Seeding experiments at SPARC

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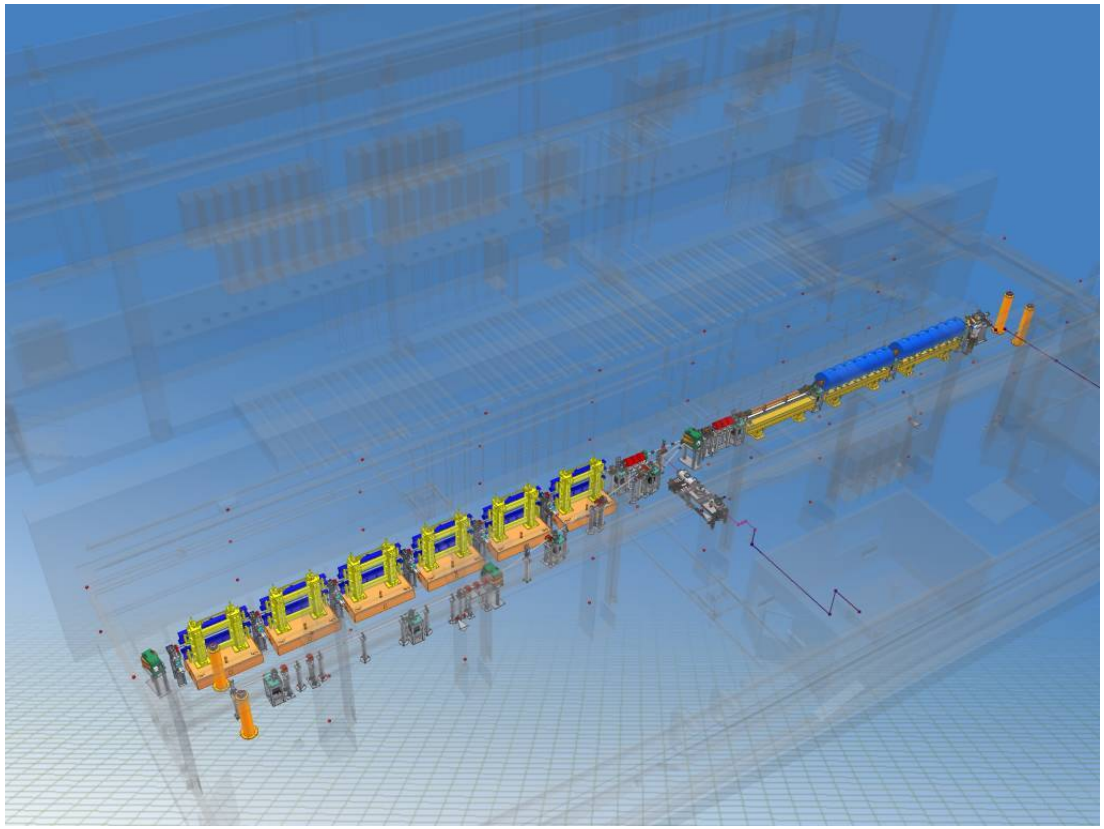
Experimental setup

The SPARC FEL is located at Frascati, Italy.



The SPARC experimental hall

Electron beam parameters

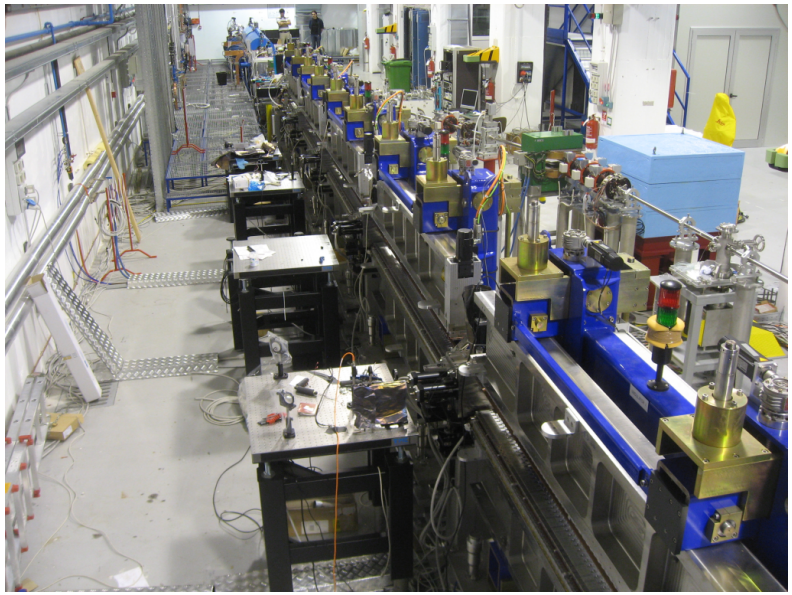
Typical electron beam parameters at the entrance of the undulator:

Parameter	Unit	Value
Energy	MeV	< 180
Emittance	π.mm.mrad	< 3.5
Energy spread	%	< 0.05
Charge	pC	< 500
Bunch length	ps-rms	< 2.5
Peak current	A	< 70

Experimental setup: Undulator

Undulator sections:

- ACCEL Gmbh
- 6 sections
- 77 periods
- Period = 28 mm
- $K_{max} \approx 2.3$
- λ_R: 100 - 500 nm



Undulator specificity:

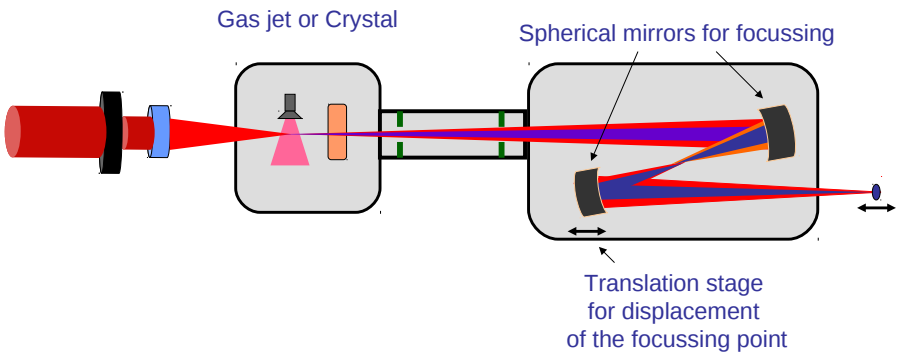
Sections are independanlty tunable !!

Experimental setup: Seeds

Harmonic generation using a Ti:Sa laser:

(Coherent system, 800 nm, 2.5 mJ, 120 fs-fwhm)

- HG in crystal:
  - λ=400 nm
  - $E < 10\ \mu J$
- HG in gas:
  - λ=266 and 160 nm
  - $E < 1\ \mu J$

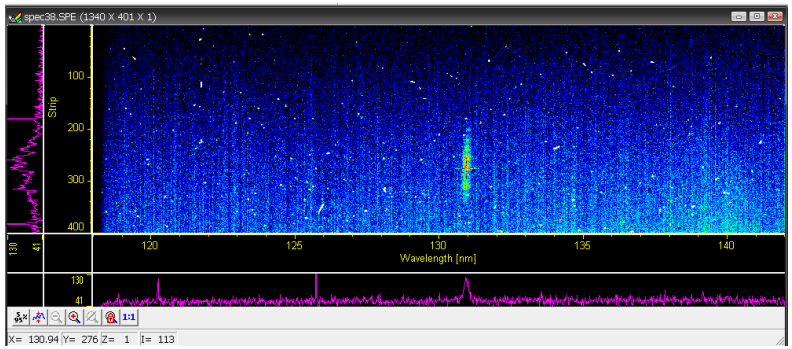


Experimental setup: Diagnostics

Spectrometer:

- LuXoR lab. (CNR, INFM)
- Normal incidence grating
- UV grade CCD camera

  (Versarray, 1300B-Princeton Instruments)
- Single shot:
  → Spectrum
  → Vert. distribution
  → Energy



FEL in amplifier configuration

- Seeding @ λ_1
- Energy modulation @ λ_1
- Bunching @ λ_1 and λ_1/n
- Radiation / Lasing @ λ_1 and λ_1/n

@ 400 nm

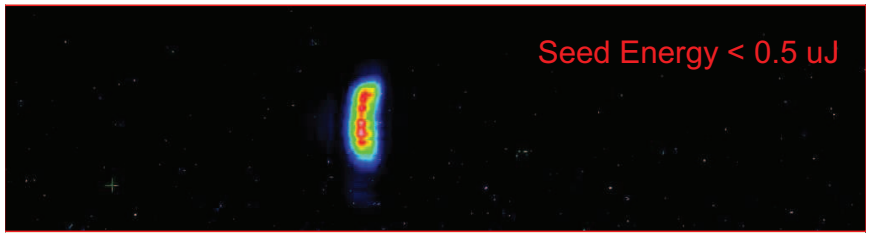
Amplifier @ 400 nm:

- E_{SASE}=100 nJ
- E_{seeded}=10 μJ

  (E_{seed}=1 μJ, HG in crystal)
- Amplification:

  $\rightarrow$ 100 $\times$ SASE

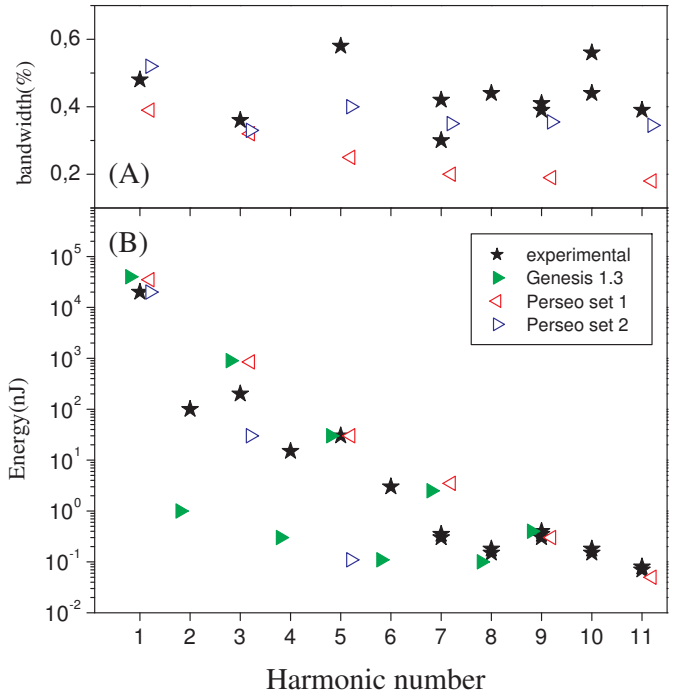
  $\rightarrow$ 10 $\times$ Seed

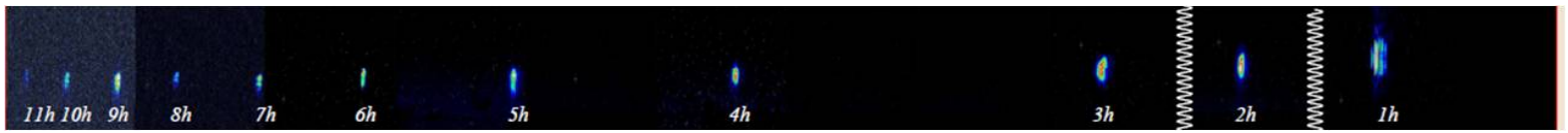


@ 400 nm: Generation of high harmonics

- Strong harmonic content:
  H1 $\rightarrow$ H11
- Agreement / simulations:
  - Odd harm.: OK
  - Even harm.: $\neq$ (Genesis)
    $\rightarrow$ misalignement ??
    $\rightarrow$ beam dynamics ??

$\rightarrow$ under investigation...

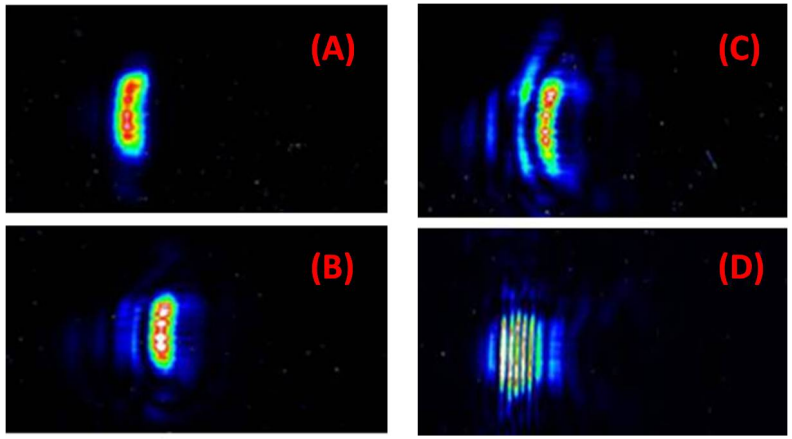




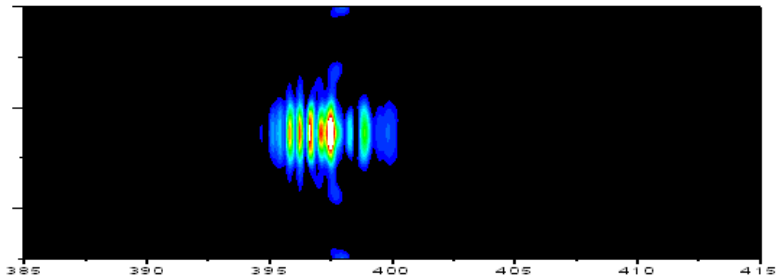
@ 400 nm: Observation of interference fringes

- Increasing seed energy:
  $\rightarrow$ Fringes in spectrum
- Agreement exp. / simu.

