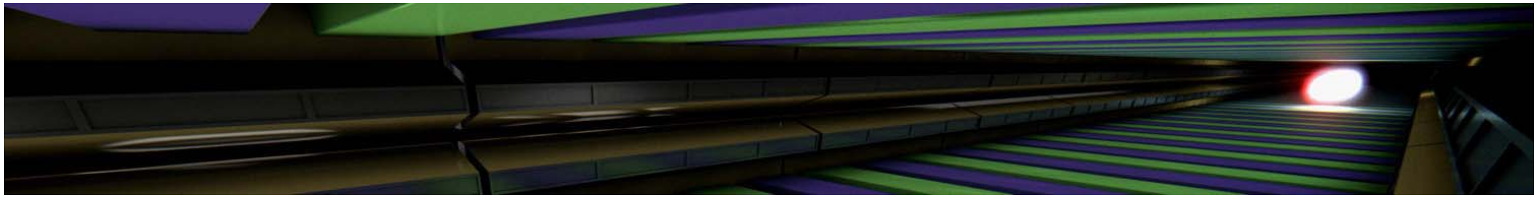


Options for Circular Polarisation at SASE3

Yuhui Li, XFEL

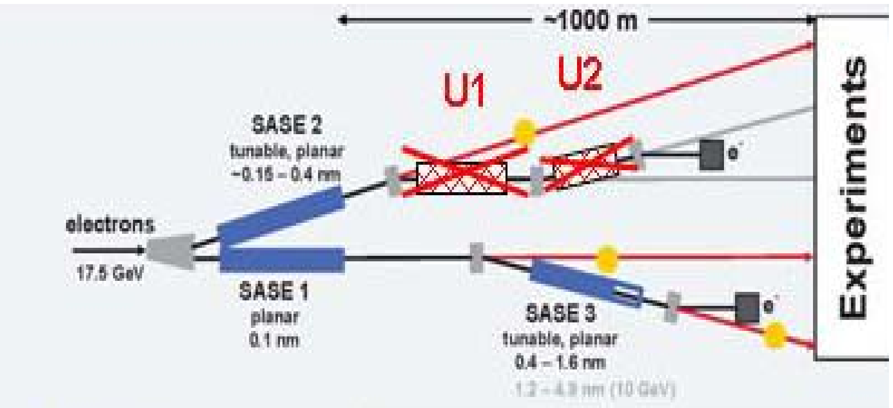
Collaborators: V. Balandin, W. Decking, N. Golubeva, B. Faatz, J. Pflueger

Layout

- Start-up scenario of SASE3 and possible solutions for helical SASE3
- Beam dynamics study for bending system
- Radiation properties
- Summary

Start up Scenario of SASE3

Start up scenario



3 Undulator systems
3 Photon diagnostics
3 Photon beamline
6 Instruments

Startup Scenario
SASE1: Full
SASE2: Shortened by 5 Seg
SASE3: Linear

Startup Szenario with reduced scope Summer 2007

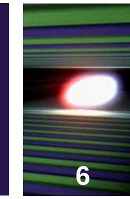
	λ_R [Å]	λ_0 [mm]	Gap [mm]	B_0 [T]	K	β_0 [m]	L_{Sat} + [m]	N_{Tot} ++	L_{Tot} +++ [m]
SASE 1 *	1	35.6	10	1.0	3.3	32	133	33	201.3
SASE 2 *	1-4	48	19-10	0.63-1.37	2.8-6.1	46-15	174 - 72	37	225.7
SASE3P *	4-16	65	23-10	0.66-1.76	4.0-10.7	15	≈100	21	128.1
							Total	91	555.1

* Planar Hybrid Undulator
** 1st Harmonic of Spontaneous Emitters
+ Net saturation length with no contingency for field errors
++ Number of 5m undulator segments including 20% contingency
+++ Total system length includes 1.1m long intersection after each undulator segment

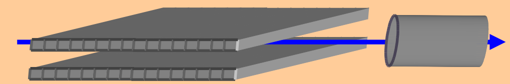
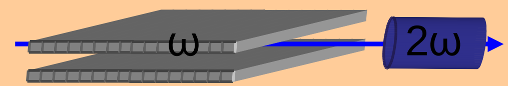
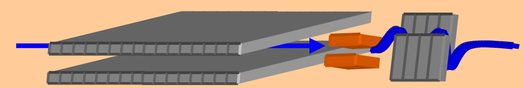
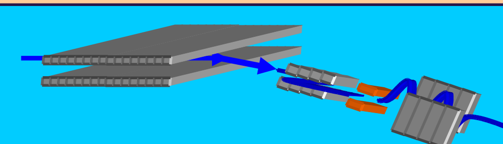
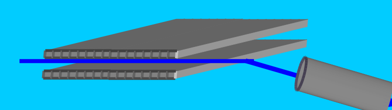
- Located after SASE1, large energy spread
- Wavelength range: 0.4 – 1.6 nm (17.5 GeV)
- Planar undulator will be constructed

