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Optical Beam Quality Analysis of the Clara Test Facility using Second Moment Analysis

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Abstract

- *We studied and characterised the FEL optical radiation in simulations of the CLARA FEL test facility under development at Daresbury Laboratory in the UK [1].*
- *We determined the radiation source properties corresponding to the long bunch operation mode via wavefront propagation in free space using OPC (Optical Propagation Code), [2], and second noment analysis.*
- *We found the shortest undulator module length suitable for schemes to be carried out in CLARA, without degrading the beam quality.*
- *We studied the way that different properties of the electron bunches (emittance, peak current, bunch length) affect the optical beam.*
- *We are now able to understand how the optical beam will propagate from the end of the undulator and through the photon transport system to the experimental stations.*

SECOND MOMENT ANALYSIS

Radiation source properties are found 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 profile,[4]

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

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

CLARA LONG BUNCH MODE

- E_{beam} 150-250 MeV.
- Bunch charge 250 pC.
- $\sigma_t = 800$ fs.
- Peak current 125 A.
- $\bar{\epsilon} = 0.5$ mm-mrad.
- E spread= 25 keV.
- λ_u=2.5 cm.
- λ_r: 100 - 400 nm.
- Maximum rms (undulator parameter)= 1.4

PRELIMINARY STUDY

Table 1: *Comparison between optical beam parameters obtained from steady state and time-dependent simulations*

Parameter	Steady state		Time-dependent	
	x	y	x	y
M²	**3.8**	**3.6**	**3.6**	**3.5**
z_0 (m)	-1.85	-1.93	-1.27	-1.27
σ_{z_0} (**μm**)	283	273	274	278

Preliminary study

- **Goal**: Comparison between steady state and time-dependent simulations in GENESIS 1.3 to **demonstrate the validity of time-dependent approach for beam quality calculations**.
- λ_r = 266 nm

Results of the simulations (Table 1)

- M² parameters for the steady state and time-dependent simulations are quite close to each other (relative difference of 5.2% and 2.8% in x and y, respectively.)
- The M² parameters in x and y are large compared to the ideal TEM_{00} Gaussian mode propagating in free space (M² =1).

IMPACT OF UNDULATOR MODULE LENGTH

Table 2: *Undulator parameters for the preliminary study in last section and each proposed undulator module. There are 1.5 undulator periods (λ_u) end pieces for all cases, per end.*

Parameter	Previous study	Undulator module length		
		0.5 m	0.75 m	1 m
λ_u (m)	0.0275	0.025	0.025	0.025
Active periods	28	17	27	37
Break sections (m)	0.4125	0.5	0.5	0.5
x/y quad. grad. (T/m)	8/10	13/13	10/10	9/9

Goal: Choose the undulator module length (proposed: 0.5, 0.75 and 1 m) with the highest beam quality (**Minimum M² at maximum brightness**).

Comparison of M² for different modules (Table 3)

- M² at maximum brightness for the 0.5 m module (in Table 3) has the largest M² of all modules (1.9 times larger than the M² obtained for the 0.75 m module in x and y). Not considered further as alternative.
- Fluctuation of $\Delta M_{x,y}{}^2 = |M_x{}^2 - M_y{}^2|$, (in Fig. 1) around a non-zero value due to the difference in focusing of the electron beam for both transversal directions while traversing the FODO cell (asymmetry in beam quality).
- The 0.75 and 1 m modules have similar beam quality (relative difference between M² of both modules less than 1% in x and 3.1% in y). 0.75 m module chosen as it is compatible with proposed schemes **without degrading beam quality**.

Table 3: *Comparison between source properties at n_{sec} at maximum brightness for the proposed modules.*

L (m)	$M_x{}^2$	$M_y{}^2$	z_{0_x} (m)	z_{0_y} (m)	$\sigma_{z_{0x}}$ (μm)	$\sigma_{z_{0y}}$ (μm)
0.5	**8.32**	**7.29**	-1.99	-2.1	509	471
0.75	**4.40**	**3.80**	-1.41	-1.50	300	287
1	**4.41**	**3.92**	-1.86	-1.97	348	329

