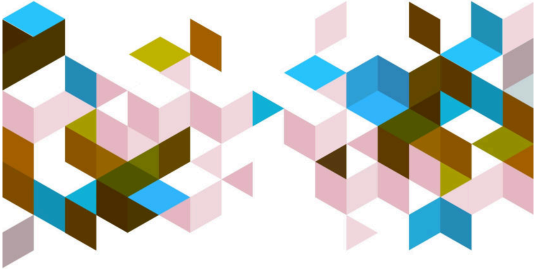
European XFEL



eurizon

European network
for developing new horizons for RIs

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 871072

Introduction to X-ray FELs and the European XFEL

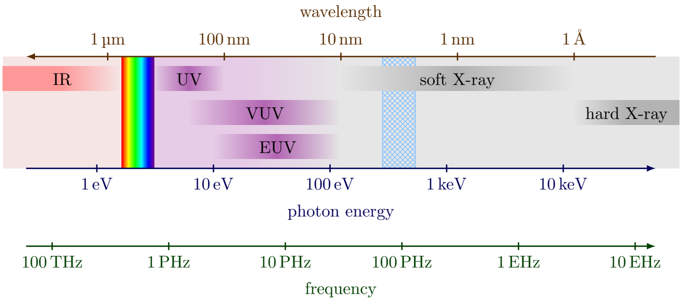
Eurizon 2020+ workshop on
FEL linac driver and FEL physics applications

Fabian Pannek

European XFEL

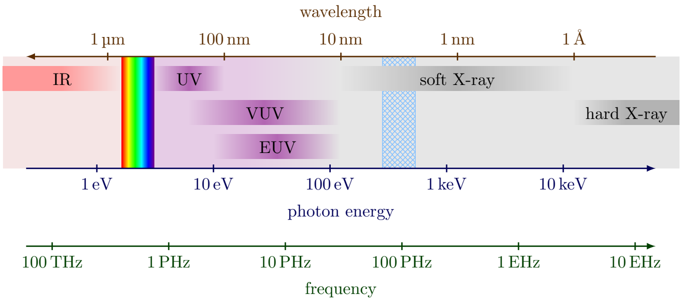
January 2024

Electromagnetic Spectrum



spectral ranges according to ISO-21348:2007

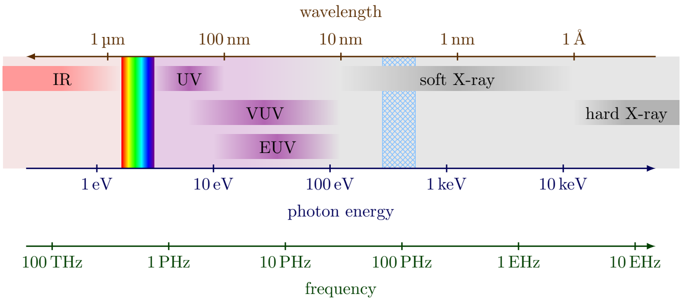
Electromagnetic Spectrum



- Soft and hard X-ray spectral range
  - plenitude of atomic resonances and high absorption
  - applications in biology, chemistry, material-, nano-, energy science, . . .

spectral ranges according to ISO-21348:2007

Electromagnetic Spectrum



- Soft and hard X-ray spectral range
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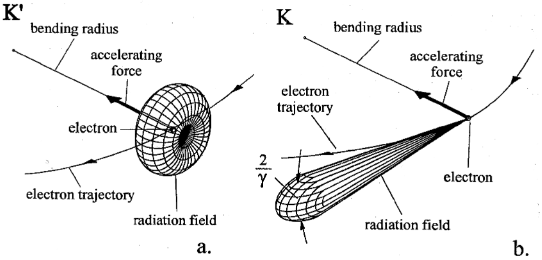
- Free-Electron Lasers (FELs): femtosecond, laserlike, high-intense pulses

spectral ranges according to ISO-21348:2007

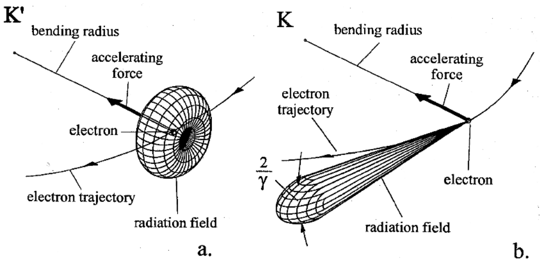
Contents

Synchrotron Radiation



Wille, K. (2000): The Physics of Particle Accelerators: An Introduction.

Synchrotron Radiation



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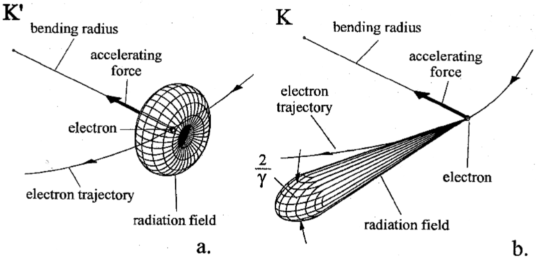

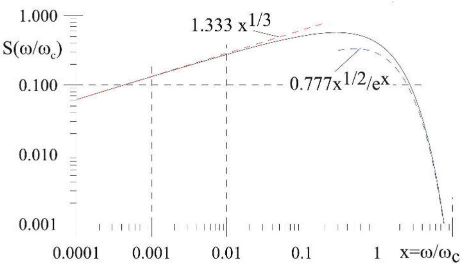

- acceleration of relativistic electron bunch perpendicular to velocity
  - bending magnets
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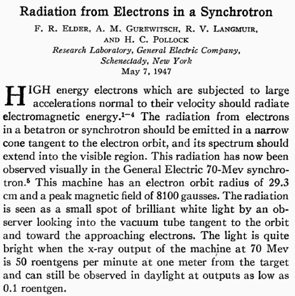
- short pulse, broad spectrum with $\omega_c \propto \frac{\gamma^3}{\rho_0}$

Wille, K. (2000): The Physics of Particle Accelerators: An Introduction.

Wiedemann, H. (2015). Particle accelerator physics, 4th edition

First Generation Light Sources



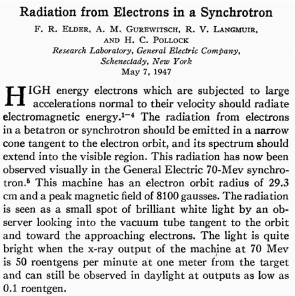
Radiation from Electrons in a Synchrotron

F. R. Elder, A. M. Gurewitsch, R. V. Langmuir,
and H. C. Pollock
Research Laboratory, General Electric Company,
Schenectady, New York
May 7, 1947

HIGH energy electrons which are subjected to large accelerations normal to their velocity should radiate electromagnetic energy.[1–4] The radiation from electrons in a betatron or synchrotron should be emitted in a narrow cone tangent to the electron orbit, and its spectrum should extend into the visible region. This radiation has now been observed visually in the General Electric 70-Mev synchrotron.[5] This machine has an electron orbit radius of 29.3 cm and a peak magnetic field of 8100 gausses. The radiation is seen as a small spot of brilliant white light by an observer looking into the vacuum tube tangent to the orbit and toward the approaching electrons. The light is quite bright when the x-ray output of the machine at 70 Mev is 50 roentgens per minute at one meter from the target and can still be observed in daylight at outputs as low as 0.1 roentgen.

