



Options for production of circularly polarized radiation at 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.

There are not so many ways to solve the problem of circular polarization:

- Deliver to user's setup linearly polarized radiation. Users prepare any desirable polarization in the experimental setup. Such an approach works well in the optical wavelength range, but is rather tricky in the x-ray wavelength range. Currently there are no users willing to follow this way.
- Develop radiation source capable to produce circularly polarized radiation:
 - Helical undulator → natural production of circular polarization.
 - 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.



Schemes for production of circular polarization studied in 2007 – 2010

- Two full-length undulators (planar and helical) placed in line and application of SASE switchers. May operate at a high power.

planar

helical

- An afterburner operating at the fundamental harmonic. Technical realizations: helical undulator (may operate at high power), and cross-planar scheme (operates at a low power only). Problem: photon beam with helical polarization is contaminated with a linear one originated from the main undulator. Design of separation beam lines (dogleg or achromatic bend) is a delicate task, especially for short wavelengths.

Planar, ω

helical, ω

- Options with an afterburner operating at the 2nd harmonic (frequency doubler). May operate at a high power. First undulator is a planar one. Helical undulator is tuned to double frequency. Linear and helical polarizations are separated with dispersive optical elements.

Planar, ω

helical, 2ω

- Self-seeding option based on planar undulators. May operate at a high power. Photon pulse has complete longitudinal coherence. Seeding section is planar undulator, and radiating section consists of two crossed planar undulators.



Schemes for production of circular polarization studied in 2007 – 2010

- Details of studies are highlighted in the research papers:
 - Y. Li, B. Faatz, J. Pflueger, E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, Study of Controllable Polarization SASE FEL by a Crossed-planar Undulator, Proc. EPAC2008.
 - B. Faatz, W. Decking, Y. Li, J. Pflueger, E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, Study of Controllable Polarization of a SASE FEL using a Crossed-planar Undulator, Proc. FEL2008.
 - Y. Li, B. Faatz, J. Pflueger, Polarization properties of crossed planar undulators, NIMA 613(2010)163.
 - Y. Li, W. Decking, B. Faatz, and J. Pflueger, Microbunch preserving bending system for a helical radiator at the European XFEL, Phys. Rev. ST Accel. Beams **13**, 080705 (2010).
 - E.L. Saldin, E.A. Schneidmiller and M.V. Yurkov, Expected Properties of the Radiation from a Soft X-ray SASE FEL (SASE3) at the European XFEL, Proc. FEL2009.
 - E.A. Schneidmiller and M.V. Yurkov, An Option of Frequency Doubler at the European XFEL for Generation of Circularly Polarized Radiation in the Wavelength Range Down to 1 - 2.5 nm, Proc. FEL2010.
- Here we present only brief summary.

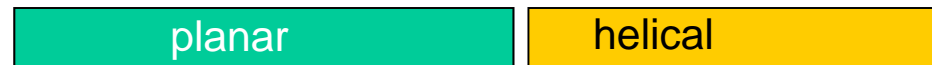


Preliminary conclusions

Long term perspectives:

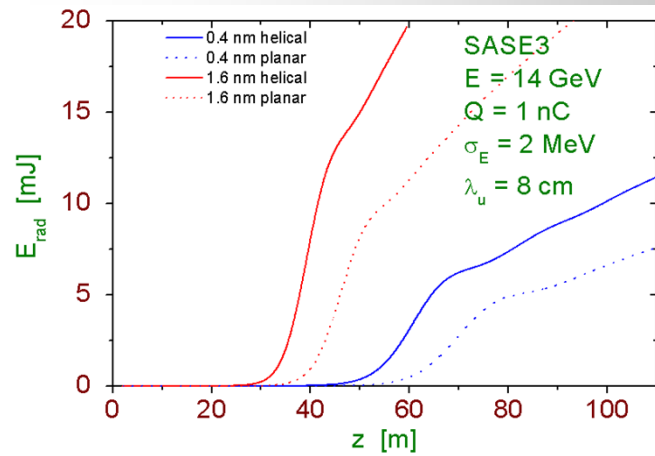
- ***In the long term of the project development it is possible to install the second full-length helical undulator.***

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.

