Nonlinear Harmonic Generation in the STARS FEL

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2004 **BESSY Soft X-Ray FEL Technical Design Report**

- design uses up to **four HGHG stages**

2005-2006 **BESSY FEL Features:**

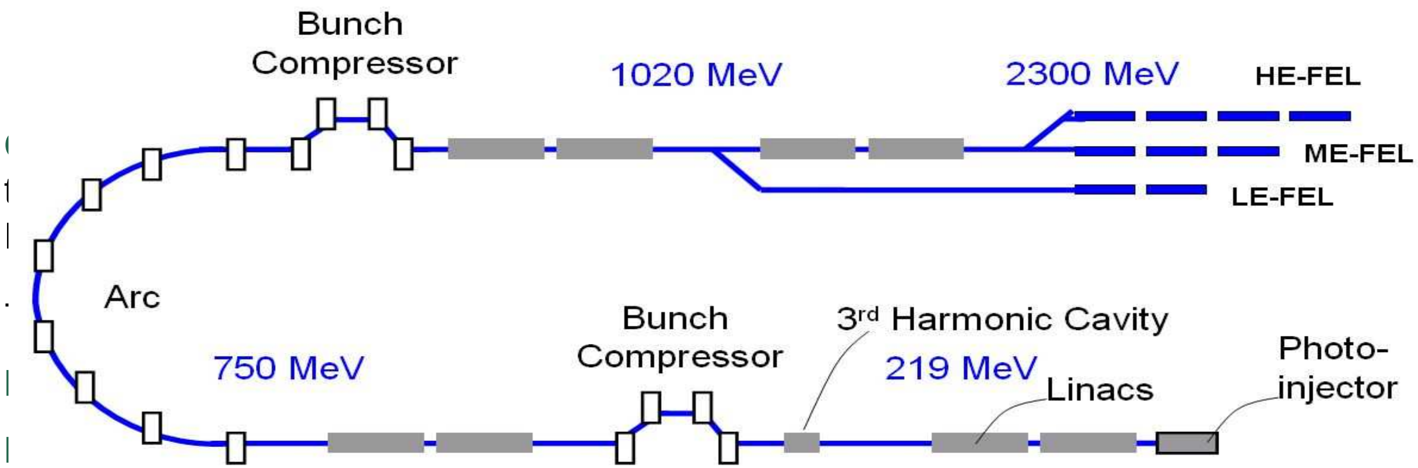
- multi-user facility
- multi-stage, full CW operation
- output wavelength range 1.24nm to 50nm
- short (20fs), reproducible pulses

Review by German Science Council

-> recommendation to first show successful HGHG cascading

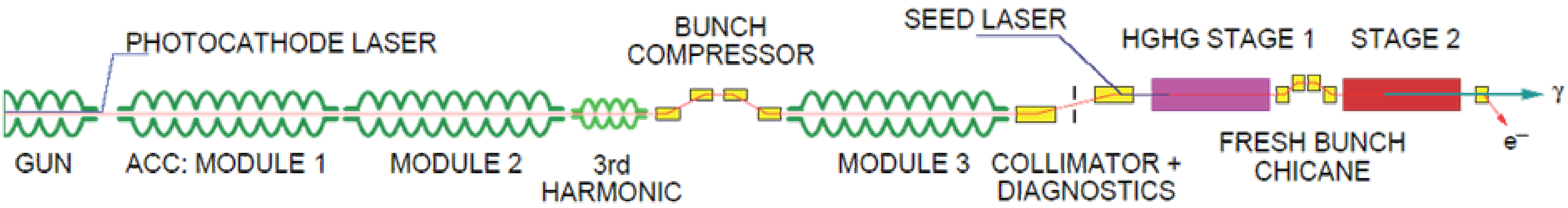
2006

2009



BESSY Soft X-Ray FEL

Overview STARS FEL



- normal conducting PITZ-type gun

- three sc TESLA-type acceleration modules

- 3rd harmonic cavity

- magnetic bunch compression

- collimator

- two HGHG stages with modulator, dispersion, radiator. Fresh bunch chicane.