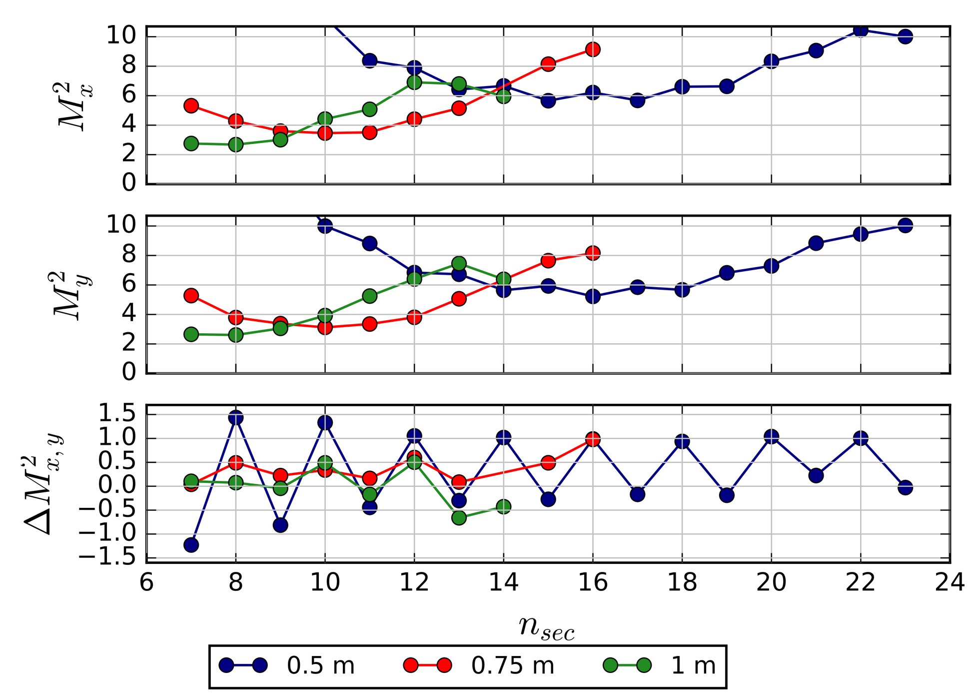

Figure 1: *M² in x (top) and y (middle) and their difference $\Delta M_{x,y}{}^2 = M_x{}^2 - M_y{}^2$ (bottom) in terms of n_{sec} (for 0.5, 0.75 and 1 m modules).*

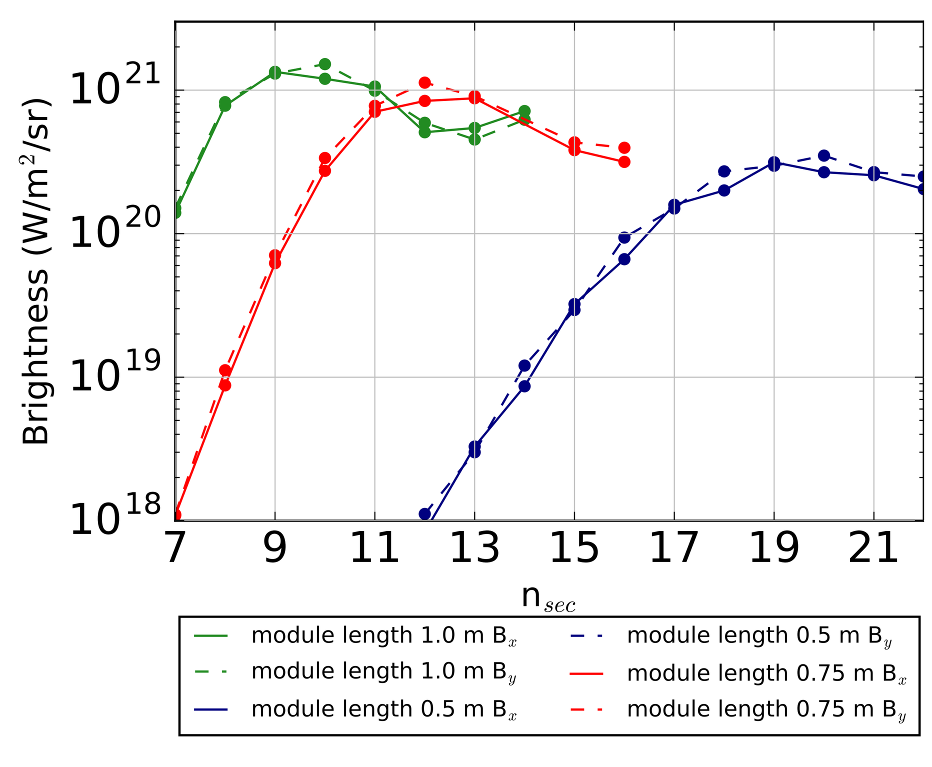

Figure 2: *Brightness for the modules as a function of n_{sec}.*

IMPACT OF BEAM PARAMETERS

Electron beam scenarios

Goal: Study the impact of electron beam properties on optical beam quality.