- SR visually observed in 1947

First Generation Light Sources



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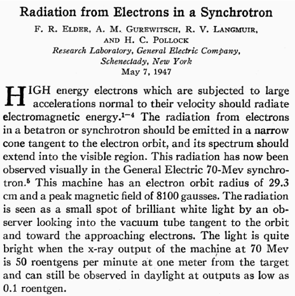

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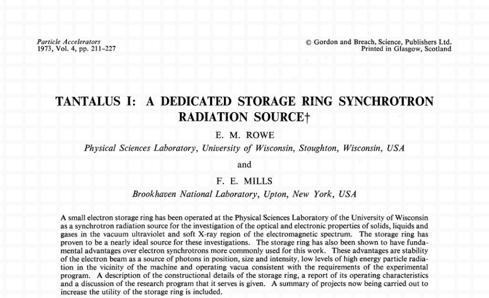

Particle Accelerators
1973, Vol. 4, pp. 211–227

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Printed in Glasgow, Scotland

TANTALUS I: A DEDICATED STORAGE RING SYNCHROTRON RADIATION SOURCE†

E. M. ROWE
Physical Sciences Laboratory, University of Wisconsin, Stoughton, Wisconsin, USA
and
F. E. MILLS
Brookhaven National Laboratory, Upton, New York, USA

A small electron storage ring has been operated at the Physical Sciences Laboratory of the University of Wisconsin as a synchrotron radiation source for the investigation of the optical and electronic properties of solids, liquids and gases in the vacuum ultraviolet and soft X-ray region of the electromagnetic spectrum. The storage ring has proven to be a nearly ideal source for these investigations. The storage ring has also been shown to have fundamental advantages over electron synchrotrons more commonly used for this work. These advantages are stability of the electron beam as a source of photons in position, size and intensity, low levels of high energy particle radiation in the vicinity of the machine and operating vacua consistent with the requirements of the experimental program. A description of the constructional details of the storage ring, a report of its operating characteristics and a discussion of the research program that it serves is given. A summary of projects now being carried out to increase the utility of the storage ring is included.

- SR visually observed in 1947
- nuisance in circular accelerators
- used parasitical at storage rings
- 1968: first storage ring exclusively dedicated to SR

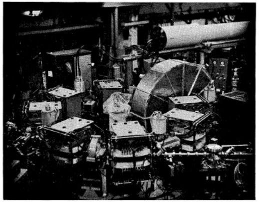
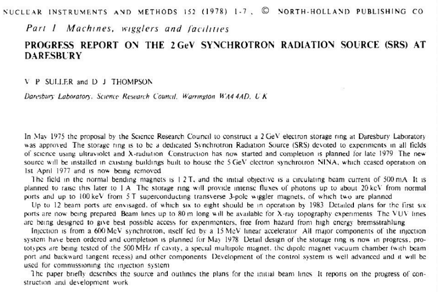


FIG. 1. Storage ring. Photon beam lines and separation chambers appear at lower right and left. Cylindrical object at top is the inflector spark gap energy storage line enclosure.

Second Generation Light Sources

- 1980s: second generation light sources
- 1980: SRS, first synchrotron light source of the second generation
- radiation produced mainly in bending magnets



NUCLEAR INSTRUMENTS AND METHODS 152 (1978) 1-7, © NORTH-HOLLAND PUBLISHING CO

Part I Machines, wigglers and facilities

PROGRESS REPORT ON THE 2 GeV SYNCHROTRON RADIATION SOURCE (SRS) AT DARESBURY

V P SULLER and D J THOMPSON

Daresbury Laboratory, Science Research Council, Warrington WA4 4AD, U K

In May 1975 the proposal by the Science Research Council to construct a 2 GeV electron storage ring at Daresbury Laboratory was approved The storage ring is to be a dedicated Synchrotron Radiation Source (SRS) devoted to experiments in all fields of science using ultraviolet and X-radiation Construction has now started and completion is planned for late 1979 The new source will be installed in existing buildings built to house the 5 GeV electron synchrotron NINA, which ceased operation on 1st April 1977 and is now being removed

The field in the normal bending magnets is 1 2 T, and the initial objective is a circulating beam current of 500 mA It is planned to raise this later to 1 A The storage ring will provide intense fluxes of photons up to about 20 keV from normal ports and up to 100 keV from 5 T superconducting transverse 3-pole wiggler magnets, of which two are planned

Up to 12 beam ports are envisaged, of which six to eight should be in operation by 1983 Detailed plans for the first six ports are now being prepared Beam lines up to 80 m long will be available for X-ray topography experiments The VUV lines are being designed to give best possible access for experimenters, free from hazard from high energy bremsstrahlung

Injection is from a 600 MeV synchrotron, itself fed by a 15 MeV linear accelerator All major components of the injection system have been ordered and completion is planned for May 1978 Detail design of the storage ring is now in progress, prototypes are being tested of the 500 MHz rf cavity, a special multipole magnet, the dipole magnet vacuum chamber (with beam port and backward tangent recess) and other components Development of the control system is well advanced and it will be used for commissioning the injection system

The paper briefly describes the source and outlines the plans for the initial beam lines It reports on the progress of construction and development work

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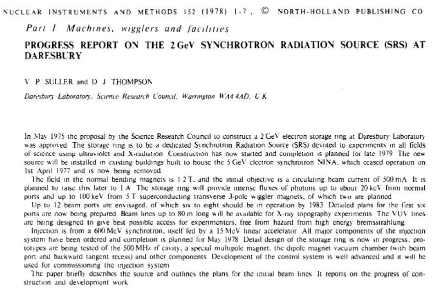

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The field in the normal bending magnets is 1.2 T, and the initial objective is a circulating beam current of 500 mA. It is planned to raise this later to 1 A. The storage ring will provide intense fluxes of photons up to about 20 keV from normal ports and up to 100 keV from 5 T superconducting transverse 3-pole wiggler magnets, of which two are planned.

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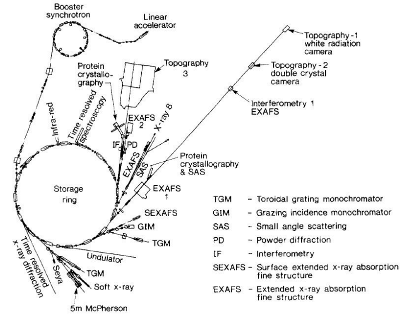
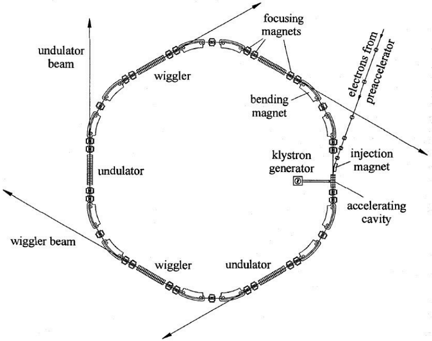


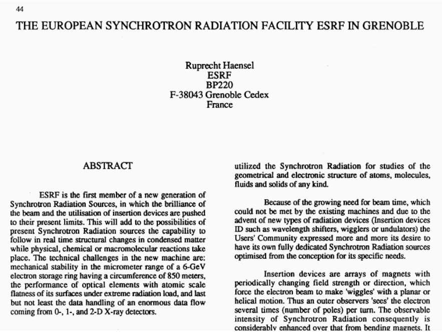
Fig. 1. Layout of the SRS and beamlines.

D. M. P. Holland: The Daresbury Synchrotron Radiation Source, Physica Scripta. Vol. 36, 22-35, 1987

Third Generation Light Sources

- straight sections for insertion devices
    - undulators, wigglers
- 1992: ESRF, first synchrotron of the third generation type





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THE EUROPEAN SYNCHROTRON RADIATION FACILITY ESRF IN GRENOBLE

Ruprecht Haensel
ESRF
BP220
F-38043 Grenoble Cedex
France

ABSTRACT

ESRF is the first member of a new generation of Synchrotron Radiation Sources, in which the brilliance of the beam and the utilisation of insertion devices are pushed to their present limits. This will add to the possibilities of present Synchrotron Radiation sources the capability to follow in real time structural changes in condensed matter while physical, chemical or macromolecular reactions take place. The technical challenges in the new machine are: mechanical stability in the micrometer range of a 6-GeV electron storage ring having a circumference of 850 meters, the performance of optical elements with atomic scale flatness of its surfaces under extreme radiation load, and last but not least the data handling of an enormous data flow coming from 0-, 1-, and 2-D X-ray detectors.

utilized the Synchrotron Radiation for studies of the geometrical and electronic structure of atoms, molecules, fluids and solids of any kind.

Because of the growing need for beam time, which could not be met by the existing machines and due to the advent of new types of radiation devices (Insertion devices ID such as wavelength shifters, wigglers or undulators) the Users' Community expressed more and more its desire to have its own fully dedicated Synchrotron Radiation sources optimised from the conception for its specific needs.

