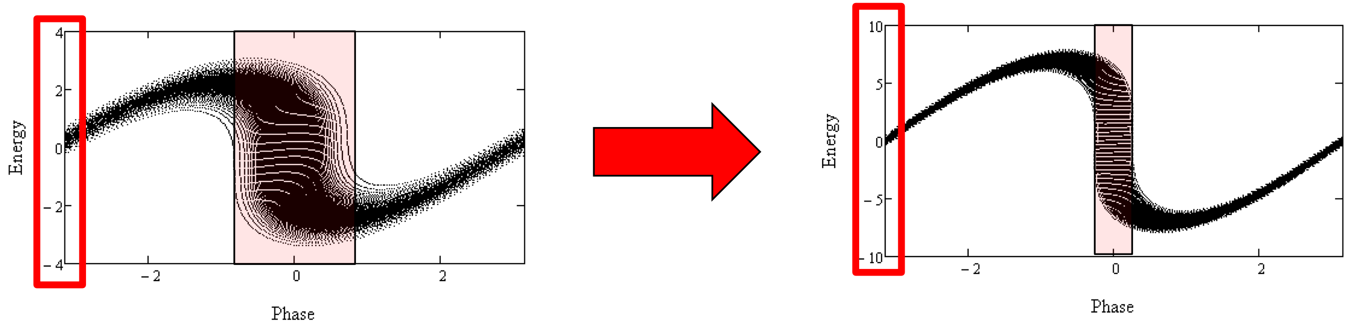
- The SZP imprints a helical phase (l=1,2,3) directly onto the EUV, and suppresses the 0th-diffraction order.

This exp. paves the way to much brighter OAM pulses than from conventional (short) IDs

P. Rebernik et al., PRX 7 , 031036 (2017)

High harmonic conversion and the energy spread budget

Virtually any harmonic order can be obtained by increasing the seed power ... at a cost of an increased energy spread



- Required energy spread in order to bunch at the n^{th} harmonic (Liouville's theorem)

$$\left(\sigma_\gamma / \gamma\right)_{induced} \approx 2n\left(\sigma_\gamma / \gamma\right)$$

- Condition to ensure high gain growth in final radiator

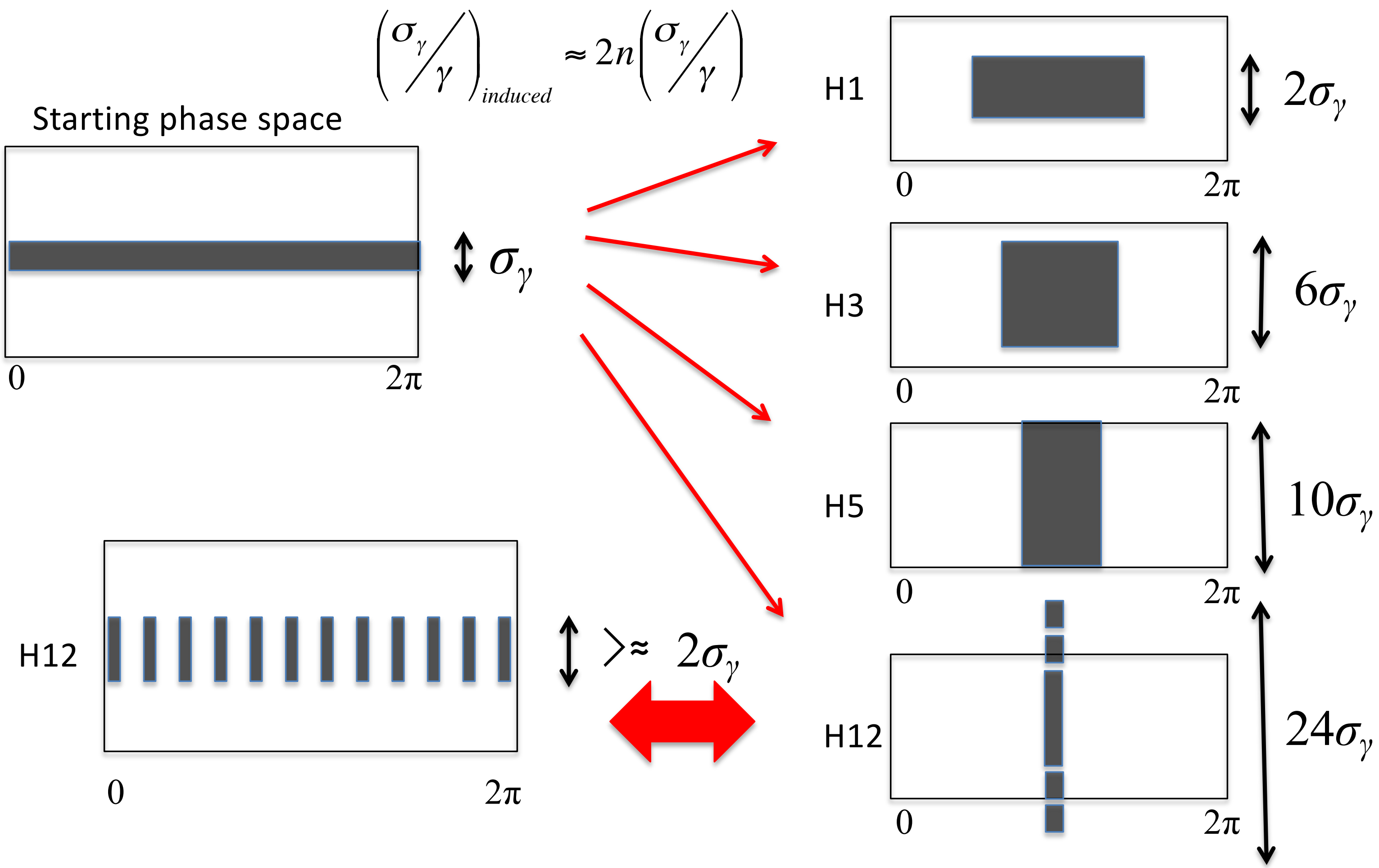
$$n < \frac{\rho_{fel}}{\sigma_\gamma / \gamma}$$

Ideas:

- Fresh bunch injection technique, *L. H. Yu, I. Ben-Zvi, NIM 1993 = FERMI FEL-2*
- Echo Enabled harmonic generation, *G. Stupakov, PRL, 2009*
- Non Gaussian energy spread distrib., *E. Ferrari et al., PRL, 2014*
- Energy spread removal by space charge, *E. Hemsing et al., PRL 2014*
- Phase merging in TGU undulator, *H. Deng and C. Feng PRL (2013)*
- ....

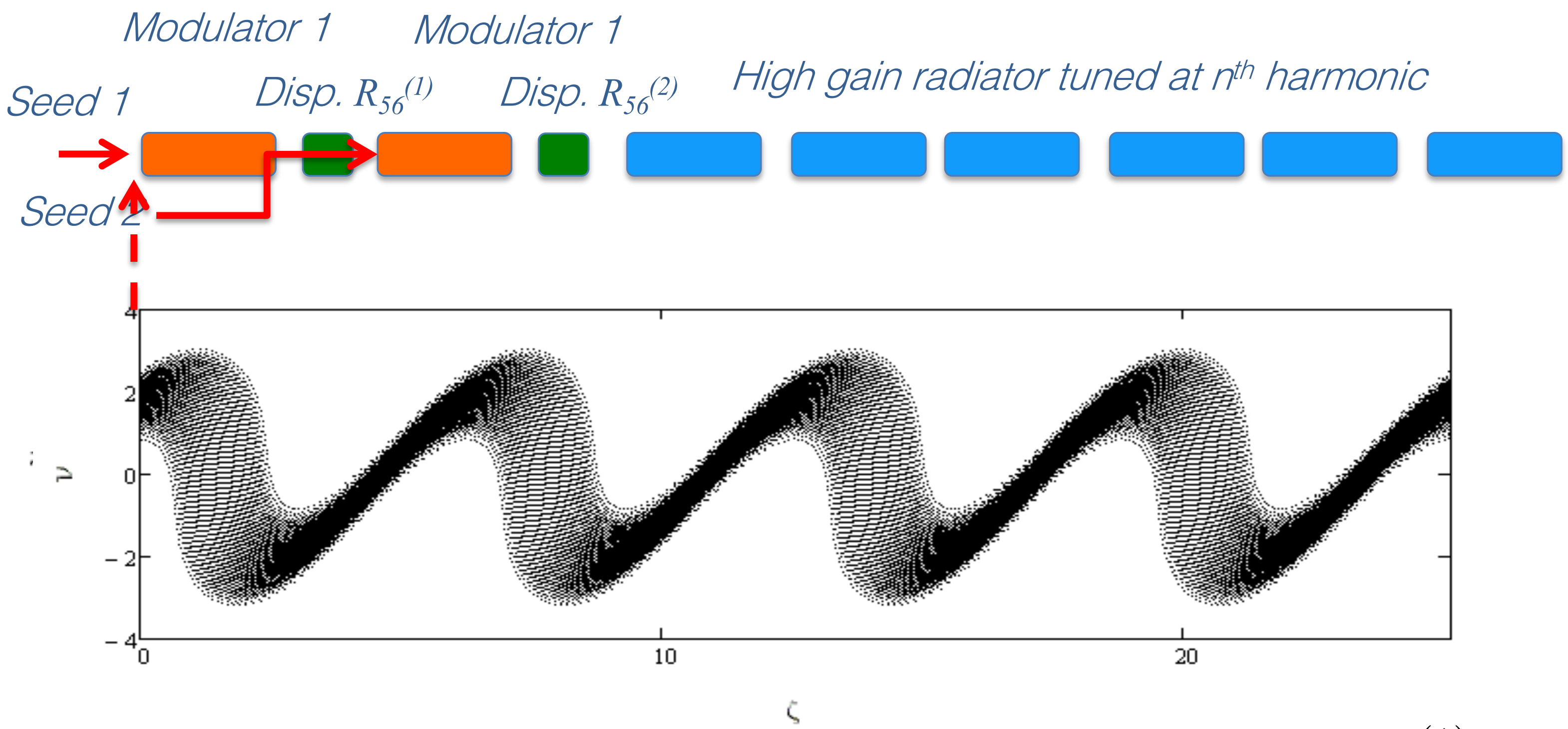
*L. H. Yu, I. Ben-Zvi NIM A**393** (1997) 96*

