FLASH II: Perspectives and Challenges

1. Scope of the Project.
2. Layout.
3. FEL Schemes.
4. Radiation Properties.
5. User Issues.

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FLASH II
Hamburg, June 28, 2010

Scope of the Project.

Present Status

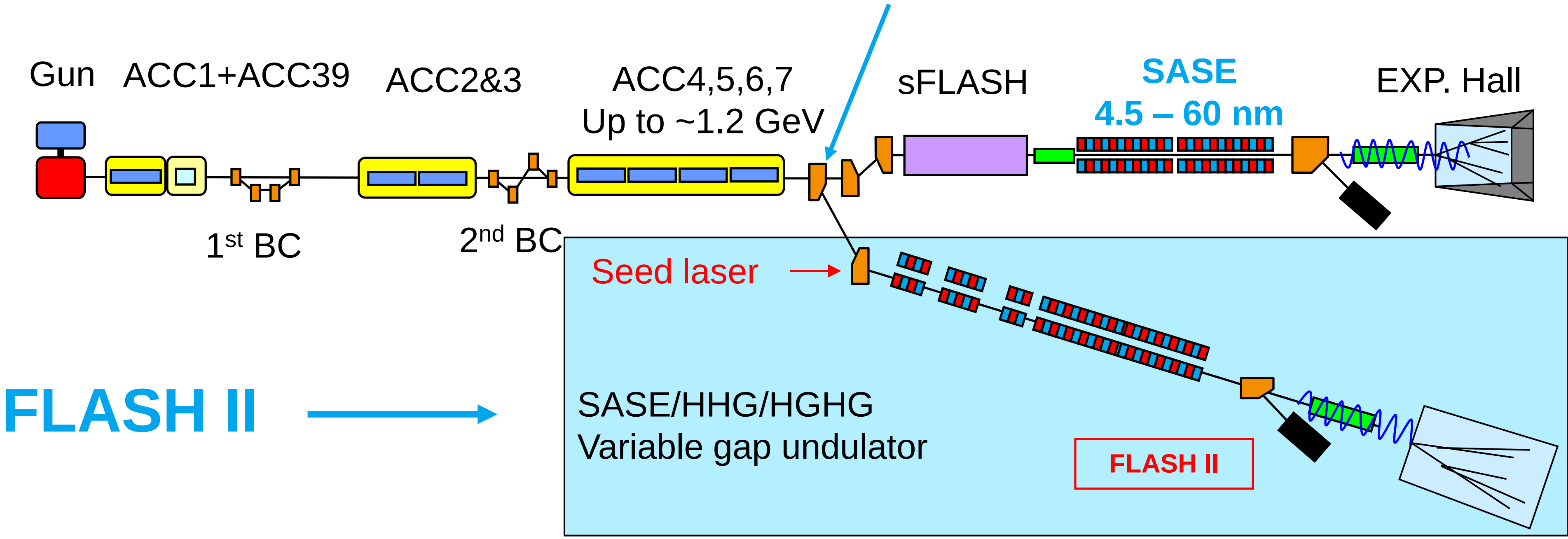
1. FLASH is overbooked by a factor 3.
2. Only SASE radiation delivered to users.
   1. *Time arrival jitter (partially corrected by fast feedback within pulse train).*
   2. *Shot-to-shot fluctuation in intensity (starting from noise).*
   3. *Wavelength variation/mode structure (coherence length versus bunch length).*
3. FLASH delivers only linear polarization.