Insertion devices are arrays of magnets with periodically changing field strength or direction, which force the electron beam to make 'wiggles' with a planar or helical motion. Thus an outer observers 'sees' the electron several times (number of poles) per turn. The observable intensity of Synchrotron Radiation consequently is considerably enhanced over that from bending magnets. It

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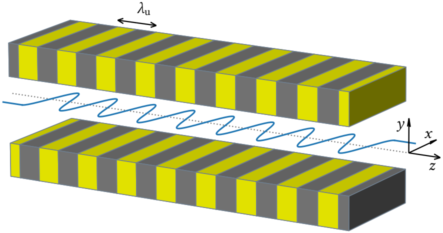
Undulator Radiation - Wavelength

- relativistic electron bunch
- alternating magnetic field
- sinusoidal electron trajectory



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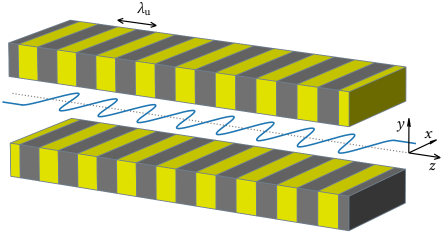
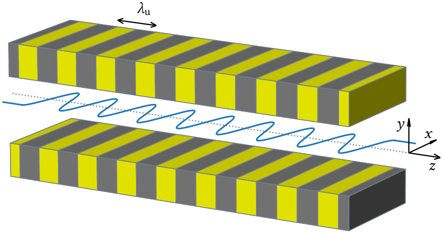


- dipole radiation in electron rest frame
  - Lorentz contracted undulator period: $\lambda_e \propto \frac{\lambda_u}{\gamma}$

Undulator Radiation - Wavelength



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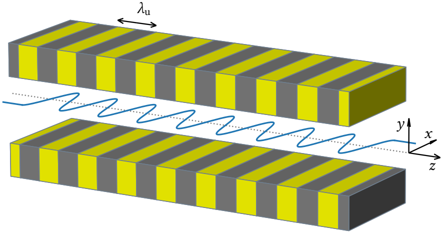

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- wavelength of undulator radiation:
  - undulator parameter $K \propto \lambda_u B$
  - radiation angle θ, on-axis: $\theta = 0$

$$\boxed{\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)}$$

Undulator Radiation - Characteristics

- tunable wavelength: $\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$
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- intensity $I \propto N_\mathrm{e}$
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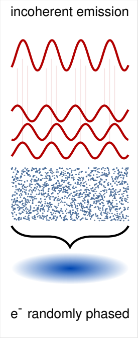

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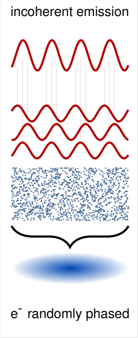
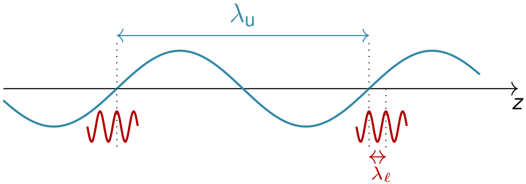
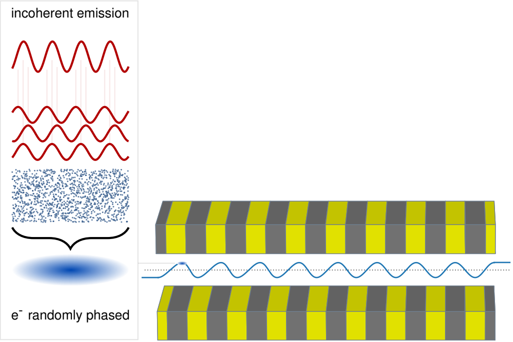
- intensity $I \propto N_e$
- electrons without any positional order
- radiation from a single electron is coherent:
  - light wave slips ahead w.r.t. emitting electron by λ_ℓ per λ_u





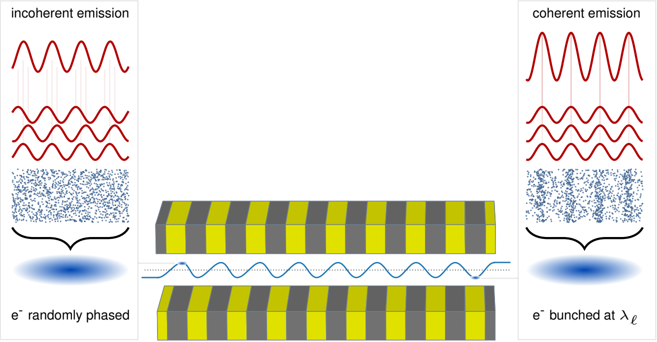
Free-Electron Laser



undulator tuned to

$$\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

Free-Electron Laser



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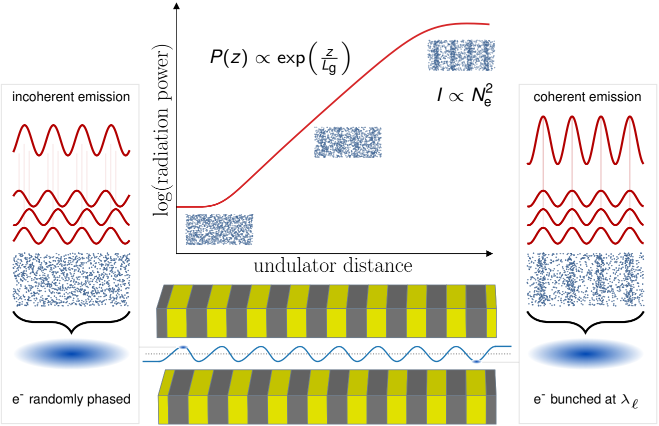
Free-Electron Laser

acts as amplifier



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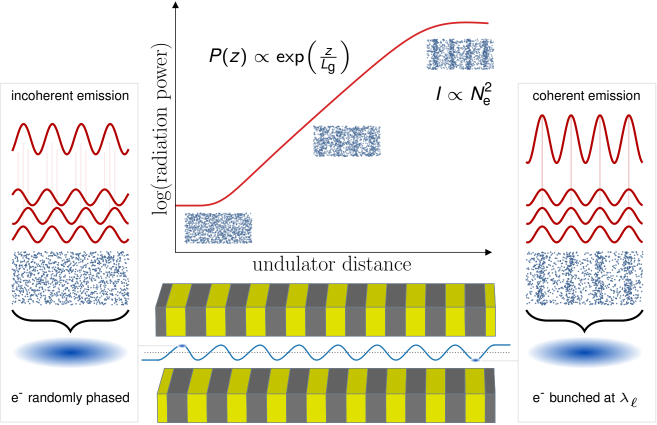
Free-Electron Laser

acts as amplifier

electrons move in radiation field



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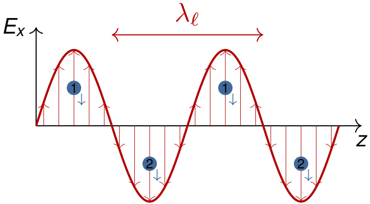
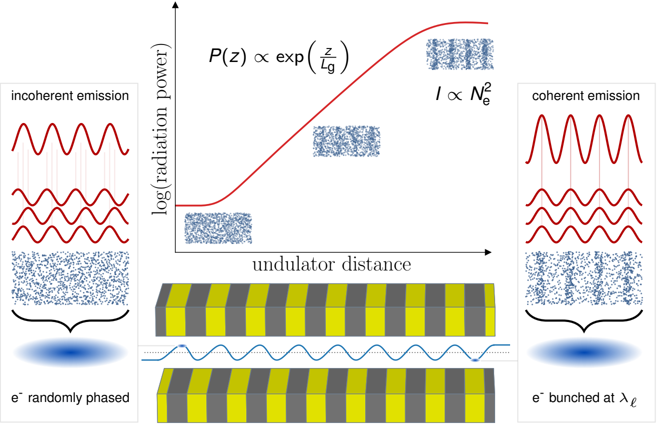


Free-Electron Laser

acts as amplifier

electrons move in radiation field

energy modulation



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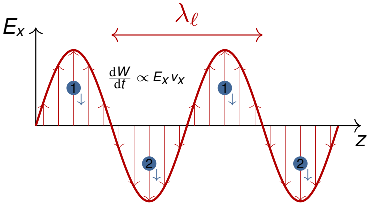


