Status and strategies for seeding at FLASH.

Jörn Bödewadt

DESY Photon Science User Meeting

FLASH2 Photon Beamline workshop

28.01.2014

Supported by BMBF under contract 05K13GU4 and 05K13PE3
DFG GrK 1355
Joachim Herz Stiftung

Bundesministerium für Bildung und Forschung

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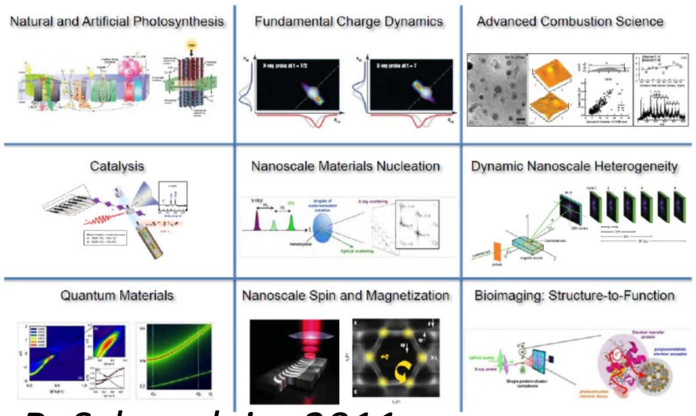
Outline

- Introduction
- Seeding schemes and facilities
- Status of seeding technology
- Seeding development at FLASH
- Strategy for FLASH2
- Summary and Discussion

Motivation

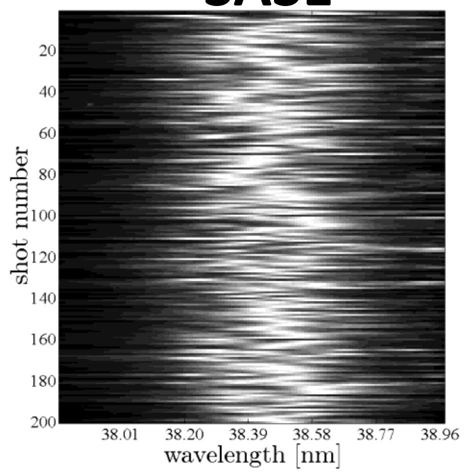
- Stable spectrum
- Stable time profile
- Longitudinal coherence
- Two-color/two pulse generation
- Intr. synchronization with IR pulses