-> conservative, robust design

-> concentrate on demonstration of HGHG cascading

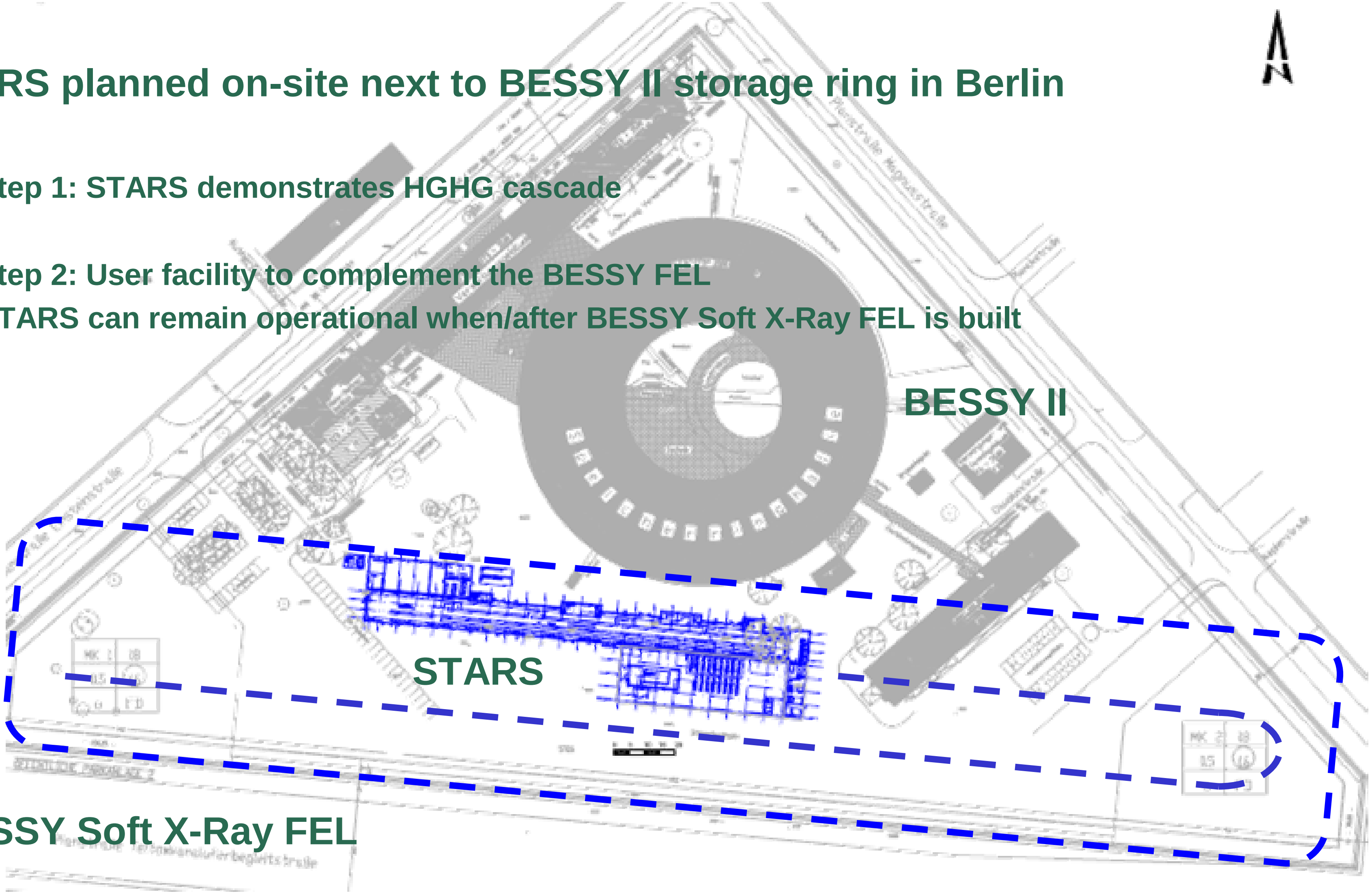
Parameter	Value	Unit
Beam energy	325	MeV
Bunch charge	1	nC
Peak current	500	A
Bunch rep. rate	100	Hz
Slice emittance	1.5	mm mrad
Slice energy spread	<32	keV
Accelerating gradient	17.2	MV/m
HGHG stages	2	
Wavelength range	40-70	nm
Output power	100-1000	MW