Phase space "stretching" to reach high harmonics:



Echo Enabled Harmonic Generation

G. Stupakov, Phys. Rev. Lett. **102**, 074801 (2009)

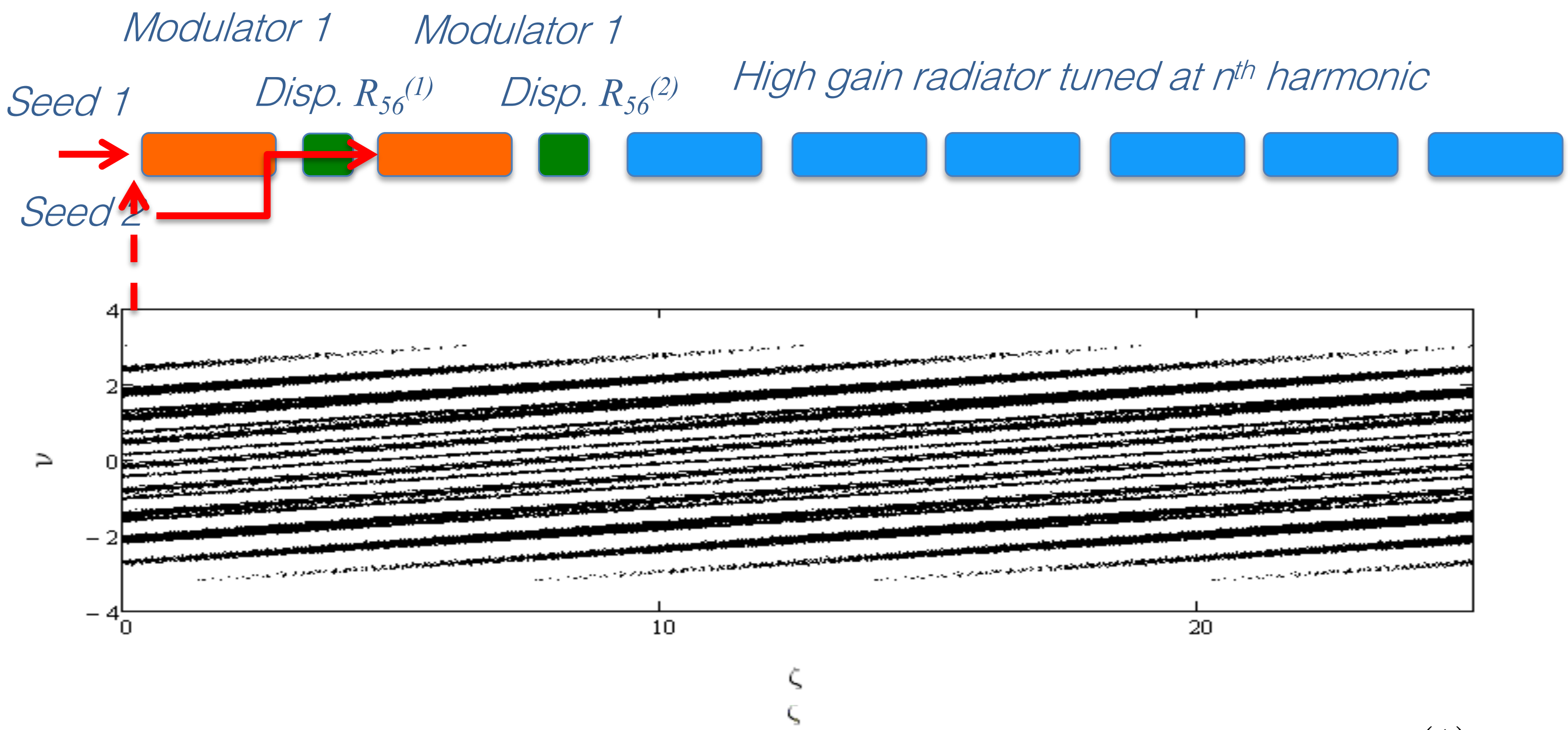


Frequency mixing,
resonance at $k_h = nk_1 + mk_2$

bunching maximized at harmonic $h \simeq \frac{\lambda_2}{\lambda_1} \frac{nR_{56}^{(1)}}{R_{56}^{(2)}}$

Echo Enabled Harmonic Generation

G. Stupakov, *Phys. Rev. Lett.* **102**, 074801 (2009)



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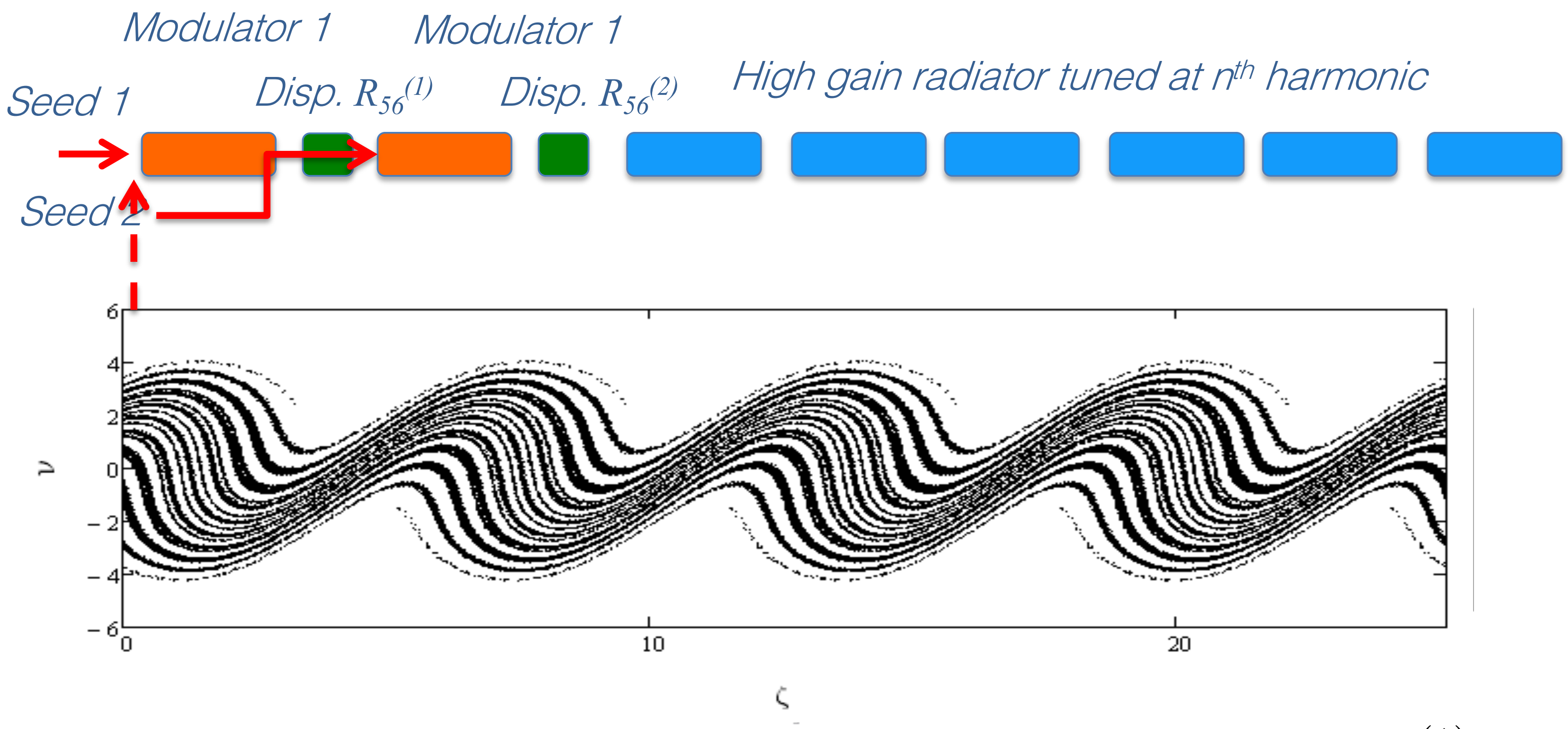