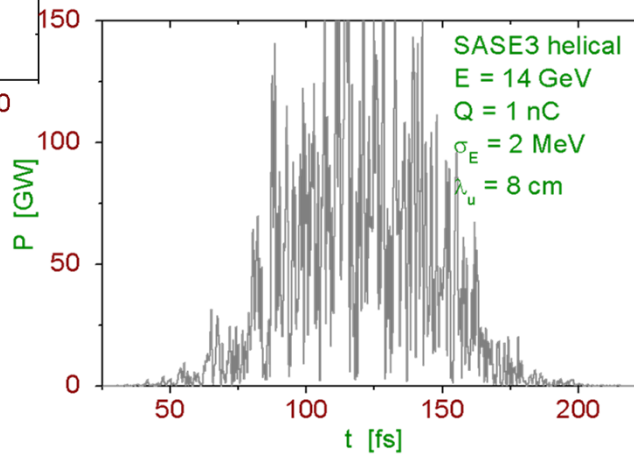


Location of undulators on XFEL site

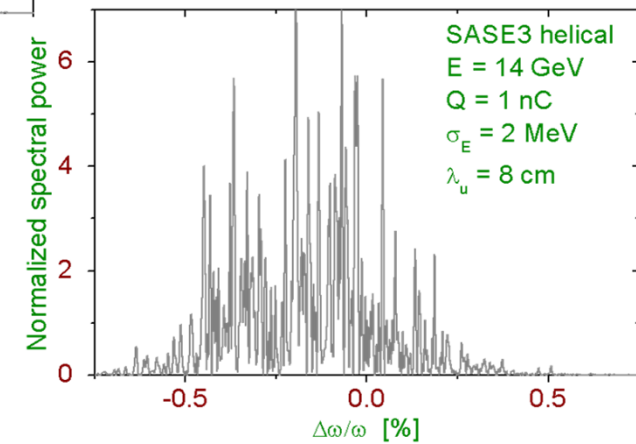
Location	Tunnel length	Undulator
XS1-XS3	620 m	SASE1
XS3-XHDU1	310 m	SASE3
XS1-XS2	550 m	SASE2
XS2-XS4	190 m	Spont.
XS4-XHDU2	250 m	SASE4



Pulse energy



Peak power



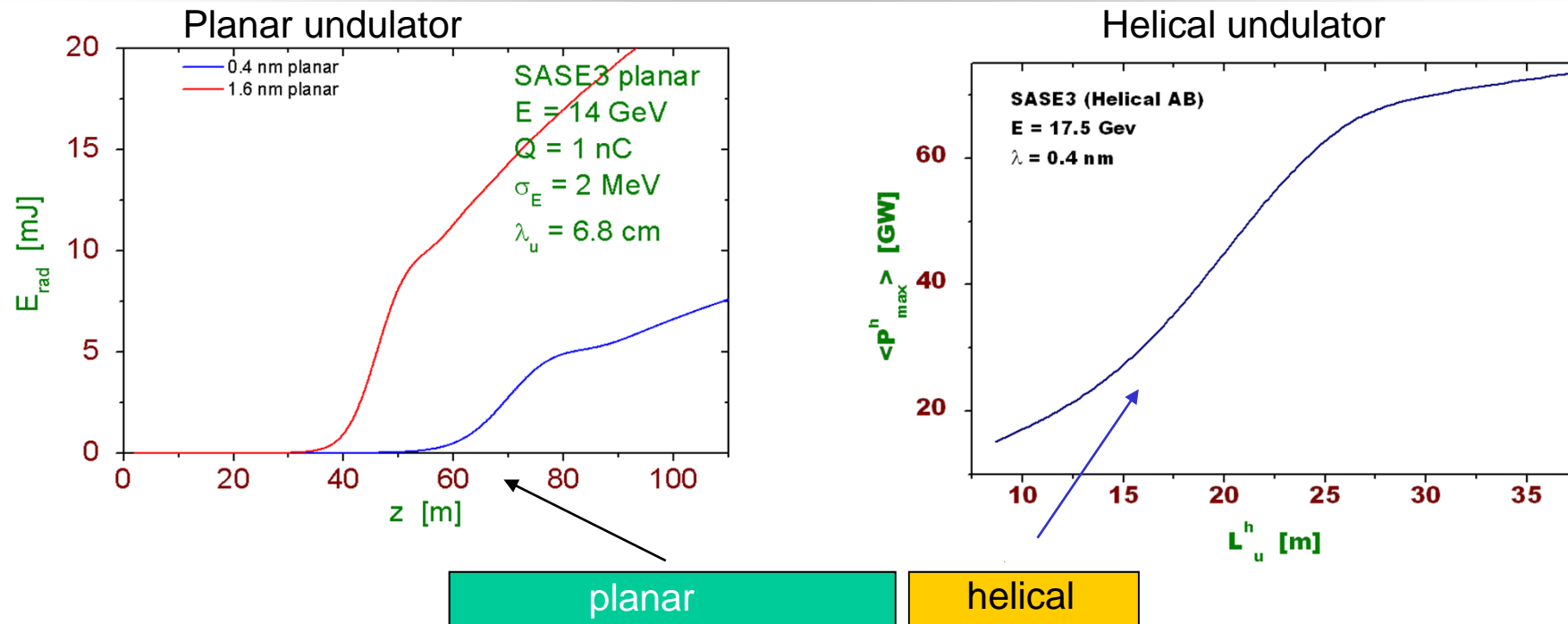
Spectrum



Preliminary conclusions

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 radiation in this case will be close to that of the full-length option.***



- 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 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.