STARS planned on-site next to BESSY II storage ring in Berlin

Step 1: STARS demonstrates HGHG cascade

Step 2: User facility to complement the BESSY FEL

STARS can remain operational when/after BESSY Soft X-Ray FEL is built

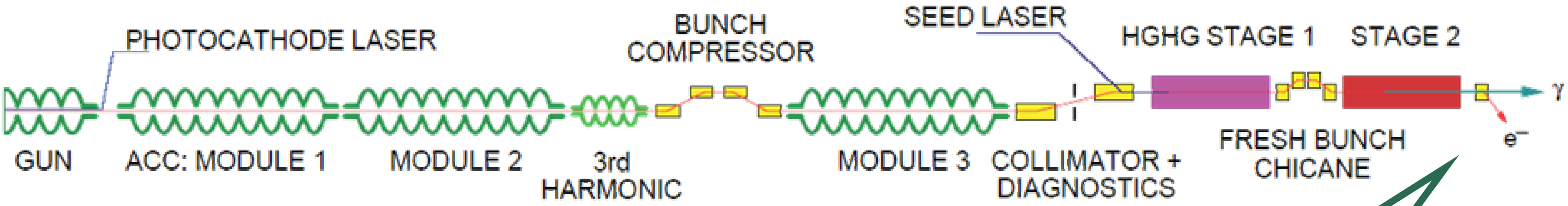


Demonstration of cascaded HGHG

- stable FEL operation
- wavelength range below 100nm
- variable polarization output
- reproducible, short pulses

Test of BESSY FEL technology

- superconducting RF
- high rep rate operation of gun and linacs (1kHz)
- seeding and timing