Future

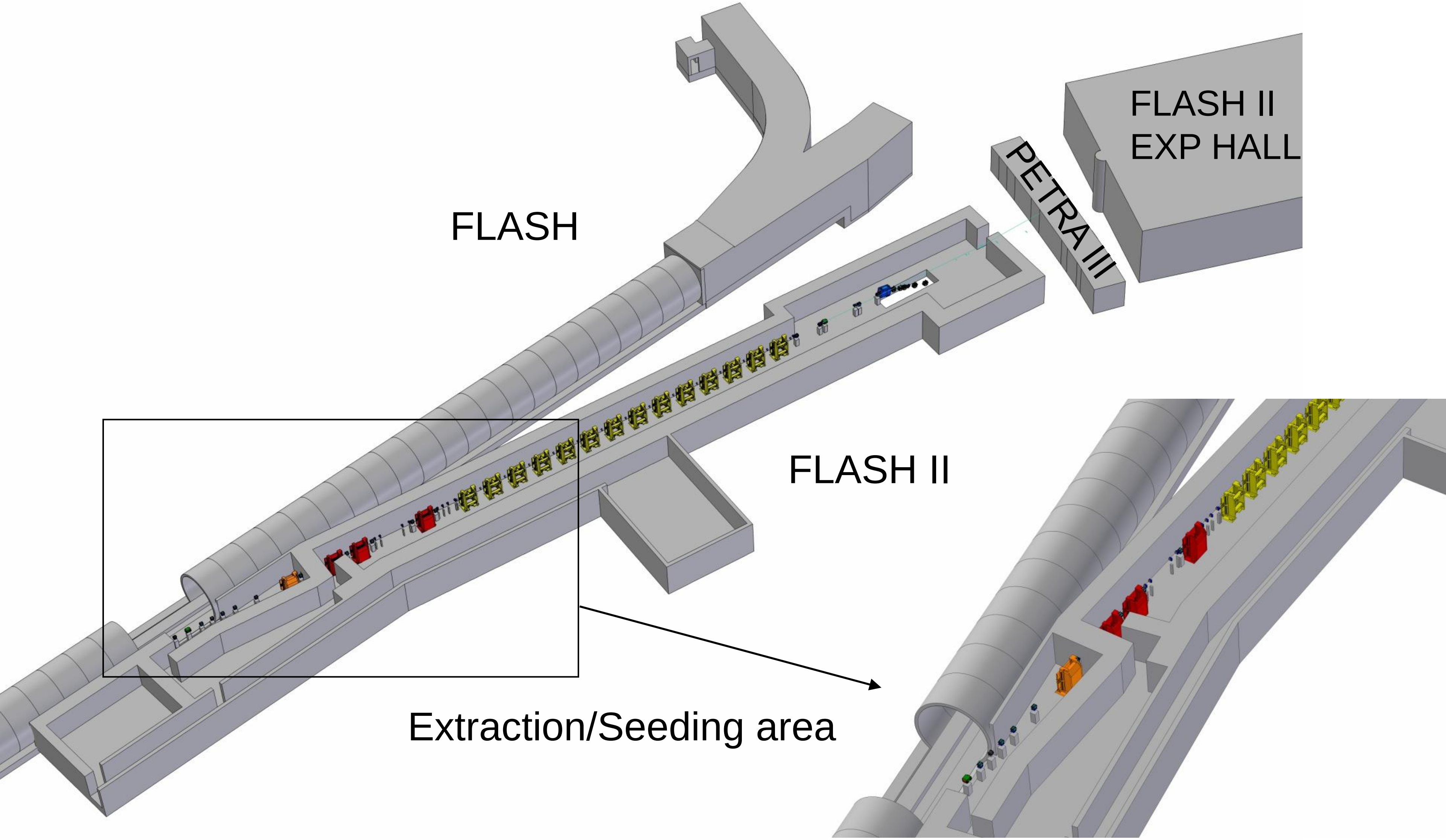
1. Doubling number of experimental stations (simultaneous operation?).
2. Seeding
   1. *Timing stability.*
   2. *Frequency Stability.*
   3. *Single Mode.*
3. Complementary properties to FLASH I.
   1. *No copy of existing beamlines.*
   2. *No copy of wavelength range.*
   3. *Variable polarization.*

Upgrade: layout after upgrade FLASH II.

- Tunability of FLASH II by undulator gap change
- Extend user capacity with SASE and HHG/HGHG seeding
- Use of existing infrastructure up to last accelerating module



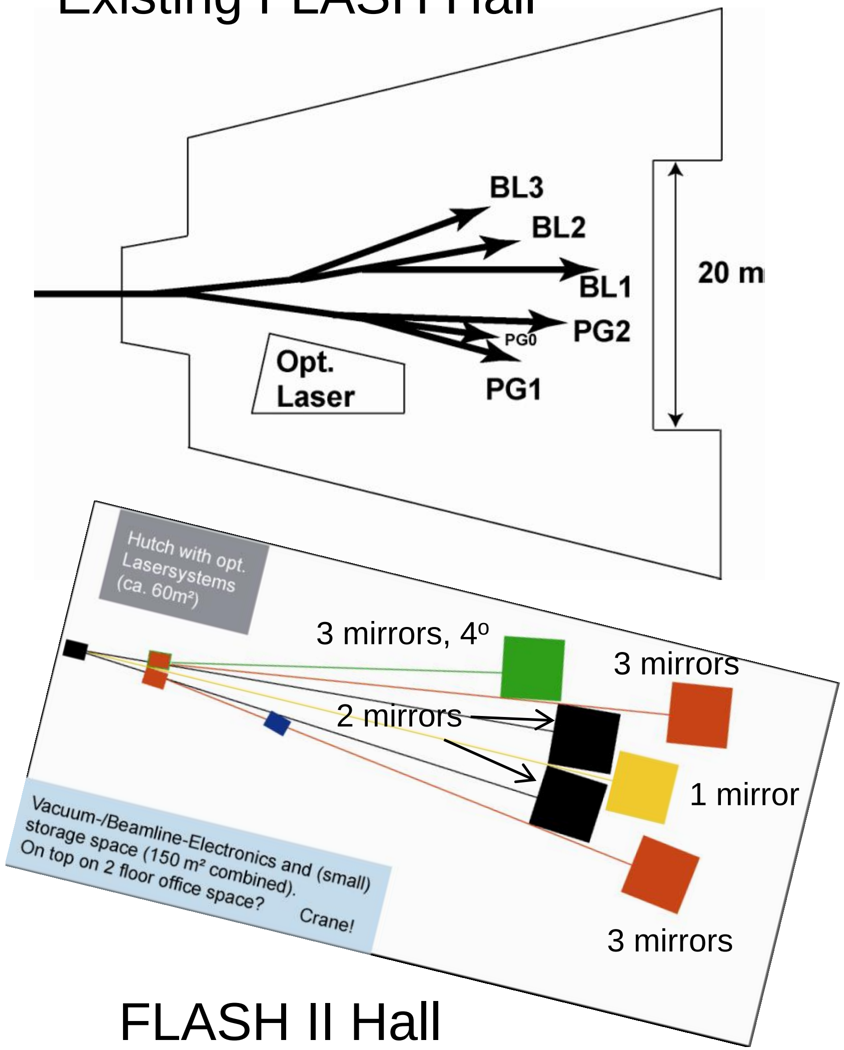
Upgrade: layout after upgrade FLASH II.