- FEL seeding enables broad range of science

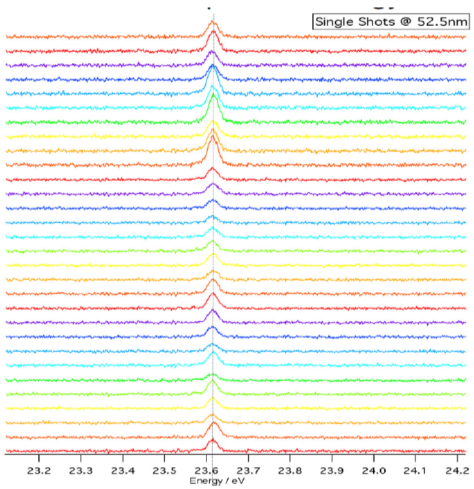


B. Schoenlein, 2011

SASE

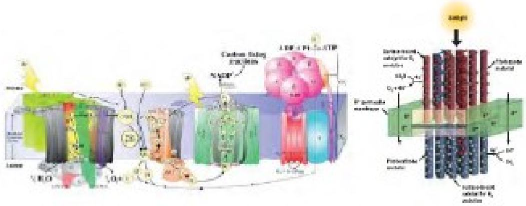


Seeded

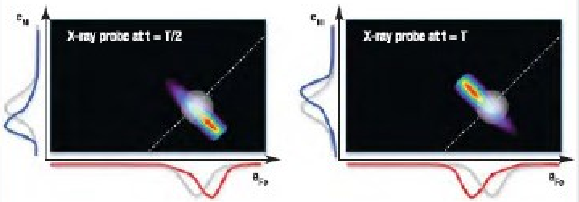


Motivation

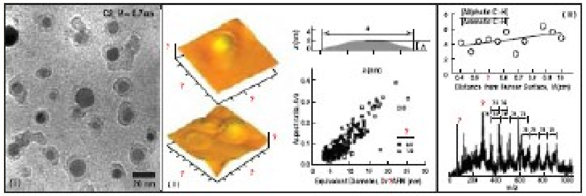
Natural and Artificial Photosynthesis



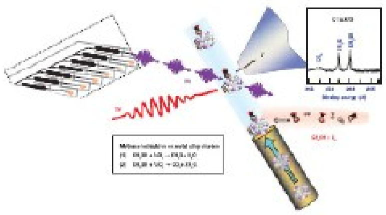
Fundamental Charge Dynamics



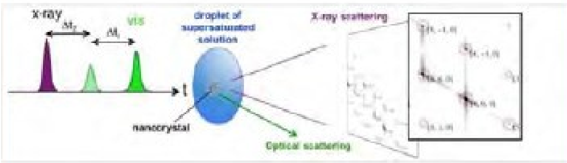
Advanced Combustion Science



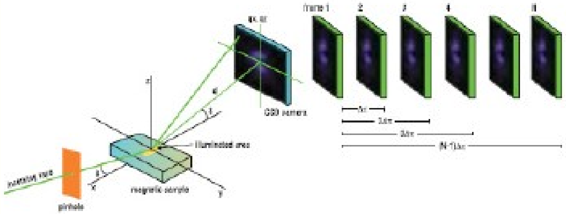
Catalysis



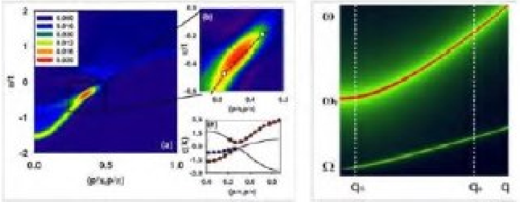
Nanoscale Materials Nucleation



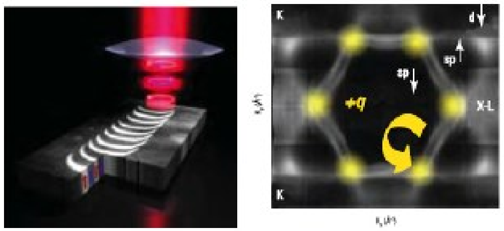
Dynamic Nanoscale Heterogeneity



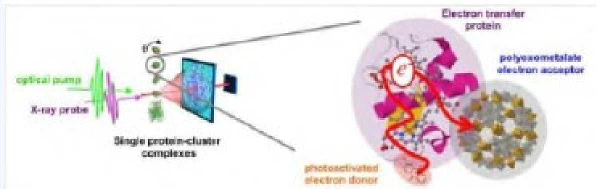
Quantum Materials



Nanoscale Spin and Magnetization



Bioimaging: Structure-to-Function



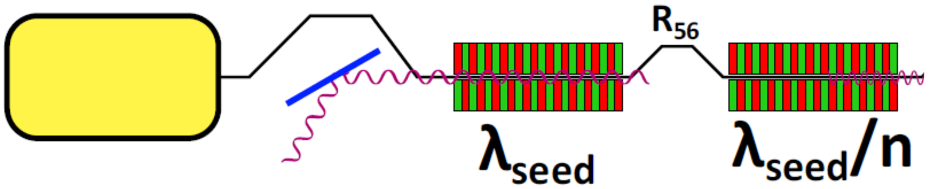
B. Schoenlein, 2011

FEL Seeding schemes

What are the available seed sources:

- External conventional laser (visible to UV)
  - Electron beam manipulation for high-harmonic generation (CHG, HGHG, EEHG, …)
- Short wavelength external laser, e.g. HHG (UV – XUV)
  - FEL works as an amplifier (direct seeding)
- A free-electron laser (IR – X-ray)
  - Radiation from the FEL is used to seed a second FEL (self-seeding, oscillator FEL)

High-gain harmonic generation (HGHG)



Proposed: 1991 (BNL)
Proof of Principle: 2000 (BNL)

$$n \sim \Delta E/\sigma_e$$

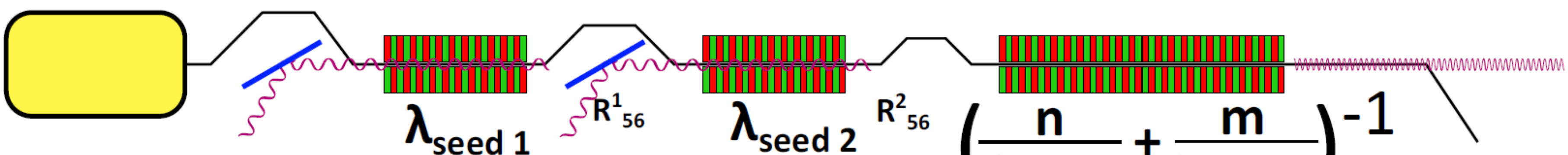
Wavelength record: 20 nm (FERMI)

HGHG-cascade

Proposed: 1992 (BNL)
Proof of Principle: 2013 (SINAP)