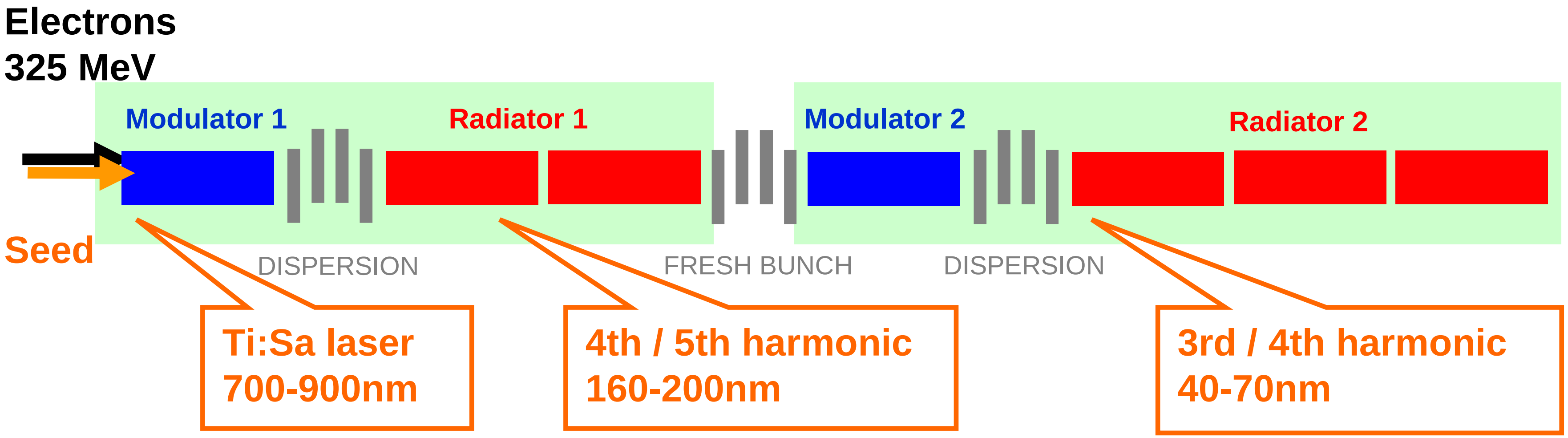


Design leaves space for upgrade options
- HHG seeding

Provide short-wavelength radiation for experiments

- coherent output
- harmonic radiation to reach shorter wavelengths

Undulator section of STARS FEL



Modulator 1, Radiator 1

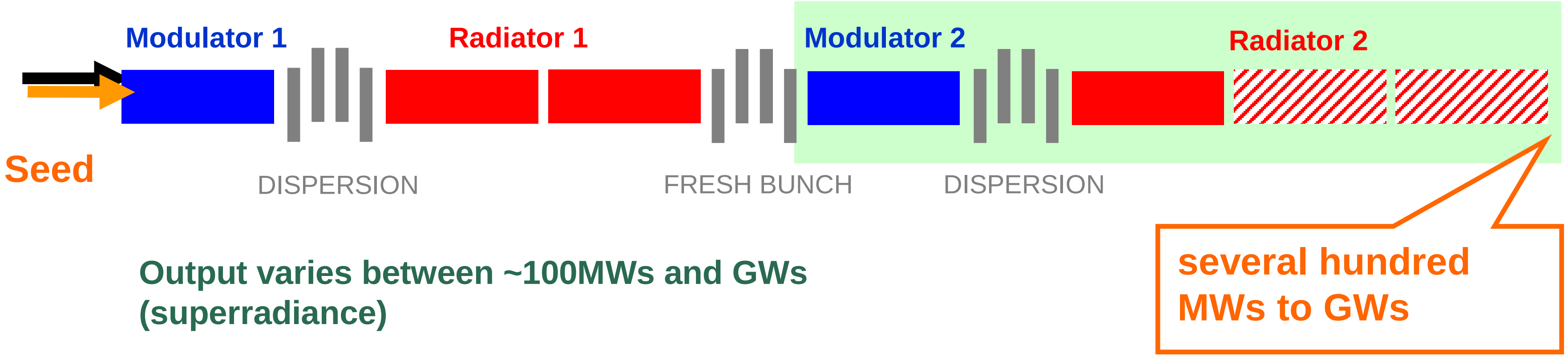
(and Modulator 2)

- planar undulators
- undulator period length 50 mm
- minimal gap 10-20 mm

Radiator 2 configured as APPLE III undulator

- high field
- variable field polarization
- wide resonance tuning range
- minimal gap 7 mm

Electrons
325 MeV



Output varies between ~100MWs and GWs (superradiance)

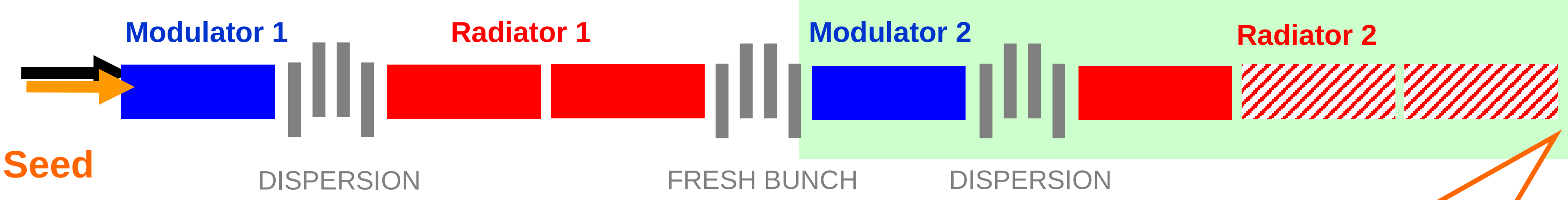
- three undulator modules
- 150 periods
- period length 2.2cm
- radiation source point variable along radiator

Simulations show that cascaded HGHG can be demonstrated at 70nm without 3rd harmonic cavity.

Requirements met.
Everything else is optional - but very interesting:

Output of STARS FEL

Electrons
325 MeV



Seed

Output varies between ~100MWs and GWs (superradiance)

- three undulator modules

- 150 periods
- period length 2.2cm
- radiation source point variable along radiator