Scenarios

- (A) Increased emittance bunch (0.8 mm-mrad).
- (B) Reduced quad strength (from 10 to 2 T/m, e-beam bigger in one plane).
- (C) Symmetric undulator focusing.
- (D) Bunch with double peak current and half the bunch length.

Table 4: *Beam quality coefficient at n_{sec} corresponding to minimum M² and maximum brightness for all scenarios.*

Scenario	Minimum M²		Maximum Brightness	
	$M_x{}^2$	**$M_y{}^2$**	**$M_x{}^2$**	**$M_y{}^2$**
Scenario (A)	3.61	3.34	**4.65**	**3.86**
Scenario (B)	3.67	2.31	**4.76**	**2.77**
Scenario (C)	3.54	3.57	**4.41**	**4.11**
Scenario (D)	3.04	2.69	**3.38**	**3.21**

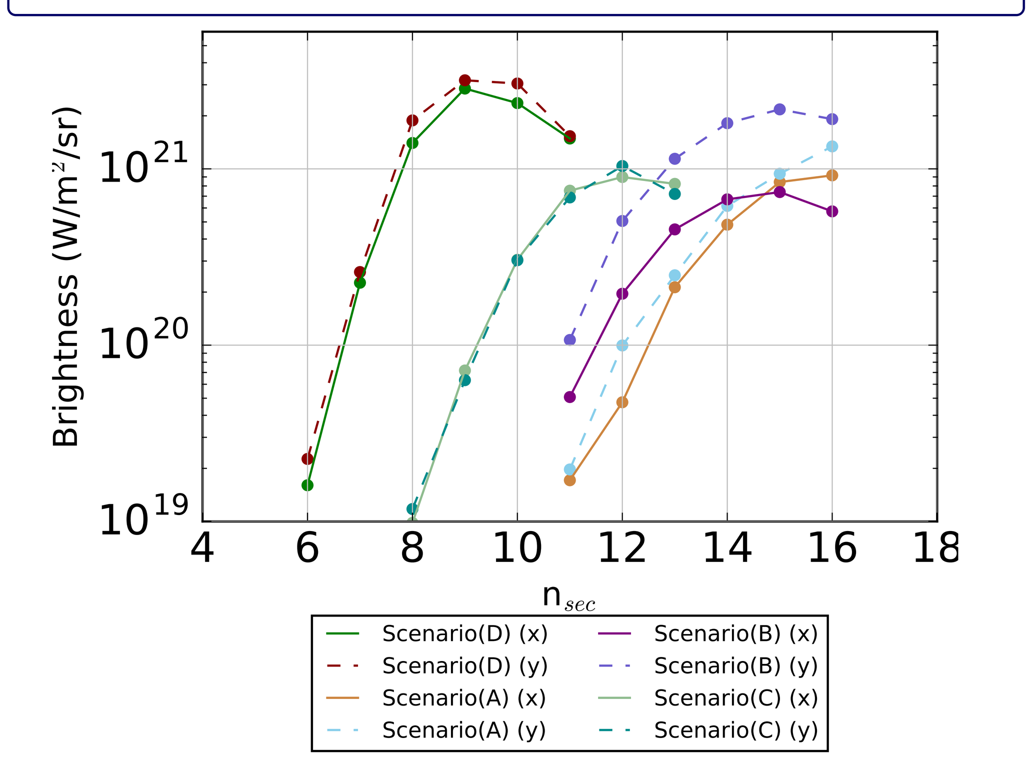

Figure 3: *Brightness as a function of n_{sec} (for the electron beam scenarios).*

M² (Table 4) compared to 0.75 m module (Table 3)

- Scenario (A): Degradation of beam quality compared to the nominal 0.75 m module (relative difference of M² in x around 5.7% and 1.5% in y).
- Scenario (B): Vast improvement of beam quality in y (relative difference compared to nominal 0.75 m module: 27%). Degradation in x (relative difference of 8.2% compared to the same nominal case).
- Scenario (C): No improvement of beam quality in either of the planes. Relative difference of 8% in y.
- Scenario (D): Minimum M² of all proposed cases. Improvement in beam quality in both tranversal planes (M² reduced to 0.77 and 0.84 of the nominal case in x and y, respectively).

Summary

- Three different module lengths (0.5, 0.75 and 1 m) were assessed to determine the impact of the undulator design on the beam quality.
- The 0.75 m undulator module was chosen, optimum for the different R&D topics proposed (mode-locking and HB SASE), without degrading the beam quality compared to longer modules.

References

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