Preliminary conclusions

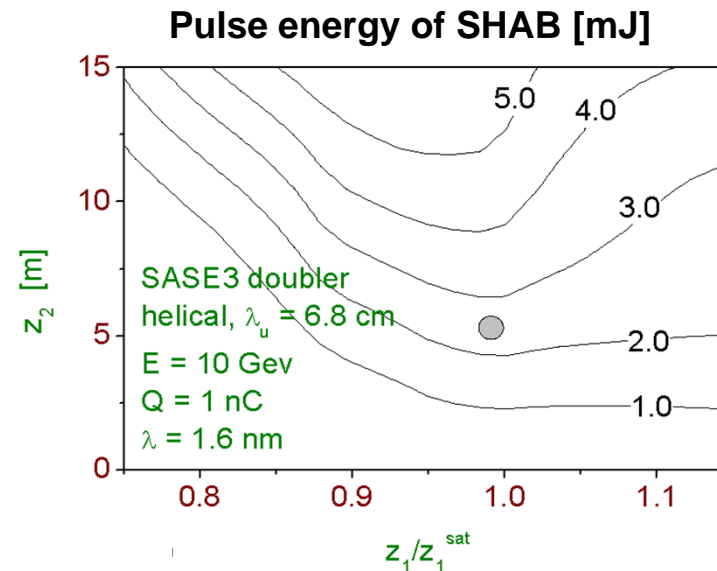
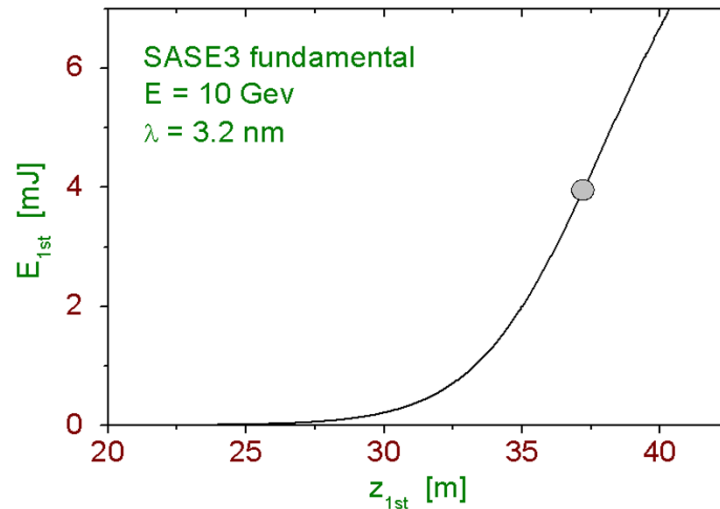
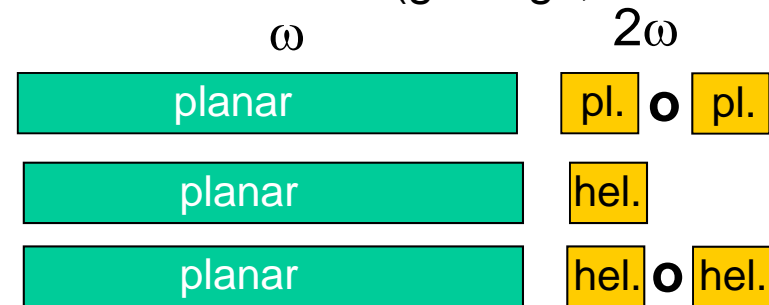
Long term perspectives:

- 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 radiation in this case will be close to that of the full-length option.