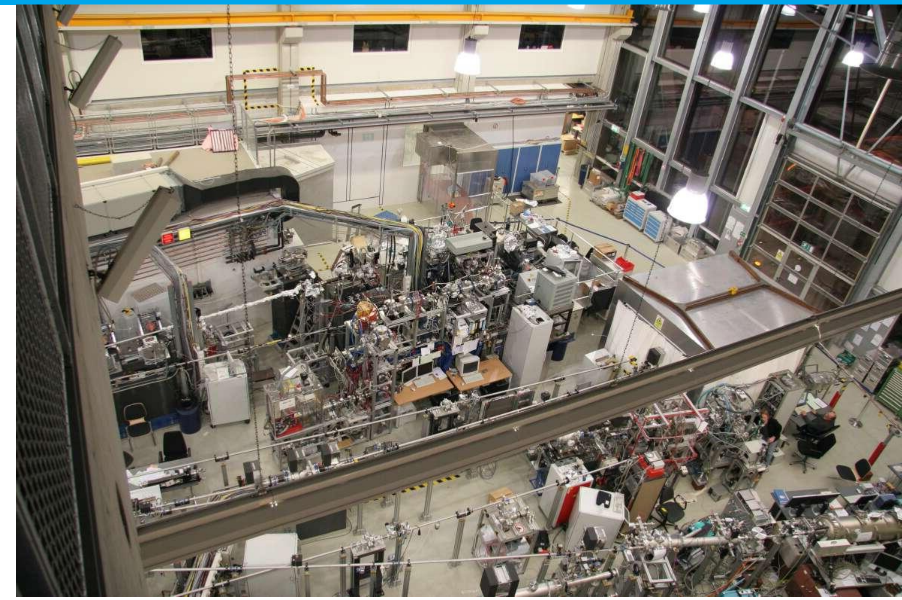
Layout experimental Hall.

Existing FLASH Hall

PETRA III ring



FLASH II Hall



More space for experiments
Two experiments in a row
Less mirrors (deformation of wave front)
….

FLASH II: foreseen operation modes.

Self Amplified Spontaneous Emission mode: Start from fluctuation in electron density
spiky, but at full rep.rate and short and long pulses possible.

SEEDING SCHEMES: Amplification of an external laser

High Gain Harmonic Generation mode:

Amplify a long wavelength seed and apply frequency multiplication in FEL process.

Only short pulses (up to ~5-30 fs), but close to single mode.

High Harmonic Generation mode (see also sFLASH):

Amplify an external, frequency multiplied seed laser.

Only short pulses (up to ~10-30 fs), but close to single mode down to ~10 nm.

Hybrid mode: HGHG with HHG source

Echo Enabled Harmonic Generation under discussion.

SASE operation: variation of pulse length by charge change.

	with harmonic module					without
Bunch charge, nC	1	0.5	0.25	0.1	0.02	0.5-1
Wavelength, nm	6.5					6
Beam energy, MeV	1000					1000
Peak current, kA	**2.5**	**2**	**1.7**	**2.6**	**2.5**	1.3-2.2
Slice emmitance,mm-mrad	**1-1.5**	**0.7-1.5**	**0.5-1.2**	**0.5-1**	**0.5-0.7**	1.5-3.5
Saturation length, m	**13-15**					22-32
Energy in the rad. pulse, μJ	700-1200	400	200	30	3	50-150
Radiation pulse duration FWHM, fs	**100-200**	**35-150**	**25-100**	**3-5**	**2-3**	15-50
Averaged peak power, GW	3-5				1	2-4
Spectrum width, %	0.4-0.5			0.3-0.4		0.4-0.6
Coherence time, fs	4-5			-	-	-

In theory, pulse length between 2 (single mode) and 200 fs possible

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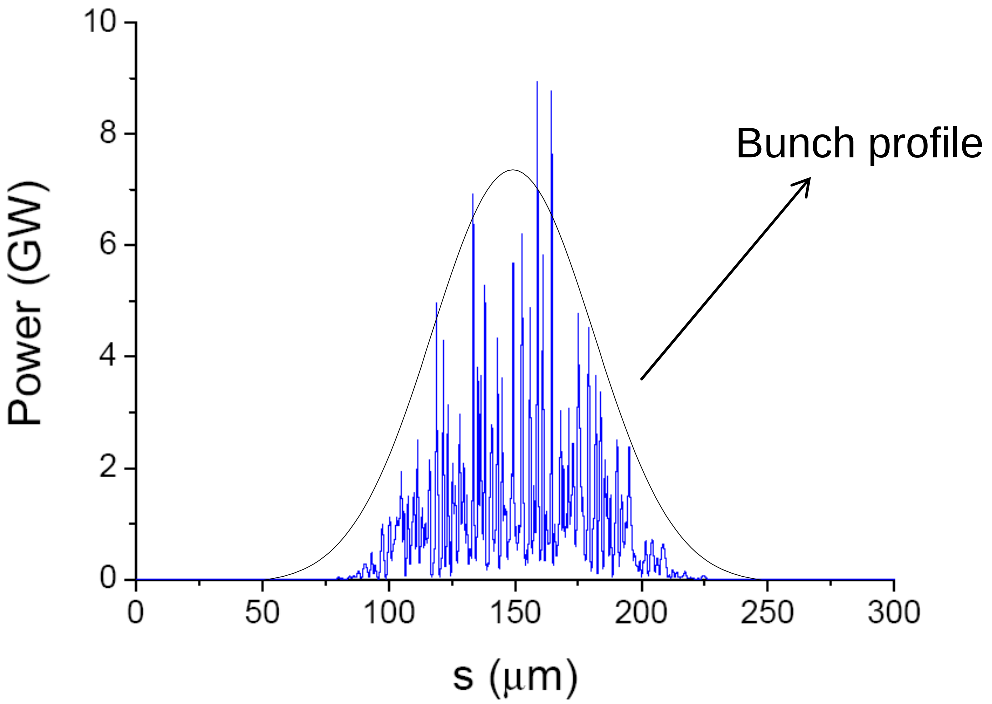
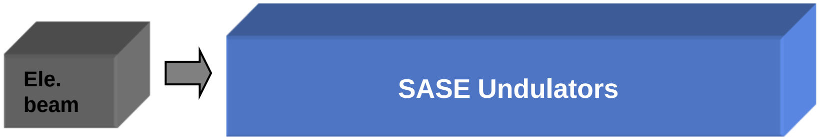
DESY