Exp.: (A) 0.5 μJ (B) 0.7 μJ (C) 3 μJ (D) 9 μJ



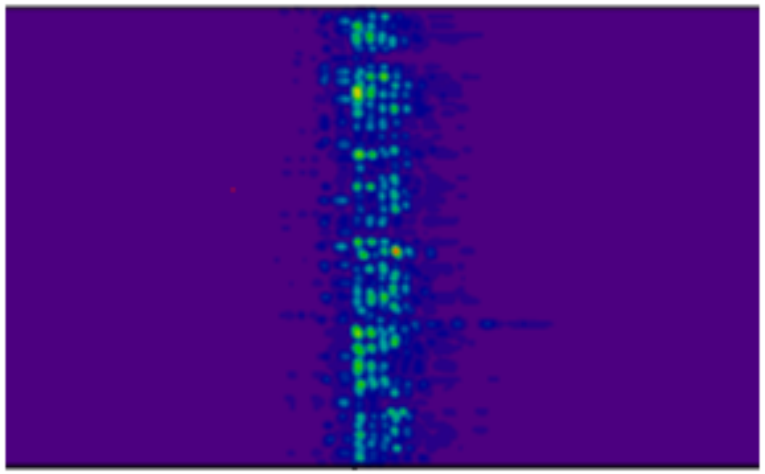
Genesis simulation. *V. Petrillo and M. Serluca.*



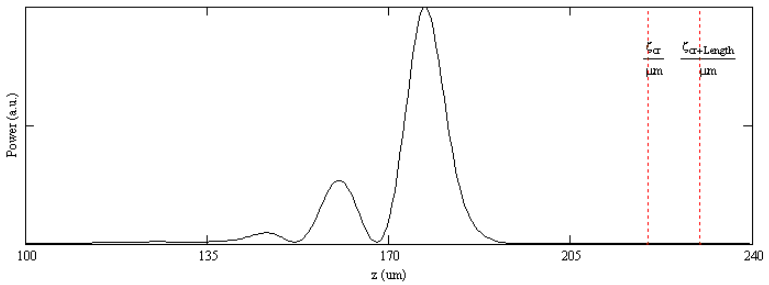
@ 400 nm: Observation of interference fringes

- Regular pattern at fixed wavelengths:
  $\rightarrow$ not SASE spikes
  $\rightarrow$ interference fringes
- Origin: $\rightarrow$ interference between head and tail

Spectra vs shot number



Simulated longitudinal profile. *L. Giannessi.*



@ 266 nm

Amplifier @ 266 nm:

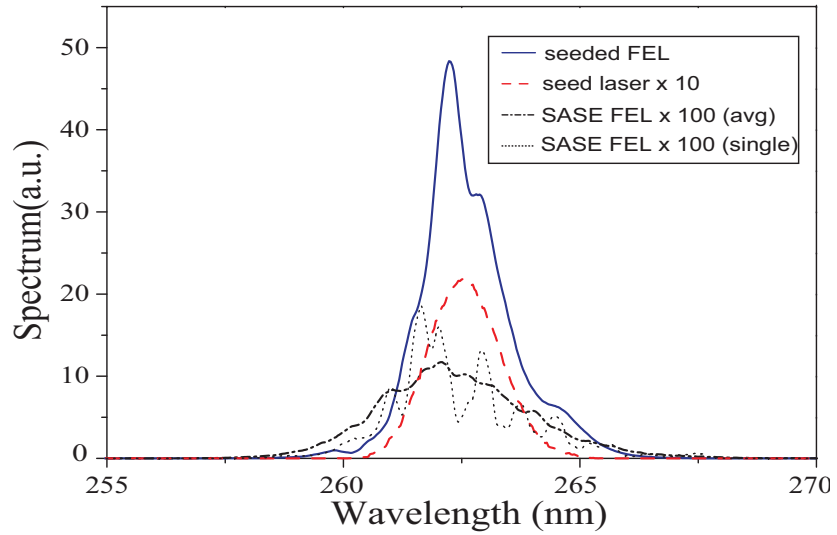
- E_{SASE}=12 nJ
- E_{seeded}=2.6 μJ

  (E_{seed}=120 nJ, HG in gas)
- Amplification:

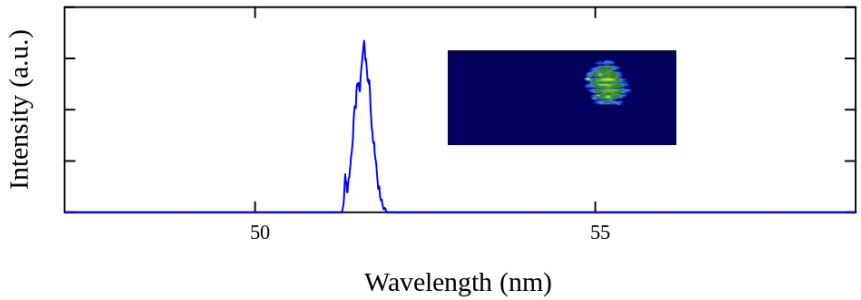
  $\rightarrow$ 200 $\times$ SASE

  $\rightarrow$ 20 $\times$ Seed

(H1)



(H5: 50 pJ @ 53 nm, using Al meshed filter)



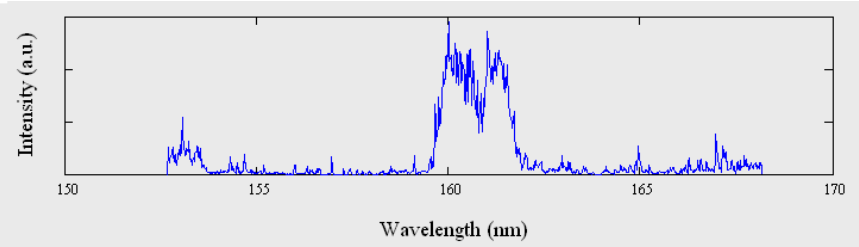
@ 160 nm

Amplifier @ 160 nm:

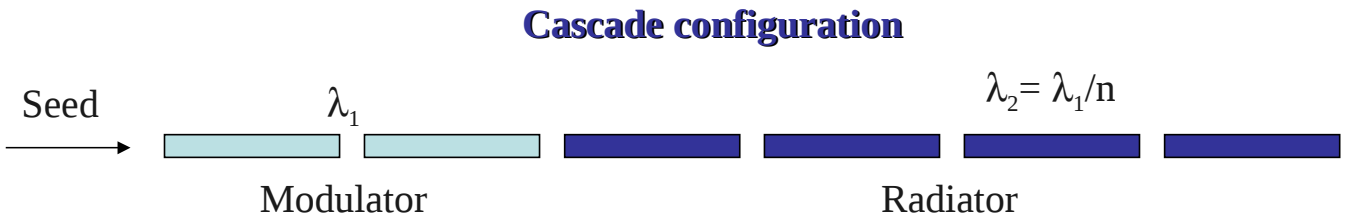
- E_{seeded}=4 nJ

But: Phase distorsion of IR laser

$\longrightarrow$ Re-do



FEL in cascade configuration



- Seeding @ λ_1
- Energy modulation @ λ_1
- Bunching @ λ_1 and λ_1/n
- Radiation / Lasing @ $\lambda_2 = \lambda_1/n$

Seeding @ 400 nm $\rightarrow$ Lasing @ 200 nm

Electron beam focussing:

- H: quadrupoles
- V: undulator

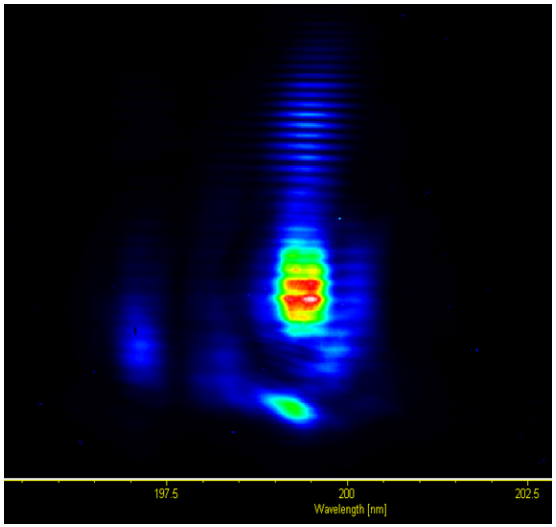
Electron beam matching:

- Mismatch in modulator @ λ_1
- $\lambda_1 \rightarrow \lambda_2$: change V focussing $\rightarrow$ match in radiator
- Match in radiator @ λ_2 with a FODO lattice