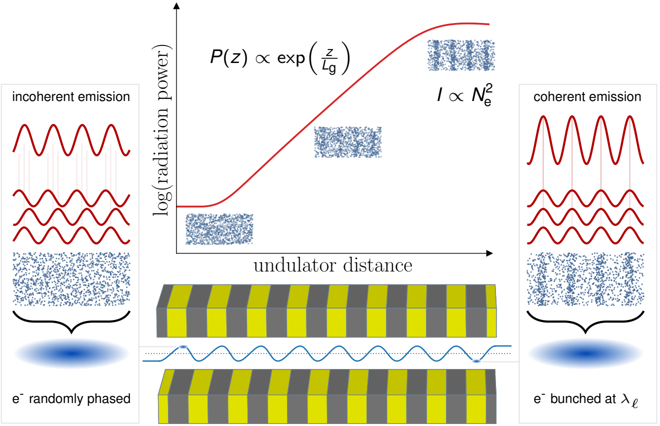
e_1^- : gains energy

e_2^- : loses energy

Free-Electron Laser

European network
for developing new horizons for RIs

acts as amplifier



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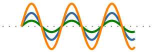
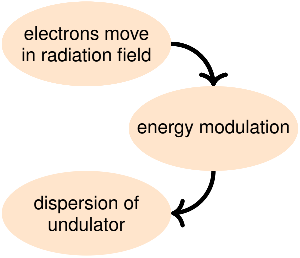
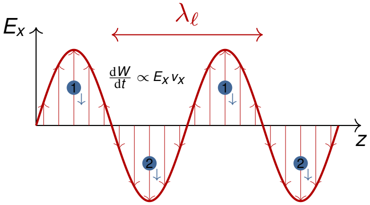
dispersion: 



electrons move in radiation field

energy modulation

dispersion of undulator

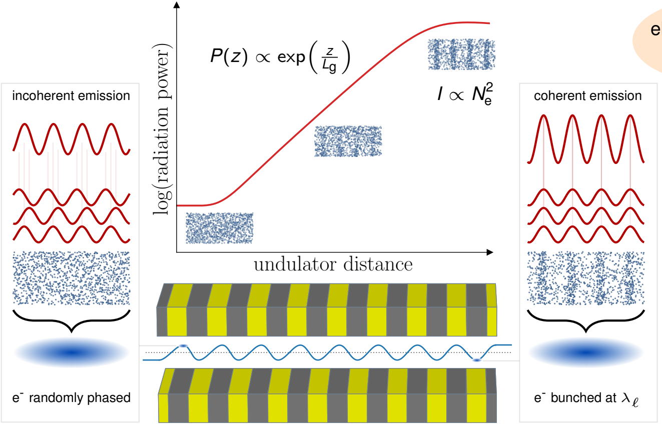


e_1^- : gains energy

e_2^- : loses energy

Free-Electron Laser

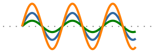
acts as amplifier

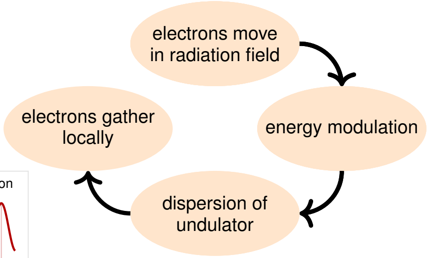


undulator tuned to

$$\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

dispersion:



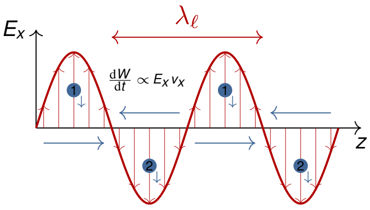


electrons move in radiation field

energy modulation

dispersion of undulator

electrons gather locally

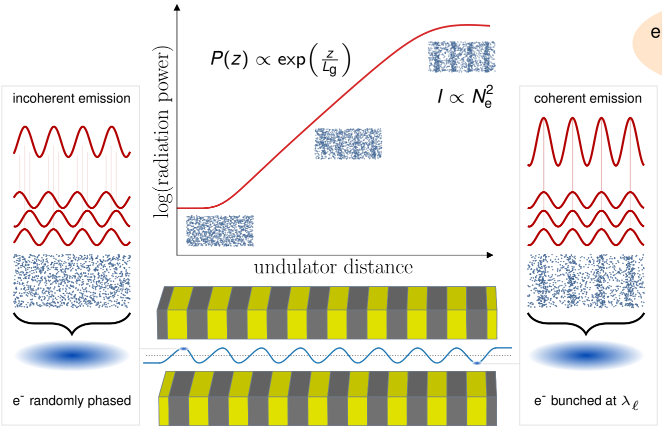


e_1^-: gains energy, shorter path

e_2^-: loses energy, longer path

Free-Electron Laser

acts as amplifier



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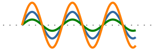
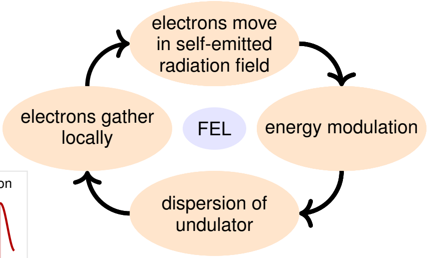




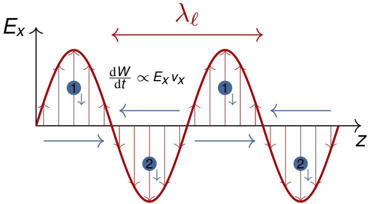
electrons move in self-emitted radiation field

energy modulation

dispersion of undulator

electrons gather locally

FEL



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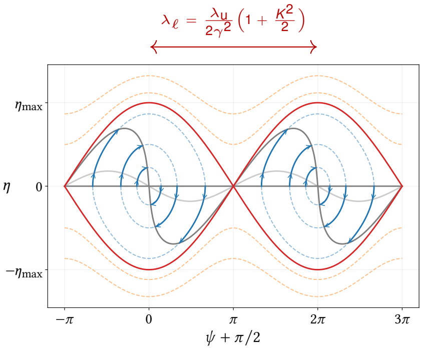
Free-Electron Laser: FEL-Bucket

- for now: neglect change of EM-field
- energy modulation + dispersion
- motion in longitudinal phase space:
  - pendulum equations
- FEL bucket/separatrix
  - electrons inside: bound
  - electrons outside: unbound



$$\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

$$\frac{\mathrm{d}\eta}{\mathrm{d}t} = -\frac{e\widehat{K}E_0}{2\gamma_r^2 m_e c}\cos(\psi)$$
$$\frac{\mathrm{d}\psi}{\mathrm{d}t} = 2k_u c\eta$$

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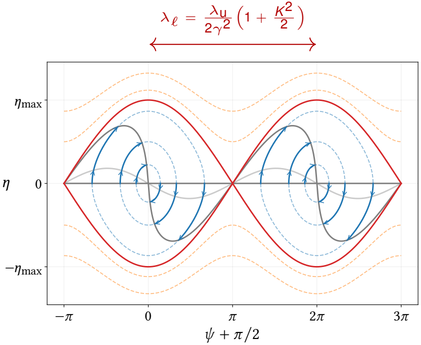

- low-gain regime
  - small gain per undulator passage
  - on resonance beam: no net energy transfer

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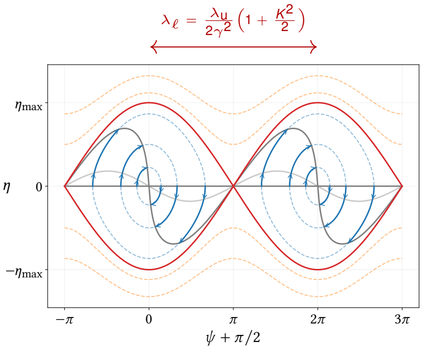

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- low-gain regime
  - small gain per undulator passage
  - on resonance beam: no net energy transfer
- we want high gain in a single pass!

$$\frac{\mathrm{d}\eta}{\mathrm{d}t} = -\frac{e\widehat{K}E_0}{2\gamma_r^2 m_e c}\cos(\psi)$$
$$\frac{\mathrm{d}\psi}{\mathrm{d}t} = 2k_u c\eta$$

High-Gain Free-Electron Laser: 1D model

- change of EM-field during passage through (long) undulator
- energy modulation + dispersion
- space charge fields due to the periodic modulations

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- Slowly Varying Envelope Approximation
- $2N + 2$ coupled first order differential equations
- describe microbunching, gain and saturation

$$\frac{\mathrm{d}\widetilde{E}_x}{\mathrm{d}z} = -\frac{\mu_0 c \widehat{K}}{4\gamma_\mathrm{r}} \widetilde{j}_1$$