General Layout (SASE).

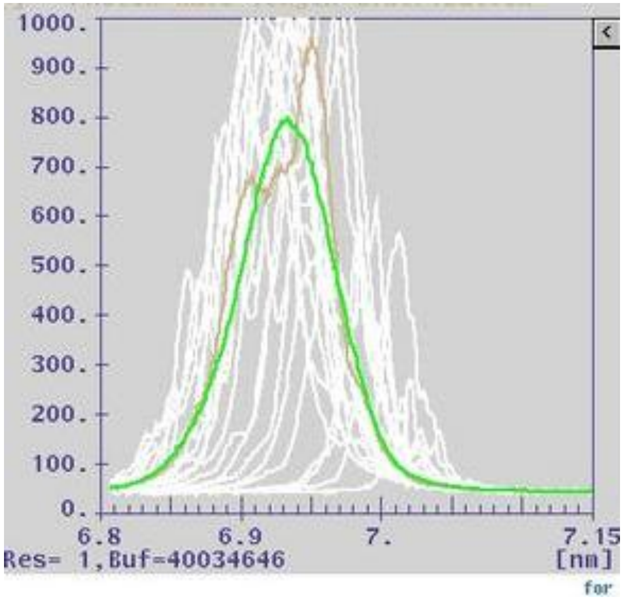


- Full wavelength range
- Full rep. rate
- Short to long pulses
- Proven technology
- **…..Not locked in time/frequency**

SASE-mode	
Wavelength	4.5-80 nm
Peak power	2-5 GW
Pulse energy	10-1000 µJ
Photons per pulse	10^{12} - 10^{14}
Pulse length (FWHM)	~10 - 200 fs
Bandwidth (FWHM)	~0.3 – 1.5 %
# Pulses / s	<=800x10

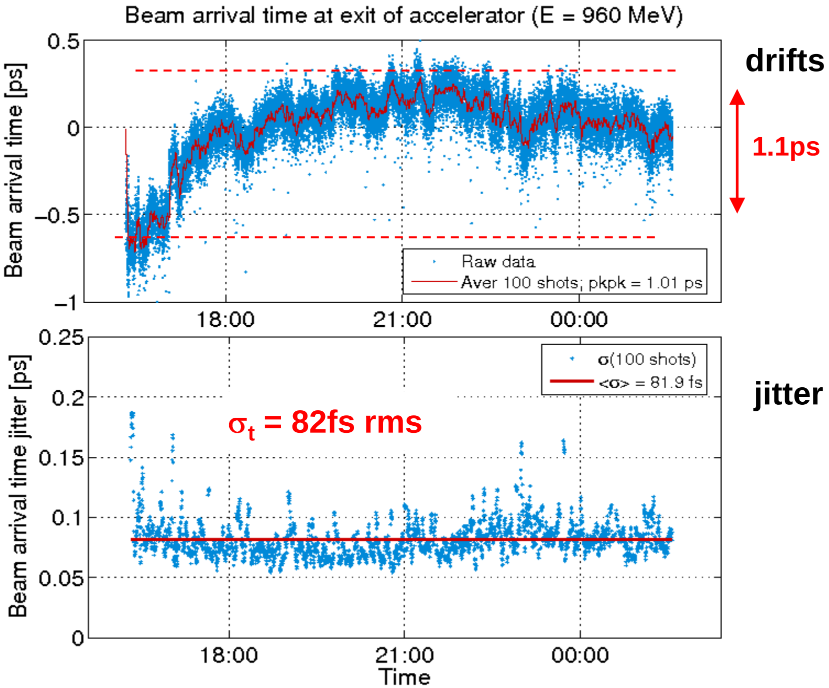


Why seeding: jitter in SASE mode.



Energy jitter → wavelength jitter

August 2009 user run



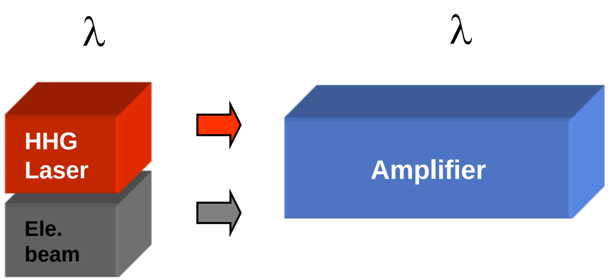
Slow drifts compensated by slow FB → 80 fs rms

Jitter within pulse train (with 1st bunches) → 20 fs rms

Seeding Modes (short pulse mode only).