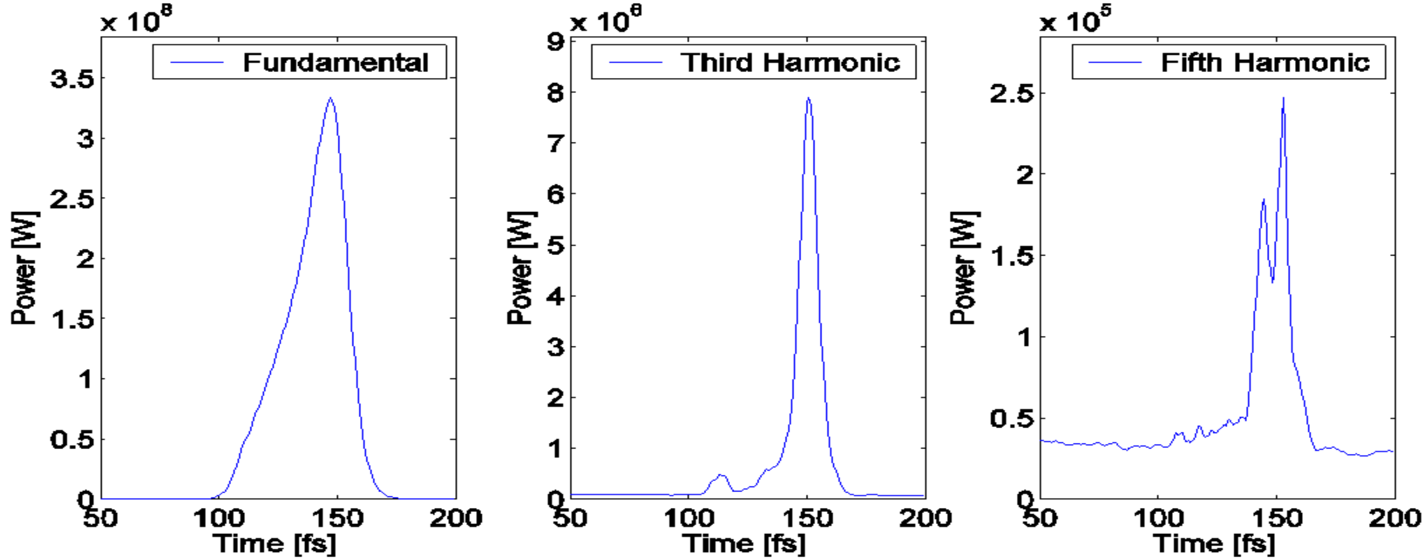
Shorter Wavelengths

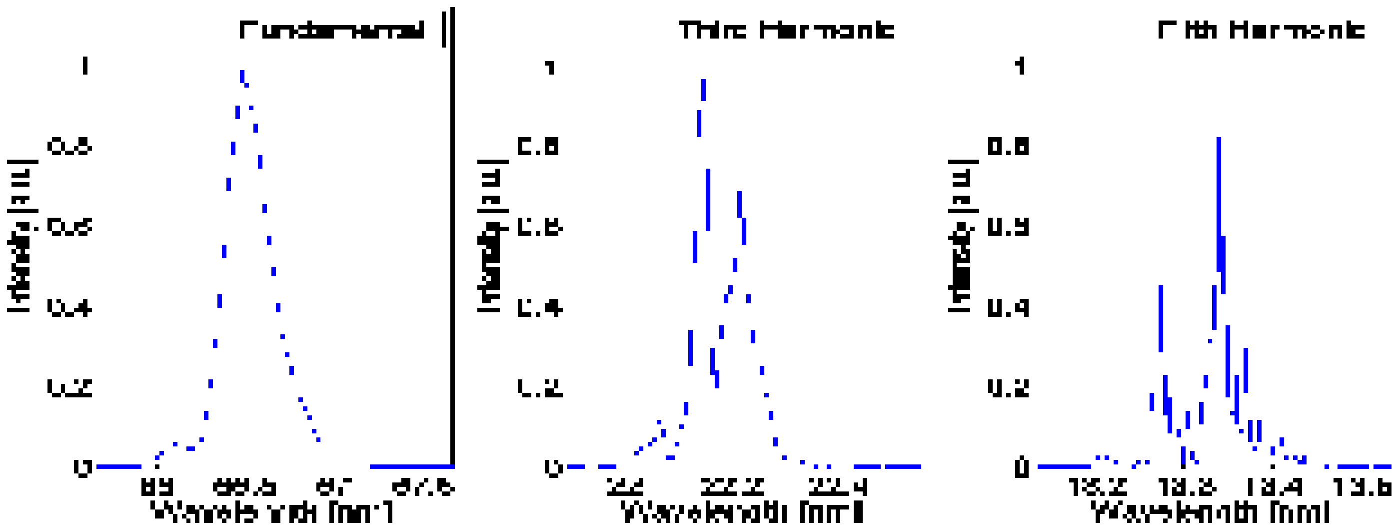
several hundred MWs to GWs

OPTION 1
Harmonic radiation in the range of 8-20nm

OPTION 2
