

Polarization options at the European XFEL (SASE3)

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- TDR 2006 assumed installation of Apple II undulator → Linear and circularly polarized radiation.
- Present start-up scenario assumes installation of a planar undulator → Linear polarization only.
- A lot of user applications will benefit from circular polarization → Dedicated study group has been organized including experts from XFEL and DESY (S. Molodtsov, V. Balandin, W. Decking, B. Faatz, J. Gaudin, E. Gluskin, N. Golubeva, Y. Li, J. Pflüger, E. Schneidmiller, M. Yurkov). Task of the group: detailed study of different options for production of circular polarization in order to make it possible at the earliest stage of the project.

Production of circular polarization

Delivering to users linearly polarized radiation and letting them to prepare any desirable polarization state is not considered as a mainstream option. We consider the following options for the radiation source providing circular polarization:

–Helical undulator → natural production of circular polarization. More general: Apple II undulator → production of any desirable polarization state including a circular one.

–Cross-planar undulators → production of any desirable polarization state including a circular one by means of mixing and appropriate phasing of two linearly polarized photon beams.

Options of different scale are under consideration:

- Full-length undulator.
- Staged (or, sandwich-like) planar-helical structure: full-length planar undulator is followed up by a helical undulator of about $1/3^{\text{rd}}$ of the saturation length.
- An afterburner (short undulator) operating at the fundamental harmonic or at the 2^{nd} harmonic (frequency doubler)

Full-length and staged options are more expensive, but provide ultimate level of the output power and better coherence properties of the radiation. Here we briefly main features of the radiation provided with different options.

Potential options of radiators

Long term perspectives:

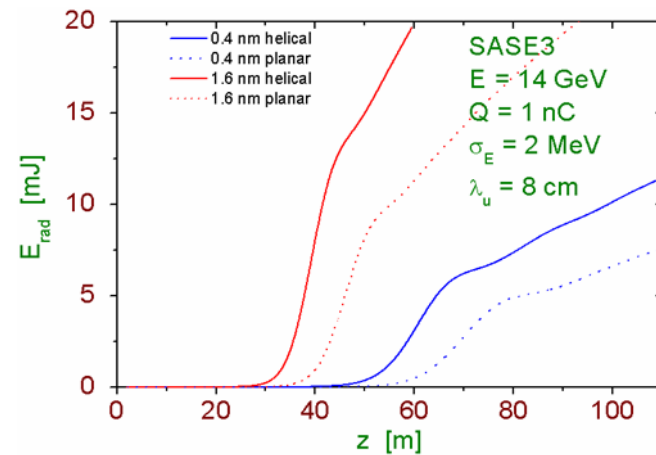
- ***In the long term of the project development it is possible to install the second full-length helical undulator.***

Tunnel length would allow to accommodate both options (planar and helical) in a row. SASE in the proceeding undulator will be switched on/off with SASE switchers. Planar undulator is installed first, and a helical one later on. Photon beams with planar and helical polarization at full power and high degree of transverse coherence would be available.



Location of undulators on XFEL site

Location	Tunnel length	Undulator
XS1-XS3	620 m	SASE1
XS3-XHDU1	310 m	SASE3
XS1-XS2	550 m	SASE2
XS2-XS4	190 m	Spont.
XS4-XHDU2	250 m	SASE4

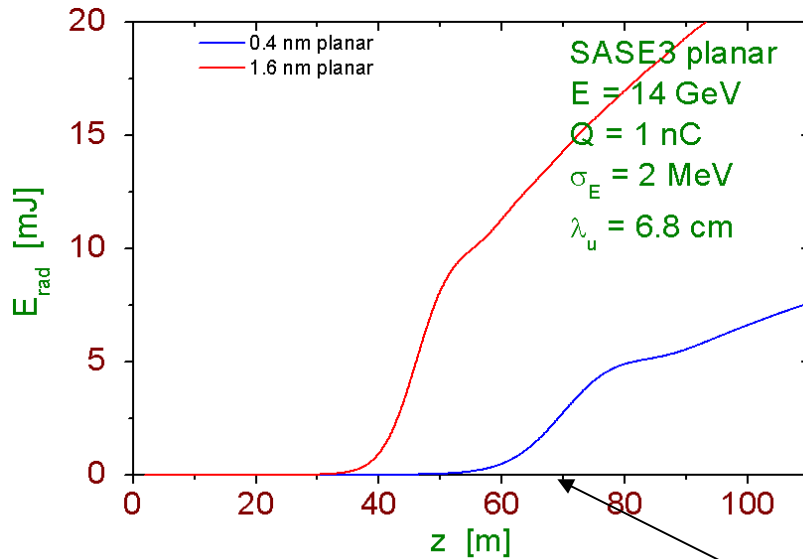


Pulse energy

Long term perspectives:

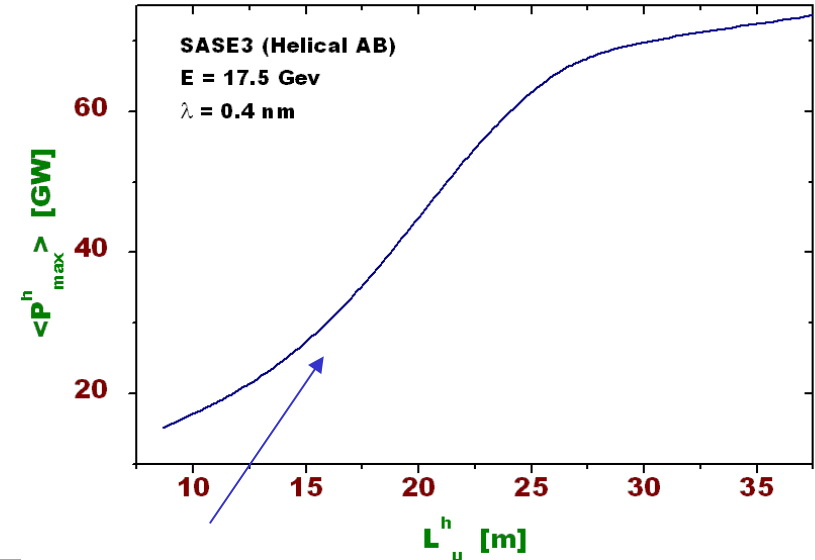
- In the long term of the project development it is possible to install the second full-length helical undulator.
- ***An intermediate solution can be staged undulator: full-length planar undulator followed up by 25 – 30 m long helical undulator. The quality of the output radiatiation in this case will be close to that of the full-length option.***

1st stage: Planar undulator



planar

2nd stage: Helical undulator



helical

- Electron beam gains density modulation in the planar undulator. This density modulation (scalar quantity) serves as a seed for FEL process in the helical undulator producing radiation with helical polarization.
- May operate at a high power. Amplification process in the main undulator may be stopped well before saturation, thus clean circularly polarized radiation may be produced without separation of the photon beams from the main undulator and a helical stage. 1/3rd of the saturation length is sufficient for operation of the second (helical) stage.
- At the moment this option is discussed for SASE3. We can discuss replacement in the future of the last modules of SASE1/SASE2 with helical modules as well.

Potential options of radiators

Long term perspectives:

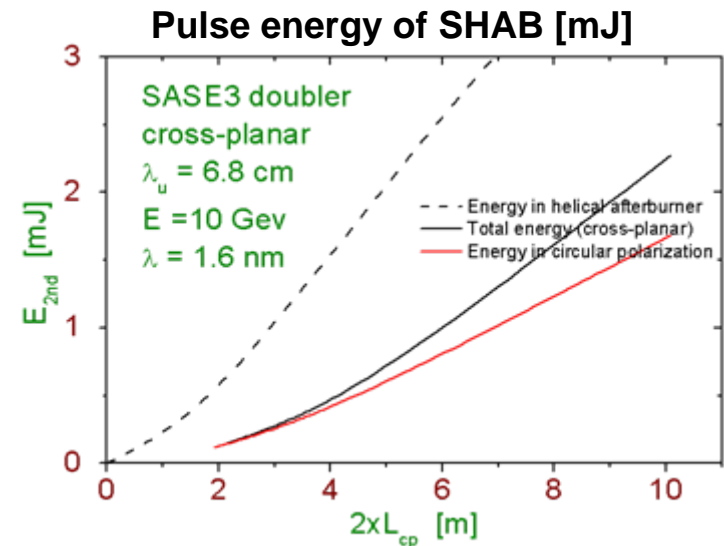
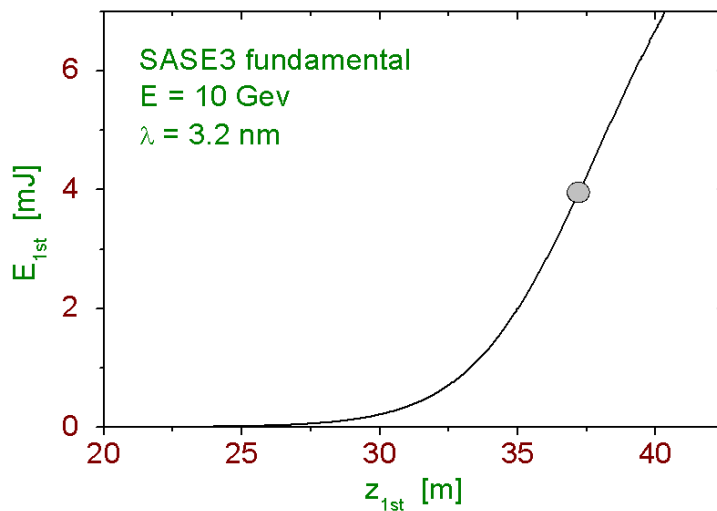
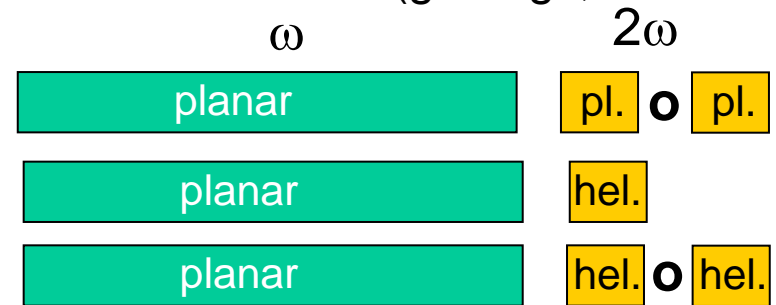
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Short-term perspectives