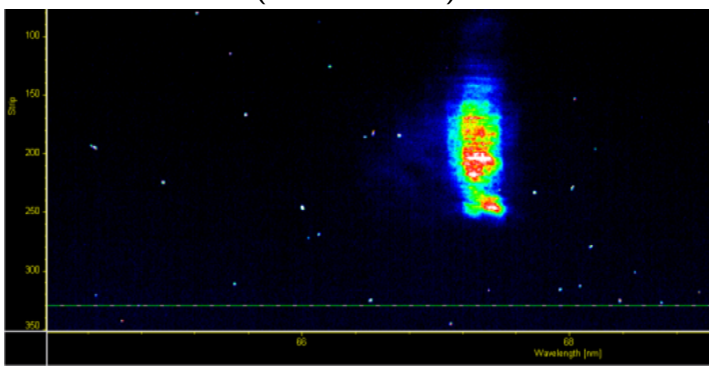
Seeding @ 400 nm $\rightarrow$ Lasing @ 200 nm

- E_{FEL-h1}=5 μJ
- E_{FEL-h3}=0.1 μJ

E_{seed}=2 μJ, HG in crystal

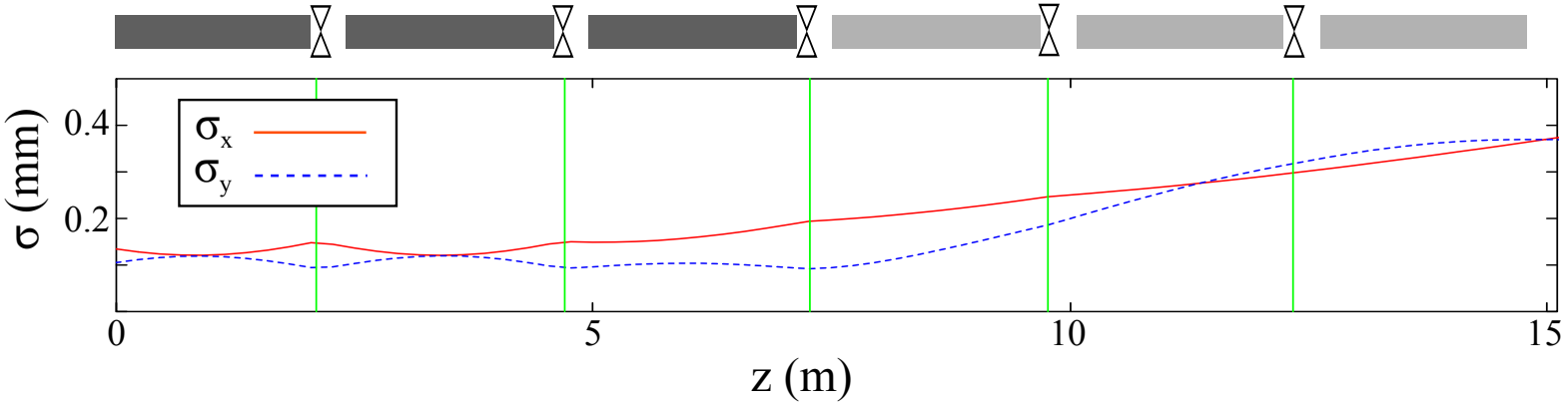


(H1: 200 nm)



(H3: 66 nm)

Seeding @ 266 nm → Lasing @ 133 nm



Electron beam focussing:

- H: quadrupoles
- V: undulator

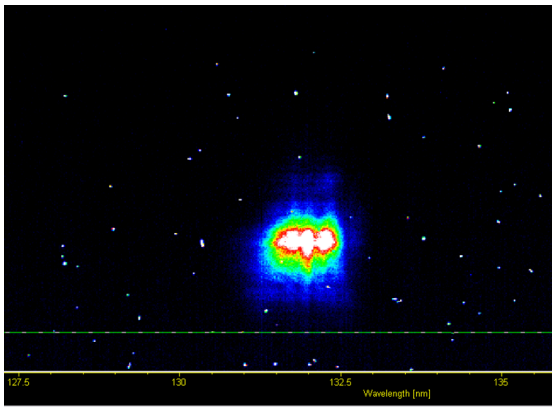
Electron beam matching:

- Match in modulator @ λ_1 with a FODO lattice
- $\lambda_1 \rightarrow \lambda_2$: change V focussing → mismatch in radiator
- Minimize beam size in radiator with Qpoles