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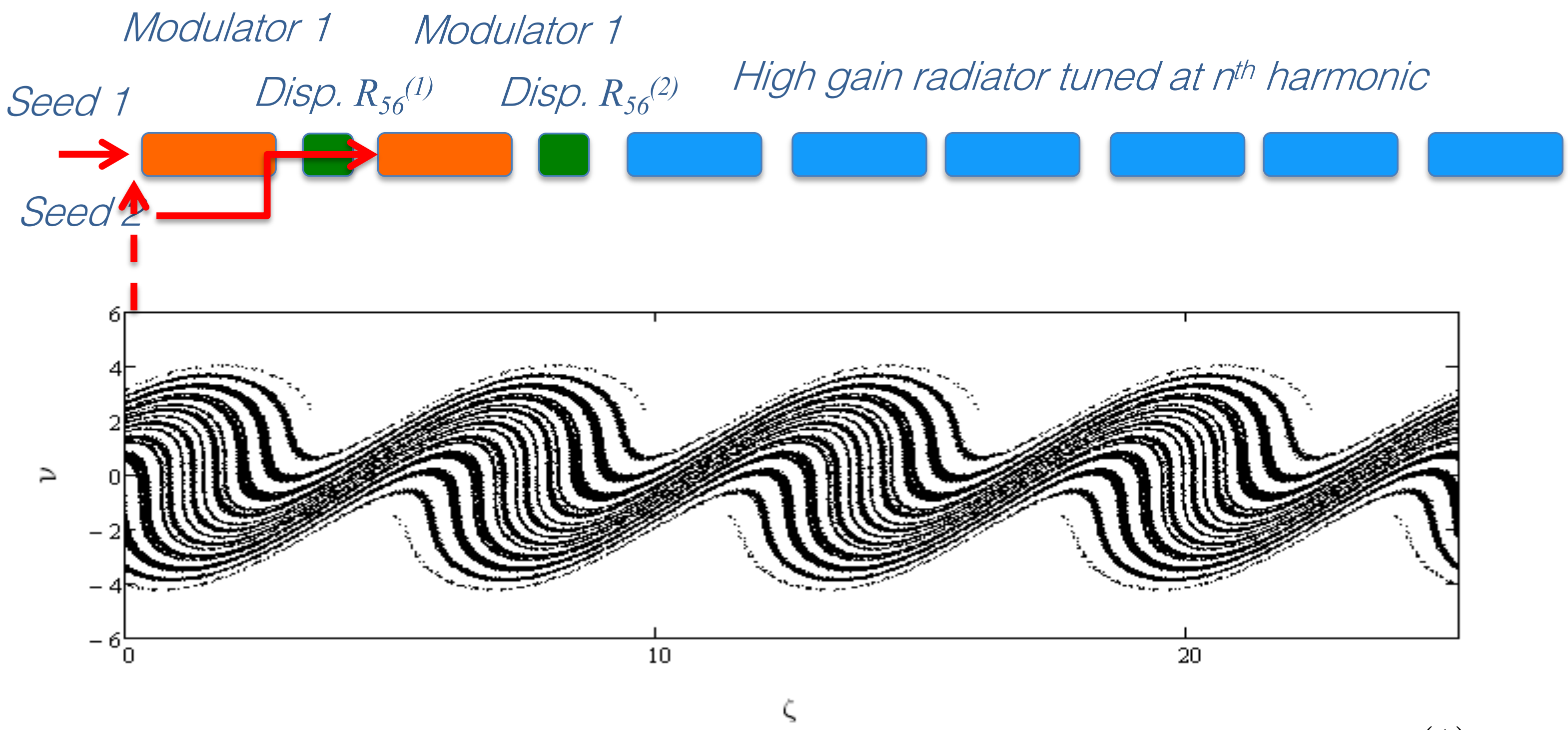
G. Stupakov, Phys. Rev. Lett. ***102****, 074801 (2009)*

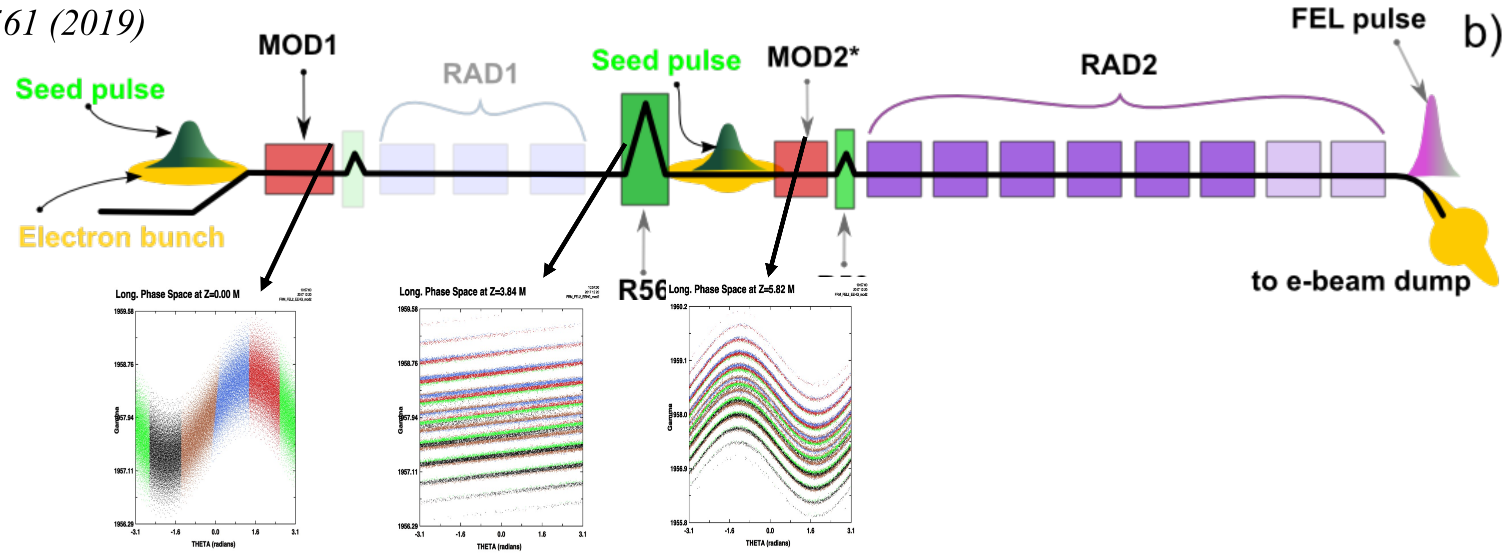


Frequency mixing,
resonance at $k_h = nk_1 + mk_2$

bunching maximized at harmonic $h \simeq \frac{\lambda_2}{\lambda_1} \frac{nR_{56}^{(1)}}{R_{56}^{(2)}}$

EEHG Experiments: High harmonics in a single stage conversion

- **Demonstrated at harmonic 3 ECHO 3 at SLAC NLCTA** *D. Xiang et al., PRL 2010* **and SINAP** *Z. T. Zhao Nat. Phot. 2012*
- **ECHO 7** *D. Xiang et al., PRL 2012* demonstrated lower sensitivity to energy spread
- **ECHO 15** *E. Hemsing et al. PRL 2014*, confirmed lower sensitivity to energy spread & improved stability and spectral quality with respect to HGHG
- **ECHO 75** Bunching up too h75: *E. Hemsing et al. Nature Photonics 10, 512–515 (2016))*
- **In first semester 2018 experiment at FERMI Single stage EEHG 266nm->5nm** first FEL amplification experiment *P. Rebernik Ribič et al. Nat. Photonics 13, 555–561 (2019)*

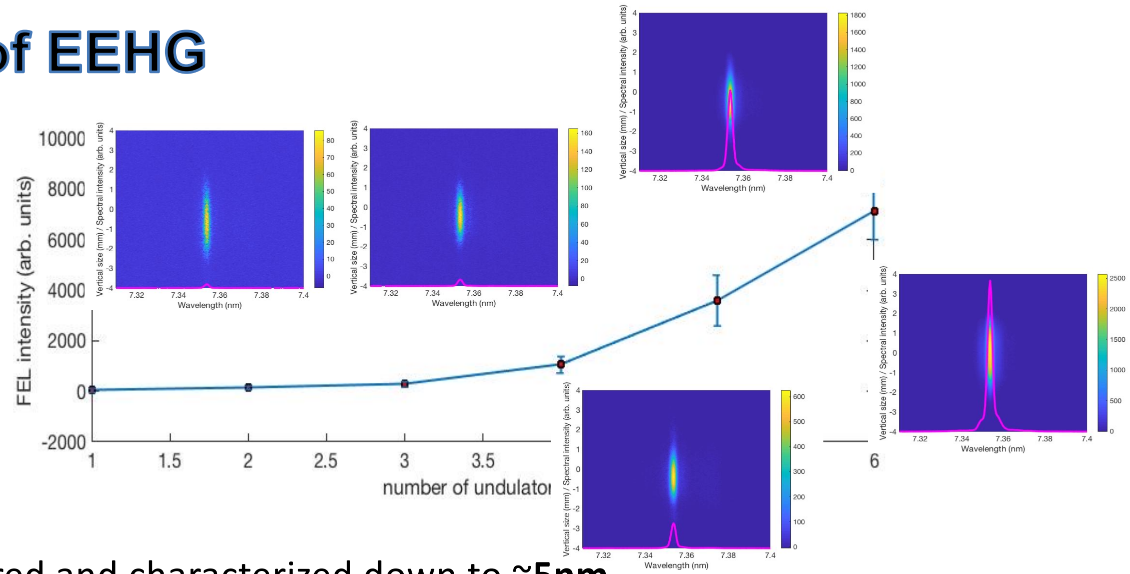


Results at FERMI:

- **Gain up to H45**
- **Low sensitivity to uBI** even at intermediate harmonic orders (H30-50)
- **Mild dependence of energy spread on harmonic order**
- **Reasonably «clean» spectra measured up to harmonic 101 (ECHO 101 ?)**

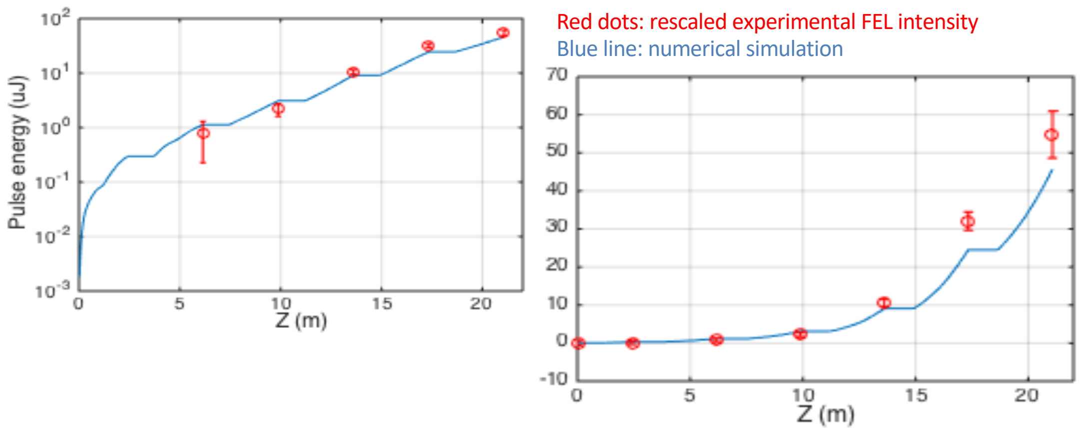
Amplification of EEHG

With recent experiments at FERMI we have measured FEL pulses with ~10 μJ down to 5 nm with very narrow bandwidth spectra.



