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FEL performance and beam quality assessment of undulator line for the CompactLight facility

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Abstract

- *We assess via simulation studies the performance of a variably polarising APPLE-X afterburner positioned downstream of a helical Super Conducting Undulator (SCU).*
- *We discuss the optimum balance between the active SCU length and the afterburner length, considering the peak brilliance and pulse energy of the output.*
- *We carried out an analysis of the optical beam quality of the afterburner output to determine the design constraints of the photon beamline that delivers the FEL output to the experimental areas.*

CompactLight baseline design

- ◀ Compactness is one of the driving goals of the H2020 CompactLight Project, aiming to design next generation light sources which provide competitive FEL performance.
- ◀ **Super conductive undulator (SCU)** as main undulator (tuned to cover spectral range up to 16 keV) .
- ◀ **APPLE-X afterburner:** to change polarisation (up to 12 keV).
- ◀ Design to be optimised in terms of FEL figures of merit (peak brilliance, pulse energy at highest peak brilliance and total length of the undulator line).

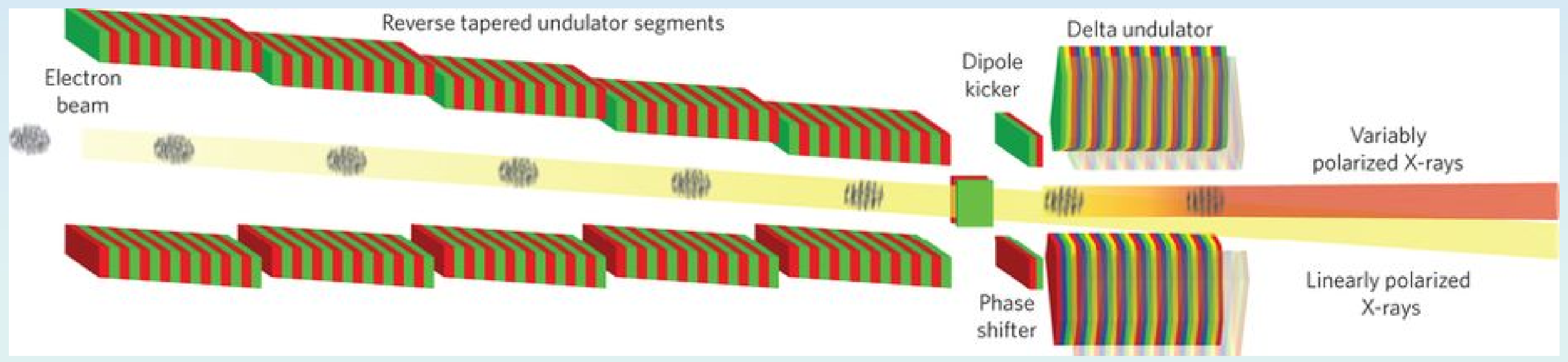

Figure 1: *Reverse taper and beam diverting scheme to achieve variable polarisation. H2020CompactLight baseline undulator line considers a helical SCU as main undulator followed by an APPLE-X to achieve variable polarisation pulses. The inverse taper is one of the solutions to be studied in order to divert the electron beam from the generated radiation at the SCU, [1, 2].*

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Comparison of FEL performance.

Undulator and beam parameters

Table 1: *Undulator parameters defined for SCU and APPLE-X undulator. Here $l_{section}$ is the length of the undulator section, a_w is the undulator parameter, and λ_u is the undulator period.*

Undulator type	a_w		λ_u	$l_{section}$
	SXR	HXR		
Helical SCU	2.42	0.91	13 mm	2.27 m
APPLE-X	1.93	0.507	19 mm	2.28 m

Table 2: *Electron beam and radiation parameters. Here $\epsilon_{x,y}$ corresponds to transverse emittance.*

Electron beam parameter	SXR	HXR
Beam Energy	1.54 GeV	5.5 GeV
Peak Current	5 kA	
Normalised $\epsilon_{x,y}$	0.2 mm − mrad	
RMS slice energy spread	0.04%	0.01%
Charge	75 pC	
Current distribution	Flat-top	
Photon Energy	250 eV	12 keV