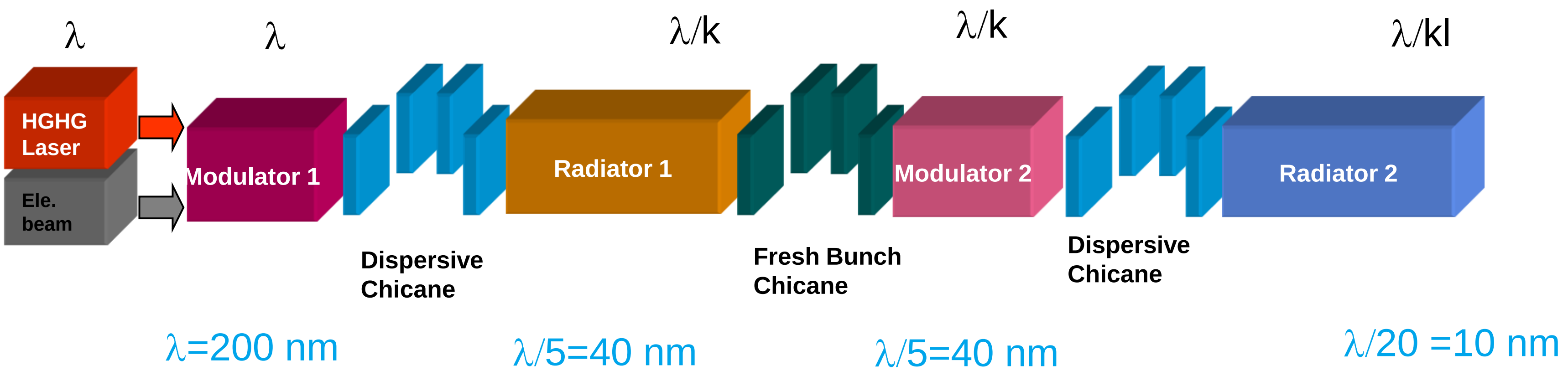
HHG-mode

Wavelength	10-40 nm
Peak power	1-5 GW
Pulse energy	10-100 μJ
Photons per pulse	10^{12} - 10^{13}
Pulse length (FWHM)	~10 - 30 fs
Bandwidth (FWHM)	Fourier limited
# Pulses / s	<=80x10**



Has been shown at longer wavelengths at SCSS, Sparc and soon at sFLASH

Seeding Modes (short pulse mode only).



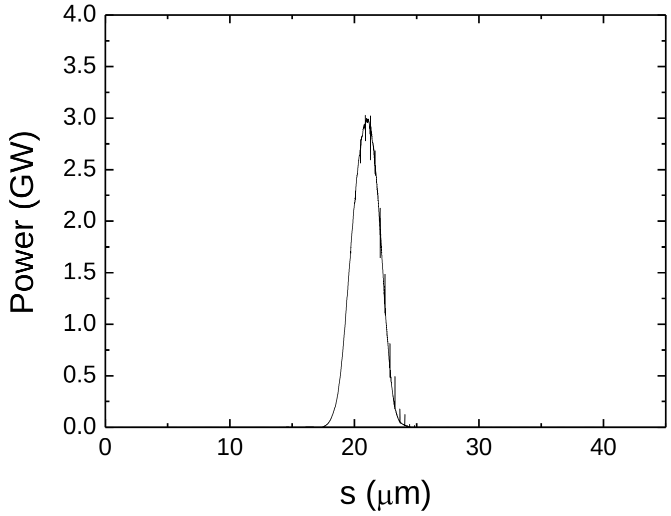
Energy → phase modulation at long wavelength and all higher harmonics
Subsequent lasing at harmonic
Fresh bunch → seed pulse much shorter than electron bunch

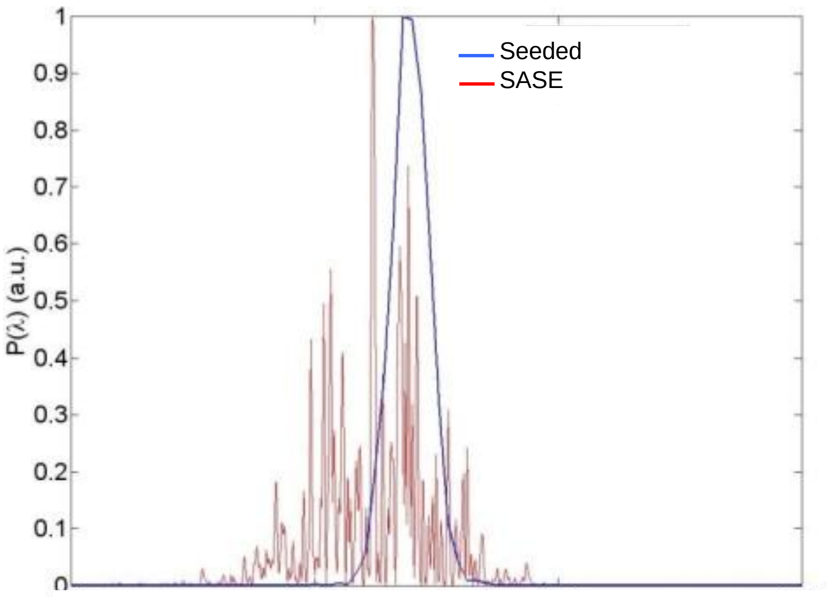
HGHG-mode

Wavelength	4-40 nm***
Peak power	0.2-5 GW
Pulse energy	1-100 μJ
Photons per pulse	10^{12} - 10^{13}
Pulse length (FWHM)	~5 - 30 fs
Bandwidth (FWHM)	Fourier limited
# Pulses / s	<=80x10**

**** short wavelength only at reduced power*

General output (HHG or HGHG).