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.***

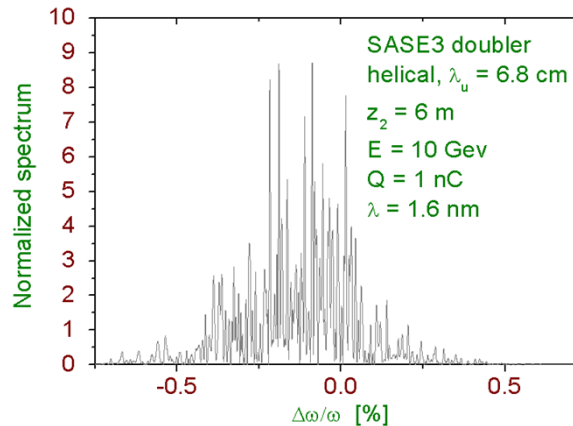
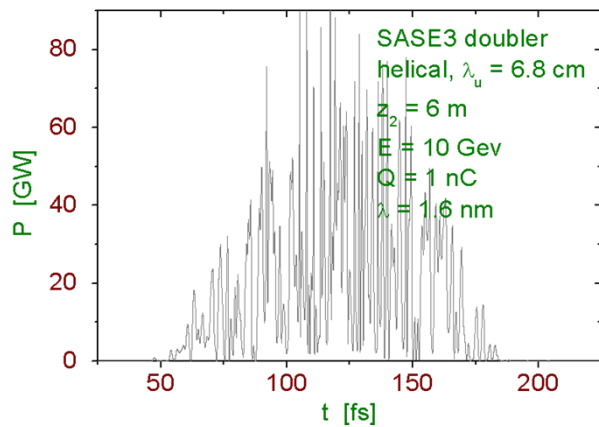
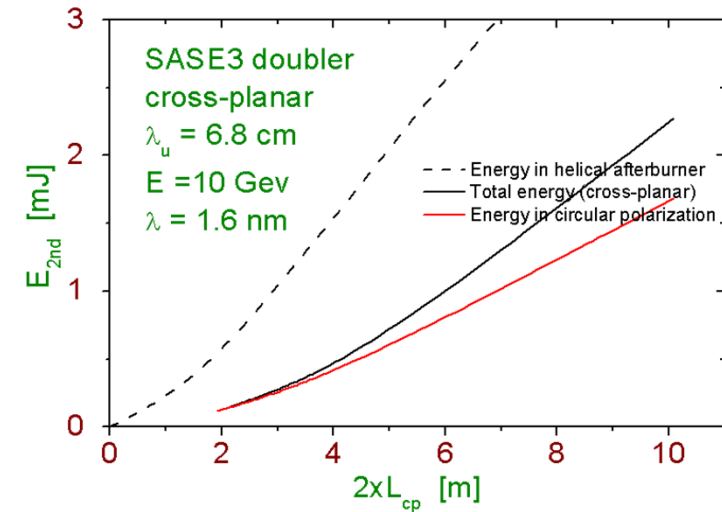
- The simplest and reliable realization of a scheme for production of powerful radiation with high degree of circular polarization in the wavelength range around 1 nm is frequency doubler with helical undulator or cross-planar undulator.
- Problems with separation of the 2nd harmonic (circular polarization) 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;



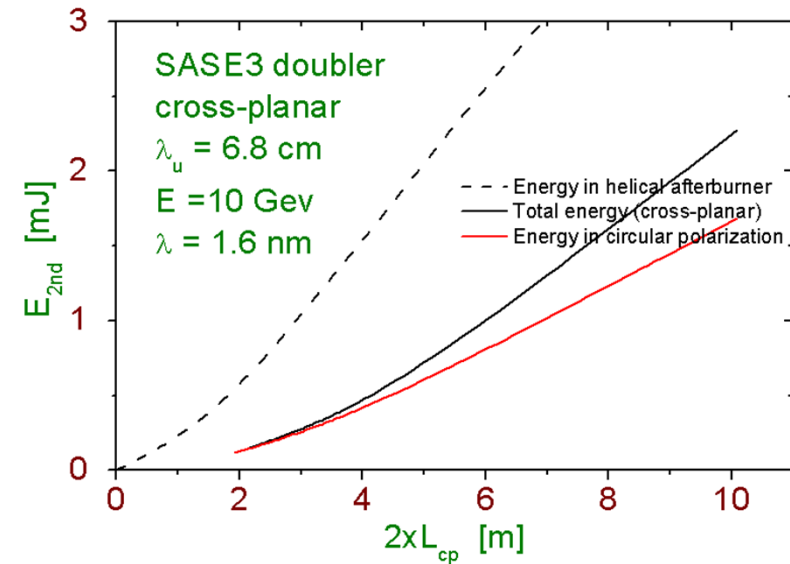
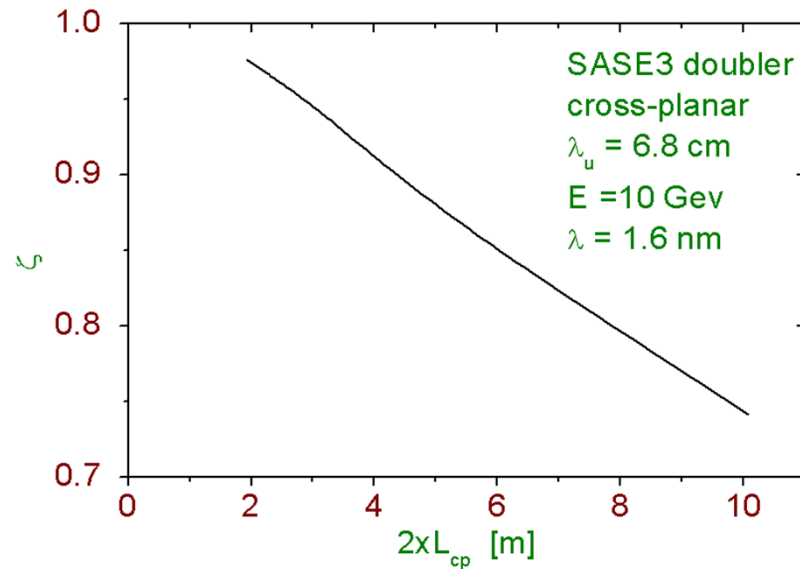
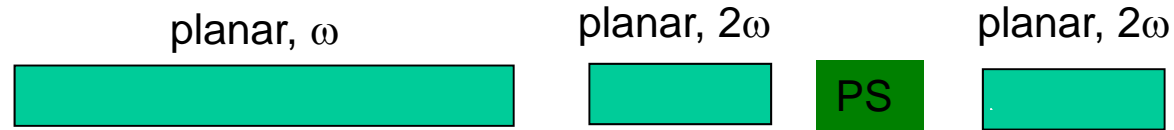
Planar, ω