- ***Options with a short afterburner (helical or cross planar) operating at the 2nd harmonic seem to be rather attractive for realization at the first stage of the project.***

2nd harmonic afterburner (frequency doubler)

- The simplest and reliable realization of a scheme for production of powerful radiation with high degree of circular polarization in the wavelength range around 1 nm is frequency doubler with helical undulator or cross-planar undulator.
- Problems with separation of the 2nd harmonic (circular polarization) and the fundamental harmonic (linear polarization) needs detailed studies (gratings, attenuators, etc).
- Several options for the helical undulator:
 - Permanent magnet (e.g. APPLE);
 - Superconducting with helical windings;
 - Pulsed electromagnetic with helical windings;



Potential options of radiators

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Short-term perspectives

- Options with a short afterburner (helical or cross planar) operating at the 2nd harmonic seem to be rather attractive for realization at the first stage of the project.
- Options with a short afterburner (helical or cross planar) operating at the fundamental harmonic need further studies in the part of development of the beam separation systems (photon or electron).

Technical realization

Several options for technical realization are under consideration:

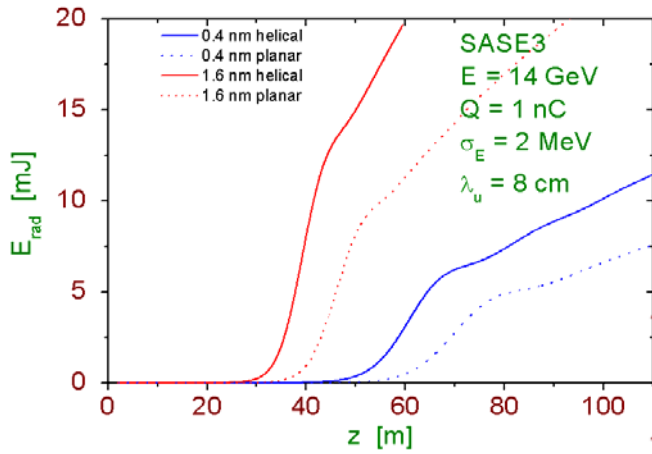
- Apple-type undulators are developed intensively at different locations such as BESSY, PSI and Elettra (Kima company). For instance, scale of the Fermi Elettra project is comparable with “sandwich” option at SASE3. So, we keep an eye on the success of this project.
- An option of electromagnetic undulator has been proposed and is under development by Efim Gluskin from Argonne National Laboratory.
- We keep an eye on the progress with superconducting undulators.
- Installation of a simple helical undulator with pulsed bifilar helical windings is not excluded - well compatible with the “burst” mode of operation of EXFEL.

Where we are now

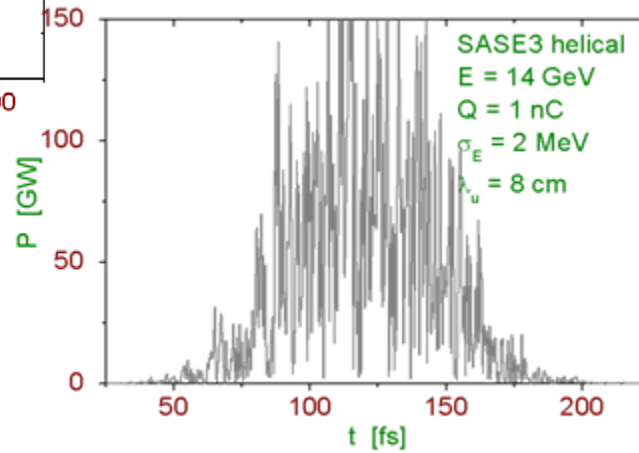
- An option of an upgrade of SASE3 with helical radiator received strong support from the Scientific Advisory Committee - it has been suggested to include this option in the baseline CDR.
- Decision on specific technical realization will be made soon after next iteration of the selection process.
- Selection process is governed by: i) wish to have circularly polarized radiation at SASE3 beamline from the very beginning of the experiments; ii) provide more flexible properties of the radiation source in terms of wavelength range, intensity and coherence properties; iii) allow perspective upgrades of the beamline(s).