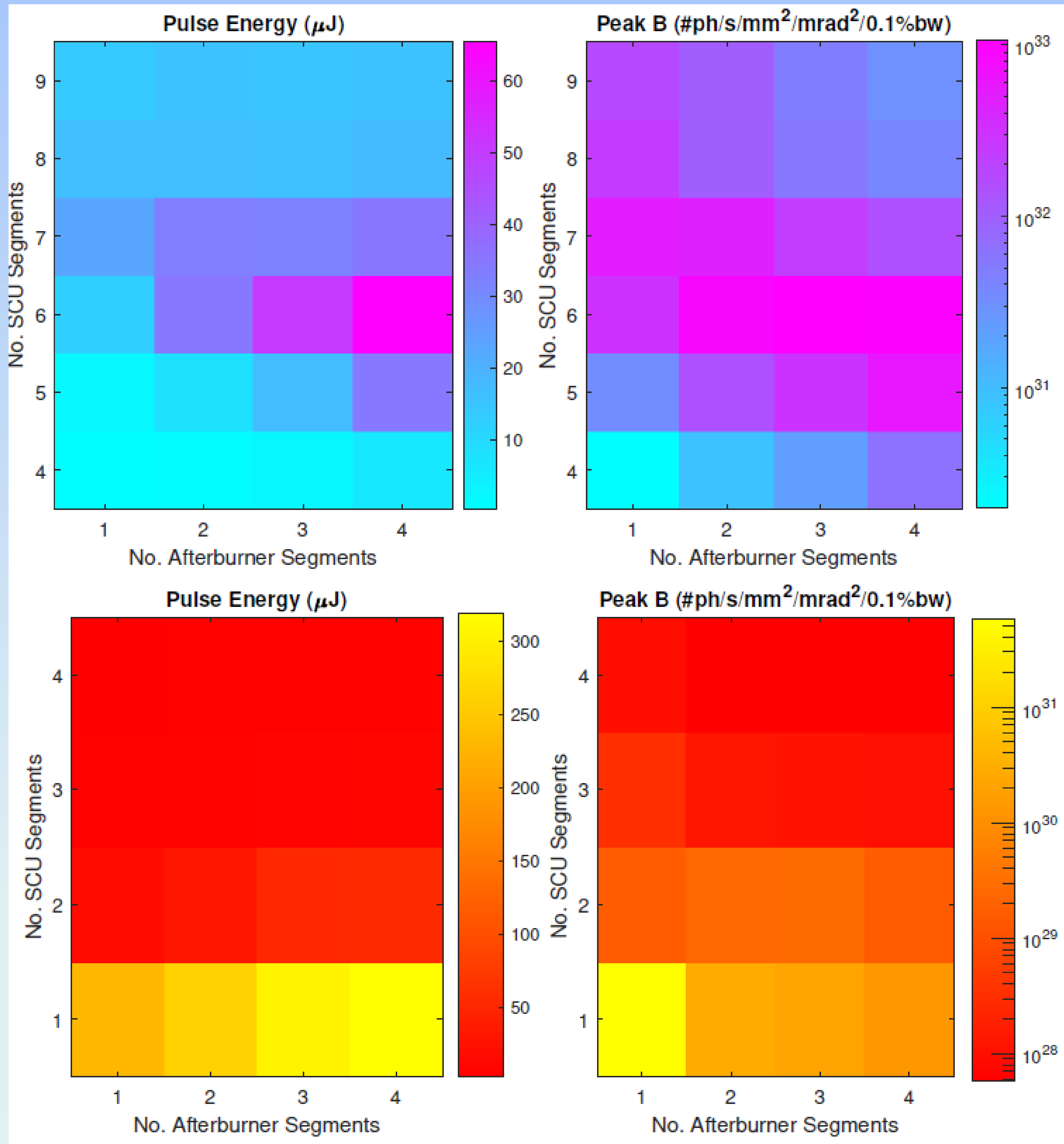

Figure 2: *Top: Afterburner pulse energy and peak brightness in the HXR at 12 keV photon energy, as a function of the number of SCU modules and number of afterburner modules. Bottom: Equivalent results in the SXR at 250 eV photon energy[3].*