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



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.



Preliminary conclusions

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 radiation in this case will be close to that of the full-length option.

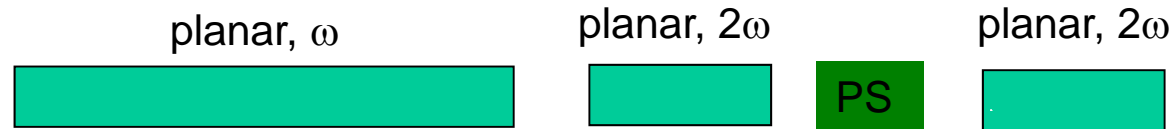
Short-term perspectives

- 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.

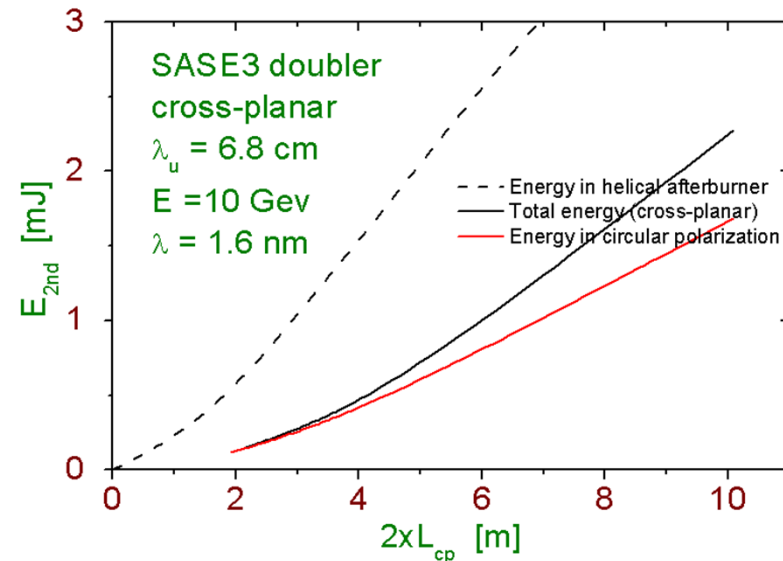
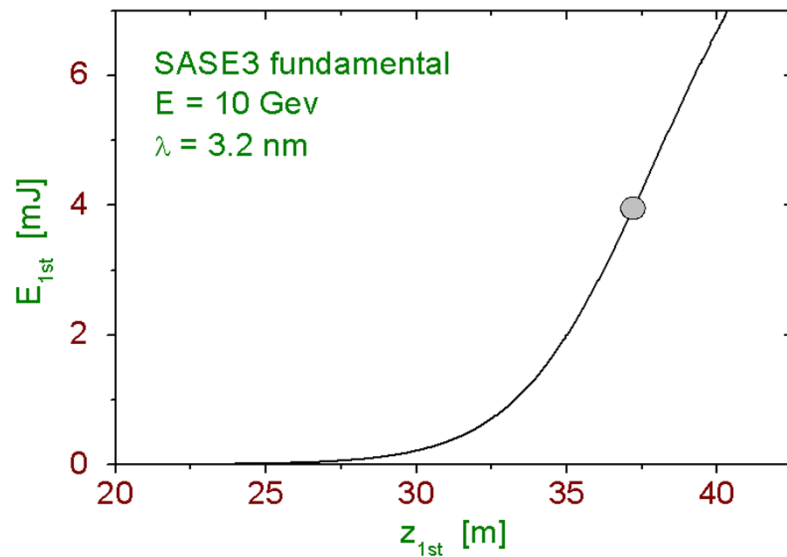
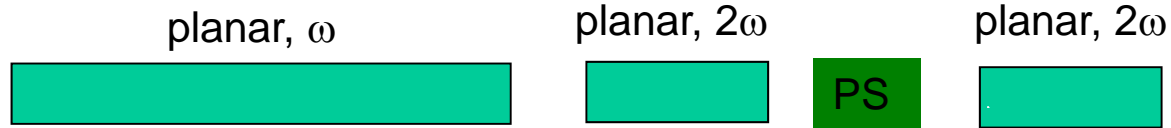