HHG seeding of second radiator plus harmonic radiation

Harmonic Content at 66nm





Output at 66nm, planar *("power optimized")*

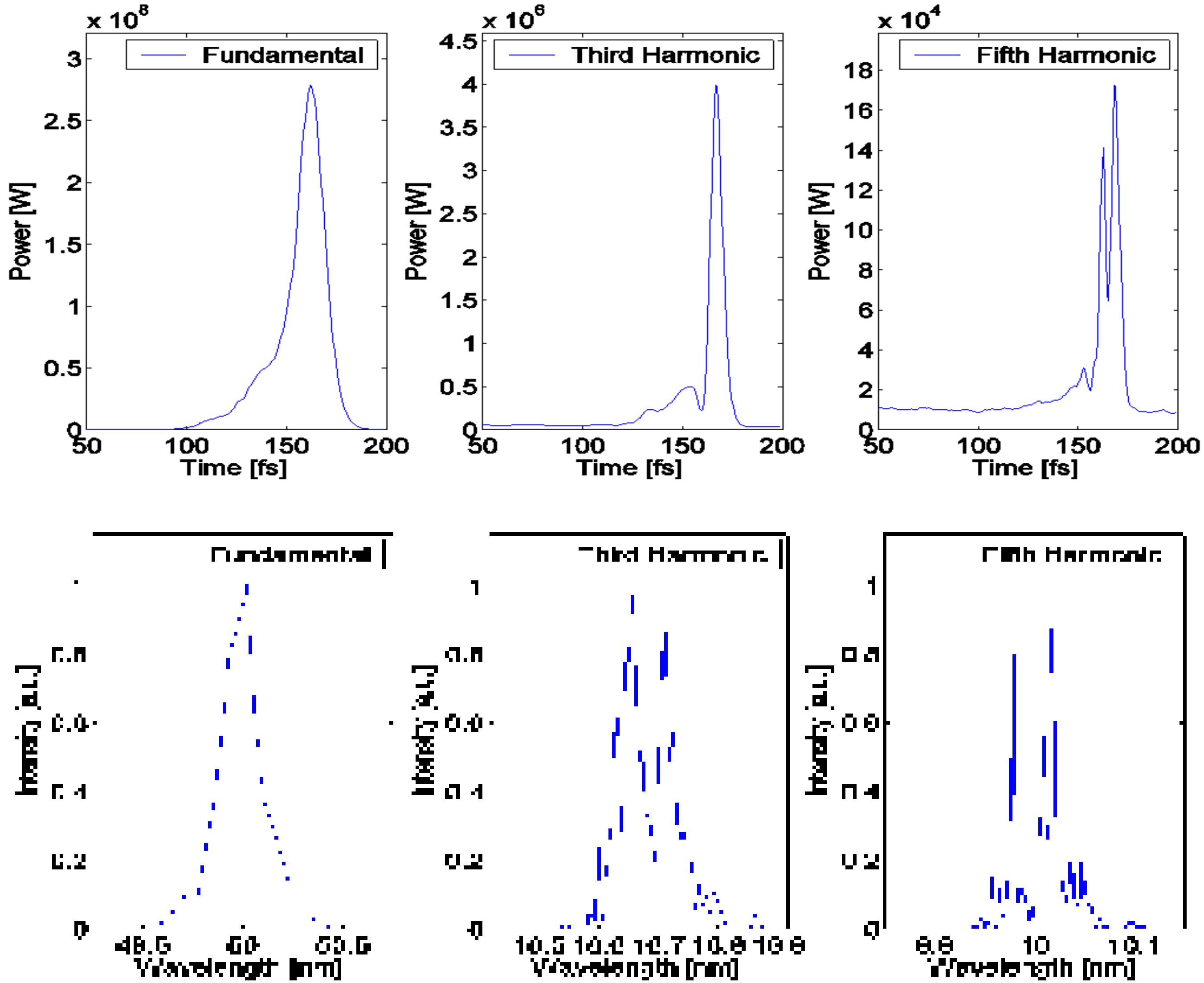
- simulations with new version of Genesis 1.3

(S. Reiche et al, PAC07)