For the first time **amplification** of **EEHG** has been measured and characterized down to ~**5nm**.

Experimental exponential **growth rate matches** results of **numerical simulations** with our parameters.

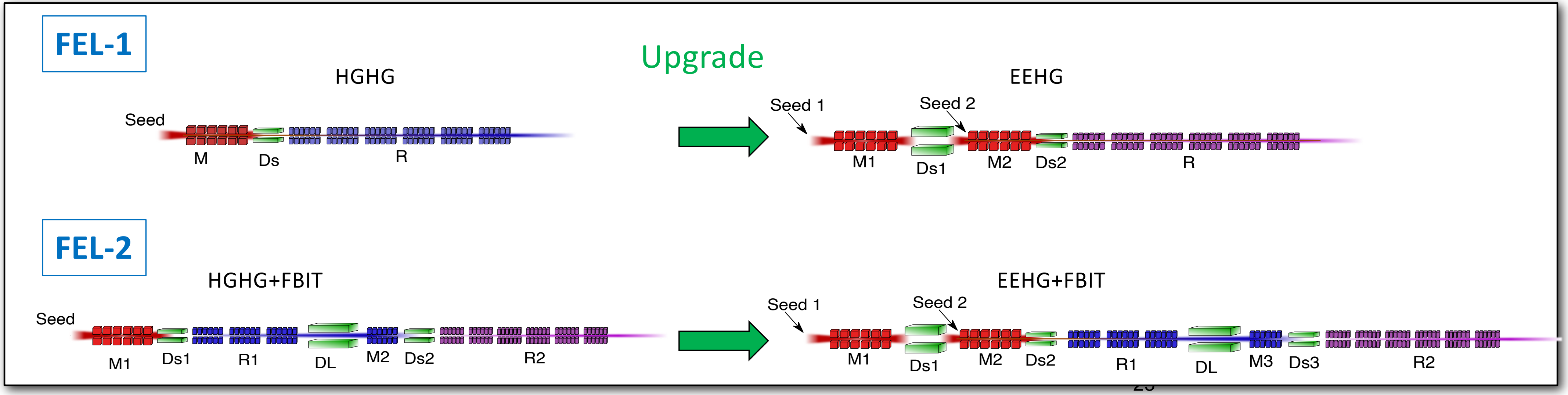


Clear indication of FEL amplification is demonstrated with exponential growth of the power along the radiator.

FERMI Future Upgrade strategy

(see https://www.elettra.eu/lightsources/fermi.html)

According to the past experience and to the feedback coming from the user community, FERMI is undergoing though an upgrade plan, as described in the **FERMI 2.0 Conceptual Design Report***



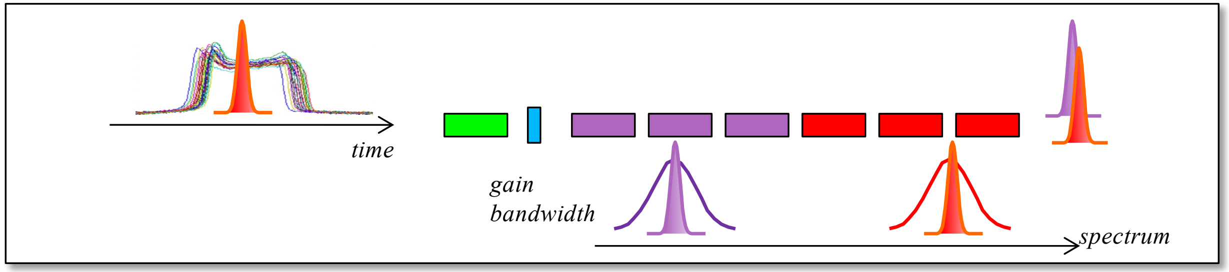
1. FEL-1 in HGHG (as in the present configuration) **and EEHG with double-seed / double-modulator (100-10nm) (2023)**

2. Beam energy increase up to 1.8 GeV (2.0 GeV under investigation) **(2028)**

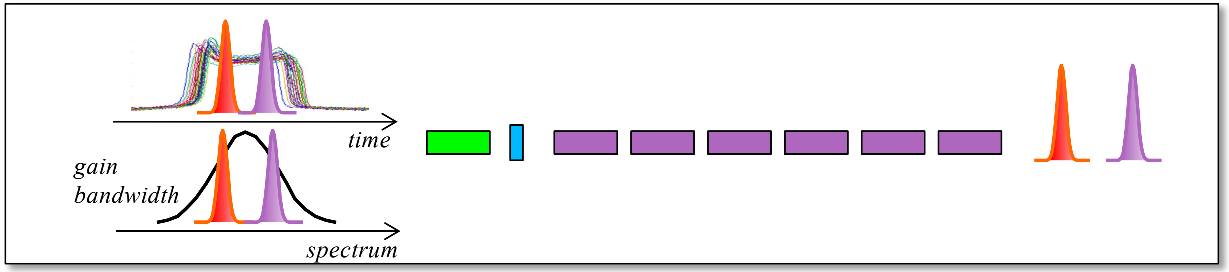
3. **FEL-2 first stage in EEHG second stage (fresh-bunch) in HGHG (10 - 2 nm) (2028)**

Multiple pulses multiple colours

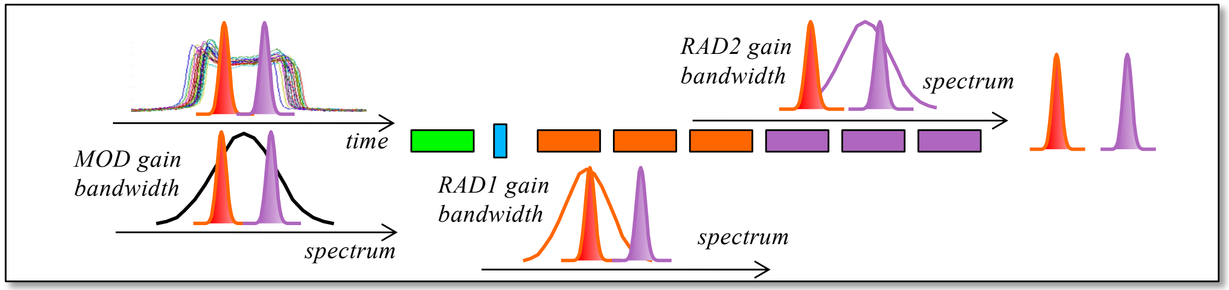
About 30% of the experiments carried out at FERMI require "special" modes of operation. Starting the amplification from a pre-modulated beam reduces the required undulator length: The undulator can be separated in segments dedicated to one harmonic each. Multiple pulses can be generated **by single or double pulse seeding** in different ways, depending on the requirements on the output radiation. Temporal **separation between 100-200 and 700-800 fs depending on the seed duration and on the e^- bunch duration.** Larger separations require the split & delay line.



Frequency separation:
Single seed – double color or "double polarization"



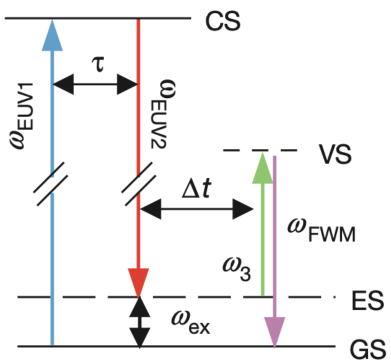
Temporal separation:
Double seed double color
Spectral separation 0.4-0.7%
Allaria et al., Nat. Comm., 2013

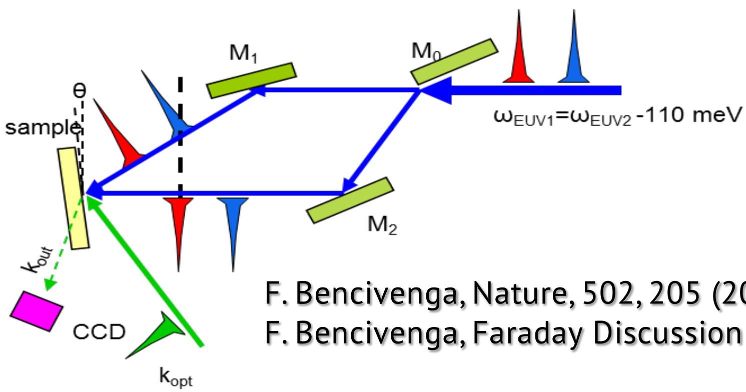


Double seed double color at different harmonics
Spectral separation 2-3% or much larger if the two radiators are tuned at different harmonics
Ferrari et al., Nat. Comm, 2016

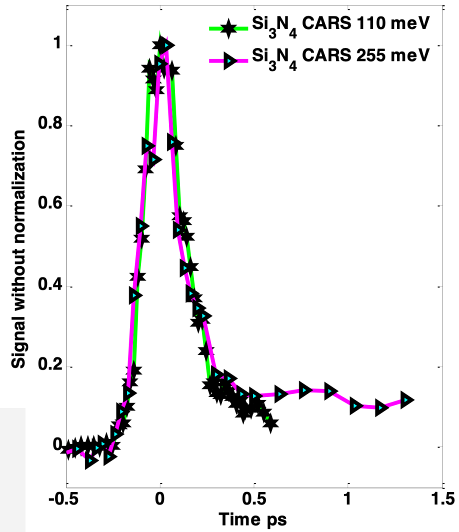
EUV – Four Wave Mixing (DIPROI & TIMER)