High demand of circularly polarized light by SASE3

Different schemes

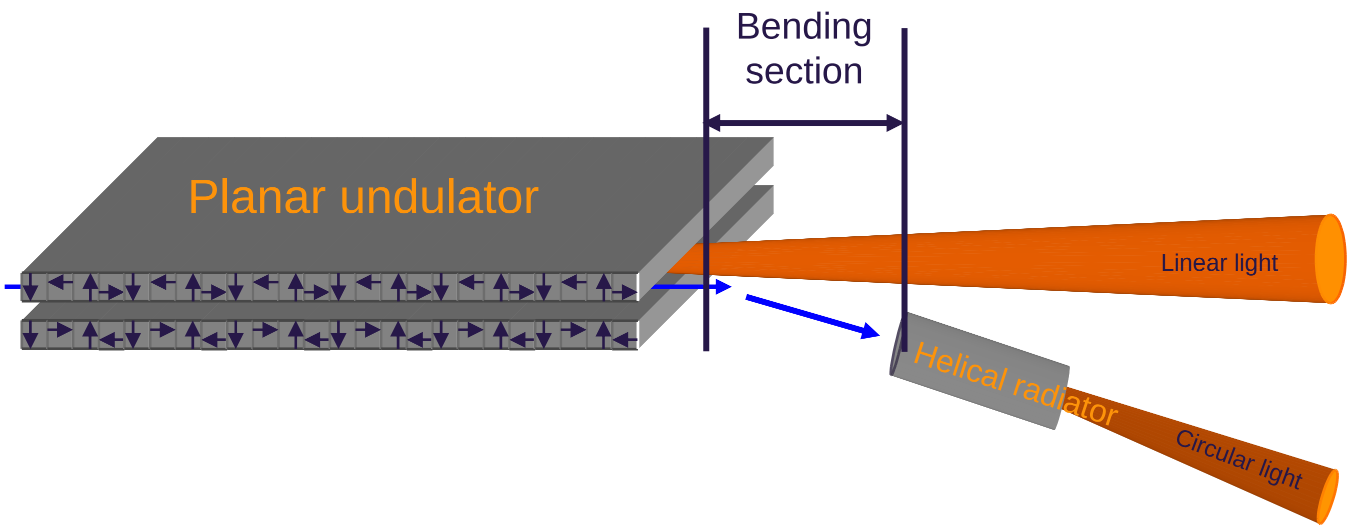


- Based on the SASE3 start up scenario, there are several helical polarization solutions:

Scheme	Power	S_3/S_0	Polarization Fluctuation	Helical Und. Length	Planar Und. Length	Beam line
Planar Und. (start-up)	**50~100 GW 100%**				**~100 m**	
Full helical	**~100%**	**1**	**0**	**~80 m**		
Planar + Helical	**~100%**	**∓ 1**	**∓ 0**	**~30 m**		
8 Å Planar + 4 Å Helical	**~100%**	**?**	**?**	**~40 m**		
Planar + Crossed Planar	**~10%**	**∓ 1**	**∓ 0**	**0 m**	**+ ~3 m**	
Crossed Planar	**~10%**	**~ 0.95**	**>2%**	**0 m**	**+ ~ 6 m**	
Helical	**>10%**	**1**	**0**	**~10 m**		

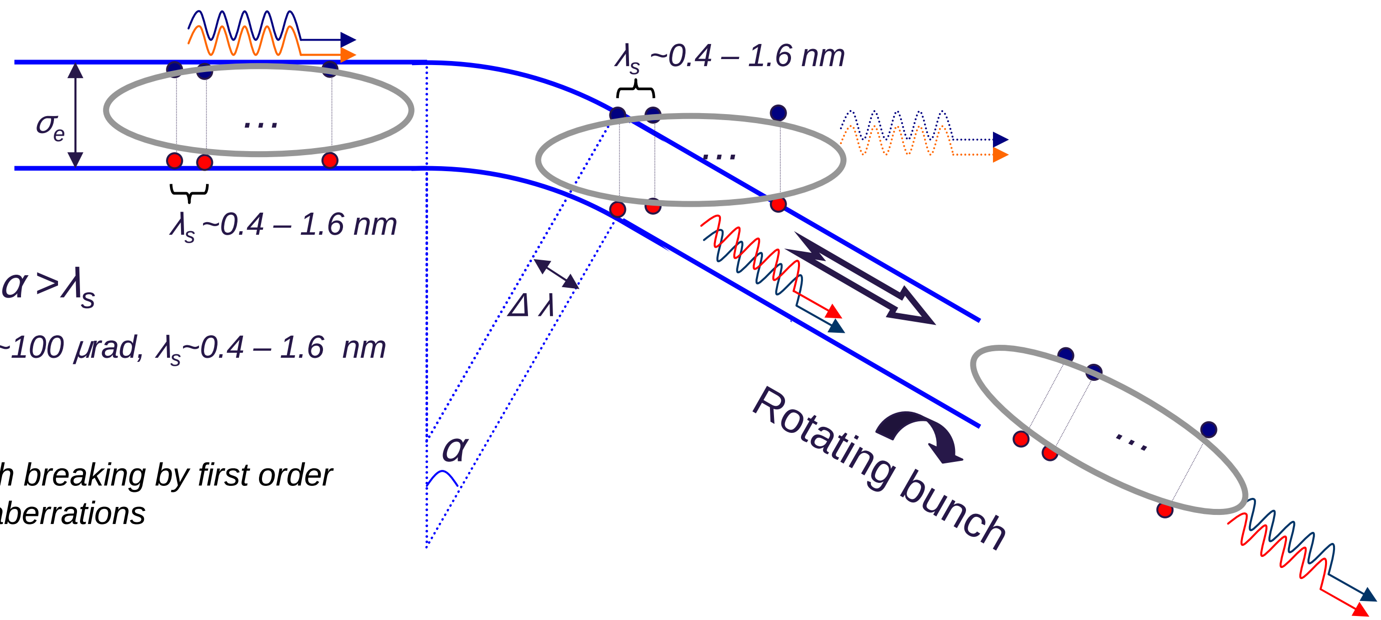
Difficulty and minimum angle for bend

- Main Difficulty: Preserving the micro bunch structure, as short as 0.4 nm, is the challenge for the bending system.
- Additional benefit: In principle two beam lines can be available (linear + arbitrary polarization)
- Depend on the radiation open angle, the minimum safe bending angle is 0.1 mrad.