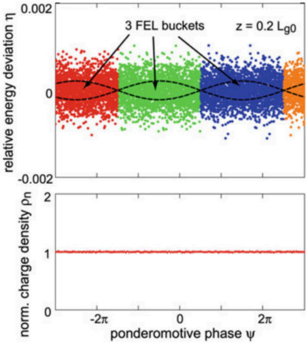
$$\widetilde{j}_1 = j_0 \frac{2}{N} \sum_{k=1}^{N} \exp(-i\psi_k)$$

$$\frac{\mathrm{d}\eta_k}{\mathrm{d}z} = -\frac{e}{m_\mathrm{e} c^2 \gamma_\mathrm{r}} \mathrm{Re}\left(\left[\frac{\widehat{K}}{2\gamma_\mathrm{r}} \widetilde{E}_x - \frac{i\mu_0 c^2}{\omega_\ell} \widetilde{j}_1\right] \exp(i\psi_k)\right)$$

$$\frac{\mathrm{d}\psi_k}{\mathrm{d}z} = 2k_\mathrm{u}\eta_k$$

High-Gain Free-Electron Laser: Exponential Growth

- electrons captured in FEL buckets



Schmüser *et al.* (2014). Free-Electron Lasers in the Ultraviolet and X-Ray Regime

High-Gain Free-Electron Laser: Exponential Growth

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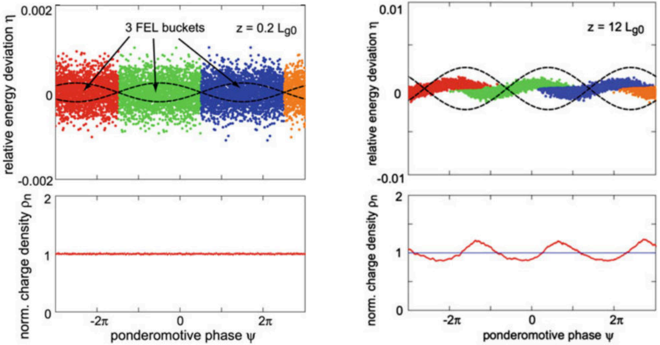
- FEL buckets not fixed!
  - height of separatrix changes
  - FEL buckets change phase



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High-Gain Free-Electron Laser: Exponential Growth

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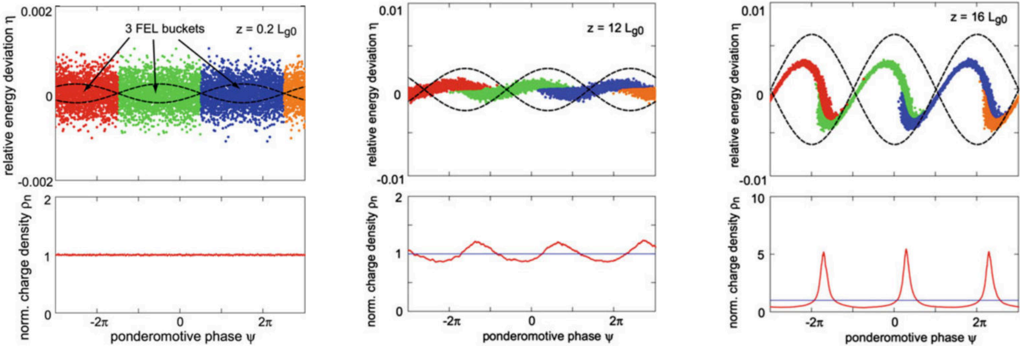
  - FEL buckets change phase
- net energy transfer from electrons to light wave



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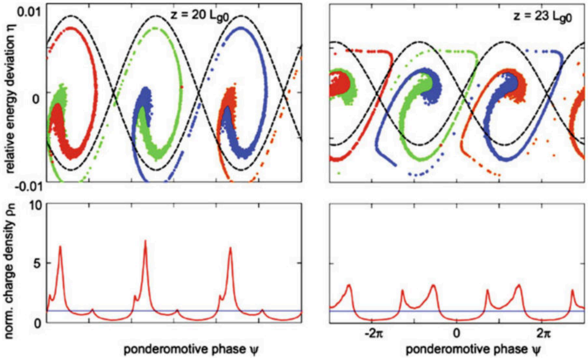
High-Gain Free-Electron Laser: Saturation

- energy spread increases
- energy is transferred back and forth between electron beam and light wave



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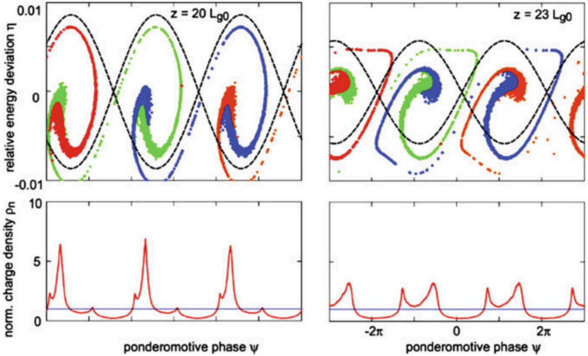
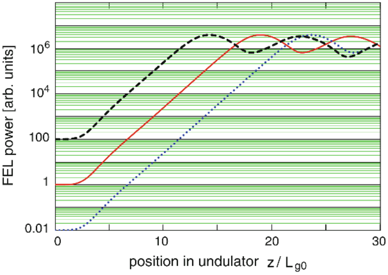
High-Gain Free-Electron Laser: Saturation

- energy spread increases
- energy is transferred back and forth between electron beam and light wave
- same saturation level for different input

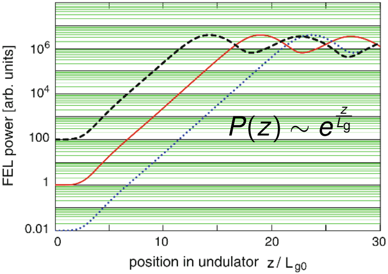




Schmüser *et al.* (2014). Free-Electron Lasers in the Ultraviolet and X-Ray Regime

Linear Regime and Approximations

- gain length describes FEL power growth
- analytical 1D solution in linear/exponential growth regime
  - mono-energetic beam
  - no space charge forces
  - 1D gain length $L_{\mathrm{g0}} = \frac{\lambda_{\mathrm{u}}}{4\pi\sqrt{3}\rho_{\mathrm{FEL}}}$
- fundamental FEL / Pierce parameter
  - $\rho_{\mathrm{FEL}} = \left(\frac{\mu_0 \widehat{K}^2 e^2 n_{\mathrm{e}}}{32 \gamma_{\mathrm{r}}^3 k_{\mathrm{u}}^2 m_{\mathrm{e}}} \right)^{1/3}$



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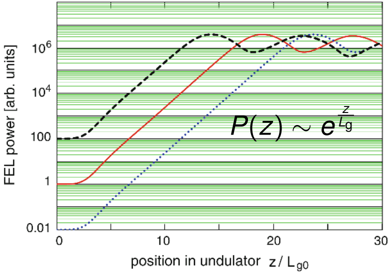
  - $\rho_{FEL} = \left(\frac{\mu_0 \widehat{K}^2 e^2 n_e}{32\gamma_r^3 k_u^2 m_e}\right)^{1/3}$
  - determines FEL performance
  - gain length
  - saturation power $P_s \approx \rho_{FEL} P_{beam}$
  - FEL bandwidth $\sigma_\omega/\omega_\ell \approx \rho_{FEL}$ at saturation



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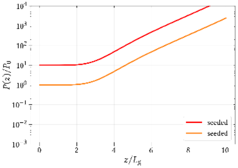
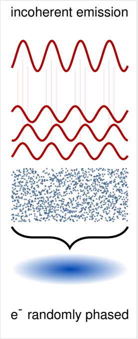
High-Gain Free-Electron Laser: Start-Up

- Seeded FEL
  - initiate FEL process with already existing laser light
  - requires suitable laser source in desired wavelength regime





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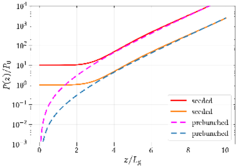
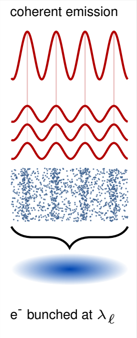