Thank you very much for listening.

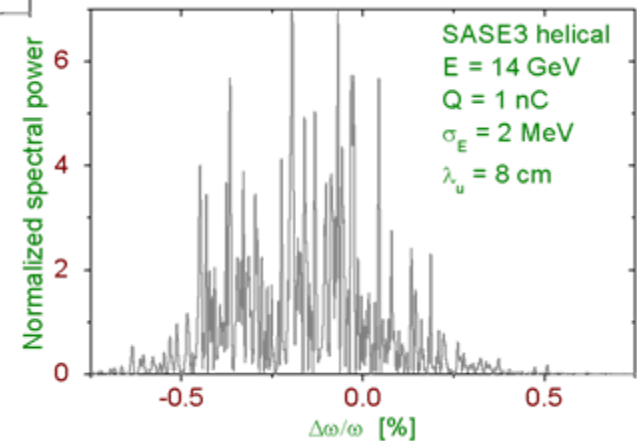
Supporting material:



Pulse energy



Peak power



Spectrum

Planar, ω

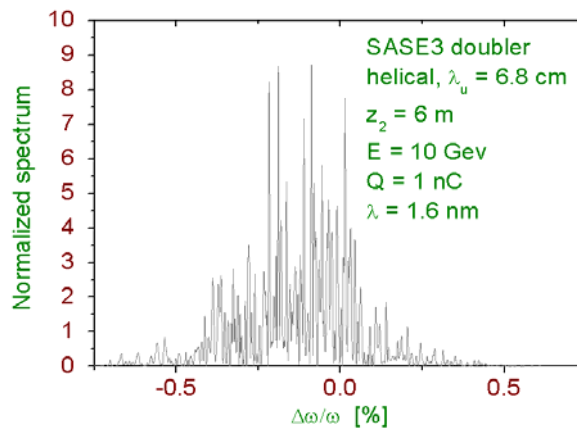
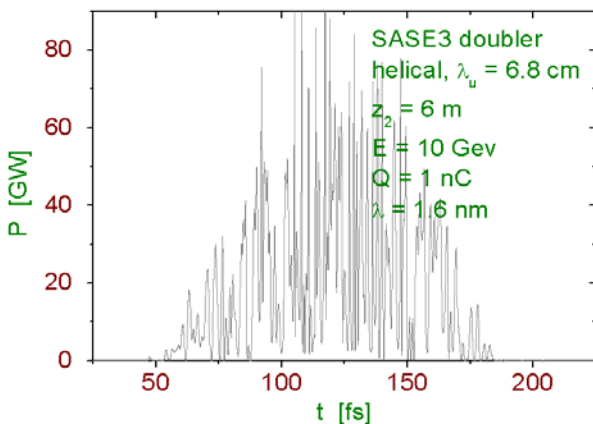
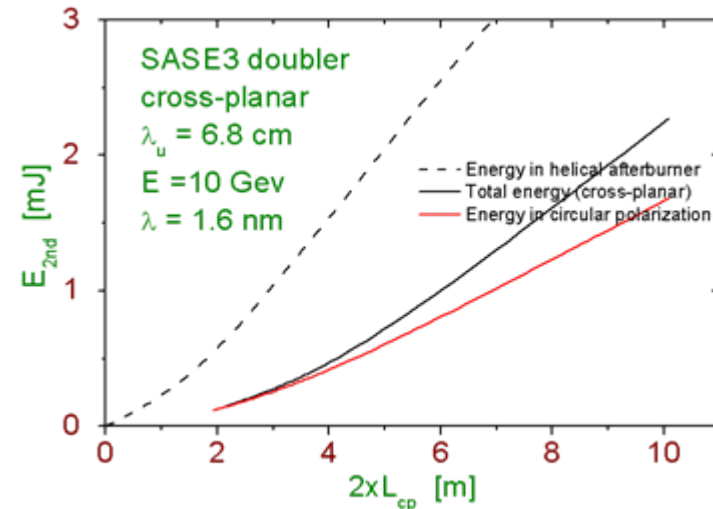
helical, 2ω

Undulator (2nd harmonic, 10 GeV)

Type	helical, PPM
Wavelength range	0.8 - 2.5 nm
Period	6.8 cm
Gap	10 - 20 mm
Peak magnetic field	0.45 - 0.8 T
Undulator length	6 m

Coherent radiation at $\lambda = 1.6$ nm

Energy per pulse	2.5 mJ
Peak power	25 GW
Bandwidth (FWHM)	0.3%
Pulse duration (FWHM)	100 fs

