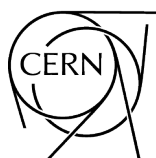




## **Free Electron Lasers and Energy Recovery Linacs**

Hamburg, Germany  
31 May– 10 June 2016

Editor: R. Bailey



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## **Abstract**

These proceedings collate lectures given at the course on Free Electron Lasers and Energy Recovery Linacs (FELs and ERLs), organised by the CERN Accelerator School (CAS). The course was held at the Hotel Scandic Hamburg Emporio, Hamburg, Germany from 31 May to 10 June 2016, in collaboration with DESY. Following introductory lectures on radiation issues, the basic requirements on linear accelerators and ERLs are discussed. Undulators and the process of seeding and lasing are then treated in some detail, followed by lectures on various beam dynamics and controls issues.



## Preface

The aim of the CERN Accelerator School (CAS) is to collect, preserve and disseminate the knowledge accumulated in the world's accelerator laboratories over the years. This applies not only to general accelerator physics, but also to related sub-systems and associated technologies, and to the development of novel, dedicated facilities. These wider aims are achieved by means of specialized courses currently held twice per year. The topic of the first 2016 specialized course was Free Electron Lasers and Energy Recovery Linacs (FELs and ERLs) and was held at the Hotel Scandic Hamburg Emporio, Hamburg, Germany from 31 May to 10 June 2016.

The course was made possible through the fruitful collaboration with DESY, in particular through the efforts of Ruth Mundt, Christel Oevermann and Kay Wittenburg.

A full day visit to DESY and the European XFEL in Hamburg Bahrenfeld provided a practical insight into the field. Participants also had the opportunity to work on realistic case studies as an integral part of the programme. For the organisation and execution of the latter we are indebted to Sven Reiche from PSI. The backing of the CERN management and the guidance of the CAS Advisory and Programme Committees enabled the course to take place, while the attention to detail of the Local Organising Committee and the management and staff of the Hotel Scandic Hamburg Emporio ensured that the school was held under optimum conditions.

Special thanks must go to the lecturers for the preparation and presentation of the lectures, even more so to those who have written a manuscript for these proceedings.

For the production of the proceedings we are indebted to the efforts of Barbara Strasser and to the CERN Publishing Service, especially Valeria Brancolini for her very positive and efficient collaboration.

These proceedings have been published in paper (black and white) and electronic form. The electronic version, with full colour figures, can be found at <https://e-publishing.cern.ch/index.php/CYRSP/issue/view/47>.

Roger Bailey, Editor  
CERN Accelerator School

PROGRAMME  
Free Electron Lasers and Energy Recovery Linacs (FELs and ERLs), 31 May – 10 June, 2016

Time	Tuesday 31 May	Wednesday 1 June	Thursday 2 June	Friday 3 June	Saturday 4 June	Sunday 5 June	Monday 6 June	Tuesday 7 June	Wednesday 8 June	Thursday 9 June	Friday 10 June
08:30		Opening Talks	Wakefields	Lasers in FEL Facilities	Concept of ERL		Quantum FEL	LLRF Controls and Feedbacks	Advanced Undulator Concepts	Undulator Tapering	
09:30		Electromagnetic Theory	U. Van Rienen	M. Divall	A. Jankowiak	<b>E</b>	G. Robb	S. Pfeiffer	J. Rosenzweig	M. Yurkov	<b>D</b>
09:30	<b>A</b>		Linear Beam Optics I	Motion in an Undulator	High Gain Regime I	<b>X</b>	High Gain Regime 3D	Coherence Properties of the Radiation from SASE FEL	Photon Beam Transport	Cystallography and Molecular Imaging using X-Ray Lasers	
10:30		W. Herr	B. Holzer	S. Reiche	K.-J. Kim	<b>C</b>	K.-J. Kim	M. Yurkov	M. Yabashi	T. White	<b>P</b>
11:00	<b>R</b>	<b>COFFEE</b>	<b>COFFEE</b>	<b>COFFEE</b>	<b>COFFEE</b>		<b>COFFEE</b>	<b>COFFEE</b>	<b>COFFEE</b>	<b>COFFEE</b>	<b>P</b>
	<b>R</b>	Special Relativity	Linear Beam Optics II	Pendulum Equations and Low Gain Regime	High Gain Regime II	<b>U</b>	Temporal Coherence	The European XFEL	Electron Beam Diagnostics	Machine Protection	<b>A</b>
12:00	<b>I</b>	W. Herr	B. Holzer	S. Reiche	K.-J. Kim	<b>R</b>	K.-J. Kim	H. Weise	R. Ischebeck	L. Froehlich	<b>R</b>
12:00	<b>V</b>	Synchrotron Radiation I	Coherence in Beams	Bunch Length Compressors	Seeding Schemes I	<b>R</b>	Experience from FLASH: FEL Theory versus Experiment	Plasma Wake Driven FEL	Timing and Synchronisation	Different ERL Applications	<b>T</b>
13:00	<b>A</b>	L. Rivkin	J. Rossbach	S. Di Mitri	L. Giannessi	<b>S</b>	M. Yurkov	R. Assmann	M. Bellaveglia	K. Aulenbacher	<b>R</b>
	<b>L</b>	<b>LUNCH</b>	<b>LUNCH</b>	<b>LUNCH</b>	<b>LUNCH</b>		<b>LUNCH</b>	<b>LUNCH</b>	<b>LUNCH</b>	<b>LUNCH</b>	<b>LUNCH</b>
14:30	<b>D</b>	Synchrotron Radiation II	Space Charge Mitigation	Coherent Synchrotron Radiation and Microbunching Instability	Seeding Schemes II	<b>I</b>	XFEL		Case Study Work	Case Study Presentations	<b>E</b>
15:30		L. Rivkin	M. Ferrario	S. Di Mitri	L. Giannessi	<b>O</b>	K.-J. Kim	<b>V I S I T T O</b>			
15:30	<b>A</b>	Undulators	SC Cavities (High Q)	Electron Sources and Injector Systems	Beam Dynamics of ERLs	<b>N</b>	Case Study Work		Case Study Work	Case Study Presentations	<b>D</b>
16:30	<b>Y</b>	J. Pflueger	J. Knobloch	E. Chiodroni	A. Jankowiak			<b>D E S Y</b>			<b>A</b>
		<b>TEA</b>	<b>TEA</b>	<b>TEA</b>	<b>TEA</b>		<b>TEA</b>	<b>TEA</b>	<b>TEA</b>	<b>TEA</b>	<b>TEA</b>
17:00	<b>Registration</b>	Linear Accelerator Technology	Historical Survey of FELs	Energy Efficiency	Transverse Optics in the ERL Arcs		Case Study Work		Case Study Work	Seminar Gravitational Waves	<b>Y</b>
18:00		D. Alesini	M. Couprie	E. Jensen	A. Valloni					R. Schnabel	
18:30		Case Study Introduction									
19:30		<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>	<b>Dinner</b>

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