- Pre-Bunched Beam via External Seeding
  - imprint periodic density modulation on electron bunch before FEL
  - requires seeding section for harmonic up-conversion schemes
  - limited to certain harmonic of seed wavelength



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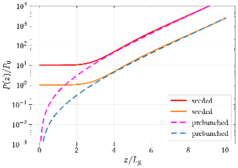

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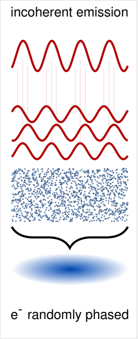

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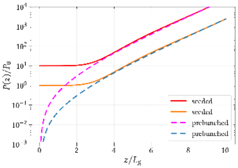

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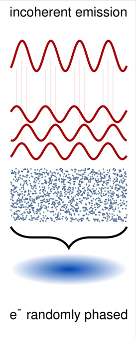
    → non-vanishing spectral components around resonant wavelength

$$\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$



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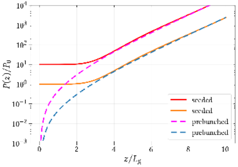

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  - saturation within 18-20 gain lengths
  - limited longitudinal coherence

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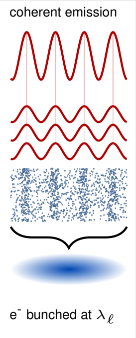
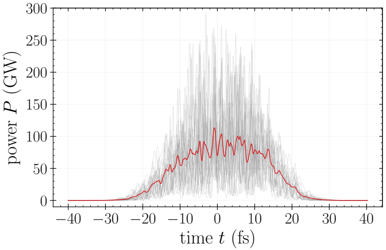
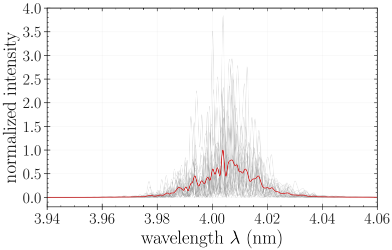


High-Gain Free-Electron Laser: SASE

- statistical fluctuations of the spontaneous emission
- shot-to-shot fluctuations, temporal and spectral

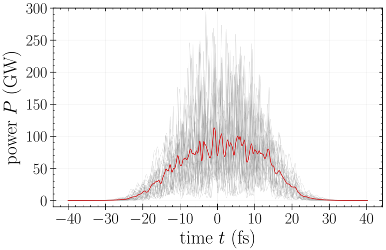


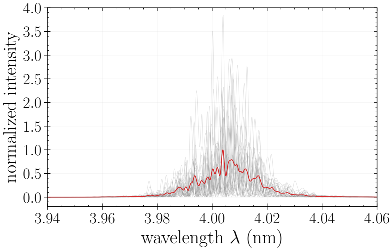


simulation performed with GENESIS1.3, v4

High-Gain Free-Electron Laser: SASE

- statistical fluctuations of the spontaneous emission
- shot-to-shot fluctuations, temporal and spectral
- sufficiently large statistics is essential for experiments





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High-Gain Free-Electron Laser

- need for high quality electron beam → energy spread, emittance, current
  - provided by linear accelerator

High-Gain Free-Electron Laser

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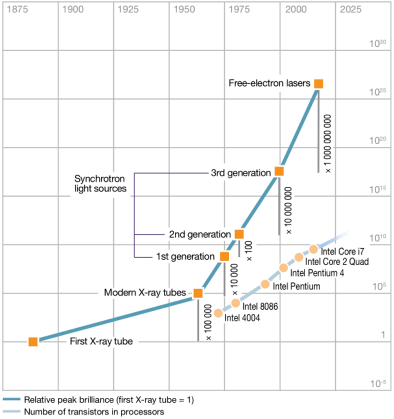
  - provided by linear accelerator
- spectral brightness
  - $\dfrac{\text{photons per second}}{\text{angle (mrad}^2\text{)}\cdot\text{area (mm}^2\text{)}\cdot\text{relative bandwidth (0.1 \%)}}$
- up to $\sim 10^{34}$ in hard x-ray regime
  - atomic positions, chemical selectivity
- short pulses (order of fs)
  - atomic motion, diffraction before destruction



Enlightening Science (2017), European XFEL brochure

Free-Electron Lasers – Brief History

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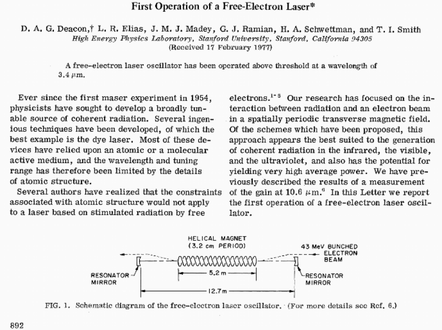

First Operation of a Free-Electron Laser*

D. A. G. Deacon,† L. R. Elias, J. M. J. Madey, G. J. Ramian, H. A. Schwettman, and T. I. Smith
High Energy Physics Laboratory, Stanford University, Stanford, California 94305
(Received 17 February 1977)

A free-electron laser oscillator has been operated above threshold at a wavelength of 3.4 μm.

Ever since the first maser experiment in 1954, physicists have sought to develop a broadly tunable source of coherent radiation. Several ingenious techniques have been developed, of which the best example is the dye laser. Most of these devices have relied upon an atomic or a molecular active medium, and the wavelength and tuning range has therefore been limited by the details of atomic structure.

Several authors have realized that the constraints associated with atomic structure would not apply to a laser based on stimulated radiation by free electrons.[1-5] Our research has focused on the interaction between radiation and an electron beam in a spatially periodic transverse magnetic field. Of the schemes which have been proposed, this approach appears the best suited to the generation of coherent radiation in the infrared, the visible, and the ultraviolet, and also has the potential for yielding very high average power. We have previously described the results of a measurement of the gain at 10.6 μm.[6] In this Letter we report the first operation of a free-electron laser oscillator.

FIG. 1. Schematic diagram of the free-electron laser oscillator. (For more details see Ref. 6.)

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Free-Electron Lasers – Brief History

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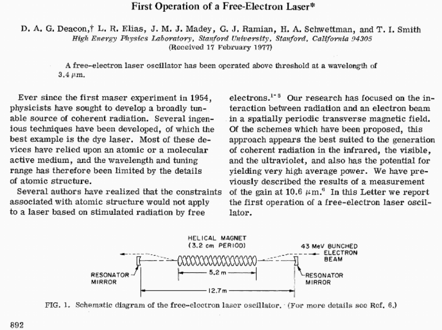
- 1980s: theoretical and numerical work about single-pass FELs



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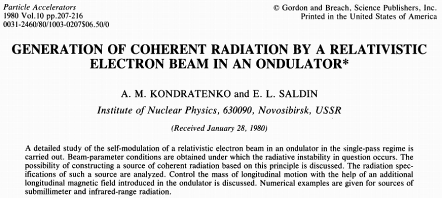

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1980 Vol.10 pp.207-216
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GENERATION OF COHERENT RADIATION BY A RELATIVISTIC ELECTRON BEAM IN AN ONDULATOR*

A. M. KONDRATENKO and E. L. SALDIN
Institute of Nuclear Physics, 630090, Novosibirsk, USSR

(Received January 28, 1980)

A detailed study of the self-modulation of a relativistic electron beam in an ondulator in the single-pass regime is carried out. Beam-parameter conditions are obtained under which the radiative instability in question occurs. The possibility of constructing a source of coherent radiation based on this principle is discussed. The radiation specifications of such a source are analyzed. Control the mass of longitudinal motion with the help of an additional longitudinal magnetic field introduced in the ondulator is discussed. Numerical examples are given for sources of submillimeter and infrared-range radiation.