Seeding @ 266 nm → Lasing @ 133 nm

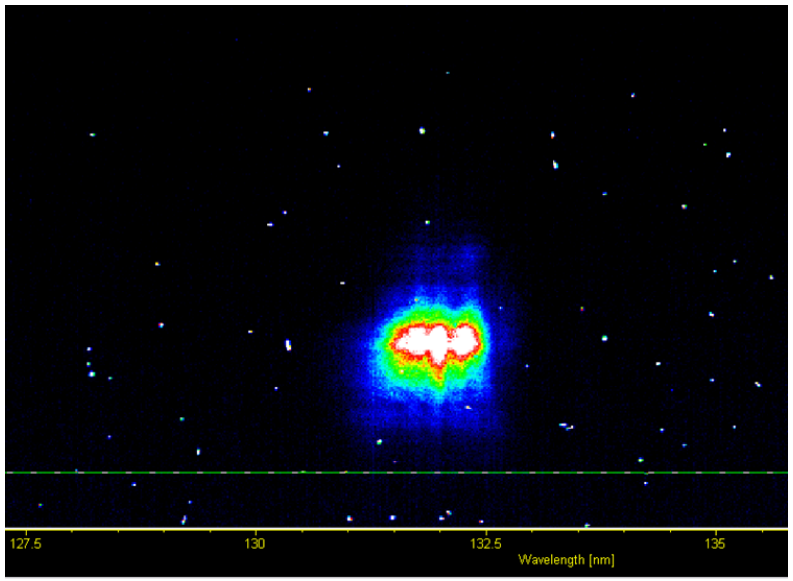
- E_{FEL-h1}=0.8 μJ

  E_{seed}=50 nJ, HG in gas



(H1: 133 nm)

Seeding @ 266 nm → Lasing @ 133 nm



(H1: 133 nm)

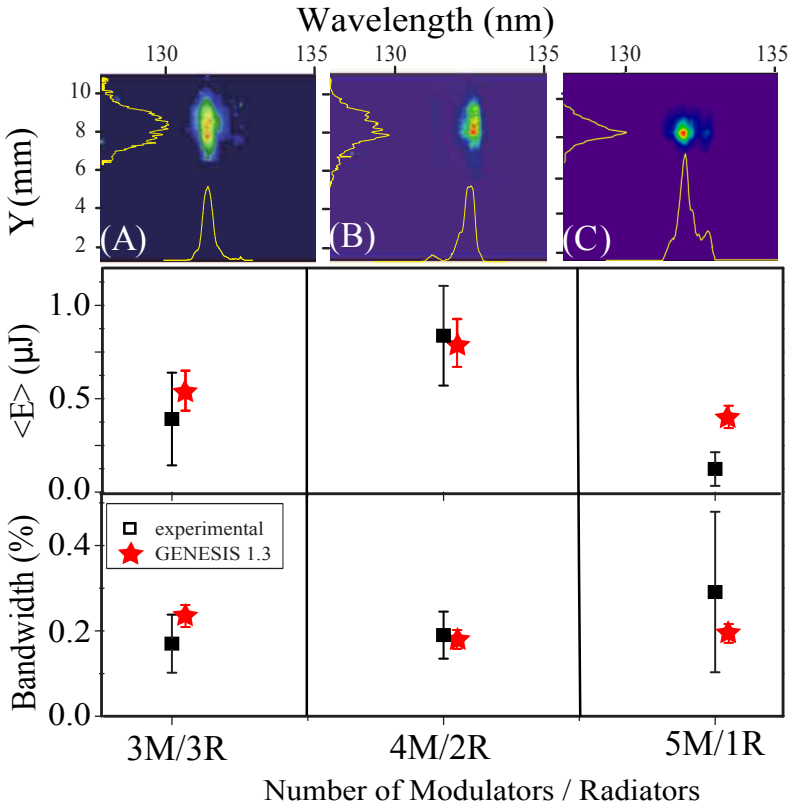
@ SPARC

First cascade seeded with harmonics in gas !!