- **F**our **W**ave-Mixing (FWM): Three coherent electromagnetic fields that may have different photon parameters (frequency, wavevector, polarization, etc.) interact in the sample, driving the radiation of a fourth (signal) field.
- **FWM:** Stimulated Raman Gain Spectroscopy, Photon Echo and Raman induced Kerr effect Spectroscopy, Femtosecond Stimulated Raman Scattering and **Coherent Antistokes Raman Scattering (CARS)**
- **FWM** methods may be carried out exploiting electronic resonances, i.e. with elemental specificity. At FERMI: ***TIMER & Minitimer@DIPROI.***

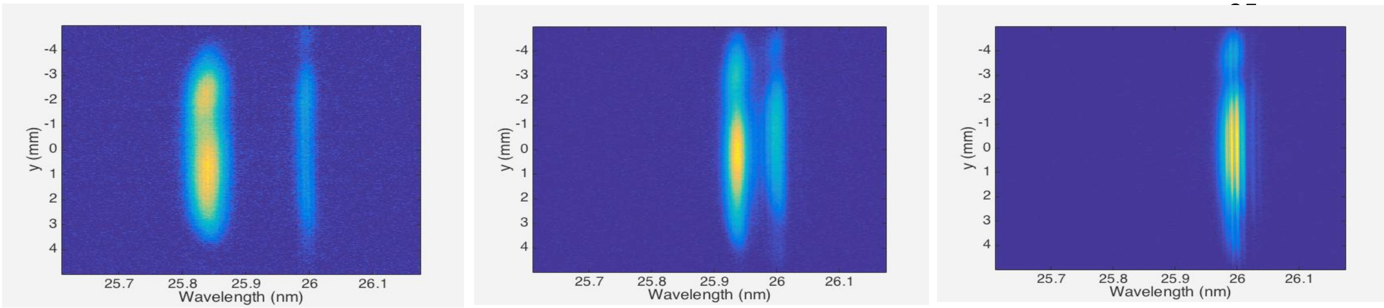




F. Bencivenga, Nature, 502, 205 (2015)
F. Bencivenga, Faraday Discussion (2016)



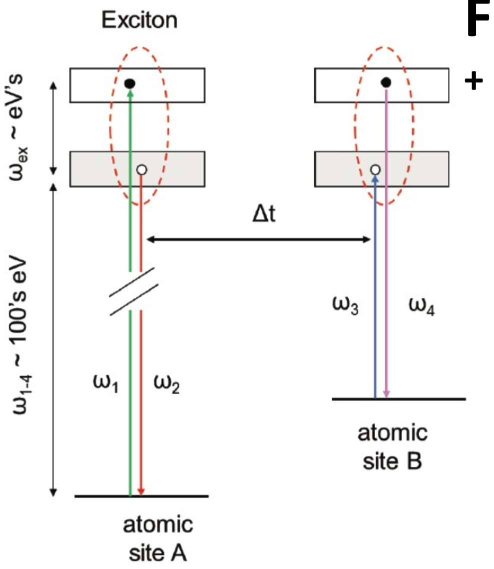
FEL-1
double seed
Ti-Sa THG
+ OPA



The two pulses 285 ± 5 fs constant temporal separation

All EUV Four Wave Mixing *(TIMER)*

EUV-induced **T**ransient **G**rating & **C**oherent **A**nti-Stokes **R**aman **S**cattering spectroscopy to *investigate* collective *atomic dynamics at the nano-scale* & *control* atomic *levels on demand*.

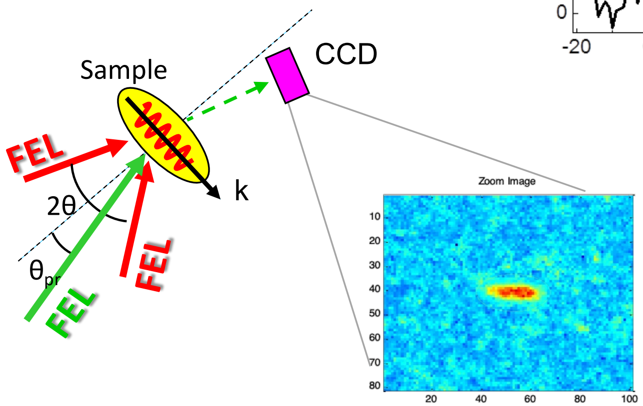


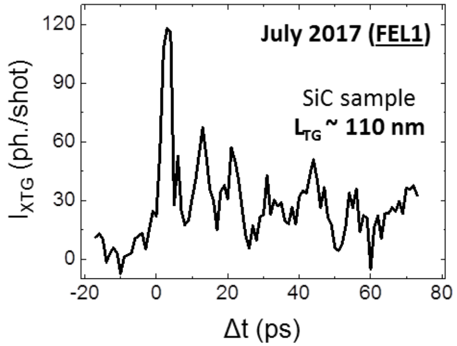
S. Tanaka and S. Mukamel, PRL (2002)

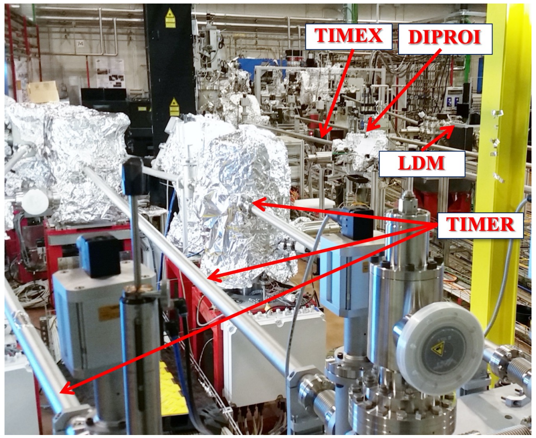
FEL-1 Two-Seeds

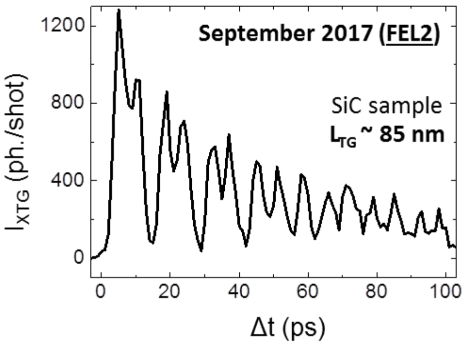
+ Split RAD:

54 nm + 3h @18 nm









FEL-2 Two-Stages

:

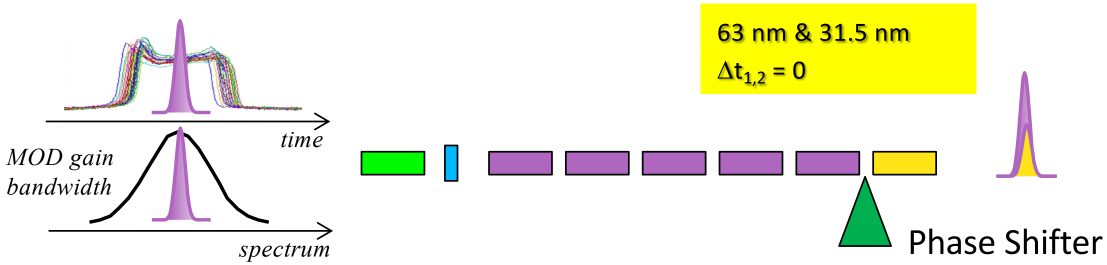
First stage 39.9 nm +

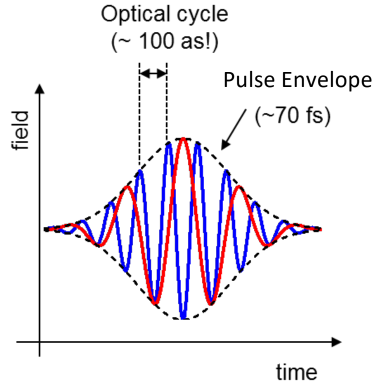
Second stage 13.3 nm

F. Bencivenga, Nature, 502, 205 (2015)
F. Bencivenga, Faraday Discussion (2016)
…

Coherent control in VUV: phase locked pulses

Two (almost) temporally superimposed pulses at harmonic wavelengths of the seed. The two pulses are correlated in phase and the phase can be controlled with the phase shifter. *K. Prince et al., Nat. Phot. 10, 176 (2016)*

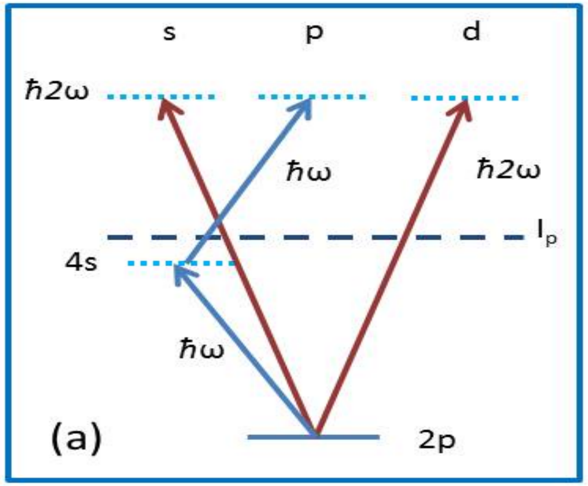




Ne (gas) has first ionization potential corresponding to 21.56 eV = 57.5 nm

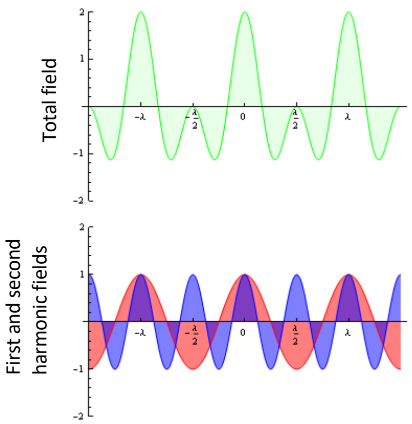
Experiment carried out with FEL-1 h4+h8, seed 252 nm

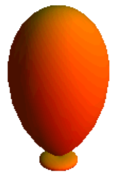
- 2-photons ionization by h 4
- 1-photon ionization by h 8
- The photoelectron wavefunctions corresponding to the two ionization channels **have different parity.**



Attoseconds delay control *(LDM)*

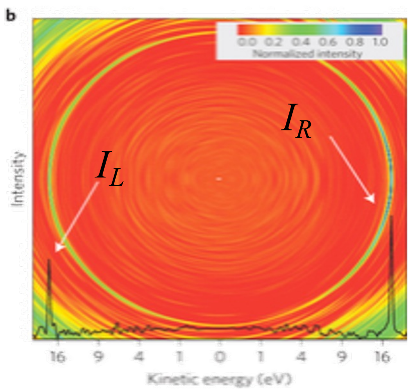
Left-right asymmetry in photoelectron angular distribution: interference between **p-wave** (2-photon process from fundamental) and **s/d-wave** (1-photon process from 2nd harmonic).
Asymmetry depends on the relative phase of coherent radiation pulses.