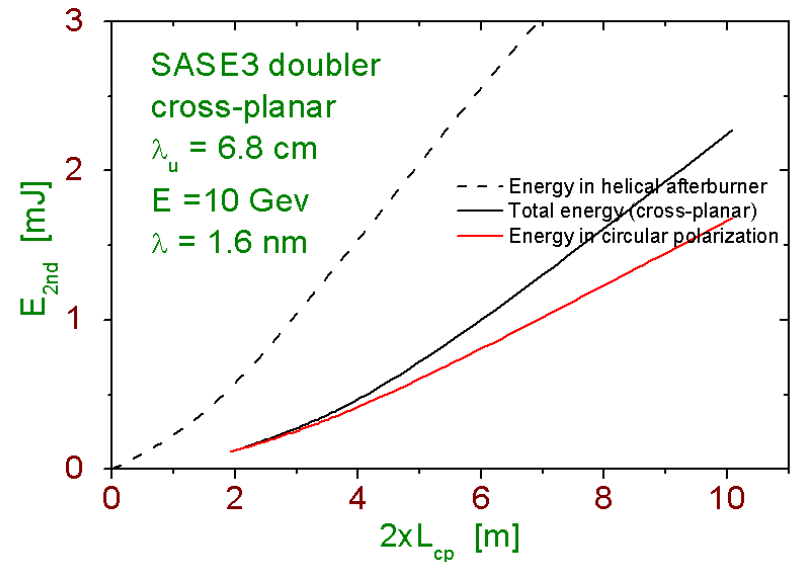
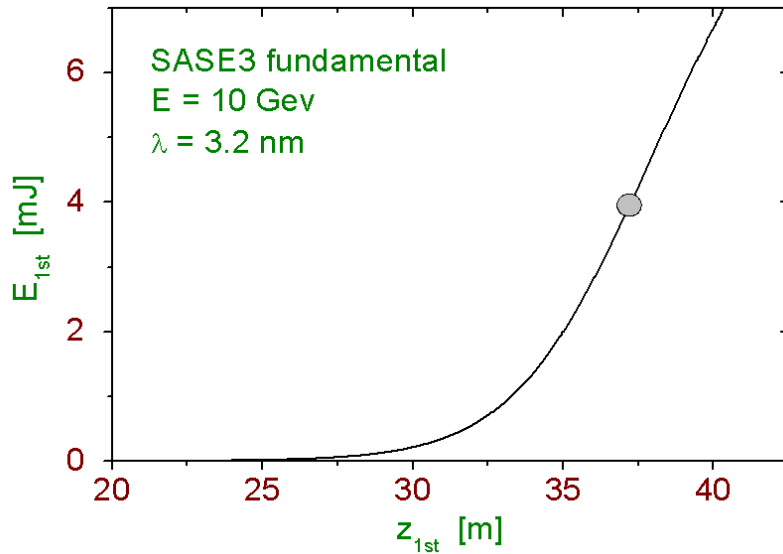


Radiation properties for $L_h = 6$ m

Frequency doubler with cross-planar undulator



- Main undulator operates in the saturation regime.
- Two short (much shorter than gain length) crossed planar undulators are tuned to the 2nd harmonic.
- Undulators of the afterburner are short: 1) operate as radiators only not disturbing density modulation gained in the main SASE undulator; 2) slippage of the radiation is much less than coherence length. Thus, radiated wavepackets are identical, but have crossed polarization. Application of phase shifter will allow to prepare helical polarization.
- Operates with small intensity fluctuations.
- Output power level is by an order of magnitude less than saturation value.
- Radiation pulses from planar undulator (ω , linear polarization) and from cross-planar undulator (2ω , circular polarization) are separated with dispersive optical elements. Contamination of circular polarization with a linear one is small due to strong suppression of the 2nd harmonic in the planar undulator.



Option of cross-planar undulator of the frequency doubler provides less output power than helical option, but is essentially simple. It is just two short pieces of the main SASE3 undulator.