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Way of working and baseline design of undulator line

- Optimal baseline undulator design compared to undulator lines comprised by stand-alone SCU and APPLE-X devices for generation of HXR and SXR.
- Time dependent simulations performed in GENESIS v1.3 [4] .
- Radiation coming from the SCU "artificially blocked" $\Rrightarrow$ SCU to prepare the electrons going to the afterburner (no inverse taper or kicker before the afterburner).
- HXR, Helical SCU with $n_{sec} > 6 \Rrightarrow$ **Electrons overbunch before they reach the afterburner.**
- HXR, Helical SCU with with $n_{sec} < 6 \Rrightarrow$ **Prebunching of electrons too weak.** *A really large afterburner will be required to achieve lasing via the FEL interaction.*
- **Optimal configuration for SXR generation: SCU with 1 section and afterburner with 2 sections.**
- Length of optimal baseline undulator line given by the length of the undulator line configuration to generate HXR.

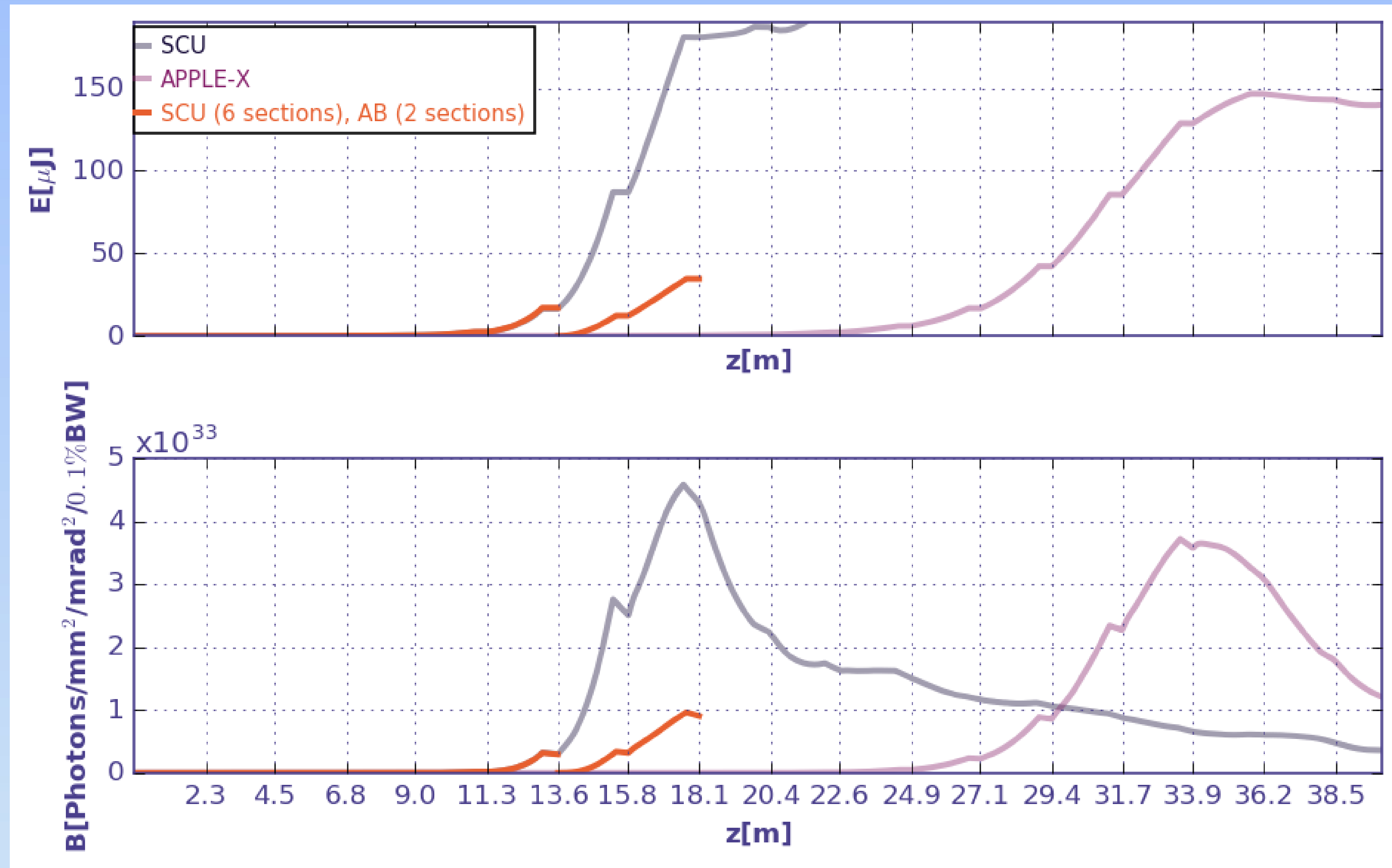