- start-to-end bunch from tracking through gun, linac and undulator

- FEL simulation stopped after first undulator module of radiator 2

Har-monic	Power (MW)	Energy (µJ)
1	330	9.35
3	8	0.11
5	0.25	0.009



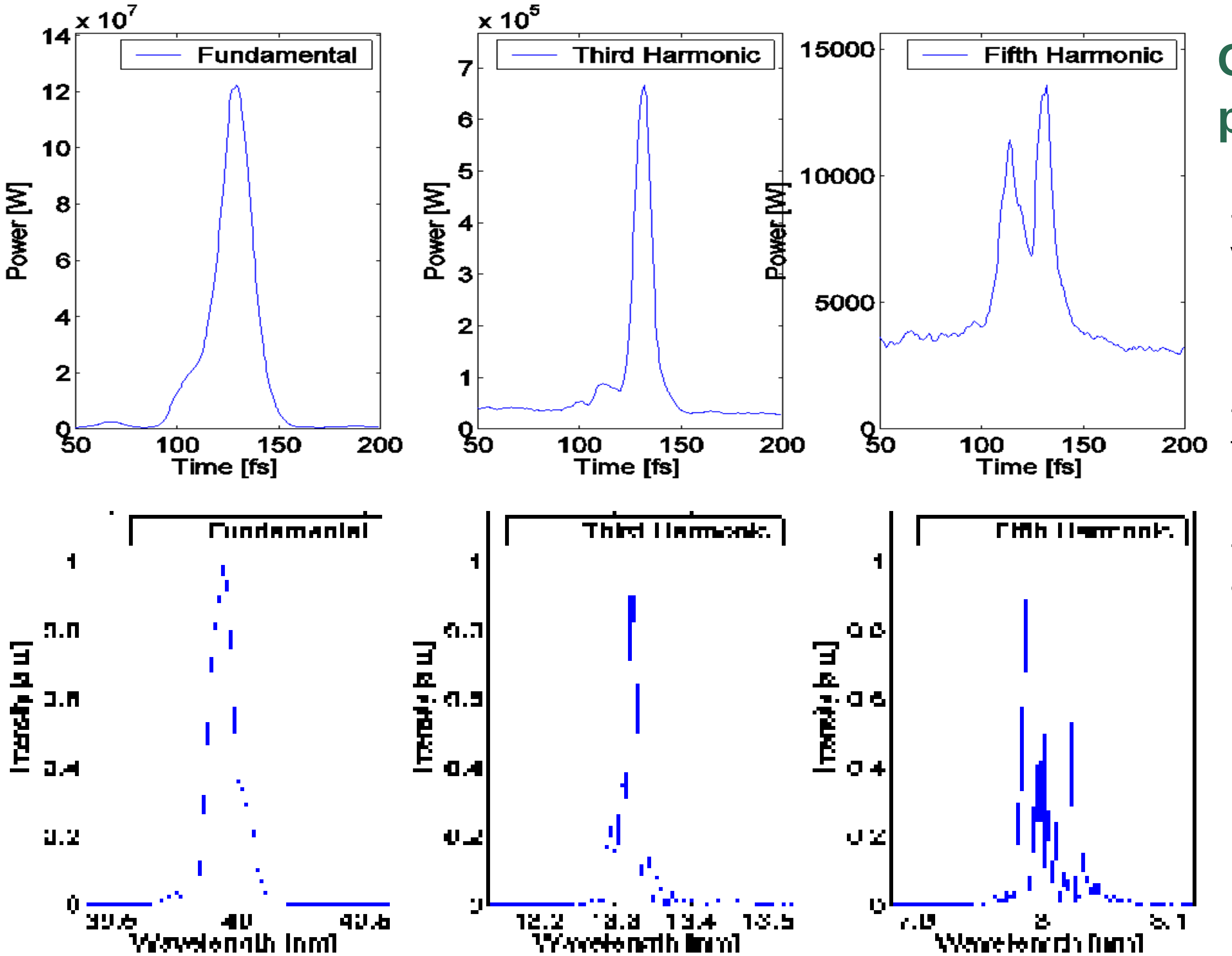
Output at 50nm, planar *("power optimized")*