Free-Electron Lasers – Brief History

- demonstration of high-gain SASE FELs:
  - millimeter wavelength range (1984, Gold et al.)
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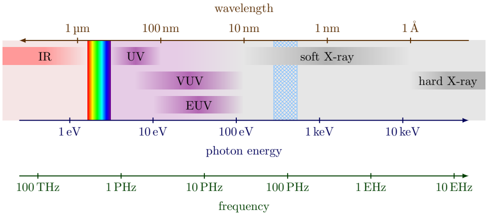

spectral ranges according to ISO-21348:2007

Free-Electron Lasers – Brief History

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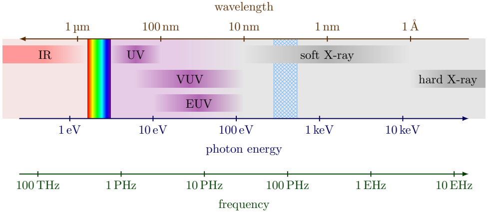
- short wavelengths require high energy: $\lambda_\mathrm{r} = \frac{\lambda_\mathrm{u}}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$
- high energy requires long accelerator



spectral ranges according to ISO-21348:2007

FEL Light Sources

Enlightening Science (2017), European XFEL brochure

FEL Light Sources

LCLS **LCLS-II**
SLAC, Menlo Park I US

2009
120 p/s

European XFEL
Schenefeld + Hamburg I DE

FLASH
DESY, Hamburg I DE

PAL-XFEL
PAL, Pohang I KR

SACLA
SCSS
RIKEN, Harima I JP

SwissFEL
PSI, Villigen I CH

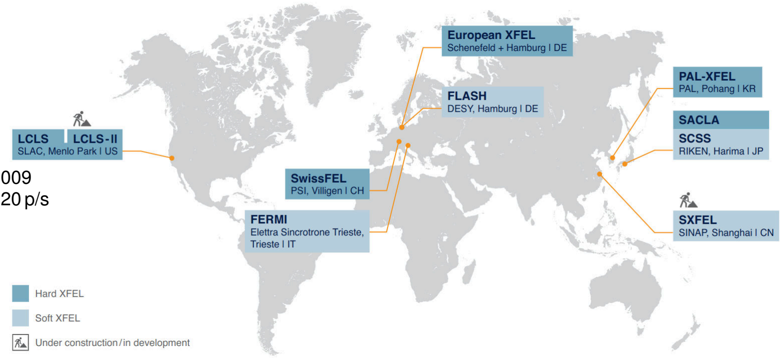
FERMI
Elettra Sincrotrone Trieste, Trieste I IT

SXFEL
SINAP, Shanghai I CN

■ Hard XFEL
□ Soft XFEL
Under construction / in development

Enlightening Science (2017), European XFEL brochure

FEL Light Sources

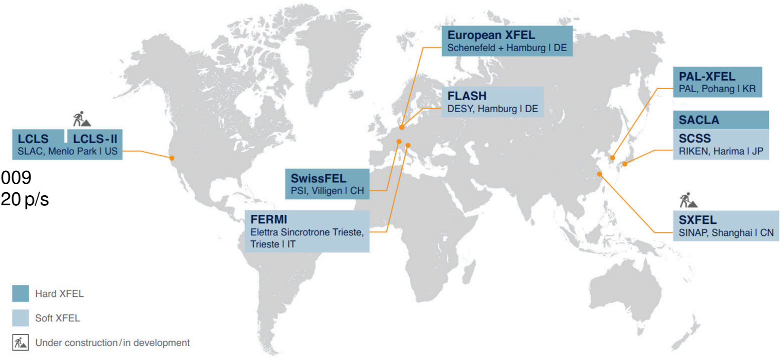


2009
120 p/s

2011
60 p/s

Enlightening Science (2017), European XFEL brochure

FEL Light Sources



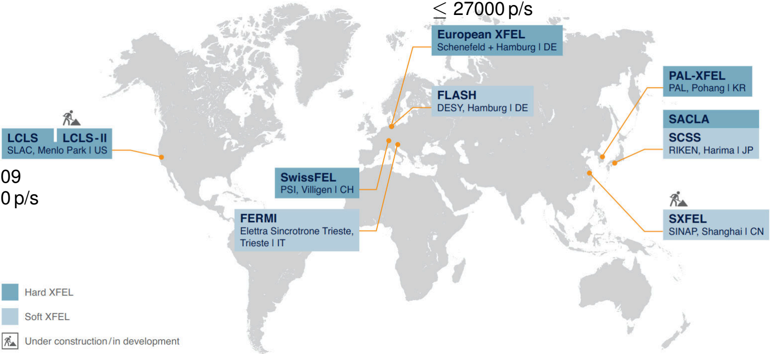
2017
60 p/s

2011
60 p/s

2009
120 p/s

Enlightening Science (2017), European XFEL brochure

FEL Light Sources



2017
$\lesssim$ 27000 p/s

2017
60 p/s

2011
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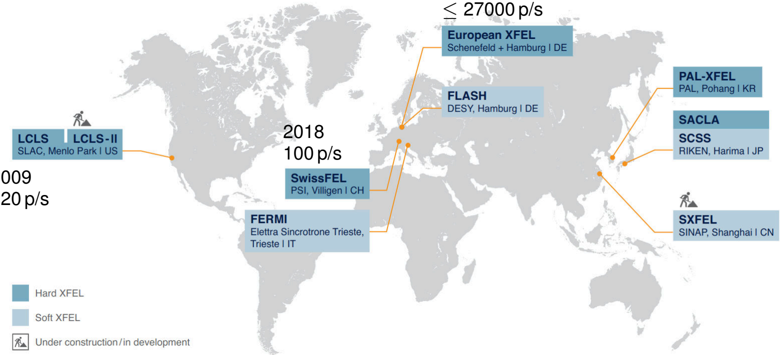
2009
120 p/s

Enlightening Science (2017), European XFEL brochure

FEL Light Sources



2017
$\lesssim$ 27000 p/s

2017
60 p/s

2011
60 p/s

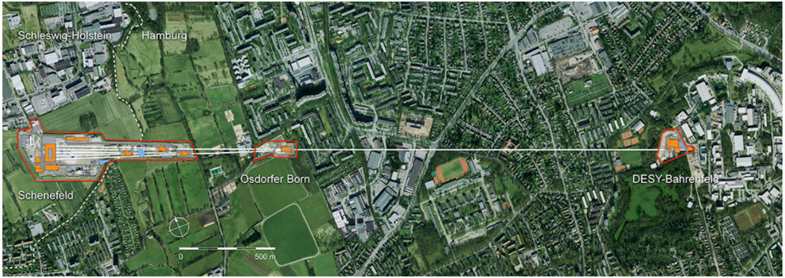
2018
100 p/s

2009
120 p/s

Enlightening Science (2017), European XFEL brochure

European XFEL facility

- Construction start early 2009, user operation start September 2017
- total length of 3.4 km (10 µs for an electron!)
- twelve European countries contribute to the European XFEL
  - Denmark, France, Germany, Hungary, Italy, Poland, Russia, Slovakia, Spain, Sweden, Switzerland, United Kingdom



https://www.xfel.eu/facility/overview/index_eng.html

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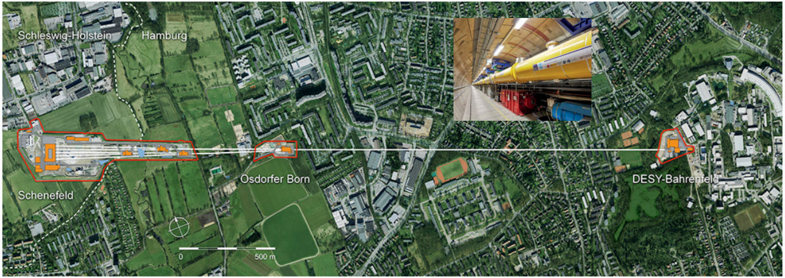

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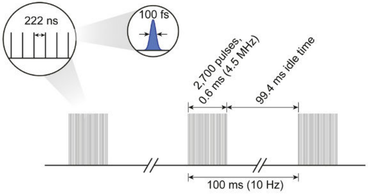
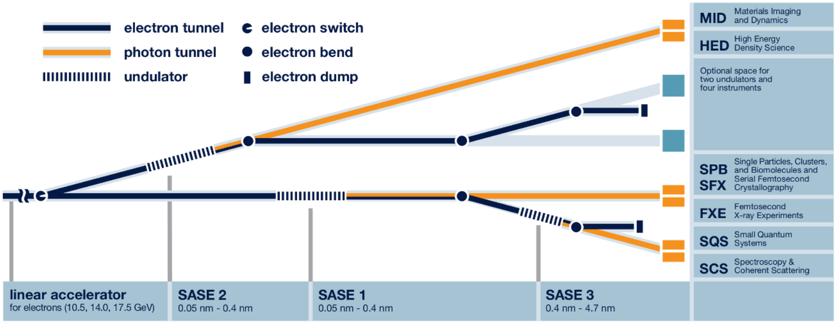
- accelerator based on superconducting technology
  - up to 4.5 MHz intra-train repetition rate
- 27000 bunches/second
- 3 SASE undulator beamlines running in parallel



https://www.xfel.eu/facility/instruments/spb_sfx/instrument_design/index_eng.html