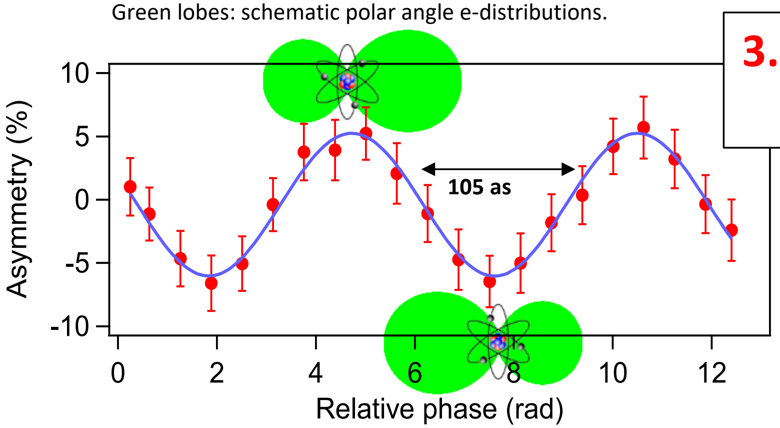


Lobes represent direction and intensity of photo-electron emission from Ne.

Photo-electron distribution is acquired with **Velocity Map Imaging**, and the ***asymmetry*** recorded ***vs. phase.***



K. Prince et al., Nat. Phot. 10, 176 (2016)



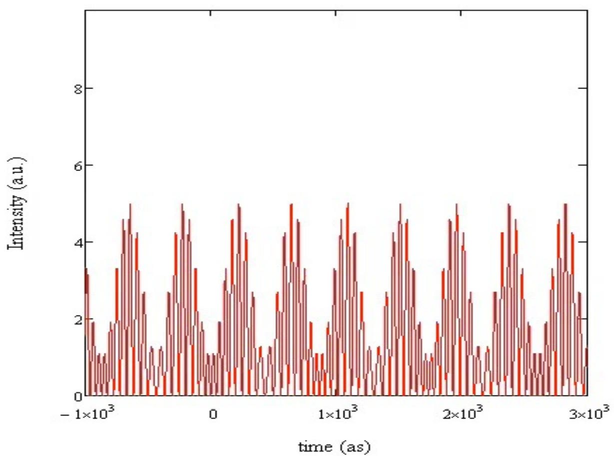
3.1 attosecond resolution

Attosecond Pulse Train *(LDM)*

“synthesis” of 3 (4..6) phase-locked harmonics of the FEL ⇒ generation of attosecond pulses

High gain radiator tuned at harmonics n, n+1, n+2 ...

ATTOSECOND PULSE TRAIN

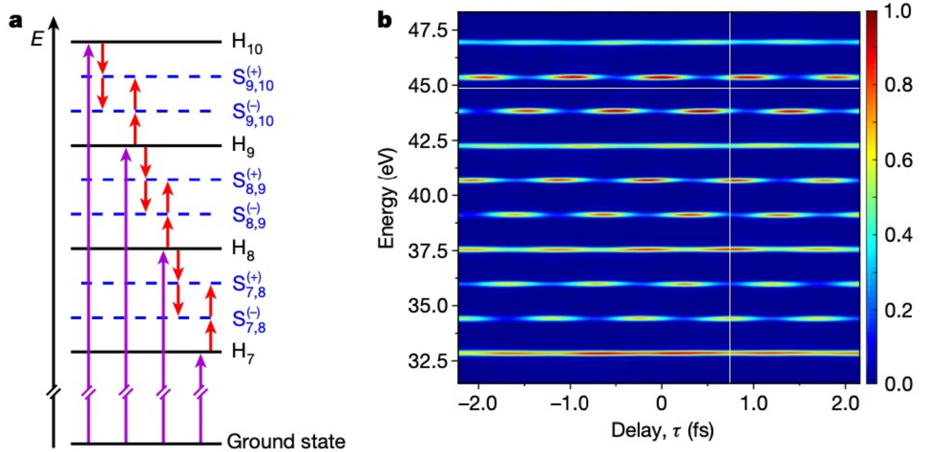


DETECTION

+ IR Laser

Similar to Rabbit technique

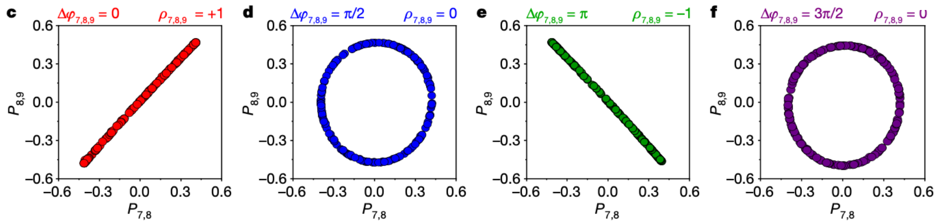
Y.Mairesse and F. Quéré, Phys. Rev. A 71 0011401(R) (2005)

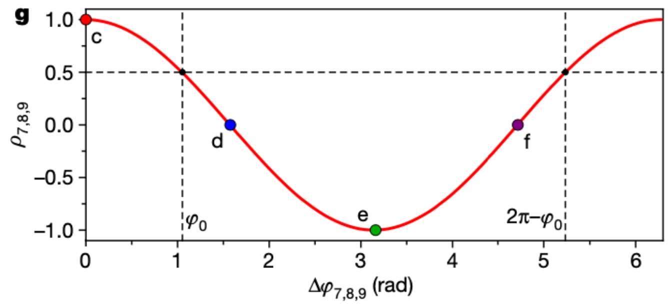


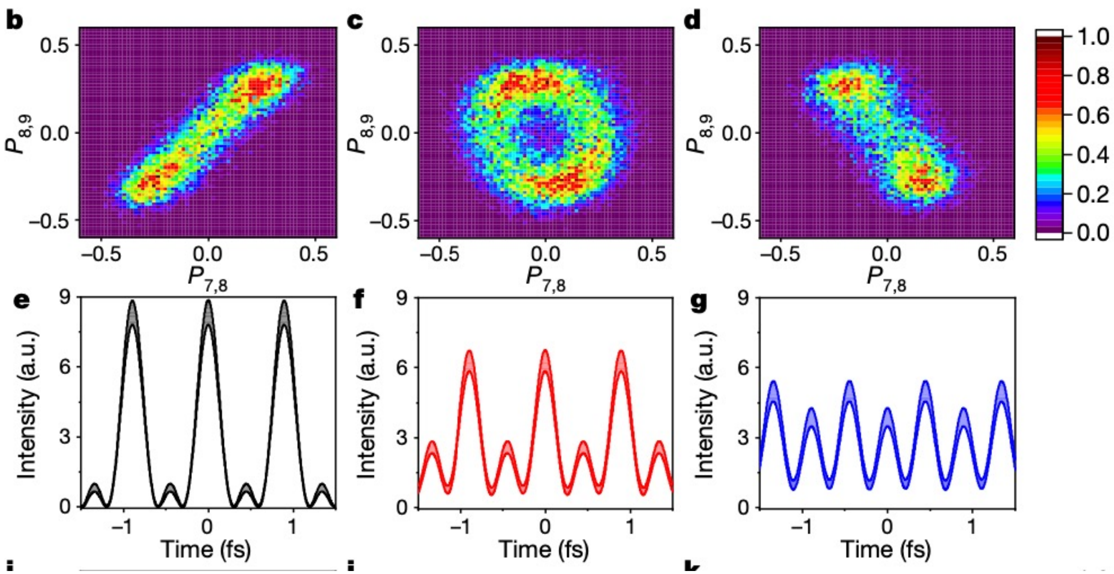
Phase jitter with the IR laser prevents us from generating this plot, but **sidebands are correlated**

Attosecond Pulse Train reconstruction *(LDM)*

Sidebands correlation depends on the phase $\Delta\varphi_{q-1,q,q+1} = \varphi_{q+1} + \varphi_{q-1} - 2\varphi_q$