Thank you very much for listening.

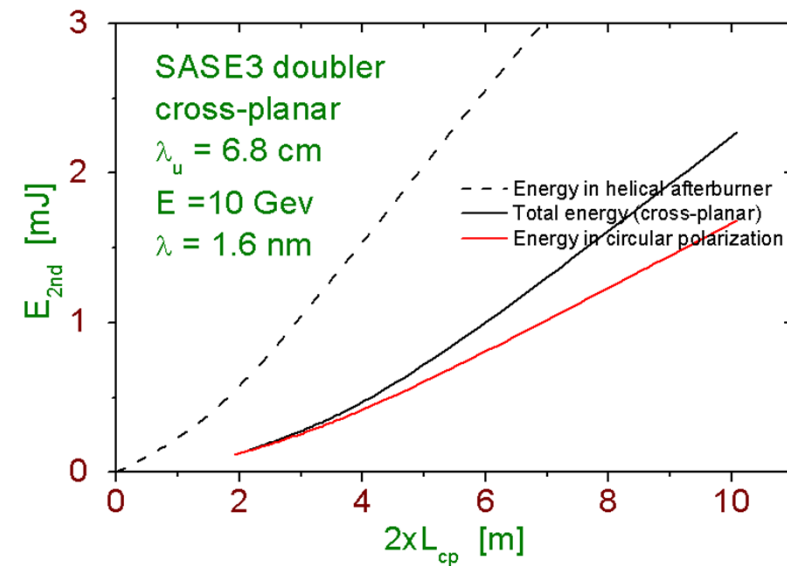
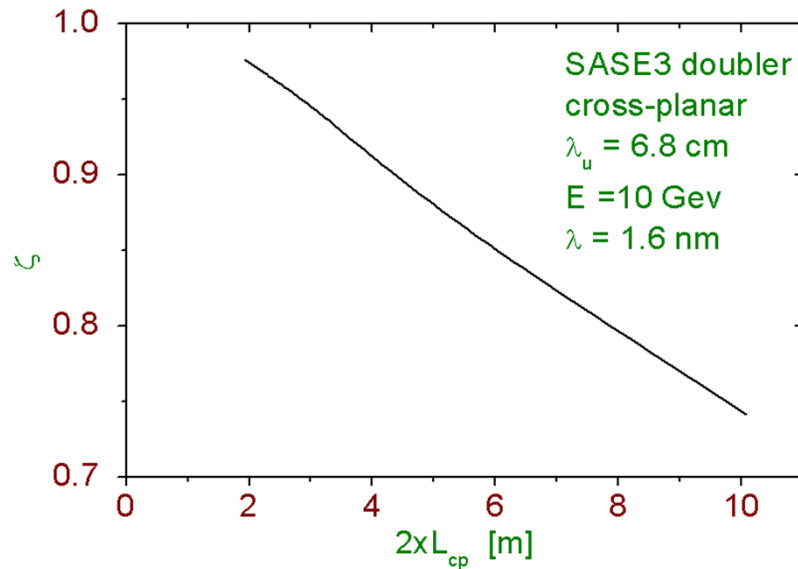
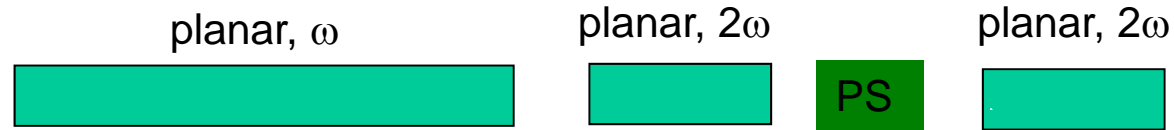
**Your feedback is highly welcome:
requests/suggestions on subjects missed
in our research received at earlier stage
may result in earlier development and
technical realization.**