Wavelength record: 4 nm (FERMI)

Echo-enabled harmonic generation (EEHG)



$$\left(\frac{n}{\lambda_{seed\ 1}} + \frac{m}{\lambda_{seed\ 2}}\right)^{-1}$$

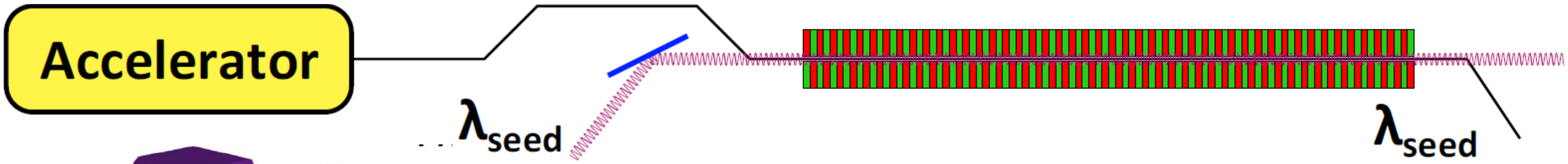
Proposed: 2009 (SLAC)
Proof of Principle: 2010 (SLAC, SINAP)

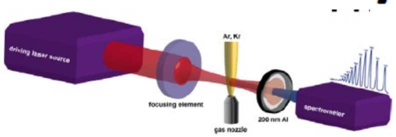
$$n >> \Delta E/\sigma_e$$

Wavelength record: 171 nm (SLAC) 14th harmonic of 2.4 µm

FEL Seeding schemes

Direct seeded FEL (amplifier mode)





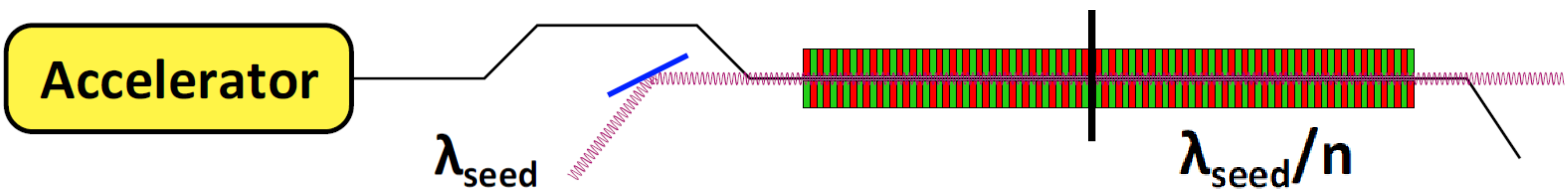
e.g. High-Harmonic Generation (HHG)

Proposed: 1980, 2004 for HHG
Proof of Principle: 2008 (Spring-8) for HHG

Input seed power determines contrast ratio

Wavelength record: 38 nm (FLASH)

Harmonic cascading

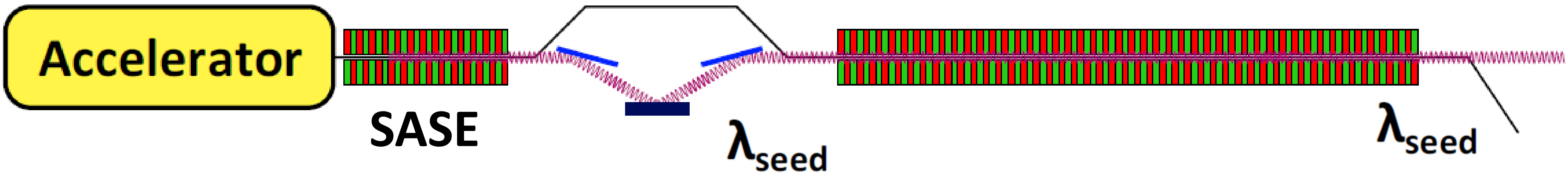


Proposed: 1980s
Proof of Principle: ?, SPARC

Wavelength record: 19 nm (FLASH)

FEL Seeding schemes

Self-Seeding



Proposed: 1997 (DESY), 2010 (DESY)
Proof of Principle: 2012 (SLAC) for hard X-rays

Wavelength record: 0.12 nm (LCLS)

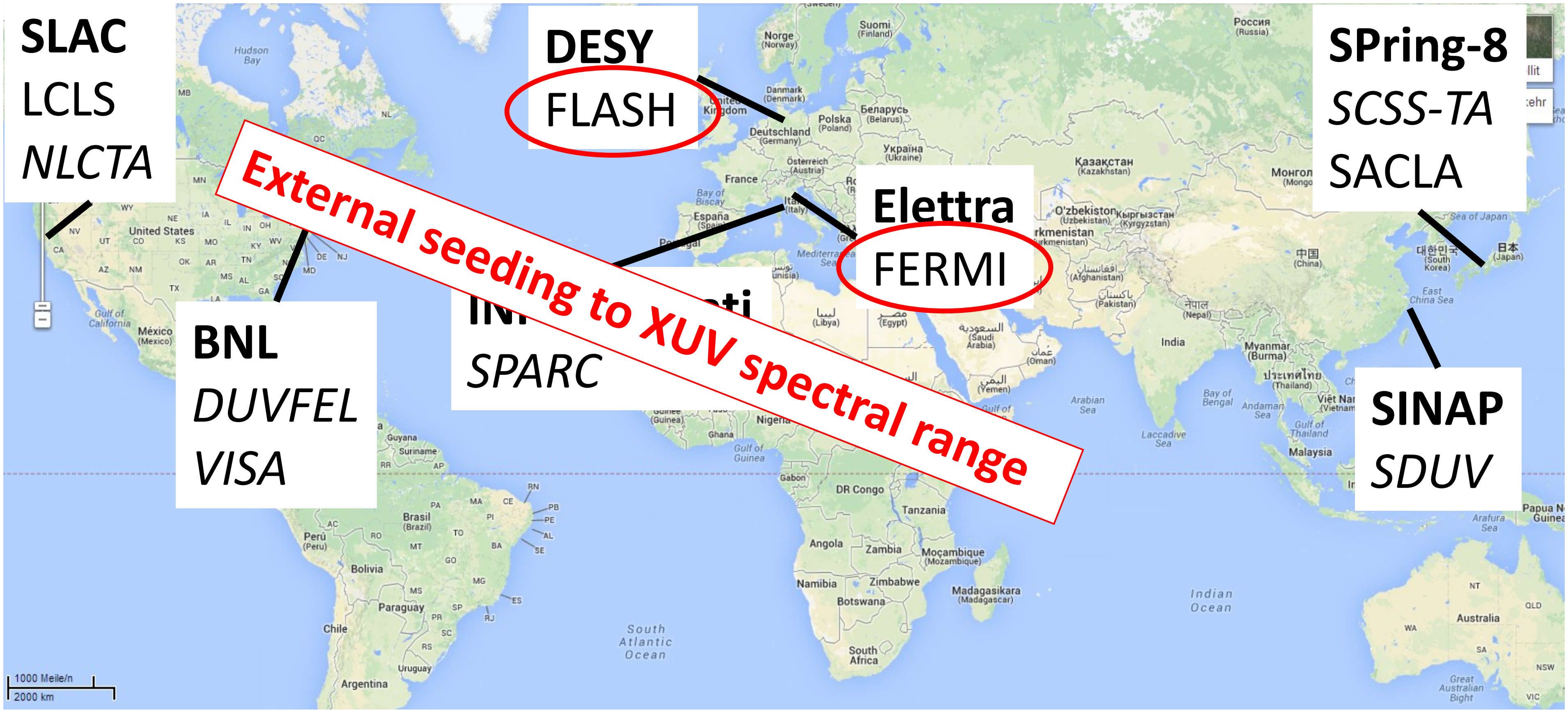
Advantages:

- no external seed difficulties

Disadvantages:

- no direct control over pulse length, chirp, synchronization, etc…

Experimental seeding activities worldwide



Italic: test facilities (LINAC beam energy ~100 MeV, ps electron bunch duration)

Other: user facilities (GeV or mulit-GeV LINAC)

Status of FEL seeding technology

	Minimum wavelength	Pulse length & Pulse energy	Limits
High-gain harmonic generation (HGHG)	20 nm FERMI	~70 fs 30 µJ	FEL power (~1 GW)
Staged HGHG	4 nm (staged) FERMI	< 25 fs ~1 µJ	FEL power (<1 GW) Intensity stability
Echo-enabled harmonic generation (EEHG)	171 nm NLCTA	? ?	Minimum wavelength (limited beam energy)
Direct seeding (with HHG)	38 nm FLASH	< 40 fs 10 µJ	Low seed success rate Limited contrast
Harmonic cascading (HC)	19 nm FLASH	< 40 fs	Low seed success rate Limited contrast
Self-Seeding	0.12 nm LCLS	5 fs 60 µJ	Intensity stability No synchronization

* I. Boscolo et al. 1980, B. Girard et al. 1984

Status of FEL seeding technology vs. user wishes

	Minimum wavelength	Pulse length & Pulse energy
HGHG	20 nm	~70 fs 30 µJ
Staged HGHG	4 nm	< 25 fs ~1 µJ
EEHG	171 nm	? ?
Direct seeding (with HHG)	38 nm	< 40 fs 10 µJ
Harmonic cascading (HC)	19 nm	< 40 fs
Self-Seeding	0.12 nm	5 fs 60 µJ

- Stable pulse parameters (“identical pulses”) needed
- Stable (smooth) spectrum / time structure
- Sufficient diagnostics
- Wavelength range <10nm - 30 nm
- Pulse duration mainly 30-50 fs (FWHM)
- “good” timing stability
- 10 Hz is acceptable (as first step …)

- Tunable …
- Pulse energy >20 µJ …

Status of FEL seeding technology – open points

- Demonstration of EEHG for XUV wavelengths
- Operation of high peak current electron beam with seeded operation (HGHG, EEHG)
- 25 fs timing jitter between seed and electron beam to fulfill seeding stability for short pulses
- Benchmarking simulations

The FLASH seeding team

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FLASH

R&D on FEL seeding:
- Test of advanced seeding schemes towards low wavelength and high peak power
- Characterization of seeded FEL radiation

Seeded FEL user facility:
- Reliable operation
- Low risks
- Failure is mission critical

R&D:
- high repetition rate and high power laser systems

DESY

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Vision for Seeding at FLASH:

Provide fully coherent FEL radiation pulse to users at wavelengths down to water window, with perspective down to 1 nm, at timing control in the few fs regime.

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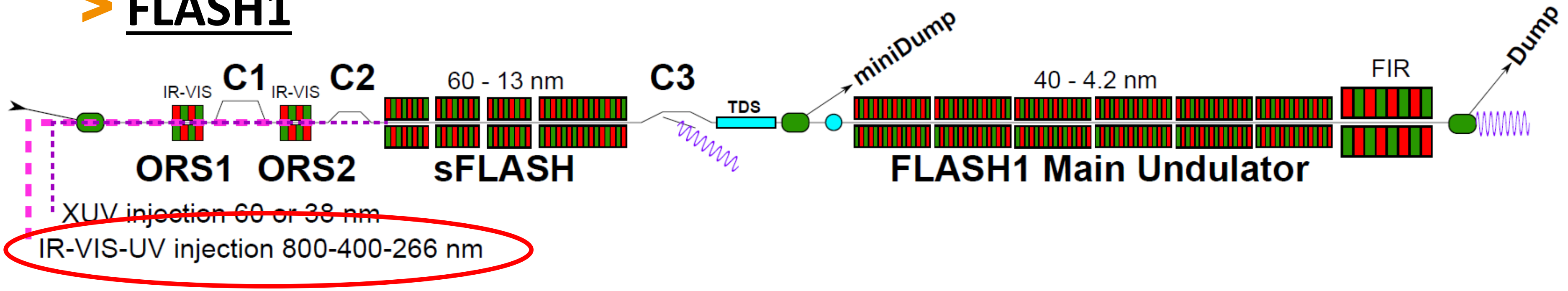
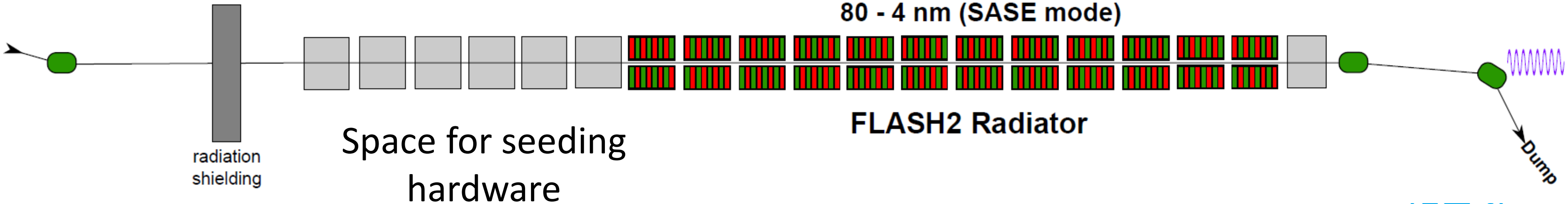
Status of seeding setup at FLASH

> FLASH1

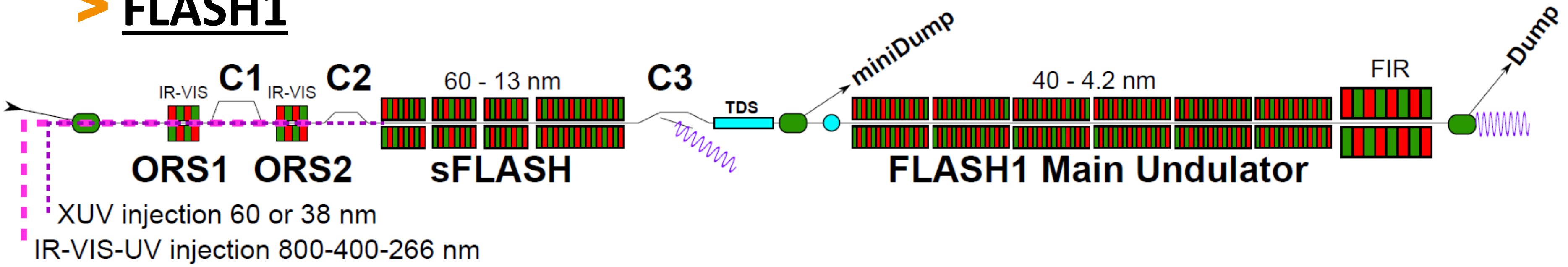


> FLASH2



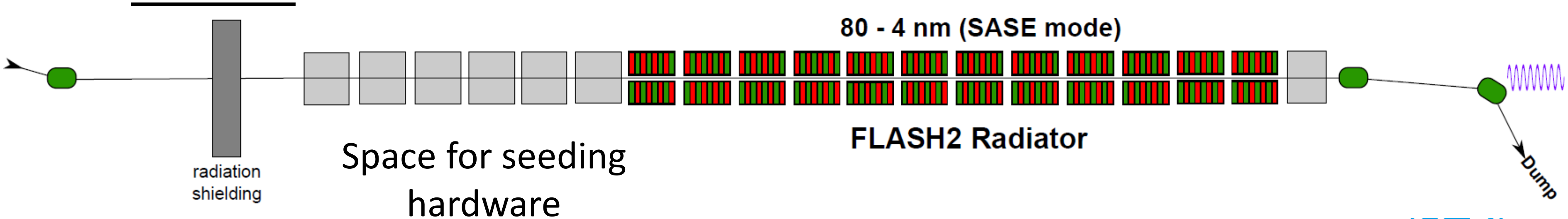
Status of seeding setup at FLASH

> FLASH1



- Capable to test HGHG, EEHG for variable seed laser properties
- Answer important questions on electron beam dynamics for seeding performance with high peak-currents
- Experiments will be performed during FLASH studies
- Results will benchmark start-to-end simulations

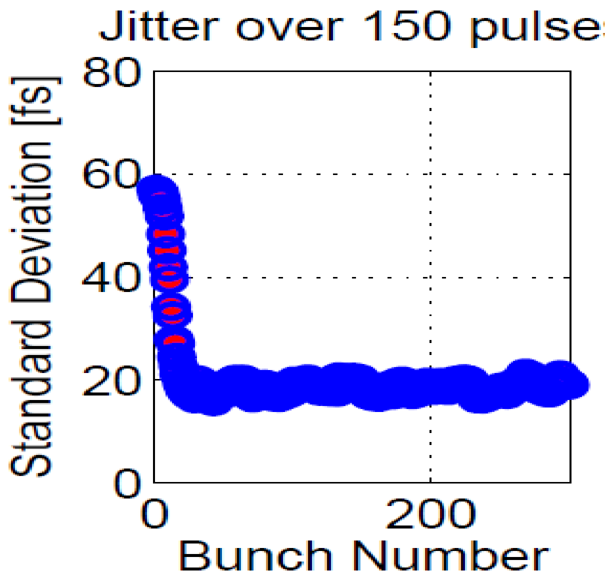
> FLASH2



1. Timing stability and synchronization

- Challenge: stable temporal overlap with short laser and electron pulses
- improve seed success rate for any seeding scheme at high peak-currents

Electron arrival time stability (pulse trains)



OXC based synchronization for seed laser

~ 5 fs rms synchronization, no drifts

Seeding development at FLASH

1. Timing stability and synchronization

2. **Seeding development (FLASH1 setup)**

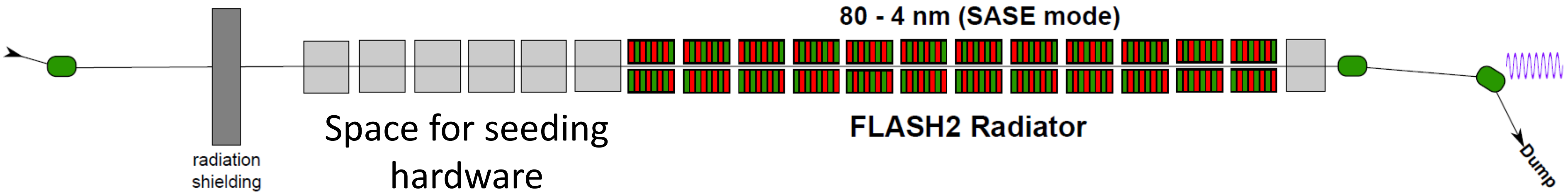
> **HGHG and EEHG** to high harmonics (XUV to soft X-ray)
  - Generation of >GW peak-power FEL pulses
  - Demonstration of intrinsic synchronization for IR-pump/FEL-probe

> Investigation of **non-linear effects** in electron beam dynamics on seeding performance
  - High peak-currents lead to non-linear effects (instabilities). How do these effects degrade seeding performance?

> **Establish parallel mode of operation** for seeding at FLASH2 and operation of FLASH1

Seeding strategy for FLASH2

> **FLASH2**



> Facility infrastructure optimally prepared for external seeding

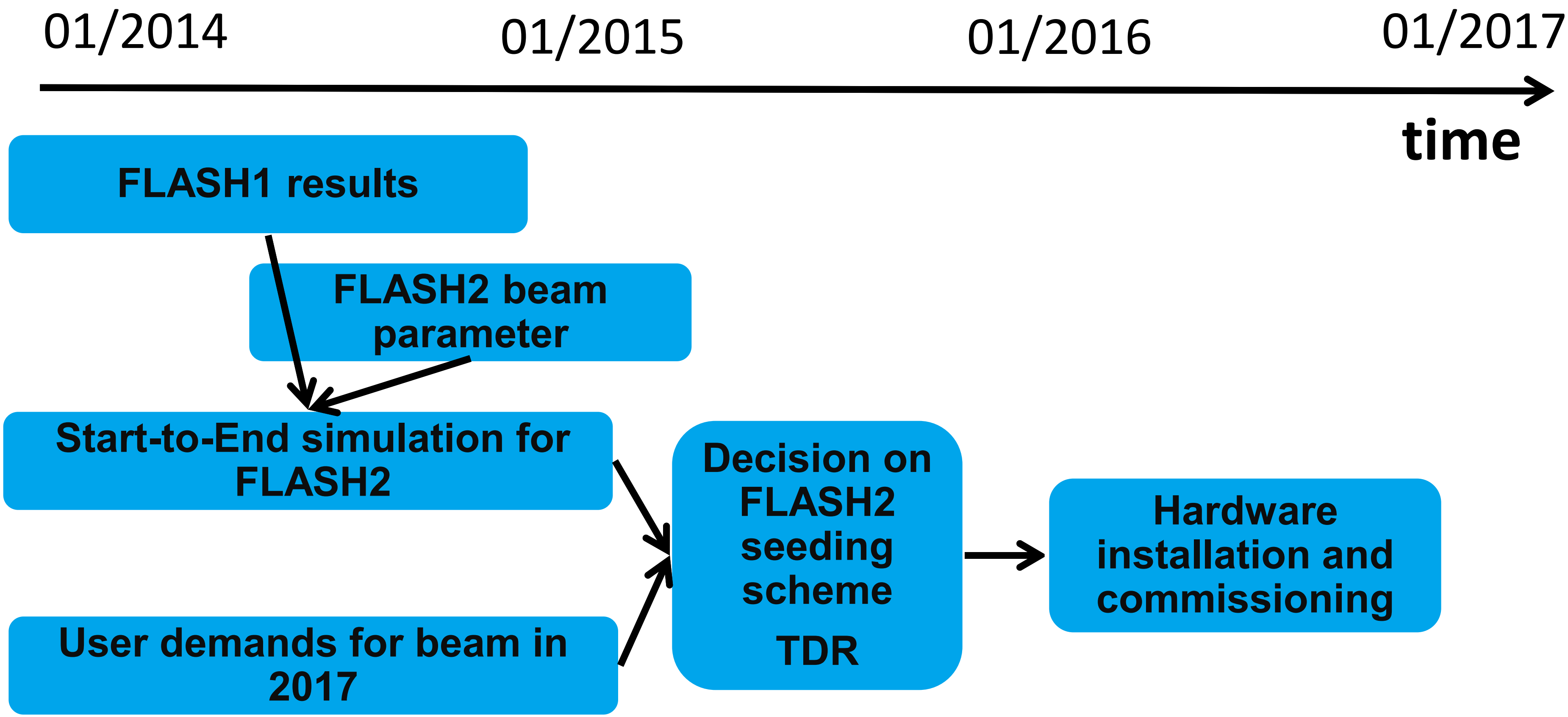
> Design process ongoing

> Final design for seeding at FLASH2 strongly depends on:

- Results and progress of seeding technology
- User demand
- Boundary conditions by FLASH1 operation
- SASE operation of FLASH2

Seeding strategy for FLASH2

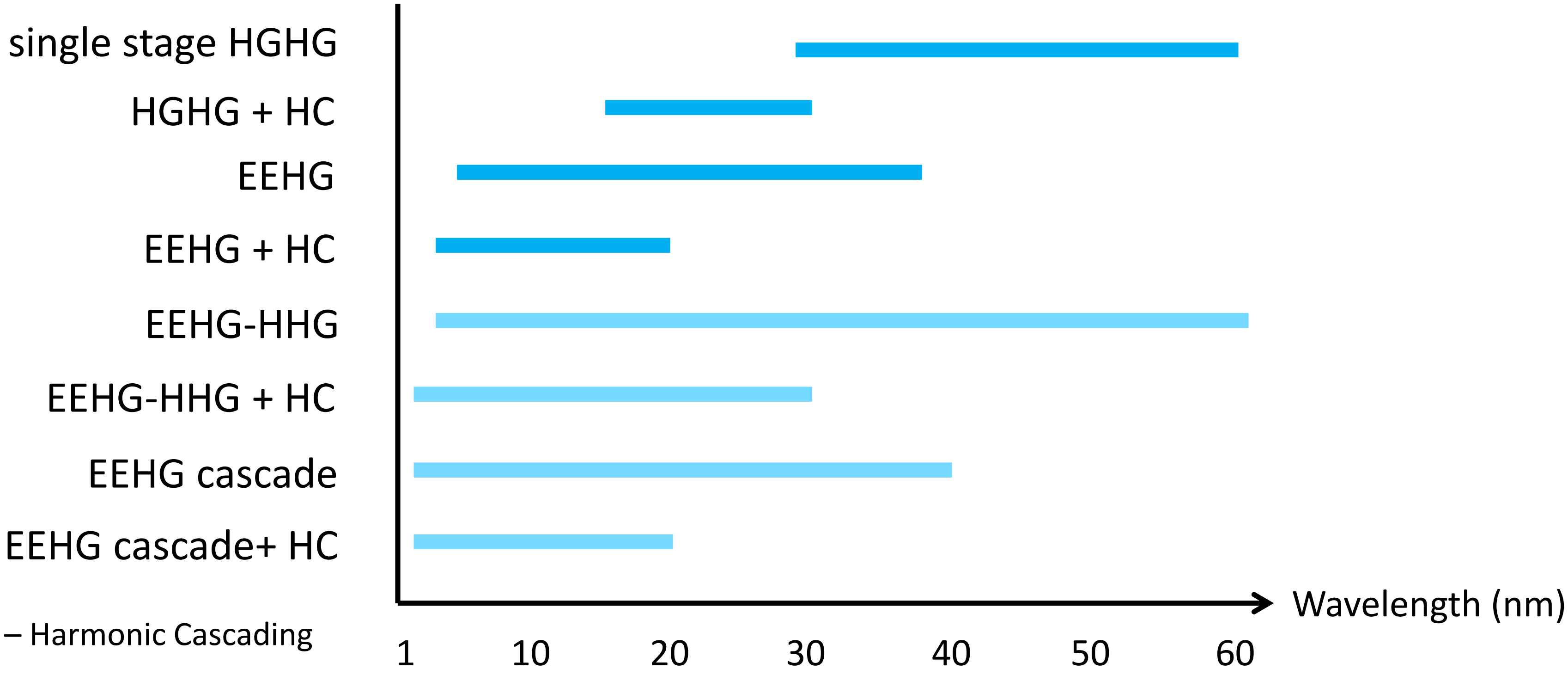
Goal: Provide high peak-power (> 1GW) seeded FEL pulses below 30 nm with sub 50 fs pulse duration



Wavelength range

K. Hacker, TESLA FEL REPORT 2013

Wavelength ranges for different schemes **compatible with SASE** (preliminary studies):



HC – Harmonic Cascading

> Detailed simulations for FLASH2 are under way

Summary

- FLASH is aiming to realize the next generation seeded FEL facility
  - Higher peak-power (> 1 GW)
  - Shorter pulse duration (< 50 fs)
  - Wavelength range below 30 nm
- the high peak-current operation for HGHG and EEHG has not yet been demonstrated
  - Experiments at FLASH1 aim to explore these operation modes
- EEHG has not been demonstrated for XUV wavelengths
  - FLASH1 is the only facility world wide to study this regime

Thank you for your attention