Seeding @ 266 nm → Lasing @ 133 nm

Varying number of Modulators / Radiators:

- Optimum: 4M / 2R
- Max. energy: 840 nJ
- Min. bandwidth: 0.19 %

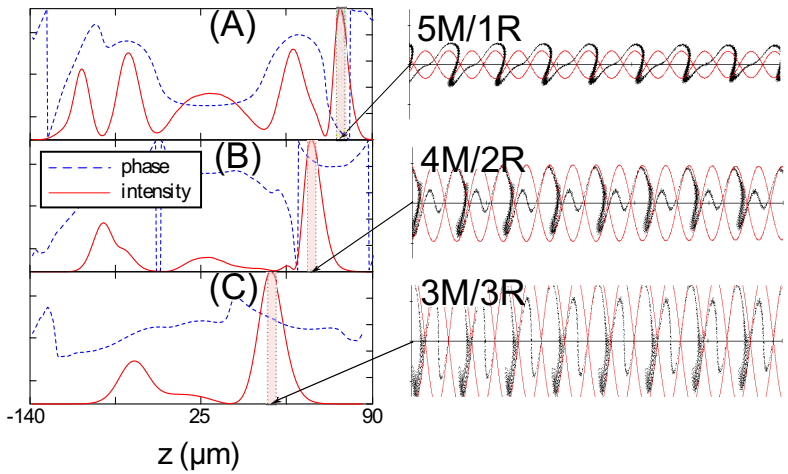


Seeding @ 266 nm → Lasing @ 133 nm

Varying M/R:

- 5M/1R:
  very strong bunching in Ms
  coherent radiation in Rs
  → Coherent Harmonic Generation
- 4M/2R:
  bunching in Ms
  strong amplification in Rs
  → Superradiance
- 3M/3R:
  bunching in Ms
  spoiled amplification in Rs
  → Superradiance with mismatched electron beam

→ Change FEL regime



What comes next ??

Machine upgrades

RF Photoinjector:

- New RF cavity
- New photocathode
  $\rightarrow$ higher charge, lower emittance

LINAC (R. Boni et al.):

- Remove last S-band section: 2.8 GHz, 10 MV/m
- Install 2 C-band sections: 5.7 GHz, 35 MV/m
  $\rightarrow$ E=220-245 MeV

FEL future experiments (Spring 2012)

Proposals:

- $E > 200$ MeV $\rightarrow$ Seeding @ $\lambda < 160$ nm
- Demonstration of the harmonic cascade configuration

  L. Giannessi et al., New Journal of Physics 8 (2006) 294.
- Spectro-temporal measurements using a FROG @ 400 nm

  G. Marcus et al., Proc. of FEL'08 (2008).
- Comparison of WF measurements with Hartman and Speckles

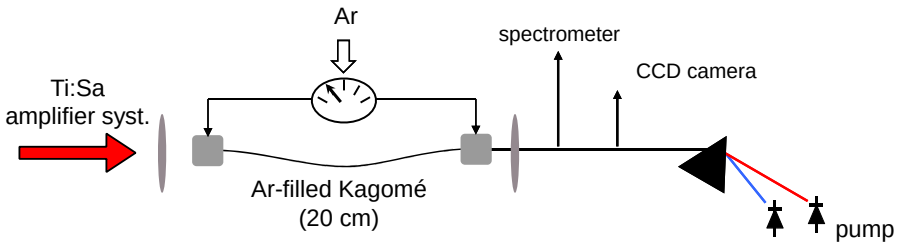
  P. Mercere et al., PRL 106, 234801 (2011) ; M. Alaimo et al., PRL 103, 194805 (2009).

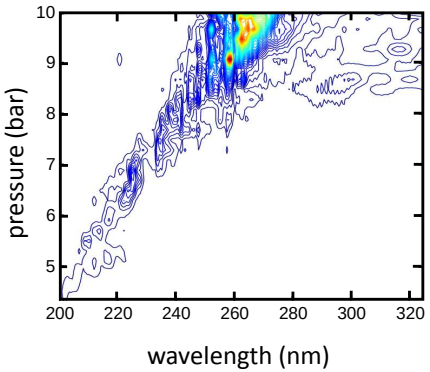
FEL future experiments

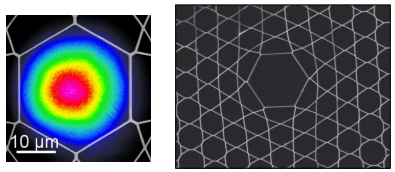
Proposals:

- Seeding with a Kagome lattice fiber

N. Joly et al., PRL 106, 203901 (2011) + POSTER MOPB16







Conclusion

- Operation in amplifier mode @ 400, 266 and 160 nm
  - Generation of high harmonics $\rightarrow$ up to h11 !
- Operation in cascade mode @ 400 and 266 nm
  - First FEL cascade with HG in gas !
  - Optimization in superradiant mode
- Next:
  - Machine upgrade $\rightarrow$ higher beam energy and quality
  - Extension of the spectral range to EUV
  - Still a lot of things...