Seed is:

- Locked in time
- Locked in frequency
- Up to 100 kHz rep. rate
- Short pulses

Alternative to HGHG to reach short wavelengths could be EEHG.
Studies have been started: both options need a similar amount of space but different hardware.

Radiation Properties.

- Wavelength range.
- Polarization.
- Pulse length.
- Timing Stability.
- Source position.
- Optical Elements, transport to users.
- Information available to users.

Wavelength range: 2.25(?) to 13.8 nm.

Choices for FLASH II depend on future of FLASH (variable gap for FLASH I, energy upgrade?).
Beam quality at FLASH I is better than at FLASH II → shorter wavelengths at FLASH I.
1.5 nm can only be reached with an SCU at this beam energy of 1.2 GeV.

13.8 nm over the entire energy (>0.6GeV) range means 31.4 mm period for 9 mm minimum gap
Minimum wavelength of 2.25 nm periods between 18 (for 8 mm gap) and 20 mm (at 1.2 GeV)

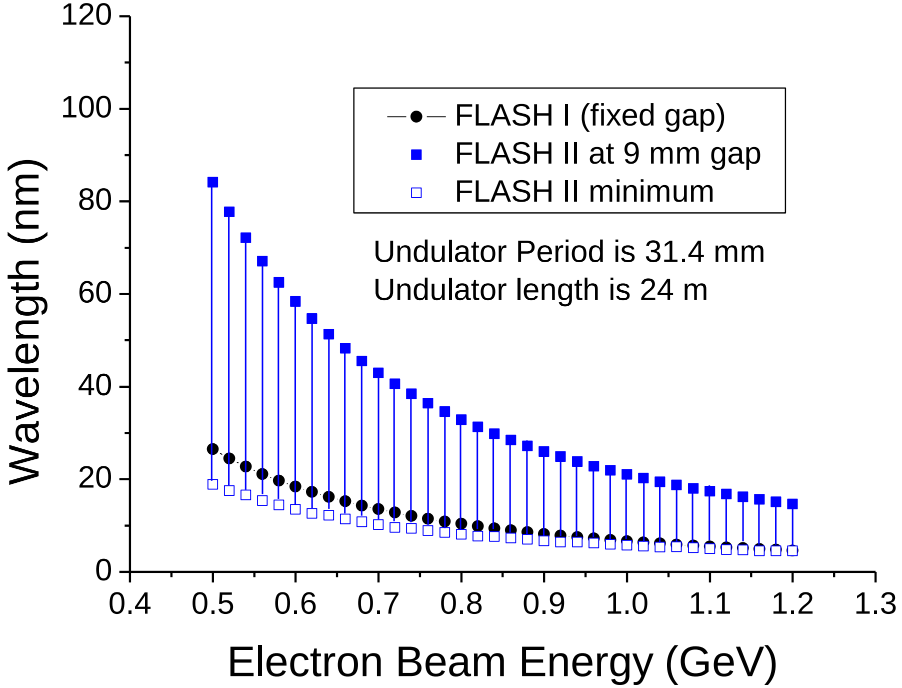
For short wavelength, beam quality critical.
Tunability FLASH II by varying undulator gap almost zero → FLASH I to FLASH II fixed ratio

Alternative for FLASH II:

2.25 nm in 2nd harmonic (variable polarization possible with APPLE III afterburner).
1.5 nm in 3rd or 4th harmonic (circular polarization possible with SCU afterburner).

Tuning of SASE.

Tune FLASH I to radiate at desired wavelength → electron beam energy is given quantity
Optics along the machine not touched, orbit only small corrections needed in undulator (gap dependence)