Beam dynamics study for bending system

First Order Achromatic bending (Geometry)



$\Delta\lambda = \sigma_e \sin\alpha > \lambda_s$

σ_e ~ 25 μm, α~100 μrad, λ_s~0.4 – 1.6 nm

Illustration of micro bunch breaking by first order geometric aberrations

- The bending system must be first order achromatic (Rotating bunch)

Energy Dependent flight time, R_{56}

- Bunch factor b_n is used to describe micro bunch quality
- b_n parabolically drops after bending:

$$\frac{b_n}{b_{n0}} = e^{-2\sigma_\delta^2 (k_u z - \frac{R_{56}\pi}{\lambda_s})^2} \approx 1 - 2\sigma_\delta^2 (k_u z - \frac{R_{56}\pi}{\lambda_s})^2$$

σ_δ: Relative energy spread $>10^{-3}$ (~20MeV)

R_{56}: Compress parameter, ~ 10^{-8}

z: Position in undulator after bending

(z=0 : exit of bending system)

Discussion:

- R_{56} =0, which means all different energy electrons have same flight time during bending, can supply highest bunch at exit of bending system (z=0).
- R_{56} >0, although drops b_n for bending system, can recover it in behind undulator.
- Try to avoid the case of R_{56} <0

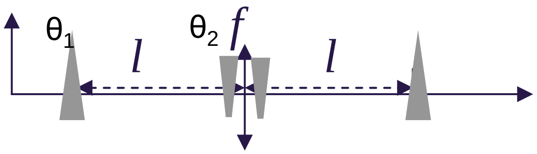
Due to quite short micro bunch, 0.4 nm, preserving, second order aberrations must be carefully considered

Properties of different bending schemes

First order bending
Only dipole & quadrupole included

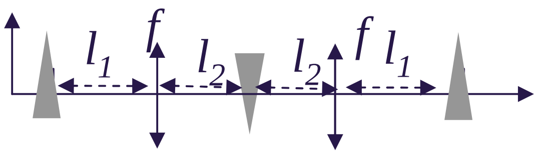
Achromatic with small R_{56}:

Length: ~10 m; total **magnets**: ~5; Bending **angle**: 0.1mrad
R_{56} <0; 0.4 nm bunch can **not** be well preserved



Isochronous:

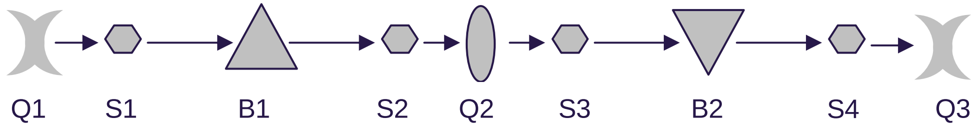
Length: ~10 m; total **magnets**: ~5; Bending **angle**: ~1 mrad
R_{56} =0; 0.4 nm bunch can **not** be well preserved



Second order bending
Using dipole, quadrupole and sextuple

Length: ~90 m; total **magnets**: ~33; Bending **angle**: ~1 mrad; dynamically adjustable **R_{56}** is possible; 0.4 nm bunch **can** be well preserved, transform Matrix is **unity**, be first order **isochronous**

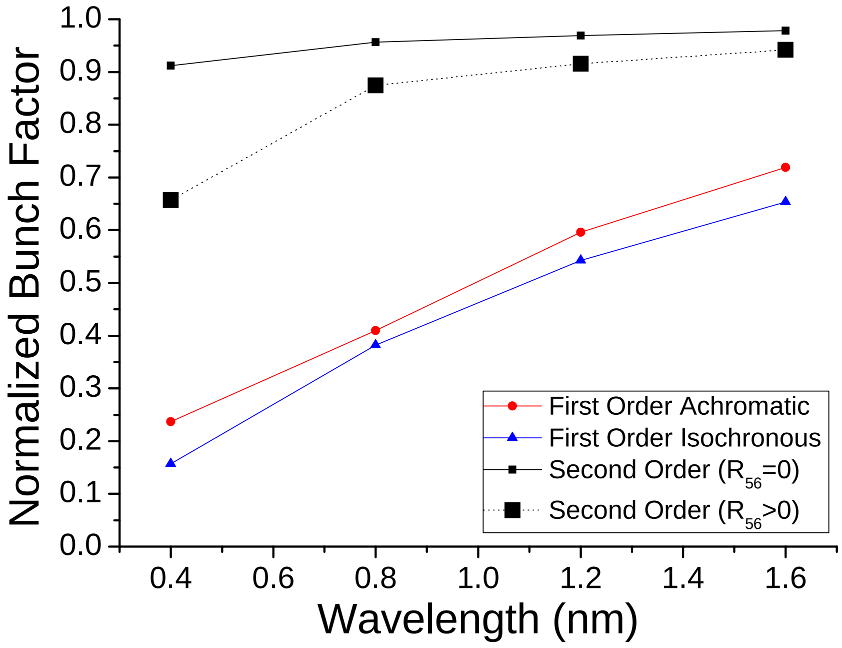
Cell:

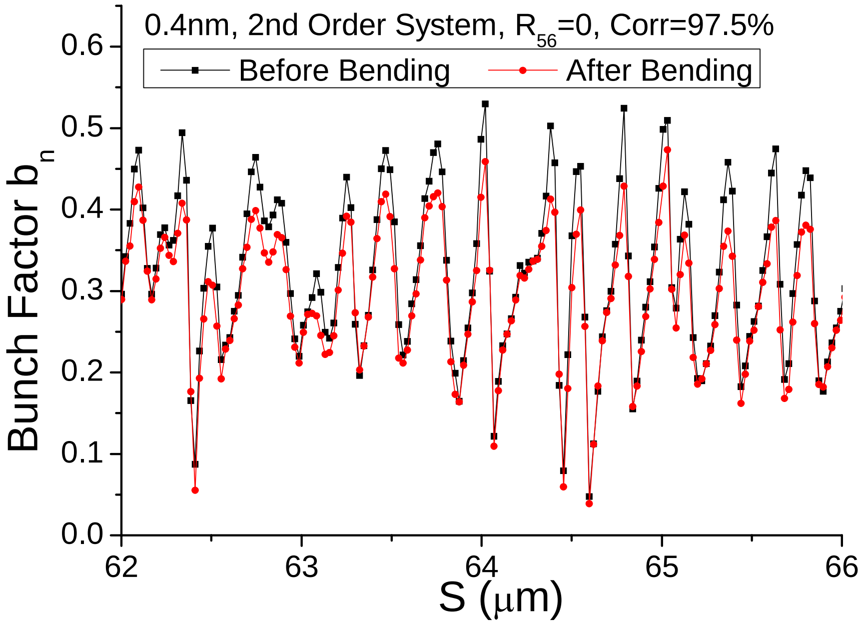


Four cell system

V.Balandin, et.al, Optics Solution for the XFEL Post-Linac Collimation Section, TESLA-FEL 2007-05

Bunch factor preserve





So far, only beam dynamics work has been done

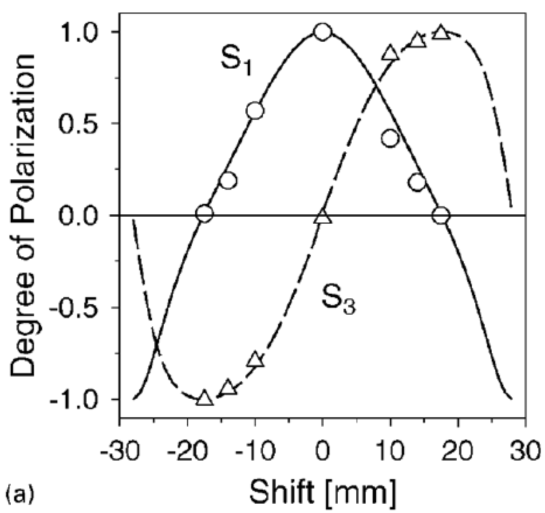
Radiation properties

- Helical undulator (APPLE II)
- Planar crossed undulators (M.V.Yurkov, et.al.)

Discussion for helical undulator

- No FEL code can simulate polarization.

DSU: 1. Harmonic (98 eV), PGM1

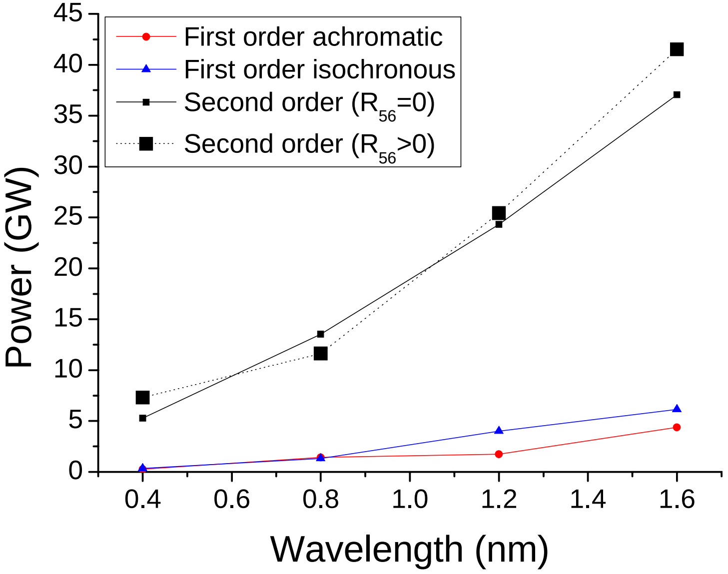


Markers: Measurements Lines: WAVE calculations

Polarization

- Copy from BESSY simulated and measured spontaneous circular polarization from helical undulator
- Completely circular polarized light can be generated.