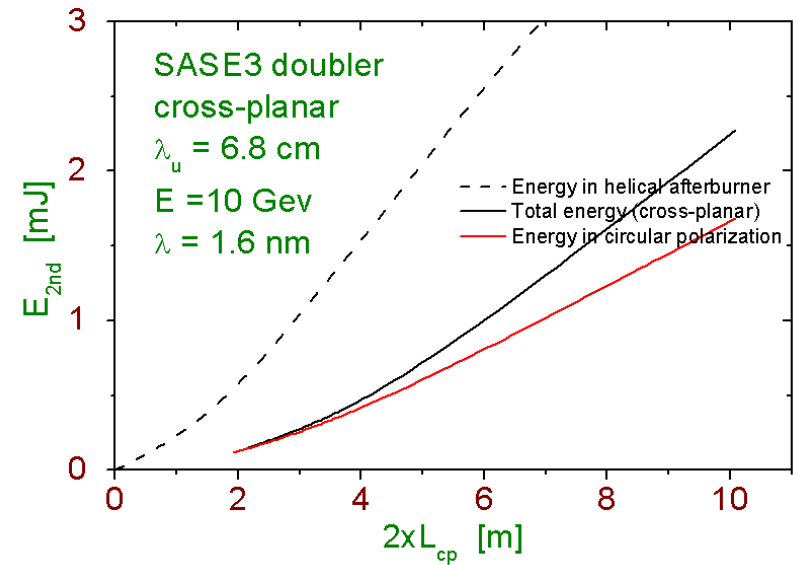
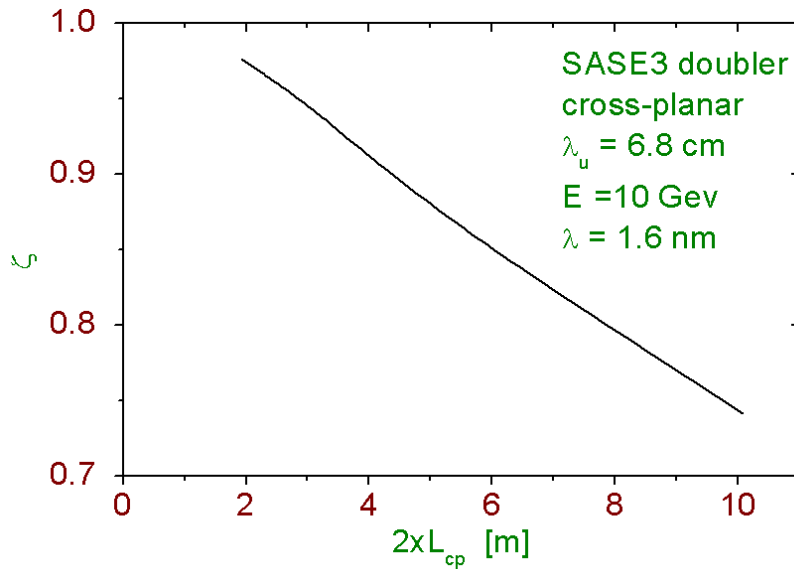
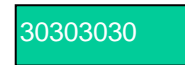
planar, ω



planar, 2ω



planar, 2ω



Degree of circular polarization is about 97% at the length of the afterburner of 2 meters. Lengthening of the cross-planar afterburner leads to the increase of the power for the price of the degradation of the polarization degree.

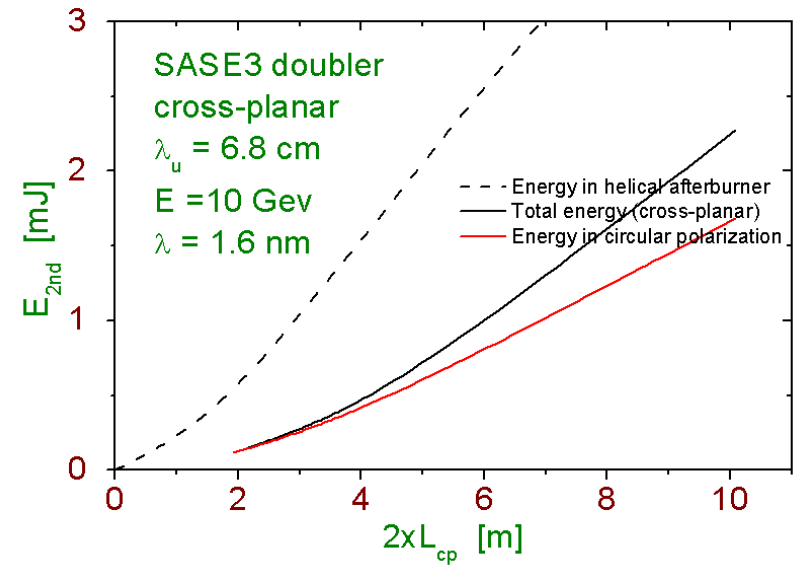
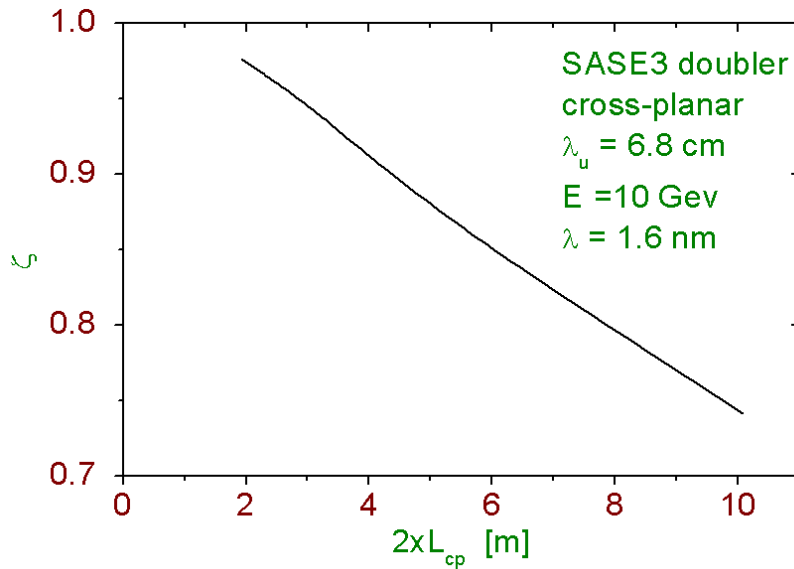
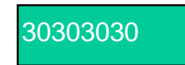
planar, ω