European XFEL Beamlines



electron tunnel
photon tunnel
undulator
electron switch
electron bend
electron dump

MID Materials Imaging and Dynamics

HED High Energy Density Science

Optional space for two undulators and four instruments

SPB SFX Single Particles, Clusters, and Biomolecules and Serial Femtosecond Crystallography

FXE Femtosecond X-ray Experiments

SQS Small Quantum Systems

SCS Spectroscopy & Coherent Scattering

linear accelerator
for electrons (10.5, 14.0, 17.5 GeV)

SASE 2
0.05 nm - 0.4 nm

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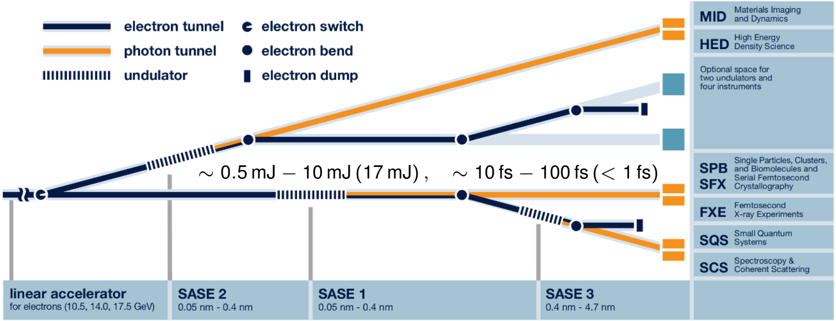
SASE 3
0.4 nm - 4.7 nm

Enlightening Science (2017), European XFEL brochure

European XFEL Beamlines



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$\sim 0.5\,\mathrm{mJ} - 10\,\mathrm{mJ}\;(17\,\mathrm{mJ})\,, \quad \sim 10\,\mathrm{fs} - 100\,\mathrm{fs}\;(< 1\,\mathrm{fs})$

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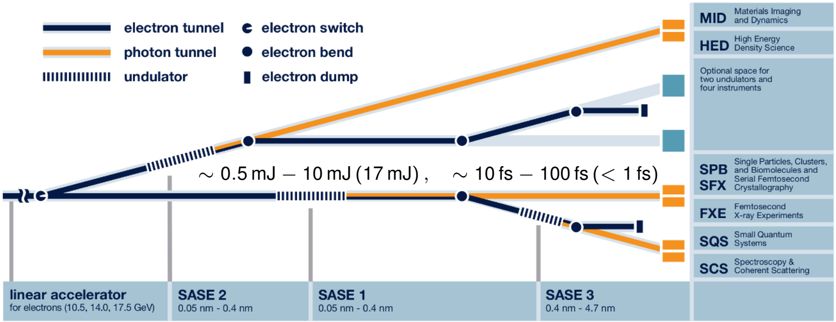
Enlightening Science (2017), European XFEL brochure `https://www.xfel.eu/facility/instruments`

European XFEL Beamlines



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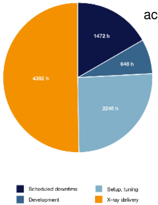
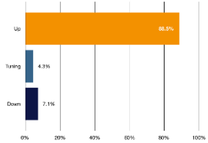


accelerator operation hours in 2022



Enlightening Science (2017), European XFEL brochure

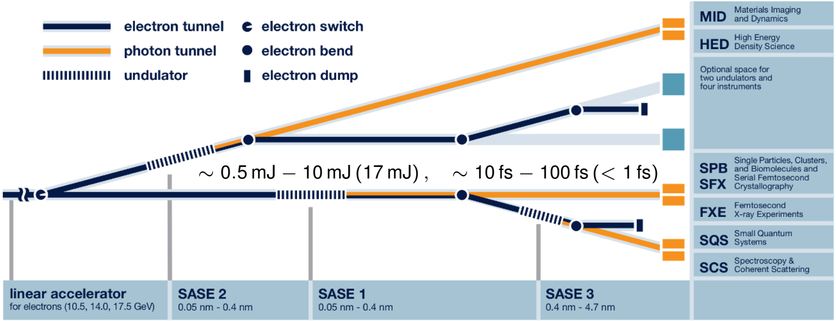
`https://www.xfel.eu/facility/instruments`

European XFEL Annual Report (2022)

European XFEL Beamlines

European XFEL

eurizon
European network
for developing new horizons for RIs



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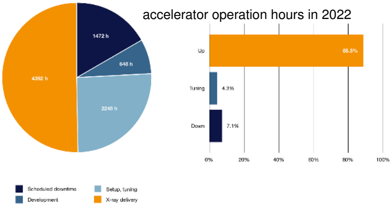
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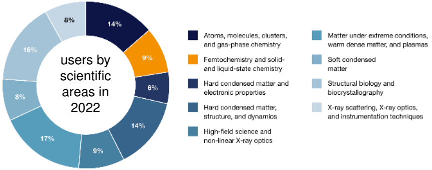

Enlightening Science (2017), European XFEL brochure

`https://www.xfel.eu/facility/instruments`

European XFEL Annual Report (2022)

European XFEL Beamlines

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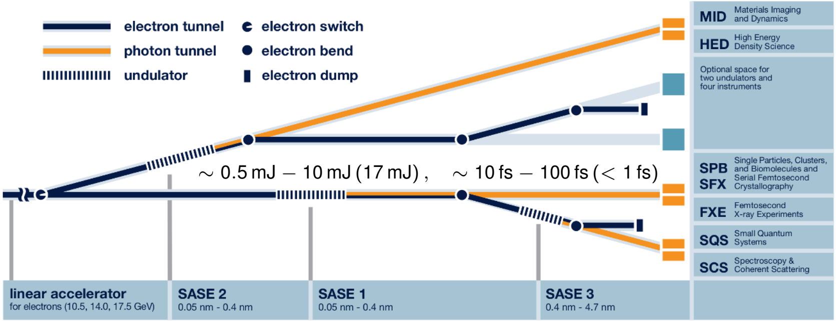

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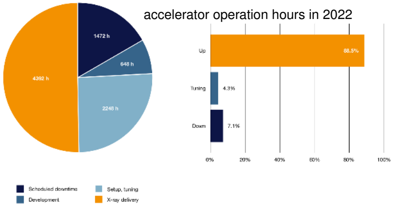
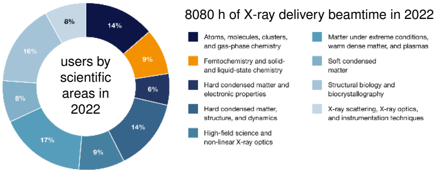


Enlightening Science (2017), European XFEL brochure

8080 h of X-ray delivery beamtime in 2022



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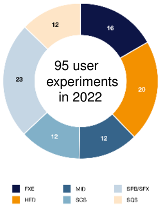

European XFEL Annual Report (2022)

Summary

- FELs deliver extremely bright, short and spatial coherent radiation
- unique light source in the soft and hard X-ray regime
- high demand from users

Session 2	**Results from the Eurizon 2020+ investigations**		
11:15-12:00	6 GeV Linac as FEL driver and storage ring injector	Anna Giribono	INFN-LNF
12:00-12:30	X-ray FEL pulse characteristics from the 6 GeV driver	Fabian Pannek	European XFEL
12:30-13:30	*Lunch*		
Session 3	**Applications of X-Ray FELs – The European XFEL instruments**		
13:30-14:10	Science at the SPB/SFX instrument	Chan Kim	European XFEL
14:10-14:50	Science at the FXE instrument	Mykola Biednov	European XFEL
14:50-15:30	Science at the MID instrument	Ulrike Boesenberg	European XFEL
15:30-16:10	Science at the HED instrument	Ulf Zastrau	European XFEL
16:10-16:40	*Coffee Break*		
16:40-17:20	Science at the SQS instrument	Tommaso Mazza	European XFEL
17:20-18:00	Science at the SCS instrument	Andreas Scherz	European XFEL
18:00-18:40	Science at the SXP instrument	Manuel Izquierdo	European XFEL
18:40:18:50	**Wrap-up**		