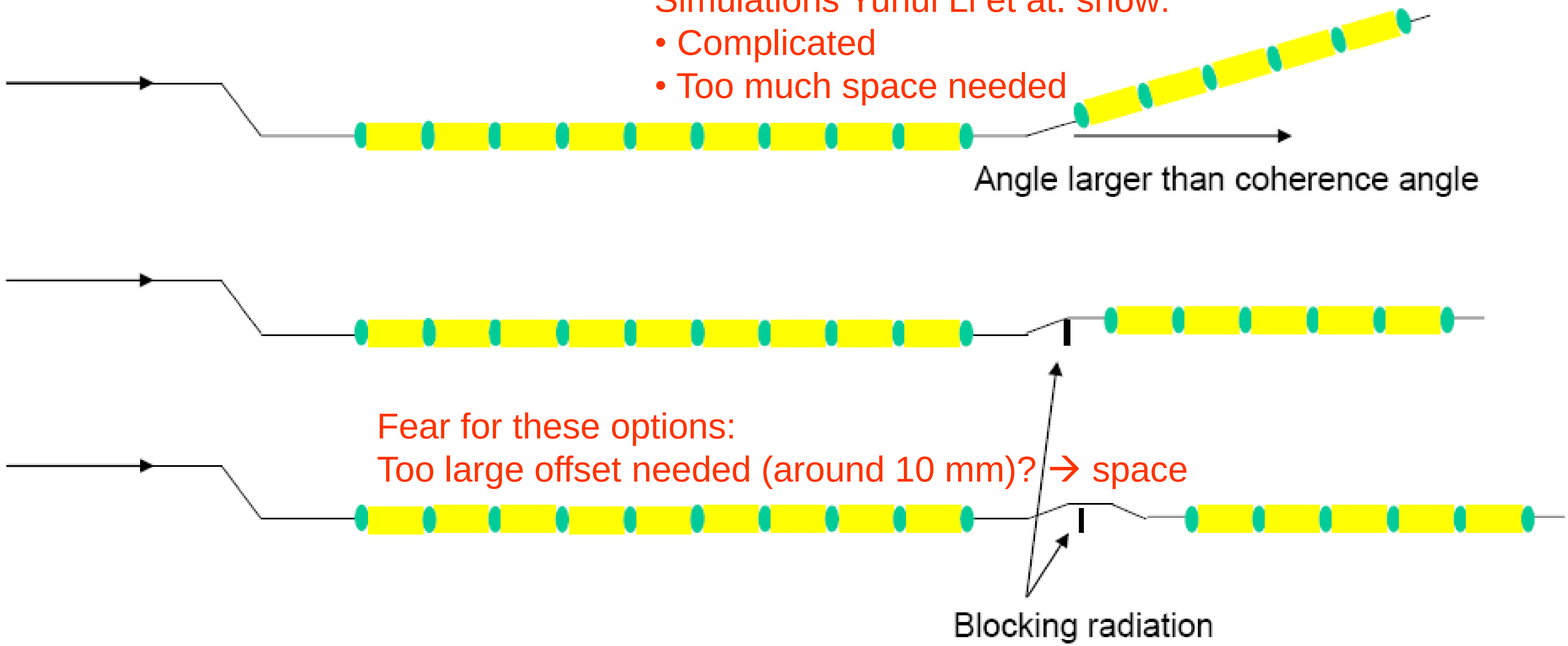
Using gap tunability

High degree of automation possible (lookup tables generated during commissioning)
Same procedure is needed for the XFEL

Polarization.

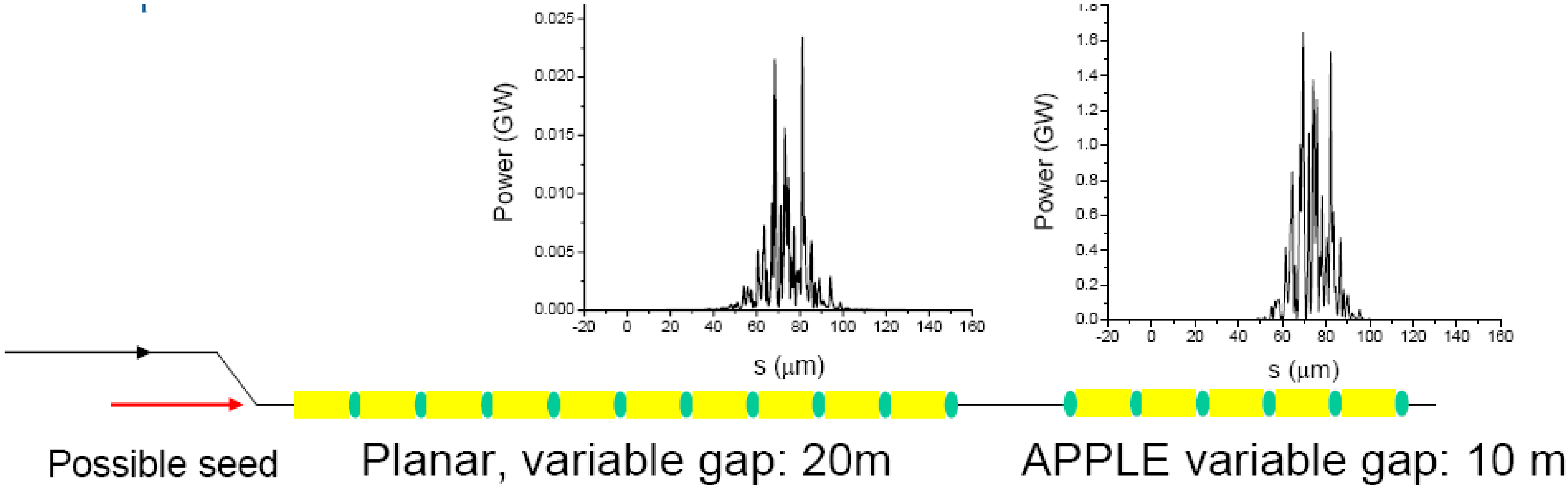
First discussion with users: special interest is 1.5 to 2.5 nm, left and right circular polarization
Degree of polarization does not have to be large (>90%), but stable from shot-to-shot (10^{-4})
→ Separation of linear and circular light
→ Different frequency of linear and circular light (even harmonics)
→ Long APPLE part of undulator: 2/3 planar and 1/3 variable