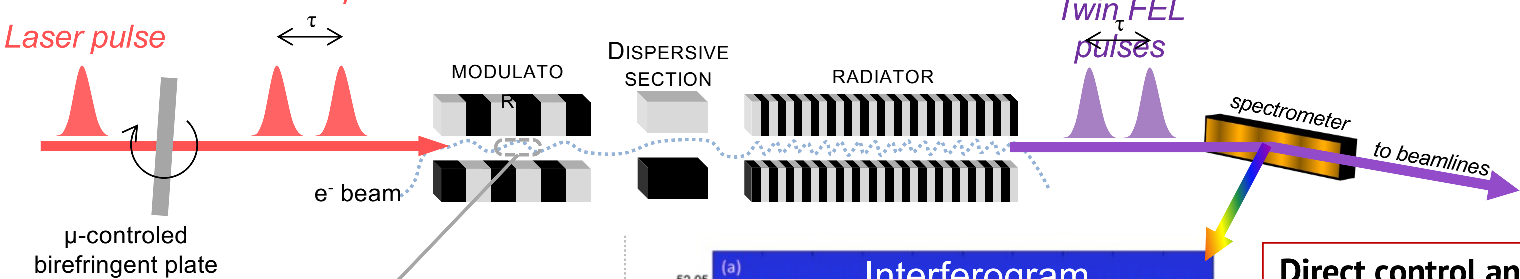


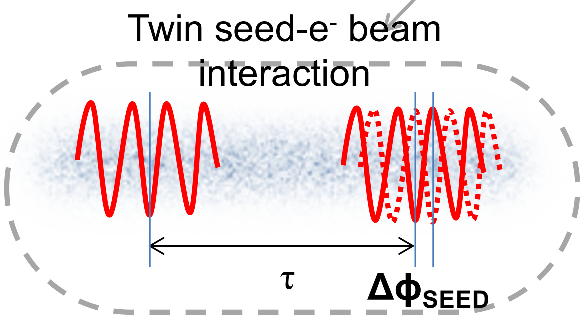
*After *Maroju et al. Nature 578, 386–391 (2020),* trains of VUV-EUV attosecond pulses with tens of as laser synchronization are almost routinely available by frequency synthesis

Phase-locked pulses *D. Gauthier et al., PRL 2016*

Elettra Sincrotrone Trieste

Two phase-locked seed pulses create two FEL pulses locked in phase. The relative phase control and stability between the two FEL pulses is demonstrated with the evolution and stability of the spectral phase



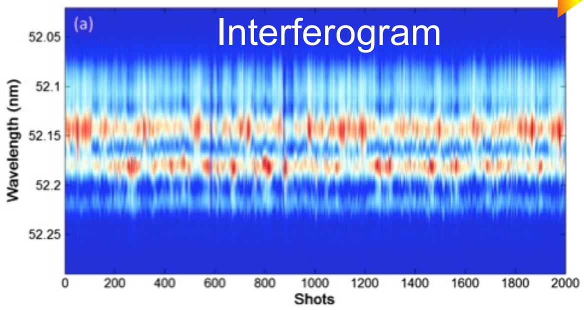


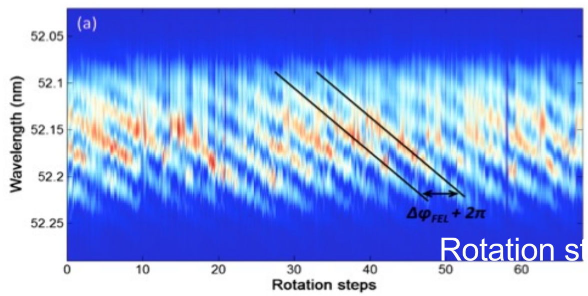
τ = 290fs and duration of the individual FEL pulse is about 70-80fs.

Rotation step: $\Delta\Phi_{SEED}$ = λ_{SEED}/28.33 → $\Delta\Phi_{FEL}$ = λ_{FEL}/5.67 (@harmonic 5) Full range of 68 steps => 12 times λ_{FEL}

At each step acquired 20 consecutive single-shot spectra.

Analysis of fringes gives rms phase stability of λ_{FEL}/10 (~ 20 as)





Direct control and manipulation of the phase of individual pulses within an XUV pulse sequence opens exciting possibilities for coherent control and multidimensional spectroscopy.

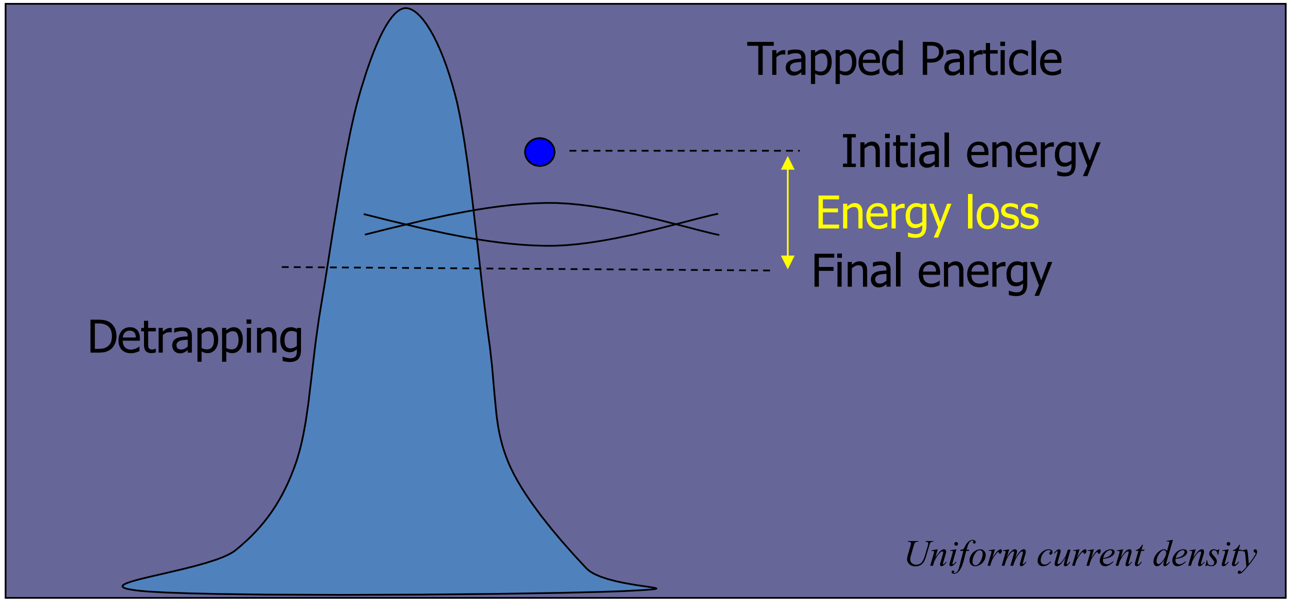
Highly time-stabilized and phase-modulated XUV-pump, XUV-probe investigating the evolution and dephasing of an inner subshell electronic coherence.

Andreas Wituschek et al., NATURE COMMUNICATIONS | https://doi.org/10.1038/s41467-020-14721-2

FEL non linear dynamics: Superradiance

- **Saturation:** When the FEL laser power reaches ~$\rho P_{E,}$ saturation occurs: there is a cyclic energy exchange between electrons and field
- **Slippage:** The light advances over the electrons of a distance Nλ over N undulator periods

Pulse duration depends on wavelength and on the FEL peak intensity



R. Bonifacio et al., Nucl. Instrum. Methods Phys. Res., Sect. A 296, 358 (1990).
R. Bonifacio et al., Riv. Nuovo Cimento Soc. Ital. Fis. 13, 1 (1990).
L. Giannessi, P. Musumeci, and S. Spampinati, J. Appl. Phys. 98, 043110 (2005).

Saturated pulse properties & scaling laws

Theory:

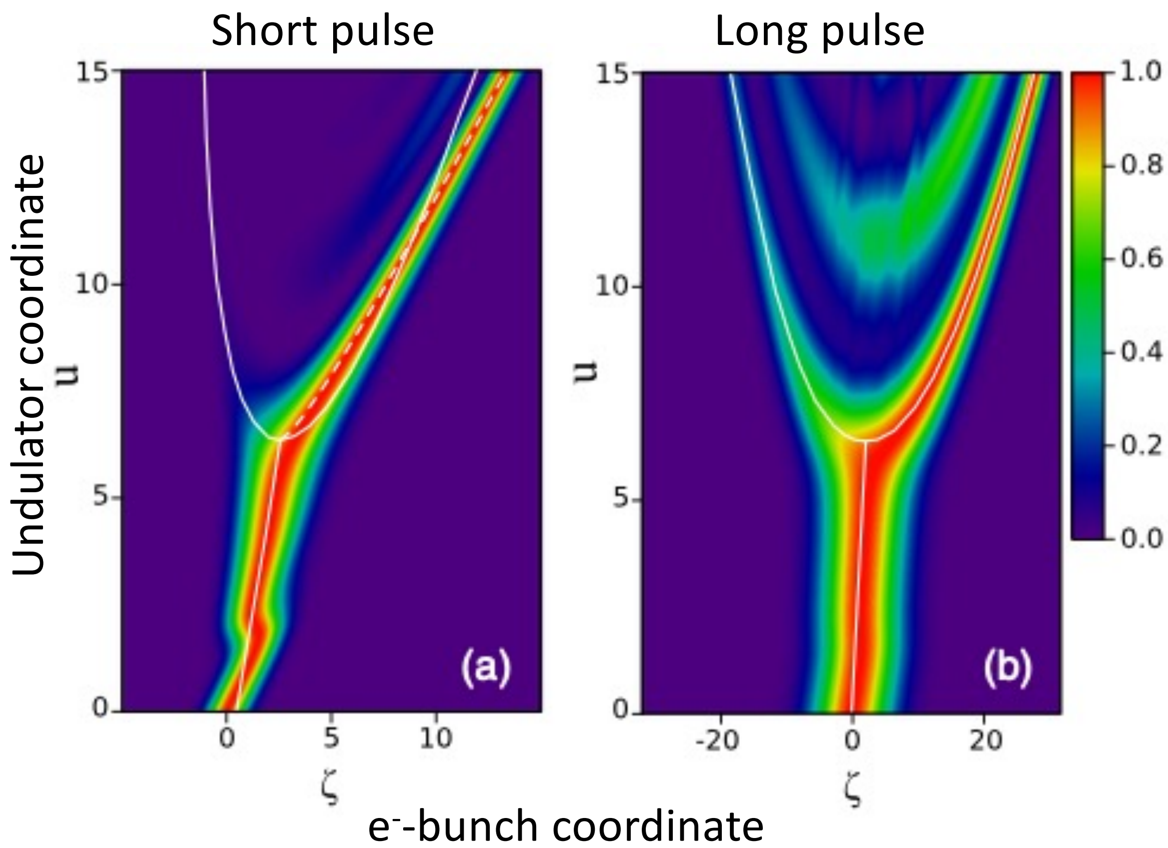
- The pulse peak power continues to grow after saturation $P \propto u^2$
- The pulse duration decreases $\boldsymbol{\sigma}_t \propto u^{-1/2}$
- The pulse energy grows $E \propto u^{3/2}$