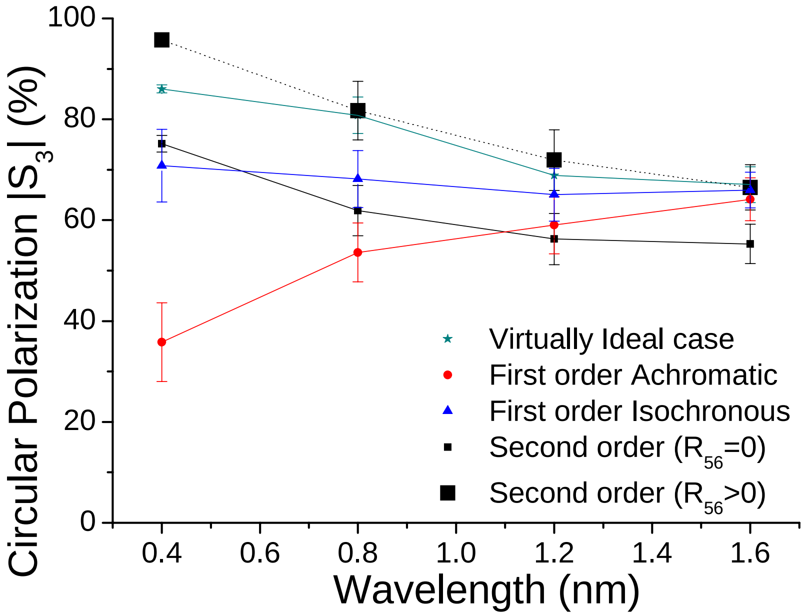
Power

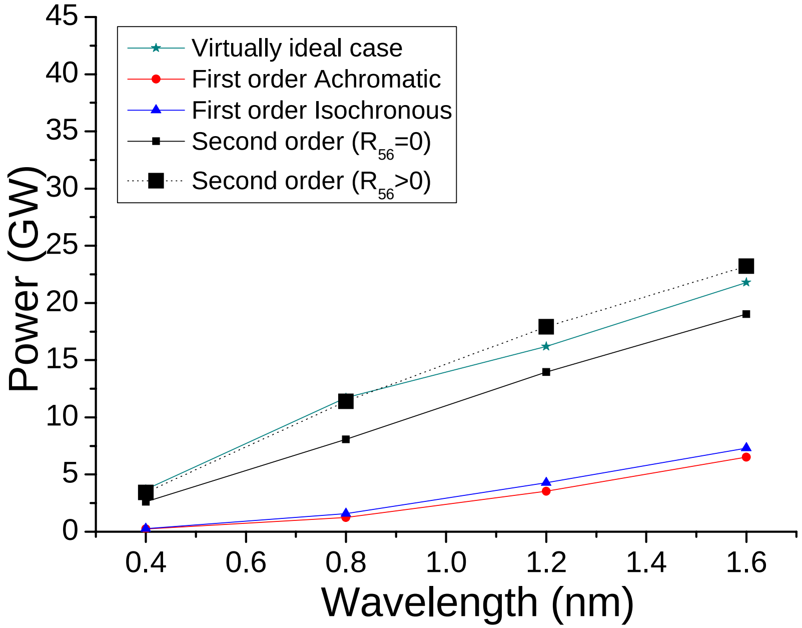


- Simulated SASE3 circular light power by helical undulator (6 m)
- For longer undulators, higher power can be expected

Discussion for crossed planar undulators

- Technically easy to be constructed
- The polarization can not be exactly 100% due to:
  - Electrons in two crossed undulators are not frozen
  - Longitudinal shift
  - Light diffraction
  - Different beta function





Each crossed undulator length is 3 m

Y.Li, B. Faatz, J. Pflueger, E.L.Saldin, E.A.Schneidrmiller, M.V.Yurkov
EPAC 08, FEL 08

Summary

- A solution which can preserve 0.4 nm bunch has been found
- Powerful and high circular polarized light can be generated by SASE3 in principle.
- Further work is:
  - Looking for better bending solution
  - Tolerance study

Thank you for your attention

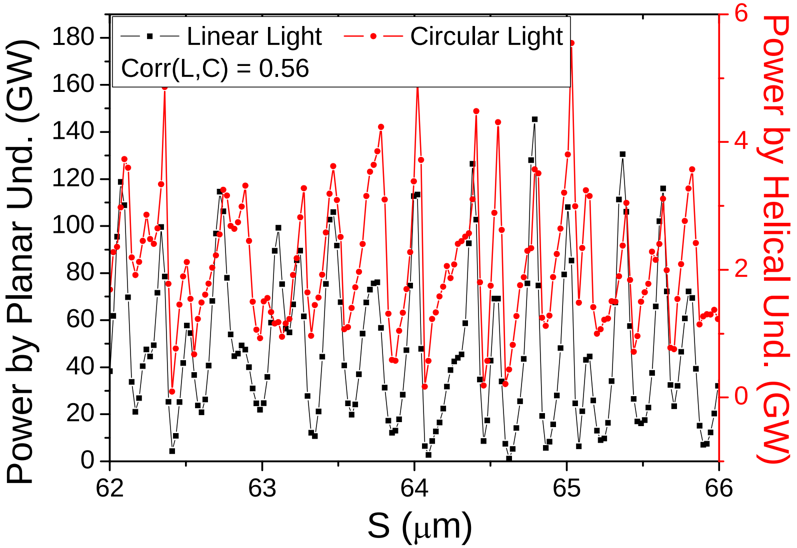
Different schemes

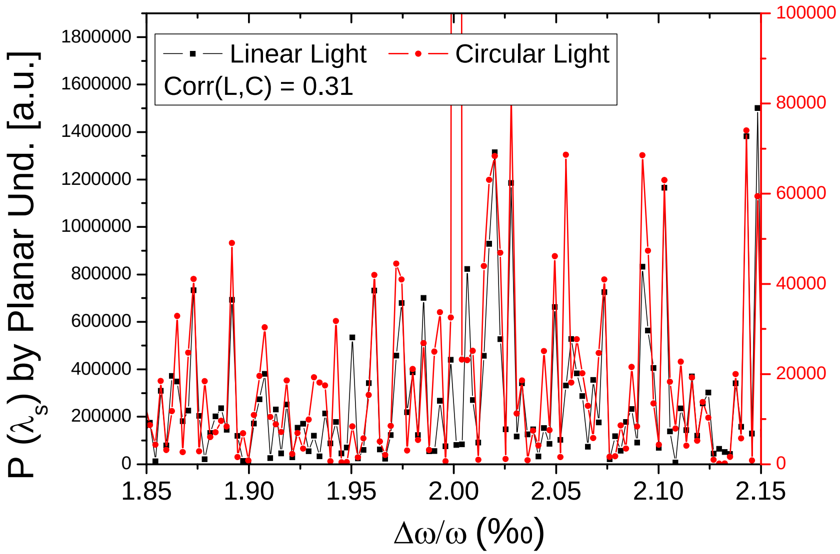
- Based on the SASE3 start up scenario, there are several helical polarization solutions:

Scheme	Power	S_3/S_0	Polarization Fluctuation	Helical Und. Length	Planar Und. Length	Requirement for Bend	Beam line
Planar Und. (start-up)	**50~100 GW 100%**				**~100 m**		**1 Linear**
Full helical	**~100%**	**1**	**0**	**~80 m**		**NO**	**1 linear or circular**
Planar + Helical	**~100%**	**∓ 1**	**∓ 0**	**~30 m**		**NO**	**1 Linear & circular mixed**
8 Å Planar + 4 Å Helical	**~100%**	**?**	**?**	**~40 m**		**NO**	**1 8 Å linear & 4 Å circular mixed**
Planar + Crossed Planar	**~10%**	**∓ 1**	**∓ 0**	**0 m**	**+ ~3 m**	**NO**	**1 Linear or circular**
Crossed Planar	**~10%**	**~ 0.95**	**> 2%**	**0 m**	**+ ~6 m**	**Need 2nd order bend**	**2 Linear & circular separated**
Helical	**>10%**	**1**	**0**	**~10 m**		*****	**2 Linear & circular separated**

* Optimization between helical length and bend complex

Spikes of Power, Spectrum





R56

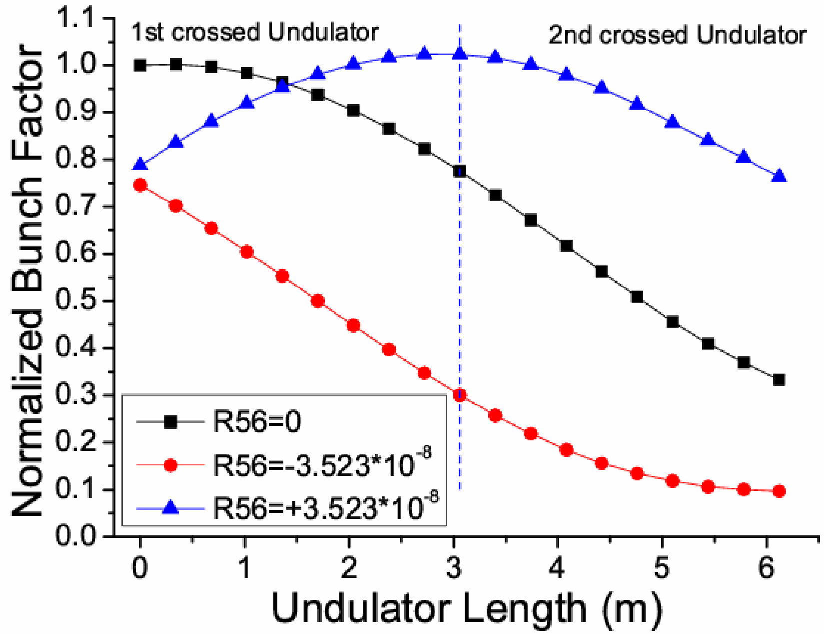


Figure 26: *Bunch factor development in behind undulators. Two 3 m long crossed undulators are used here as an example. Three cases are shown: the black square line denots* $R_{56} = 0$*, the red dot line denotes to* $R_{56} < 0$ *and the blue triangle line denotes to* $R_{56} > 0$*. These are simulation result by Genesis 1.3.*

Power and polarization for different cases

λ_s nm	Power (GW)		P_x/P_y		Polarization (%)		S_3/S_0 (%)	
	1st Ach	1st Iso	1st Ach	1st Iso	1st Ach	1st Iso	1st Ach	1st Iso
0.4	0.25	0.26	1.708	1.641	67.6~58.8	81.7~68.1	43.6~28.0	78.0~63.6
0.8	1.25	1.57	2.418	2.946	81.8~73.7	84.8~75.1	59.4~47.7	73.8~62.5
1.2	3.54	4.28	2.005	3.312	80.7~72.0	84.2~75.6	64.6~53.3	70.3~59.8
1.6	6.52	7.31	1.971	3.413	81.7~74.7	84.9~79.2	68.4~59.9	69.5~62.4