Figure 3: *HXR: Comparison of* $12\,\mathrm{keV}$ *pulse energy (top) and peak brilliance (bottom) for three different scenarios: an SCU, an APPLE-X in vertically planar configuration, and the baseline SCU and APPLE-X configuration (HXR). The tick marks and labels on the z-axis correspond to the locations of the ends of individual undulator modules [3].*

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Compactness and FEL performance

Table 3: *Comparison of FEL performance between the CompactLight baseline undulator line and the APPLE-X undulator in linear vertical configuration.*

Parameter	Baseline	APPLE-X
HXR (12 keV)		
Highest peak brilliance (h.p.b)	9×10^{32}	3×10^{33}
Pulse Energy at h.p.b	35 μJ	125 μJ
Length to h.p.b	18.1 m	33.9 m
SXR (250 eV)		
Highest peak brilliance (h.p.b)	6×10^{31}	10^{32}
Pulse Energy at h.p.b	250 μJ	450 μJ
Length to h.p.b	4.5 m	5.8 m

Compactness and FEL performance

- FEL performance in HXR: Peak brilliance 25 % of the highest peak brilliance from the APPLE-X , Table 3
- HXR baseline undulator line is a 53% shorter than an APPLE-X undulator line, Fig. 3
- FEL performance in SXR: 55% of the highest peak brilliance from the APPLE-X, Table 3.
- **A compromise must be made between compactness and FEL performance** ⇒ shorter undulator line gives linearly polarized radiation but at the cost of reduced pulse energy