➢ The pulse is not FT limited, but **FWHM spectral width = FT limit of FWHM spike temporal width**

➢ **Pulse duration halves at saturation:** pulses shorter than those supported by gain bandwidth can be generated

➢ **The pulse grup velocity > c**

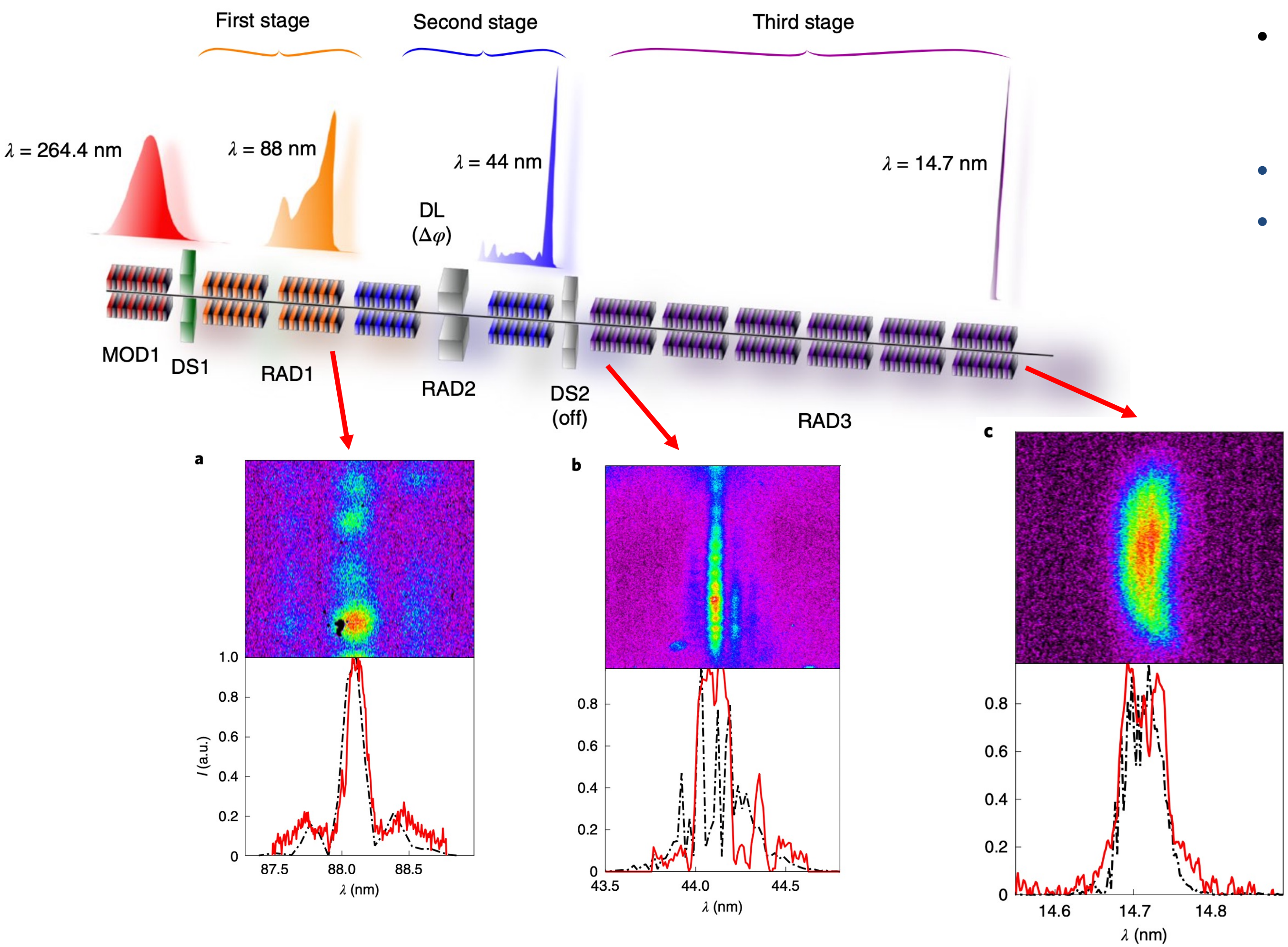
➢ Peak power higher than that at saturation



Xi Yang, et al., Phys. Rev. Accelerators and Beams 23, 010703 (2020) and references therein

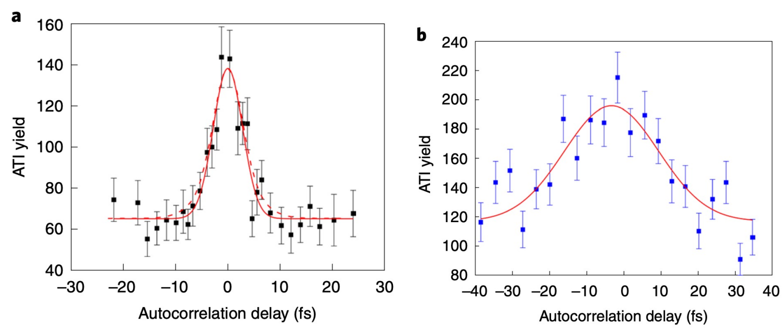
Superradiant cascade

N. S. Mirian, et al., Nat. Photonics 15, 523–529 (2021).



Demonstrated in the experiment:

- Longitudinal compression leads to **pulse duration shorter than that supported by gain bandwidth** of the amplifier (4.7 fsò 14 nm)
- **Peak power larger than the FEL saturation power**
- **FWHM spectral width corresponds to front spike FT limit pulse duration**



- Strong **frequency pulling by resonance detuning.** Central frequency dominated by resonance.

Conclusions & future perspectives at FERMI

- A laser seed has offered the possibility of controlling synchronization, polarization, pulse duration and phase, to generate multiple pulses for the implementation of multiple color schemes coherent control and ultrashort pulses via superradiance. An impressive flexibility.

- For the future the indication from the FERMI SAC and users is: **extend the wavelenght range to include k edge of Oxygen (and possibly the L-edges of transition metals) & reduce pulse duration**

- … but: **preserve of the uniqueness of FERMI, i.e. preserve the control the properties of the radiation by seeding the FEL with an external laser system.**

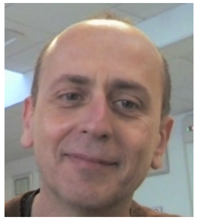
- The implementation of EEHG seeding on FEL-1 and FEL-2 and the upgrade of the linac **broadens the FELs spectral range** and **increases the flexibility** : EEHG Long seed – narrow bandwidth mode, multiple color multiple seed down to 100 eV, multiple seed multiple modulators, optical klystron seeded FEL, extended spectral range up to 600 (700) eV

Credits

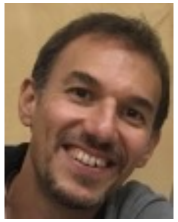
CDR Contributors:


Enrico Allaria (FEL-2 Upgrade)


Giovanni De Ninno (FEL Physics)


Carlo Spezzani (FEL-1 Upgrade)


Simone Di Mitri (Linac Upgrade)


Giuseppe Penco. (FERMI Operations)


Mauro Trovò (RF and planning)


Miltcho Danailov (Lasers)


Bruno Diviacco (Undulators)


Mario Ferianis (Timing & Diagnostics)


Marco Zangrando (Photon delivery)

and …

L. Badano, F. Bencivenga, A. Brynes, C. Callegari, F. Capotondi, D. Castronovo, P. Cinquegrana, M. Coreno, A. Demidovich, P. Del Giusto, W. M. Fawley, G. Gaio, G. Kurdi, M. Lonza, M. Malvestuto, M. Manfredda I. Nikolov, G. Penn, K. C. Prince, E. Principi, P. R. Rebernik, F. Gelmetti, C. Scafuri, N. Shafqat, P. Sigalotti,, A. Simoncig, F. Sottocorona, S. Spampinati, L. Sturari, T. Tanaka, M. Veronese, R. Visintini, and myself.


Claudio Masciovecchio
Project Director

Next FEL Conference:

https://www.fel2022.org/

Stay tuned !!!

FEL2022

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photo by marantoni2004 from Pixabay

FEL2022 TRIESTE, ITALY, AUGUST 22-26

On behalf of the International Executive Committee of the FEL Conference series, we are pleased to announce the 40th International Free Electron Laser Conference (FEL2022), to be held at the Trieste Convention Center (TCC) in Trieste, Italy, from August 22th to August 26th, 2022.

FEL 2022 will focus on recent advances in free electron laser theory and experiments, electron beam, photon beam, and undulator technologies, and applications of free electron lasers.

This edition is organised by Elettra Sincrotrone Trieste, an international, multidisciplinary research centre specialised in the generation of synchrotron and free-electron laser radiation together with their applications in material and life sciences.

The conference programme will include an optional tour of FERMI and the Elettra Storage ring.

IMPORTANT DATES

Abstract submission
15 February - 20 May, 2022

Early bird registration
15 February - 15 June, 2022

Last minute registration
16 June - 22 August, 2022

Paper submission due
18 August, 2022

FEL2022

August 22-26 Trieste, Italy