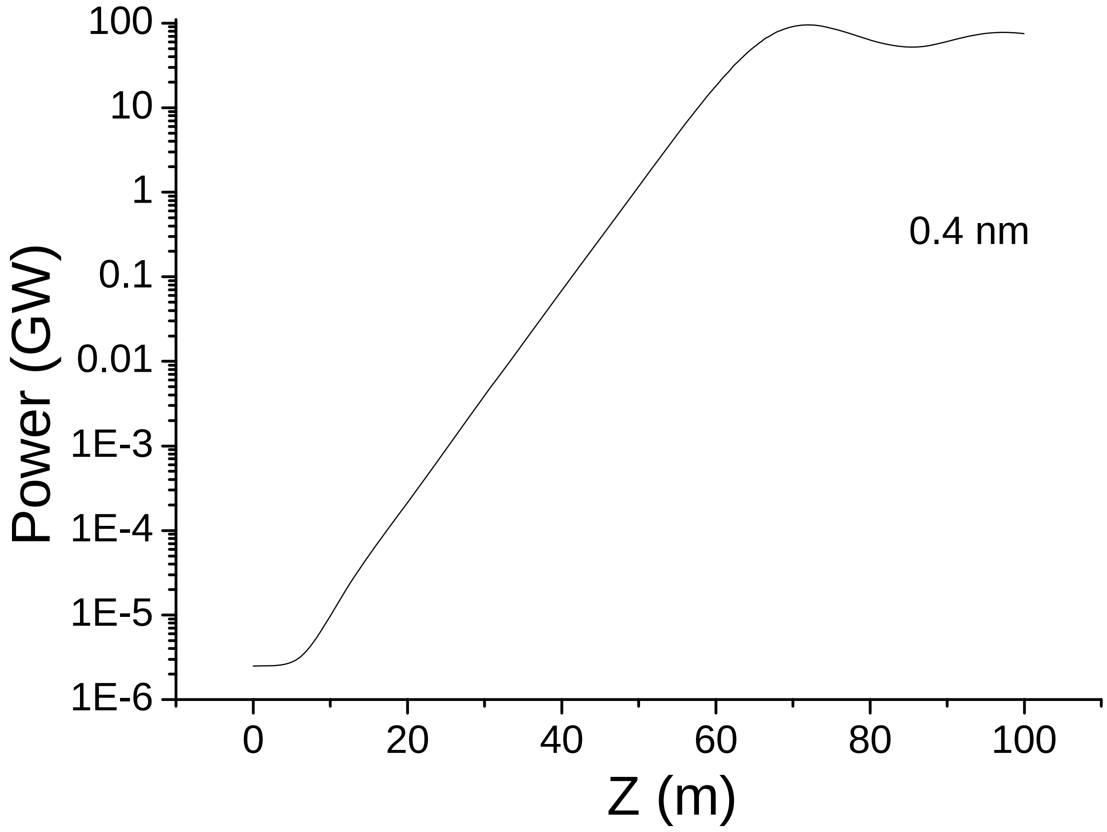
European XFEL

Power and polarization for different cases

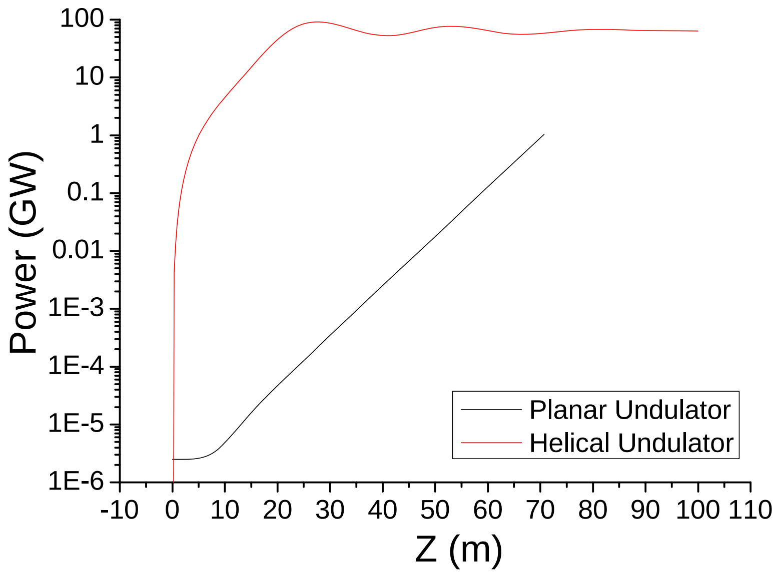
λ_s (nm)	Power (GW)			P_x/P_y			Polarization (%)			S_3/S_0 (%)		
	Idea case	2nd (R56=0)	2nd (R56>0)	Idea case	2nd (R56=0)	2nd (R56>0)	Idea case	2nd (R56=0)	2nd (R56>0)	Idea case	2nd (R56=0)	2nd (R56>0)
0.4	3.69	2.62	3.44	2.068	3.023	1.000	93.8~ 92.4	91.4~ 88.6	96.6~ 95.8	86.8~8 5.2	76.8~ 73.5	96.2~ 95.3
0.8	11.7	8.07	11.4	2.120	3.663	1.952	91.9~ 85.3	85.4~ 77.9	91.7~ 80.7	84.4~ 77.2	66.9~ 56.9	87.5~ 75.9
1.2	16.2	13.96	17.9	2.570	3.633	2.591	85.7~ 79.1	81.7~ 74.4	87.6~ 77.2	72.7~ 65.1	61.3~ 51.2	77.9~ 65.9
1.6	21.8	19.03	23.2	2.557	3.605	3.122	83.6~ 77.6	79.8~ 74.3	85.1~ 77.7	70.6~ 63.5	59.2~ 51.4	71.0~ 62.0