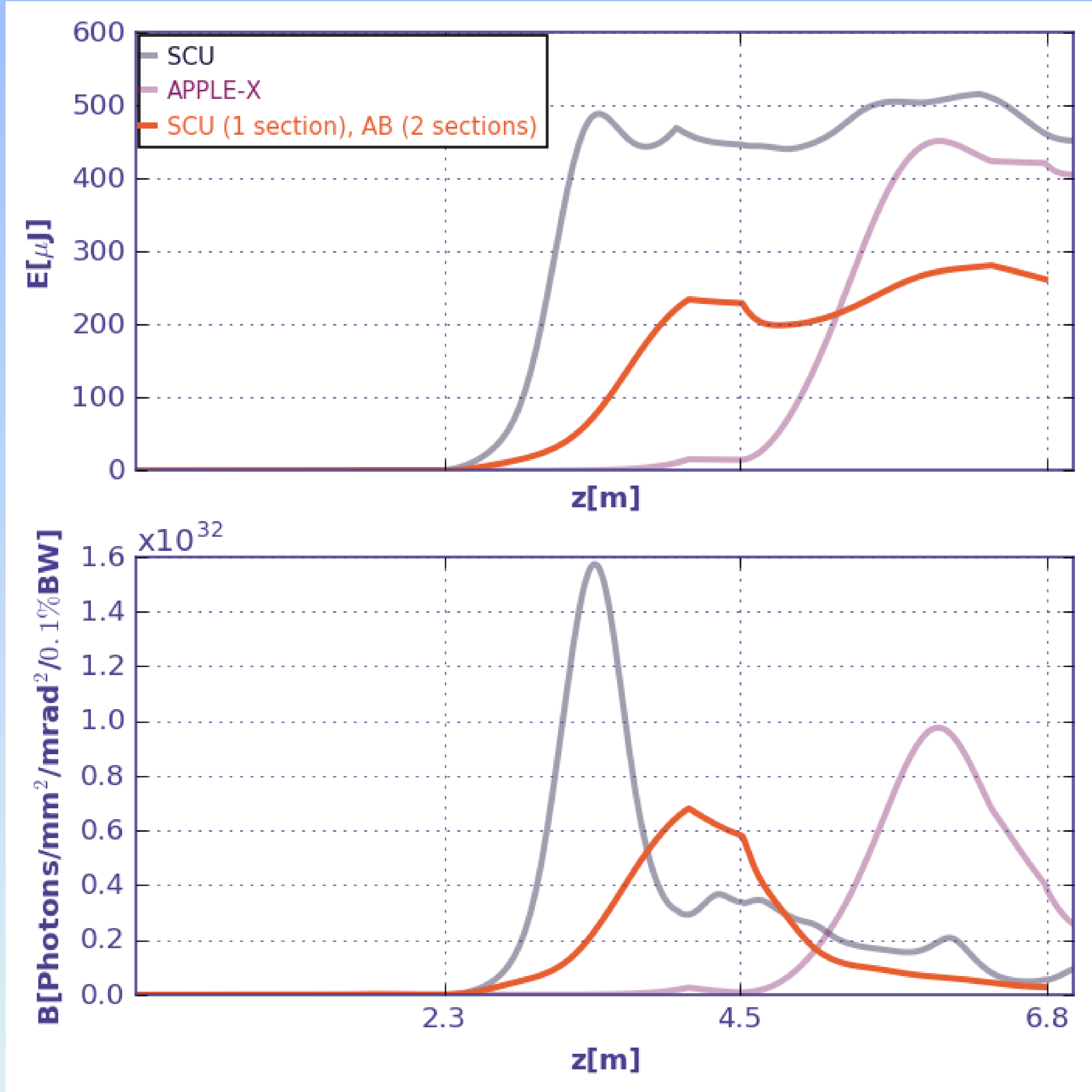

Figure 4: *SXR: Comparison of 250 eV pulse energy (top) and peak brilliance (bottom) for three different scenarios: an SCU, an APPLE-X in vertically planar configuration, and the baseline SCU and APPLE-X configuration (SXR)[3].*

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Beam quality analysis for HXR

M^2 and beam quality for HXR (12 keV)

★ Determination of the M^2 beam quality parameter from the rms of the propagated optical beam in free space, following formalism in [5, 6]

★ Source properties by fitting the evolution of the beam profile ($\sigma_i^2(z) = C_2 z^2 + C_1 z + C_0$) to the measured values of the second moments,[5]

$$*M_i^2 = \frac{2\pi}{\lambda}\sqrt{4C_0C_2 - C_1^2}, \quad z_0 = -\frac{C_1}{2C_2} \quad \sigma_{i_0} = \sqrt{C_0 - \frac{C_1^2}{4C_2}} \tag{1}$$

* M^2 being beam quality coefficient, σ_{i_0}, rms size at the beam waist and z_0 the waist position.

Table 4: *Comparison between optical beam parameters obtained for the baseline design of CompactLight, the helical SCU and APPLE-X undulator lines as stand-alone.*

Parameter	SCU		APPLE-X		SCU+AB	
	x	y	x	y	x	y
M^2	2.27	2.36	2.23	2.19	2.01	2.1
z_0 (m)	-2.19	-2.10	-3.38	-3.44	-2.22	-2.26
σ_{z_0} (μm)	8.96	9.07	10.39	10.02	7.65	8.092