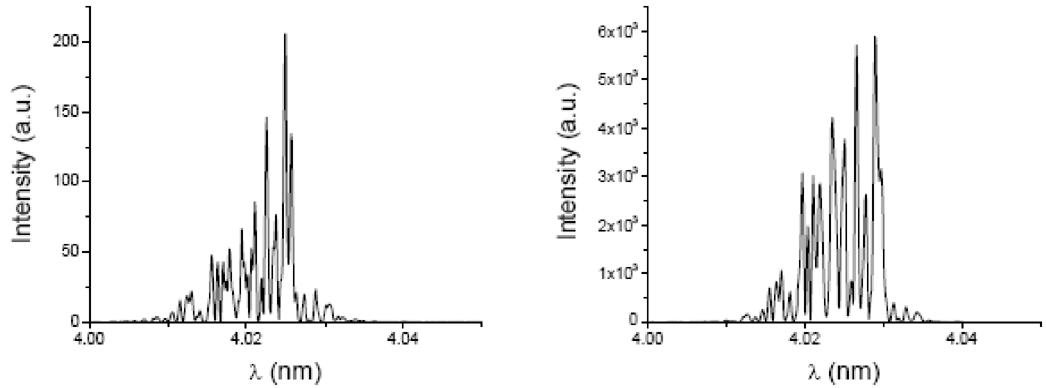
Simulations Yuhui Li et at. show:
- Complicated
- Too much space needed



Fear for these options:
Too large offset needed (around 10 mm)? → space

2/3 linear and 1/3 APPLE.





Example: SASE at 4 nm

Still (fluctuating) linear background without separation (amount depends on length APPLE part)

Pulse length.

- SASE (4-200 fs)
  - Variation in pulse length by varying charge.
  - Variation in pulse length by varying linearization of phase space.
- HHG (10-50 fs)
  - Only short pulses possible due to lack of seed power at short wavelength.
- Cascaded HGHG (5-50 fs)
  - Only short pulses possible because fresh-bunch technique.
- EEHG (?)
  - Not clear how short pulses can be due to large dispersion in harmonic bunching generation.

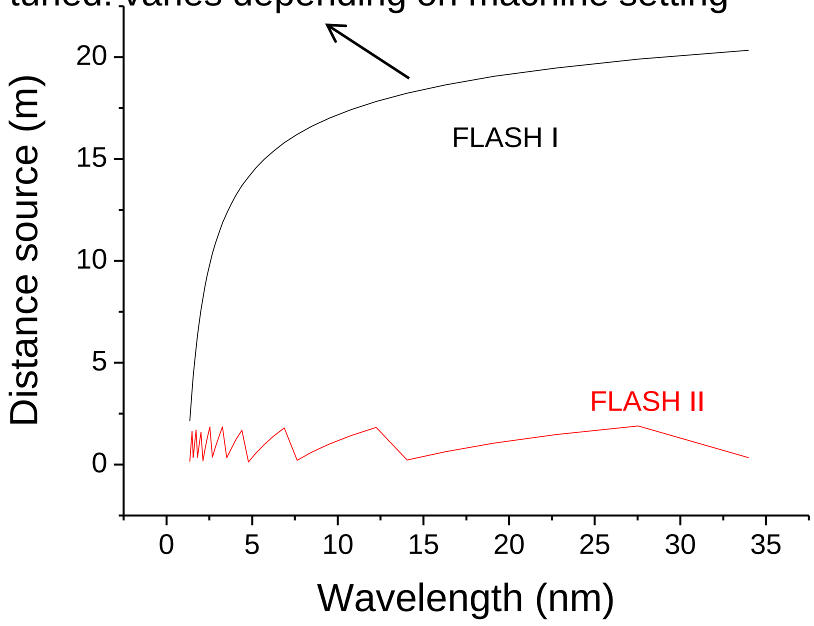
Timing Stability (FWHM).

- SASE (10 – 100 fs)
  - In pulse trains using the first few bunches to stabilize: 10 fs (24 already shown in test setup.
  - 100 fs single bunch with ongoing improvements of LLRF system.
- HHG (~10 fs)
  - Stability given by stability of seed laser.
- Cascaded HGHG (~10 fs)
  - Stability given by stability of seed laser.
- EEHG (~10 fs?)
  - Stability given by stability of seed laser (large R56 of first chicane).

Source position.

Tune FLASH I to radiate at desired wavelength → electron beam energy is given quantity
Optics along the machine not touched, orbit only small corrections needed in undulator (gap dependence)

Perfectly tuned: varies depending on machine setting



Using gap tunability

High degree of automation possible (lookup tables generated during commissioning)
Same procedure is needed for the XFEL

Opening Angle/Mirror size

Mirrors at angles < 2 degree
Foreseen are C (>4.5 nm) and Ni (>1.5 nm)

- Opening angle radiation (FWHM): 150 μrad @ 80 nm to 10 μrad @ 4 nm
- Spotsize (FWHM) at undulator exit between 250 and 150 μm (depends on emittance)
- First deflecting mirror at 25 m distance: maximum spotsize around 4 mm
- For single mirror experimental station (100 m from undulator exit), beam cut for largest wavelength (mirror at 2 degree, 500 mm maximum size)

Information available to users.

The most demanding mode of operation is the SASE mode

We want to make the following information available for each shot

- Intensity
- Wavelength (spectrum with 1 eV resolution)
- Position and angle (resolution unknown)
- Degree of polarization (1%), assuming we have more than planar undulators
- Fluctuation in arrival time (resolution unknown: <100fs)

Problematic is

- Pulse duration

Summary.

Radiation properties for users much better.

- *Stable in frequency.*
- *Stable in time.*
- *Single mode laser.*

Variable polarization (maybe not from the start).

Doubling of user time: different switching schemes need further study.
Improved intensity fluctuation needs study.
Tolerance studies needed.
EEHG studies needed.

Thank you for your attention