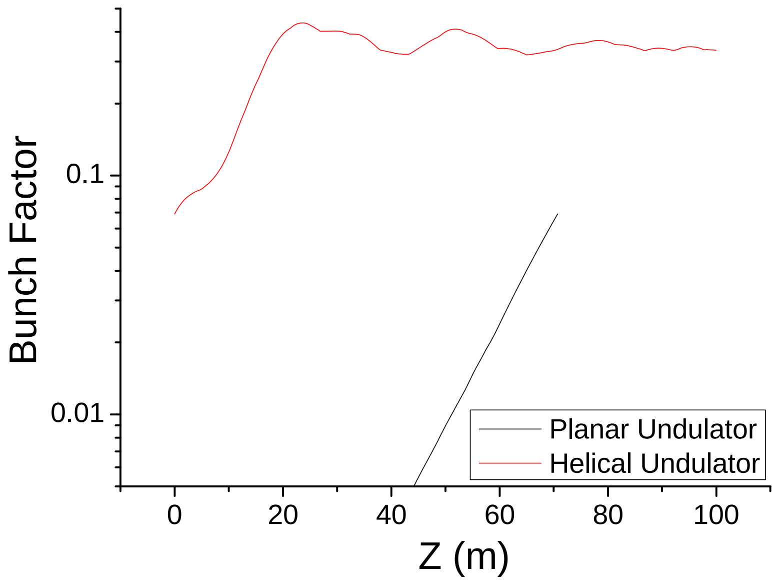
DESY HELMHOLTZ ASSOCIATION

Full Helical

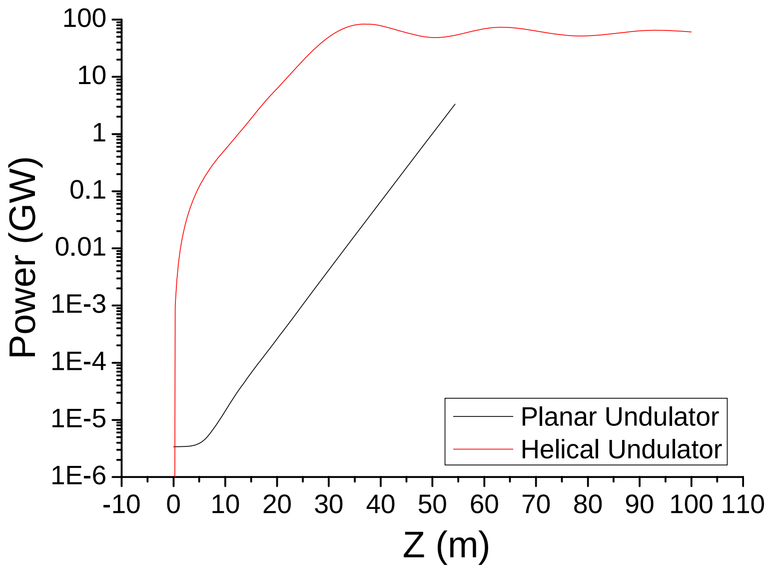


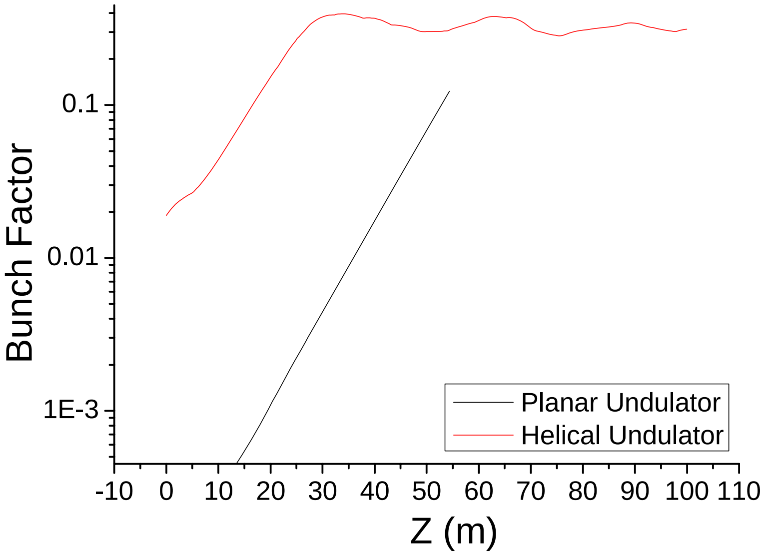
Planar + Helical



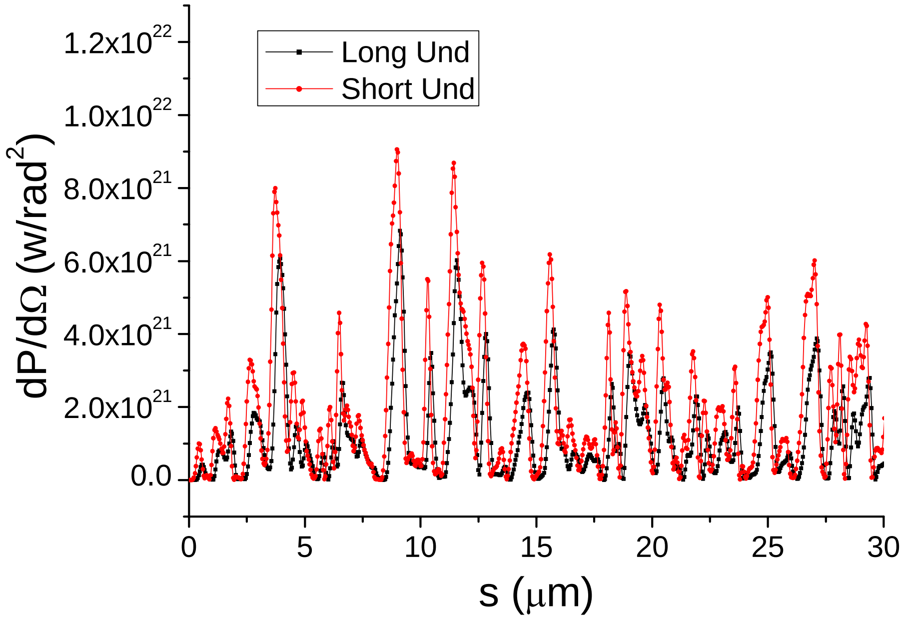


8 Å Planar + 4 Å Helical





Planar + crossed planar undulator (LCLS)



S_3/S_0=81.1%

Bending + crossed planar, Fluctuation