- simulations with new version of Genesis 1.3

- start-to-end bunch from tracking through gun, linac and undulator

- FEL simulation stopped after first undulator module of radiator 2

Har-monic	Power (MW)	Energy (µJ)
1	300	6.13
3	4	0.05
5	0.18	0.004



Output at 40nm, planar *("power optimized")*

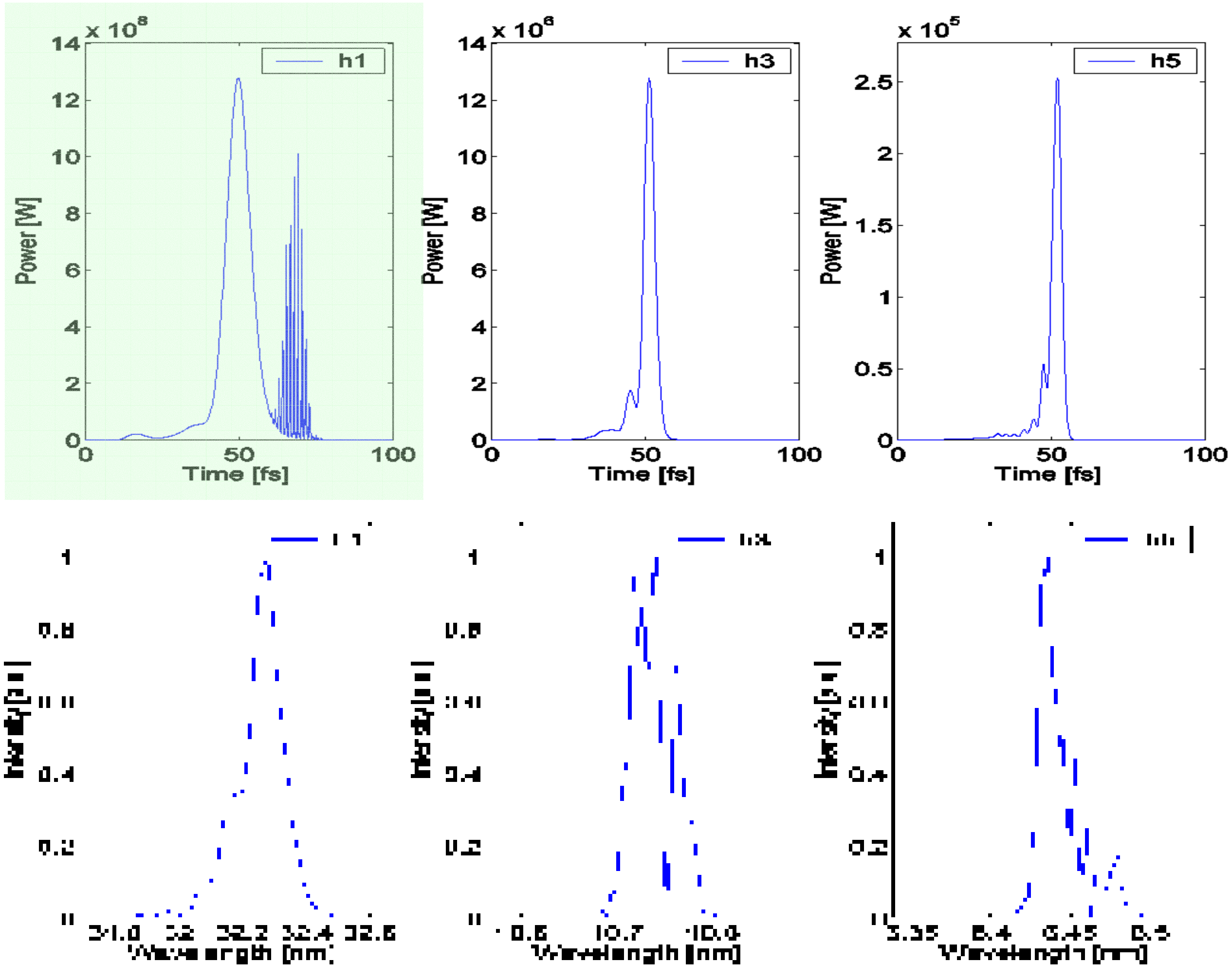
- simulations with new version of Genesis 1.3

- start-to-end bunch from tracking through gun, linac and undulator

- FEL simulation stopped after second undulator module of radiator 2

Har-monic	Power (MW)	Energy (µJ)
1	125	2.85
3	0.7	0.01
5	0.015	0.0001

Harmonic Content HHG seeded case at 32nm



HHG seeding, 32nm, planar

- 23rd harmonic of 740nm laser

- HHG pulse simulated with new code RHYNO

(T. Leitner, Diploma Thesis 2007)

simulation assumes:

- Gaussian shape laser

- 30fs FWHM duration

- waist size 17.6 μm

Har-monic	Power (MW)	Energy (μJ)
1	1300	14.9
3	13	0.07
5	0.25	0.001

STARS: Proposal for a two-stage HGHG FEL

- demonstration of multistage HGHG
- and more:

  investigation of nonlinear harmonics, HHG seeding

  test and learn gun and linac operation, timing, seeding

Output and experiments

- short pulse (20fs) short wavelength radiation (40-70nm)
- output power in range of 100MW to 1GW
- STARS planned as user-facility after BESSY FEL is built:

  e.g. for experiments usually conducted with HHG,

  example: molecular photoionization

Harmonic content

- third harmonic radiation with several MWs available at 13 to 20nm with pulse energies in range of 0.01 to 0.1μJ. Very short pulse duration (10-15fs).
- HHG seeding and harmonics very promising to reach coherent short wavelength radiation.