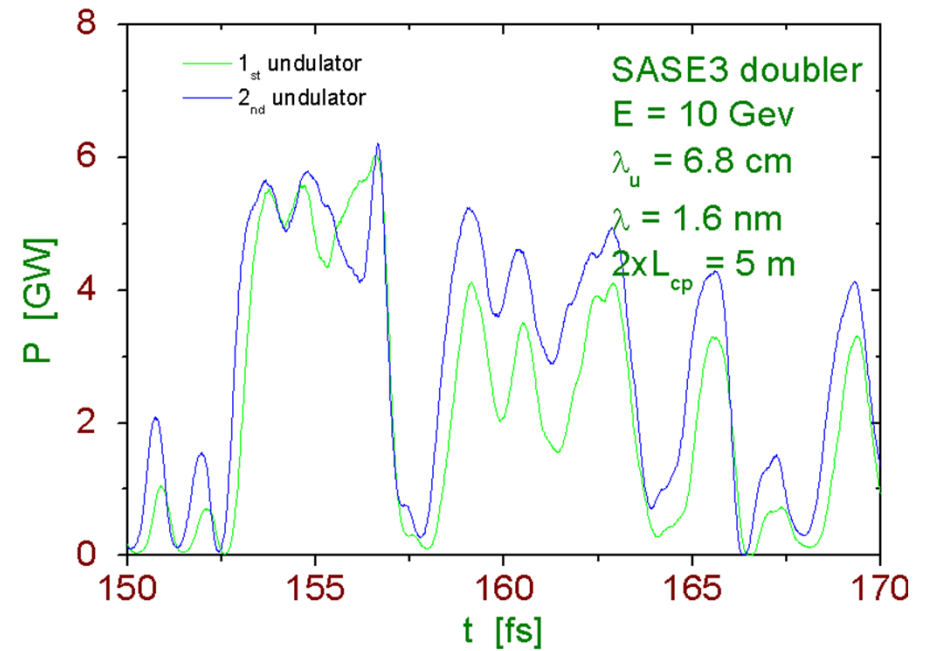
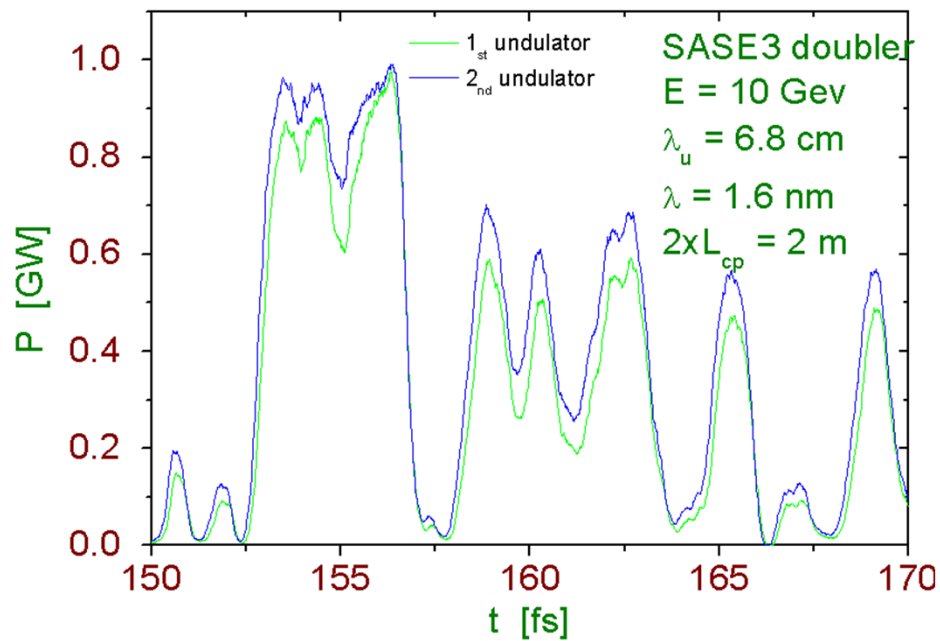
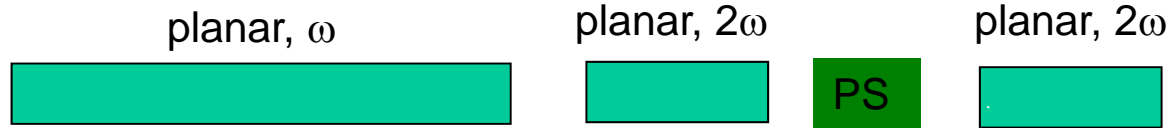
- Main undulator operates in the saturation regime.
- Two short (much shorter than gain length) crossed planar undulators are tuned to the 2nd harmonic.
- Undulators of the afterburner are short: 1) operate as radiators only not disturbing density modulation gained in the main SASE undulator; 2) slippage 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.