planar, 2ω



planar, 2ω



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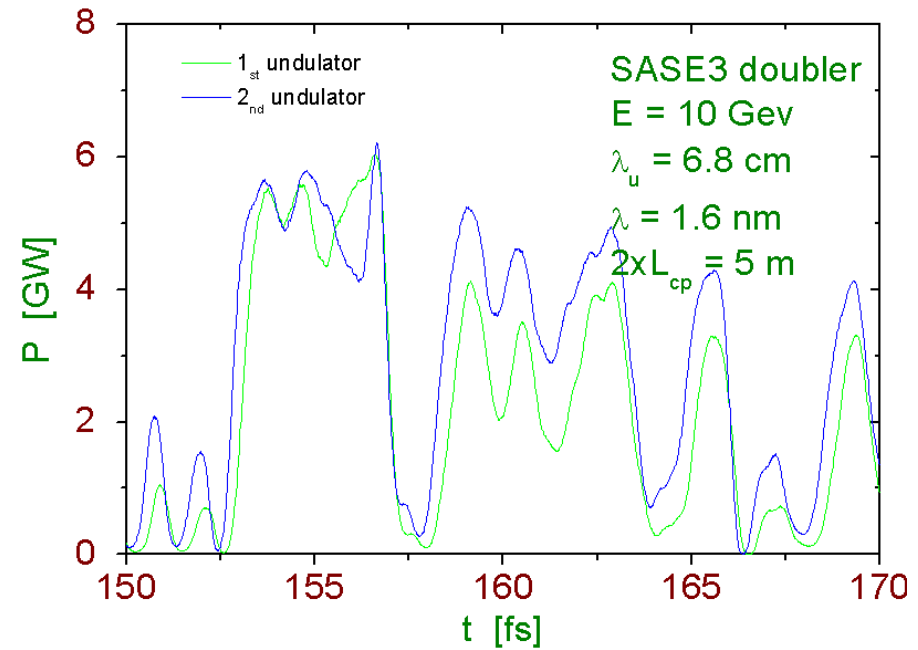
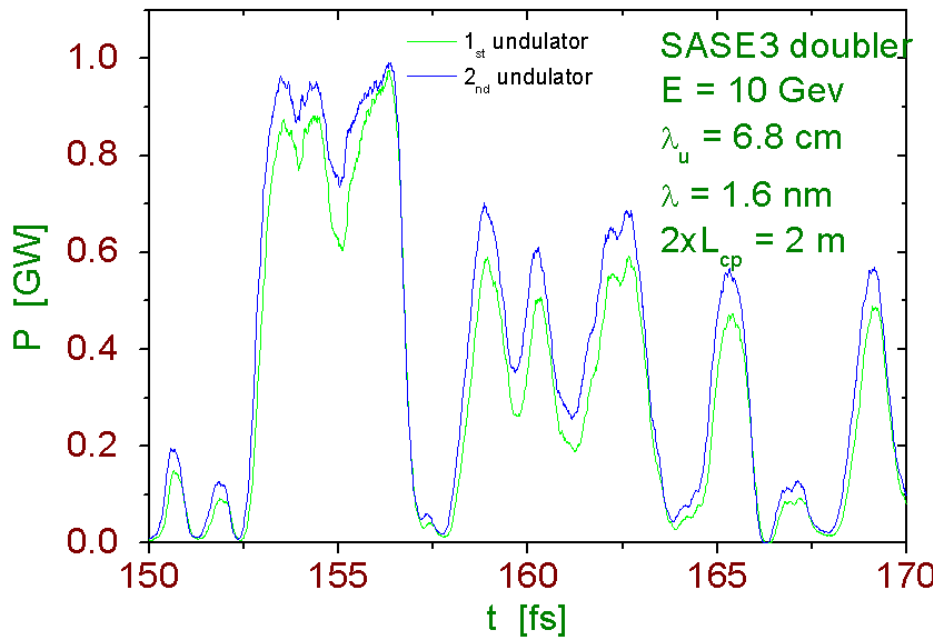
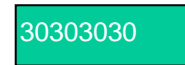
planar, ω