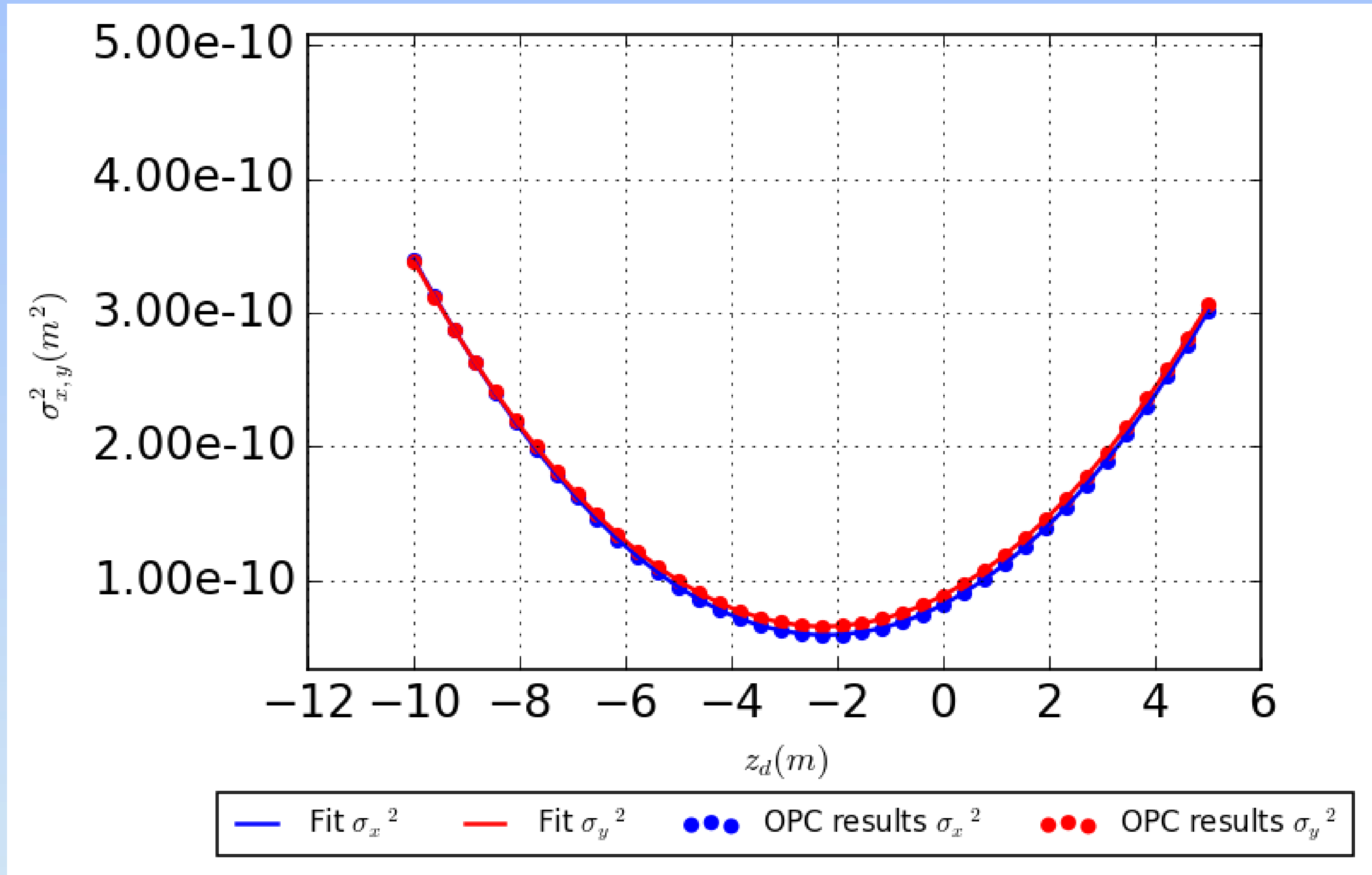

Figure 5: *RMS of the beam against propagating distance from the end of the afterburner for a photon energy of 12 keV.*

Analysis of beam quality for HXR

- **M^2 slightly better for the baseline undulator line design**, Table 4
- OPC: Code run for propagation [7]

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Summary

- For producing variable polarised output, there is a trade-off between the FEL performance and compactness of the undulator line compared to an APPLE-X stand-alone undulator line. However the advantages of the baseline design in terms of alignment with the CompactLight project goal for compactness and its performance in generating circularly polarised light are significantly it its favour.
- Optical beam quality for HXR is shown to improve with the undulator baseline design of CompactLight.

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