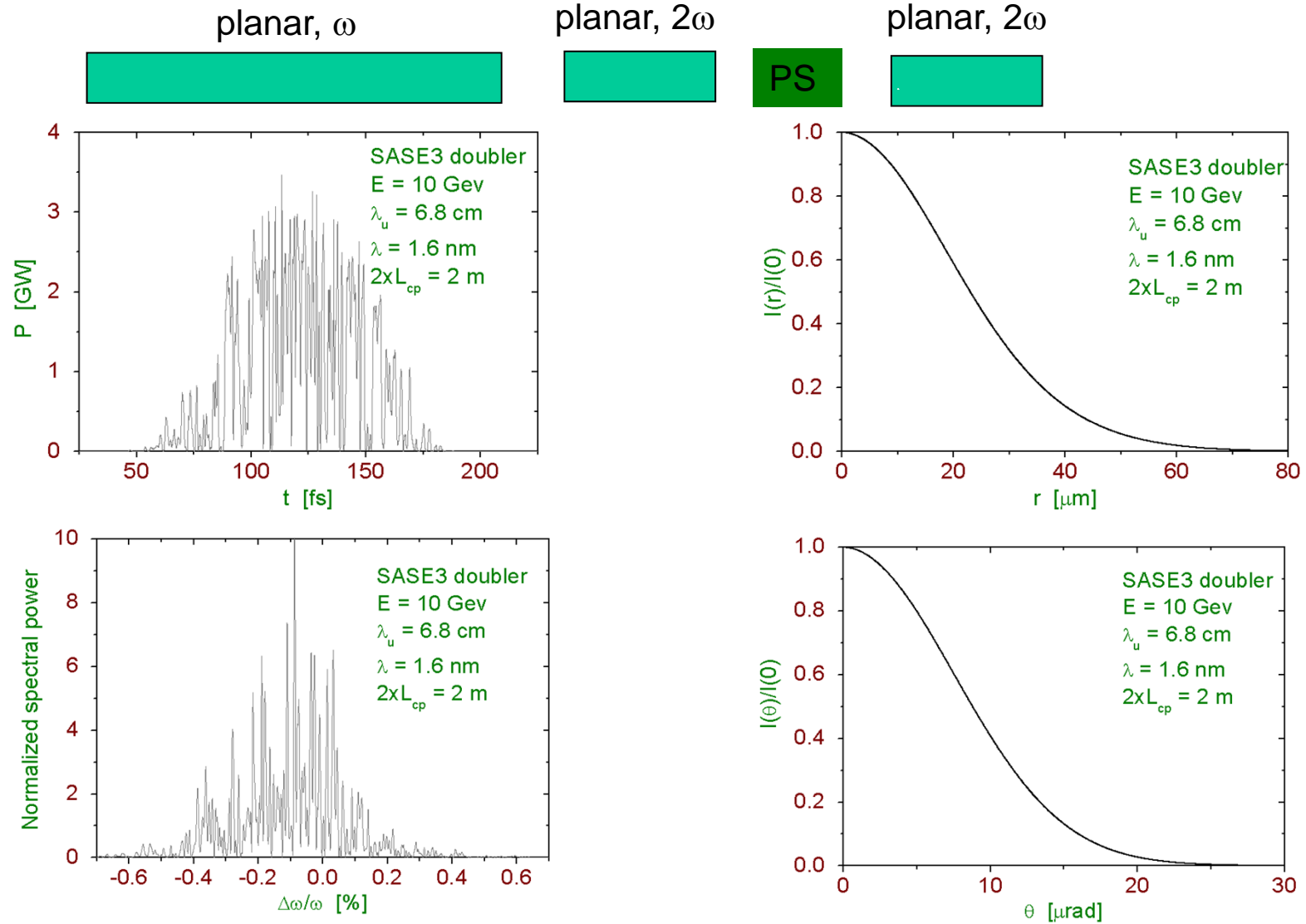
Option of cross-planar undulator of the frequency doubler provides less output power than helical option, but is essentially simple. It is just two short pieces of the main SASE3 undulator.



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.



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



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