planar, 2ω



planar, 2ω



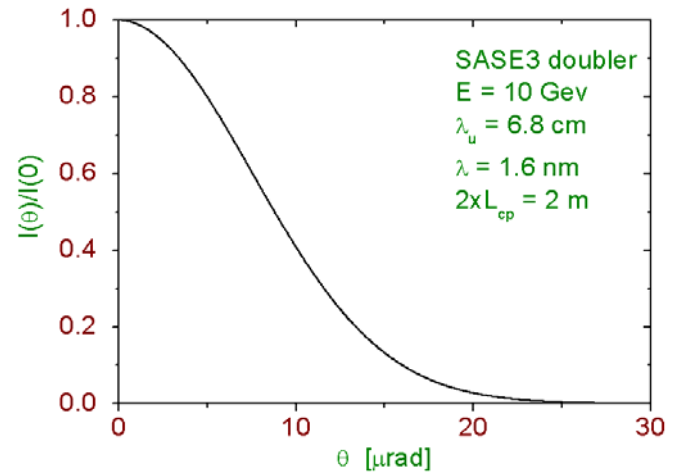
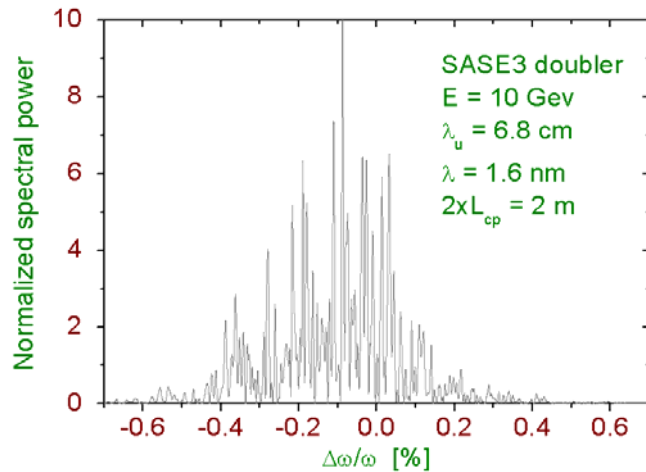
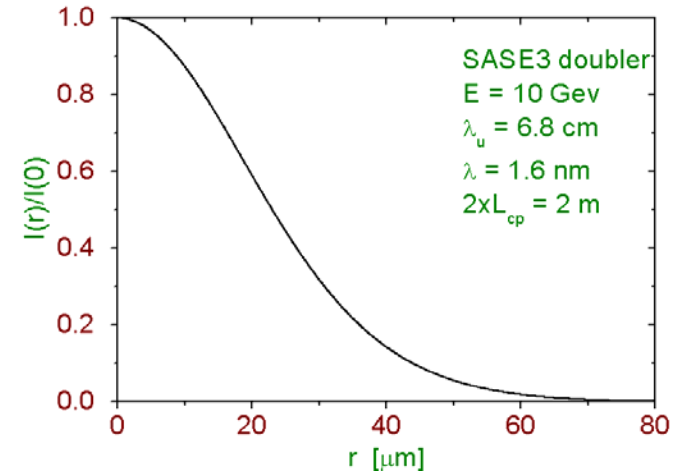
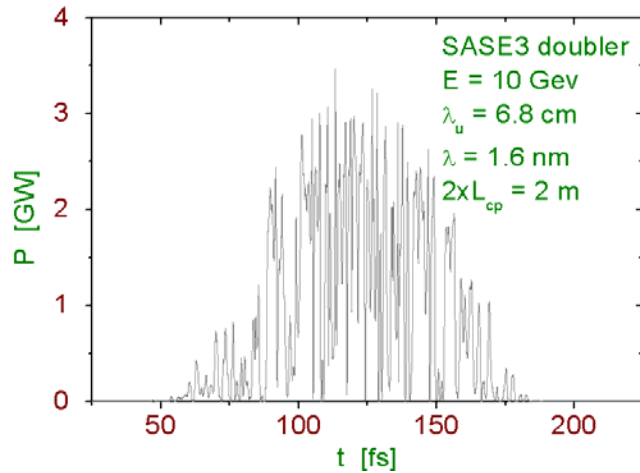
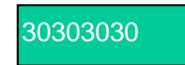
Main effects responsible for degradation of polarization degree are disturbance of density modulation due to collective effects and longitudinal velocity spread, and slippage effect.

Frequency doubler with cross-planar undulator

planar, ω

planar, 2ω

planar, 2ω



Radiation properties for $2 \times L_{cp} = 2 \text{ m}$: