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Vertical Polarization Option for LCLS-II

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Abstract

Vertically polarized light has many instrumental and transport advantages compared to horizontally polarized light. This technical note details a study of vertically polarized light production at LCLS-II in the hard X-ray (HXR) undulator using a combination of horizontally and vertically polarized undulators (H/VPU).

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1 Introduction

The polarization of the FEL light coming from the HXR undulator beamline strongly influences the performance of various downstream diagnostics and experimental measurements. For instance, the performance of the large offset monochromator systems, as well as scattering measurements made with the XCS large angle detector mover, are strongly enhanced with a vertically polarized beam[1]. While the installation of VPUs would require the reconfiguration of some experimental end stations, the benefits of a vertically polarized beam outweigh the drawbacks.

We explore the possibility of replacing a number of HPUs with VPUs along the HXR beamline for the production of vertically polarized light. The purpose of this study is to evaluate the impact of implementing this scheme on the production of FEL light from the high rep rate SCRF electron beam. In addition, replacing only a fraction of the undulators may reduce the VPU production risk and might allow for production of either vertical or horizontal FEL polarization when the full undulator is not requiired. To this end, we discuss the performance implications for the high end of the tuning range ($E_\gamma = 5$ keV), which is typically the most difficult for FEL's to reach.

2 Impact on 5 keV performance from the high rep rate SCRF electron beam

The performance outlined in the LCLS-II KPP for the production of 5 keV photons is nominally reached by employing a low charge (20 pC) electron beam from the SCRF linac where the beam brightness is sufficient to support lasing[2]. The impact on replacing a number of horizontally polarized undulators is discussed below.

2.1 Beamline Geometry

The baseline LCLS-II HXR undulator nominally consists of 32 individual undulator segments, the parameters of which can be found in Table 1. The HXR undulator beamline will also support self-seeding using the high energy CuRF electron beam and the existing LCLS infrastructure. As such, there is a break at the location where the 14th undulator segment would normally be placed to host the monochromator crystal and electron beam bypass chicane. Any VPU implementation should minimize the impact on the self-seeded performance.

2.2 Electron beam properties

High fidelity start-to-end (S2E) numerical particle simulations are used to evaluate the performance of the modified undulator beamline. Particles are tracked using `IMPACT-T/Z` from the injector to the entrance of the undulator[3]. Figure 1 shows the detailed slice properties of the low charge, 20 pC electron beam at the entrance to the HXR undulator. The current in the core of the beam is roughly $I \sim 350$ A while the normalized slice emittance is

Table 1: Nominal 20 pC electron beam and HXR undulator parameters.

Paramter	**Symbol**	**Value**	**Unit**
e-beam energy	E	4.0	GeV
emittance	ϵ	0.15	μm
current	I	350	A
energy spread	σ_E	450	keV
beta	$\langle\beta\rangle$	13	m
undulator type	-	Hybrid PM, planar	x-pol
undulator period	λ_u	26	mm
segment length	L_u	3.4	m
break length	L_b	1.0	m
# segments	N_u	32	-
total length	L_{tot}	149	m

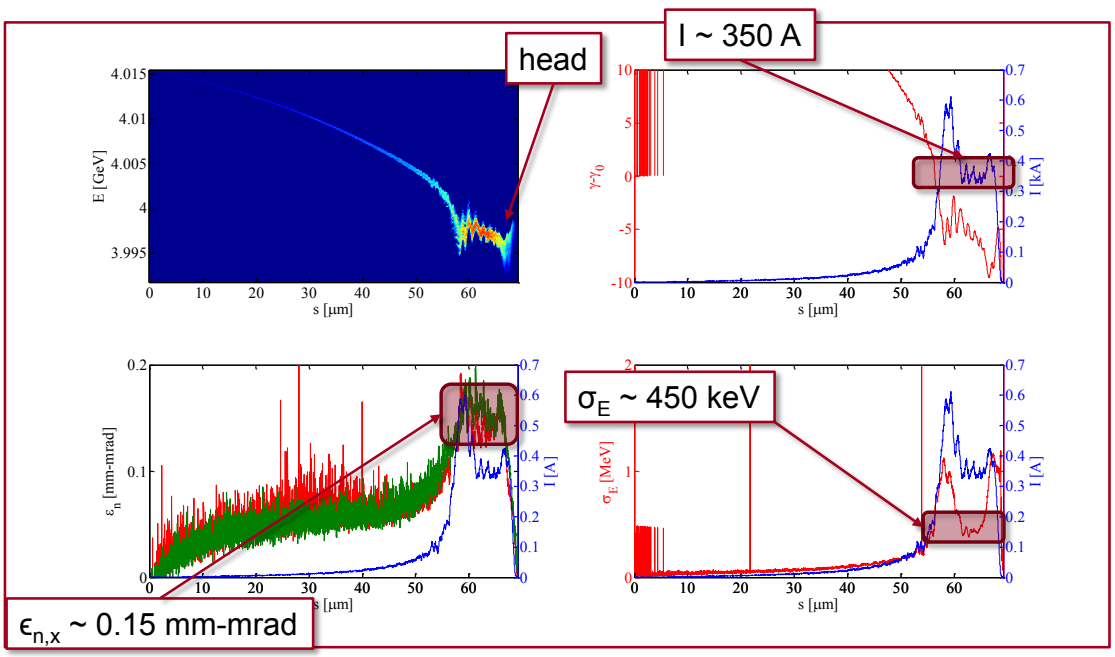

Figure 1: Top left: Longitudinal phase space. Top right: Current (blue) and slice energy (red). Bottom left: Current (blue), slice emittance (green - x, red - y). Bottom right: Current (blue), rms slice energy spread (red).

$\epsilon_{n,(x,y)} \sim 0.15$ mm-mrad and the rms slice energy spread is $\sigma_E \sim 450$ keV. This electron beam nominally produces 20 fs FEL pulses. `GENESIS` is used to simulate the FEL performance with this S2E particle distribution.

2.3 FEL simulation results

Figure 2 shows the results from simulations using the full S2E electron beam. If all of the undulators are horizontally polarized, the energy in the pulse at the end of the undulator (all 32 segments) would be ~ 8 μJ (blue curve). If one then includes an optimized taper beginning at undulator segment 20 the pulse energy at the end of the undulator increases to ~ 25 μJ (red curve). The best results from a mixed polarization undulator are obtained when the first 16 undulators are horizontally polarized (black curve) while the last 16 undulators are vertically polarized (yellow curve). Tapering around undulator 20 in this case should reproduce the nominal single undulator polarization tapered performance since the FEL is still in the linear growth regime 2 undulators after the polarization switch.

For the best performance, the switch from horizontal to vertical polarization occurs in the linear growth region well before saturation and before the onset of large slice energy spread growth. After the switch, it takes a little over one power gain length to reach similar pulse energy in the vertically polarized beam, which is consistent with previous results[4]. There is some lag, however, before the vertically polarized light returns to exponential growth (at around 100 m). Saturation is slightly delayed but the total energy in the vertically polarized light nearly returns to the nominal value obtained with a single undulator polarization. Figure 3 shows the projected intensities and mode composition of the horizontally polarized light at undulator 16 and the vertically polarized light at undulator 32. Approximately 67% of the horizontally polarized light is contained in a fundamental Gaussian mode that is estimated to have a $w_0 \sim 35$ μm waist located $z \sim 5.4$ m before the end of the 16th undulator segment with a $z_R \sim 17.2$ m Rayleigh length. Similarly, approximately 52% of the vertically polarized light is contained in a fundamental Gaussian mode that is estimated to have a $w_0 \sim 66$ μm waist located $z \sim 31.2$ m before the end of the 32nd undulator segment with a $z_R \sim 59.5$ m Rayleigh length. The vertically polarized light comes primarily from a prebunched electron beam radiating coherently. There is very little gain guiding or exponential gain, and thus, the relatively poor fit of the light to a fundamental Gaussian mode.

Delaying the switch from horizontally to vertically polarized undulators until after the 20th undulator segment severely impacts the performance (green and cyan curves). In this case, it takes just over 6 undulator segments to recover a similar pulse energy in the vertically and horizontally polarized beams. Also, the optimized taper no longer produces ~ 25 μJ pulses.

3 Conclusion

Using a limited number of vertically polarized undulators to produce vertically polarized FEL light for the LCLS-II HXR beamline has been investigated. At least half (16) of the individual

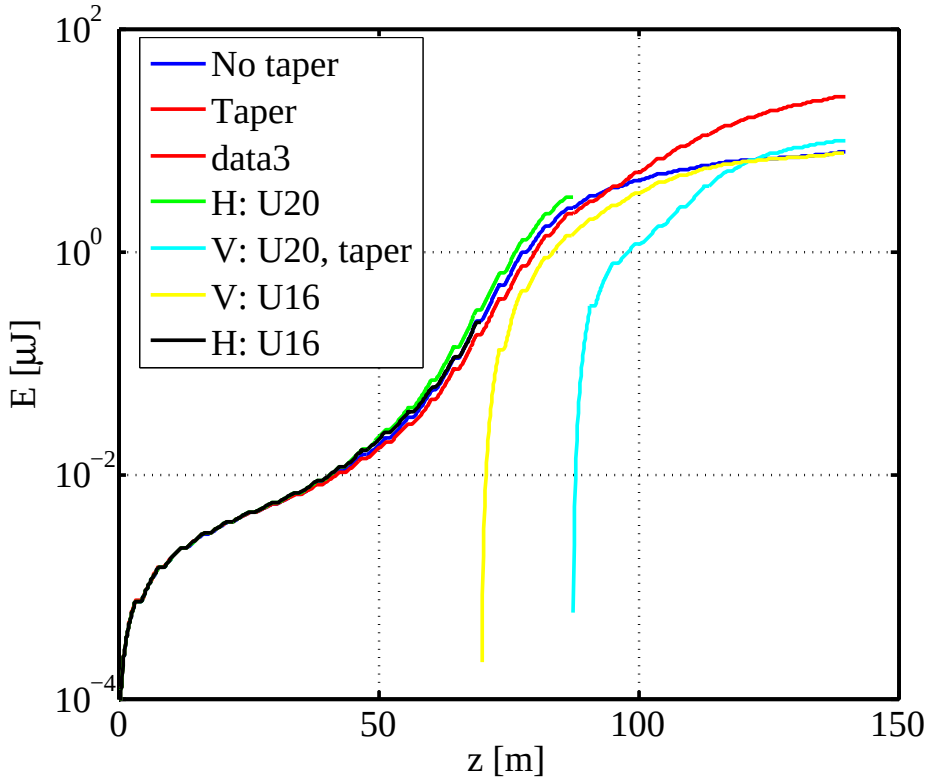

Figure 2: Gain curves using the S2E electron beam. Solid blue: Horizontal polarization to the end. Solid red: Horizontal polarization to the end with a taper. Solid green: Horizontal polarization

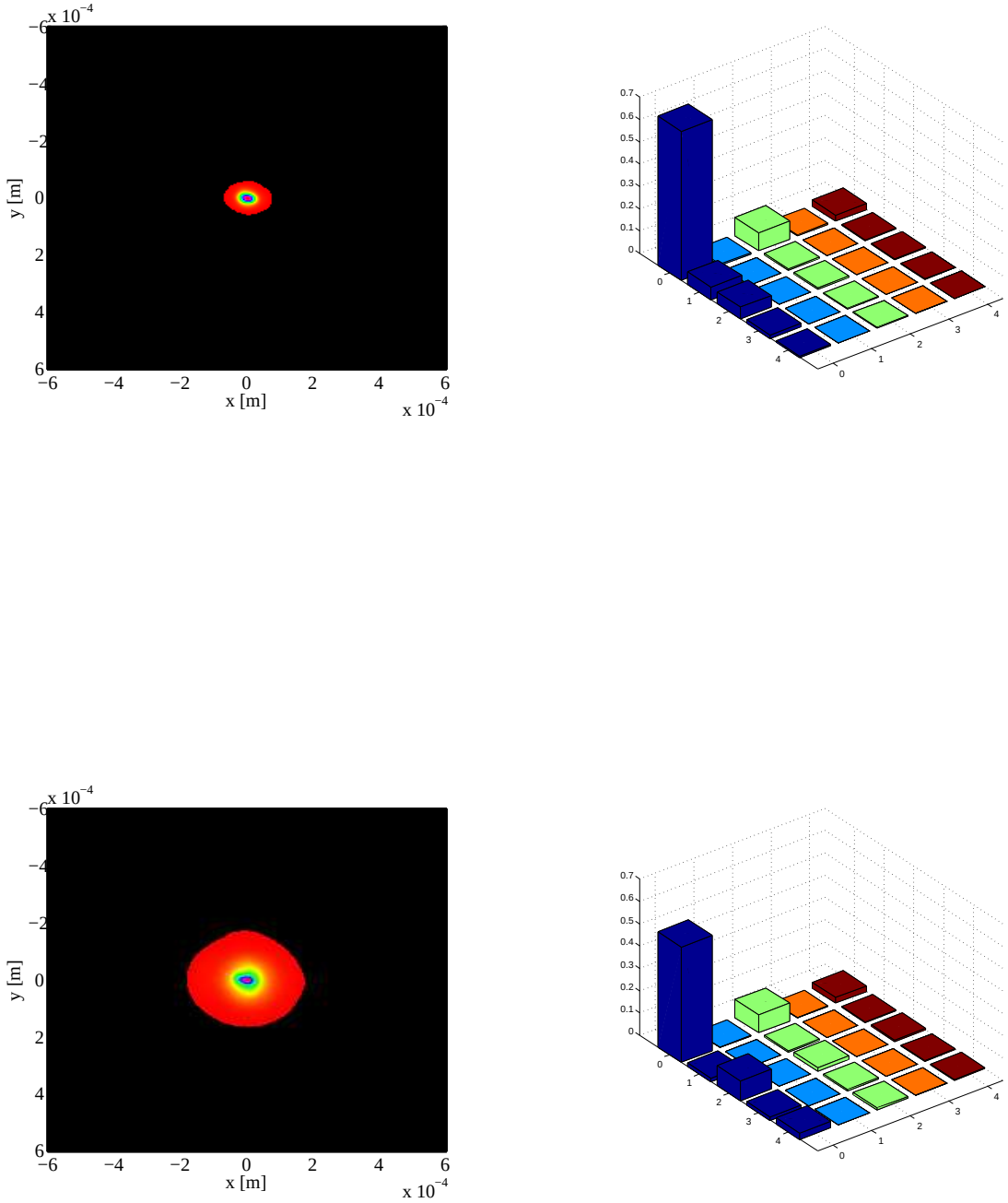

Figure 3: Top row: The projected intensity and mode composition of the horizontally polarized light after undulator 16. Bottom row: The projected intensity and mode composition of the vertically polarized light after undulator 32.

undulator segments need to be vertically polarized in order to recover the performance nominally produced at the high end of the tuning range (5 keV) using a single undulator polarization without a taper. Roughly two undulator sections are needed to recover the FEL energy in vertical polarization from the prebunched beam after the transition from horizontally to vertically polarized undulators. The mode quality of the vertically polarized light, however, is moderately impacted. Making the transition after the 16th undulator section leaves only two undulators to produce seeded bunching if running the beamline in the self-seeded mode of operation. While this should be sufficient, a more detailed study using S2E electron beams from the CuRF linac should be investigated if this option is considered further. Furthermore, the ability to taper when the beamline is tuned towards the lower end of the tuning range will be negatively impacted. In general, we expect better performance with either all horizontally or all vertically polarizing undulators.

Acknowledgments

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