Progress on sFLASH design

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Due to the start up from noise:

\[ \Rightarrow \text{shot-to-shot fluctuations of the pulse energy} \]

\[ \Rightarrow \text{the output consists of a number of uncorrelated spikes (poor temporal coherence)} \]
Motivation

goals:
⇒ high shot-to-shot stability and high peak power (GW level)
⇒ generation of fully coherent pulses of variable length (20–40 fs FWHM)
⇒ wavelength range ~12-40 nm
⇒ reduction of saturation length
⇒ HHG runs in ‘parasitic’ mode, i.e. parallel to the normal SASE operation
⇒ pump probe experiments with fs synchronization

a comparison with the output of an FEL seeded using High Harmonic Generation (HHG)
sFLASH schematic set up

Ti:SA laser
800 nm, 20mJ, 30 fs

Gas cell (e.g. Ar)
simultaneous generation of odd harmonics of the fundamental 800 nm.
\( n=1,3,\ldots,27 \ldots \)

PETRA-type undulator(s)
Z=161 m
Z=174 m

courtesy of S. Khan
Transport of HHG seed into tunnel
courtesy of M. Drescher
Properties of the HHG radiation

HHG generation

Semi-classical three step model [1,2]:

1. Close to the peak of the laser electric field, electron tunnels through the potential barrier formed by the combined Coulomb and laser fields

2. It oscillates almost freely in the laser field, gaining kinetic energy

3. The energy gained is converted into a high-energy photon through recombination with the parent ion

Properties of the HHG radiation

- The interaction between the intense laser pulse with rare gas atoms results in the generation of higher-odd harmonics of the driving laser frequency (HHG).

- The HHG radiation forms ‘combs’ in frequency and time domains, resulting in pulse structures separated by half driving laser period.

simulate time profile of the seeding HHG pulse

typical spectrum measured in Ne.
Seeding with superimposed harmonics possible provided that \(1/n > \rho\)

D. Garzella et al., NIM A 528 (2004) 502–505
Properties of the HHG radiation

from B. McNeil et al.,

Recent HHG experimental results scaled by energy and wavelength. The unconnected points are taken with an 800 nm fundamental, and are scaled to a fundamental pump pulse energy of 14 mJ.

The minimum pulse energy needed for seeding ~1nJ @ 30fs
Requirements to HHG seed

- **spatial overlap** between electron bunch and HHG pulse
  \[ \Rightarrow \] good pointing stability of optical laser
  \[ \Rightarrow \] eventually fast orbit feedback in seed undulator
- **stable HHG parameter** (pulse energy, chirp, frequency …)
- **good temporal overlap** between electron bunch and laser pulse
- with **3th harmonic cavity** \( \sigma_t \sim 250 \text{ fs} @ \text{ few kA peak current} \)
  \[ \Rightarrow \] time jitter should be much smaller than \( << \sigma_t \) for reliable operation
Modifications of FLASH beamline

Modifications apply to the section between the collimator and SASE undulators

- additional hardware to be installed
  - four HHG undulators: 1x4(m) and 3x2(m)
  - phase shifters, additional steerers
  - mirror chamber to separate HHG radiation and electron beam
  - diagnostics
    - LOLA/screen (due to installation of ACC7 in future)
- ORS+chicane to be moved upstream → HHG undulators closer to input window
- 10(mm) beam pipe in HHG undulator section. Vacuum chamber 15x7.7 mm
- Some quadrupoles should be moved → different optics is required
- Compatibility between SASE operation, HHG, ORS, LOLA is required
- Assure full transmission with no losses
FLASH beamline modifications

Sketch of the modified FLASH beamline

- **e beam**
- **LOLA**
- **HHG undulators**
- **ORS + ORS chicane**
- **TEO**
- **chicane + mirror chamber**
- **new chicane to out couple ORS radiation**
The seeding section

- Variable gap undulators. Min gap about 9 mm. Vacuum chamber inner size 15x7.7 mm
- Total undulator length 10 m
- 3 PETRA III undulators of 2 m length + PETRA II undulator of 4 m
- $\lambda_u = 31.4$ mm (PETRA III), 33 mm (PETRA II)
- Distance between undulators 70 cm
- FODO-like focusing
Mirror chamber

Ø = 50 cm
courtesy of Tim Laarmann
Optics at different energies

Goal: verify that the modified beamline satisfies the SASE undulator matching conditions (V4 optics taken as a reference)
Estimated LOLA resolution as a function of the screen position

\[ \delta t \approx \frac{\lambda E}{2\pi \nu C \sin \Psi} \sqrt{\frac{\varepsilon_n}{\gamma \beta_{LOLA}}} \]

- V = 20 MV
- \varepsilon_n = 2 \mu m
Output radiation properties (simulations)

- consider the seeding beamline and electron optics as presented above
- \( \lambda u = 31.4 \text{ mm (PETRA III), 33 mm (PETRA II)} \)
- duration HHG pulse: 20 fs (FWHM)
- energy of the 27\(^{th}\) harmonic (29.6 nm): 1 nJ

transverse emittance, \( \varepsilon_n = 2 \mu \text{m} \)
pear current, \( I_{peak} = 1.5 \text{kA} \)
bunch length, \( \sigma_z = 80 \mu \text{m} \)
E = 850 MeV
rms energy spread 0.2 MeV

longitudinal profile and spectrum after about 8 m effective undulator length
Tentative time schedule

• installation and commissioning of HHG generation - end 2008
• installation of HHG transfer line in tunnel - Feb 2009
• installation of undulators - Apr. 2009
• installation of mirror chamber - Apr 2009
• installation of HHG-FEL beamline - May 2009
• commissioning with beam - Aug 2009

work in progress
• design and construction of phase shifters (‘Efremov’ institute)
• construction of diagnostic blocks for undulator intersections
• vacuum chambers to be ordered (external company)
• design and construction of mirror chamber (T. Laarmann)
• ...