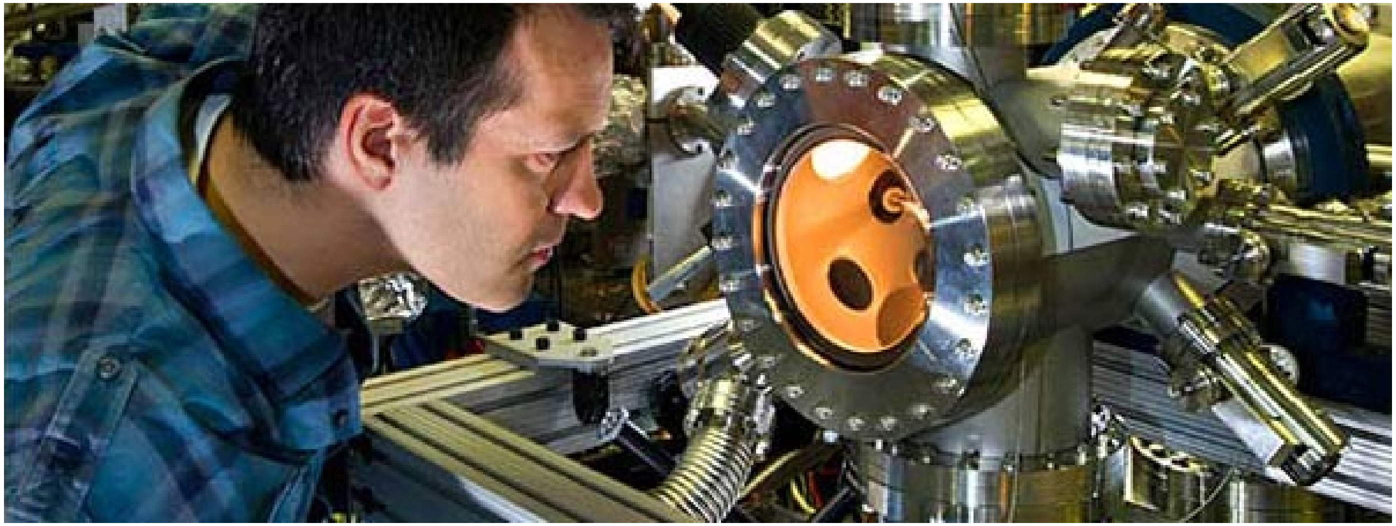
PHY684 – SBU SUNY – 2018

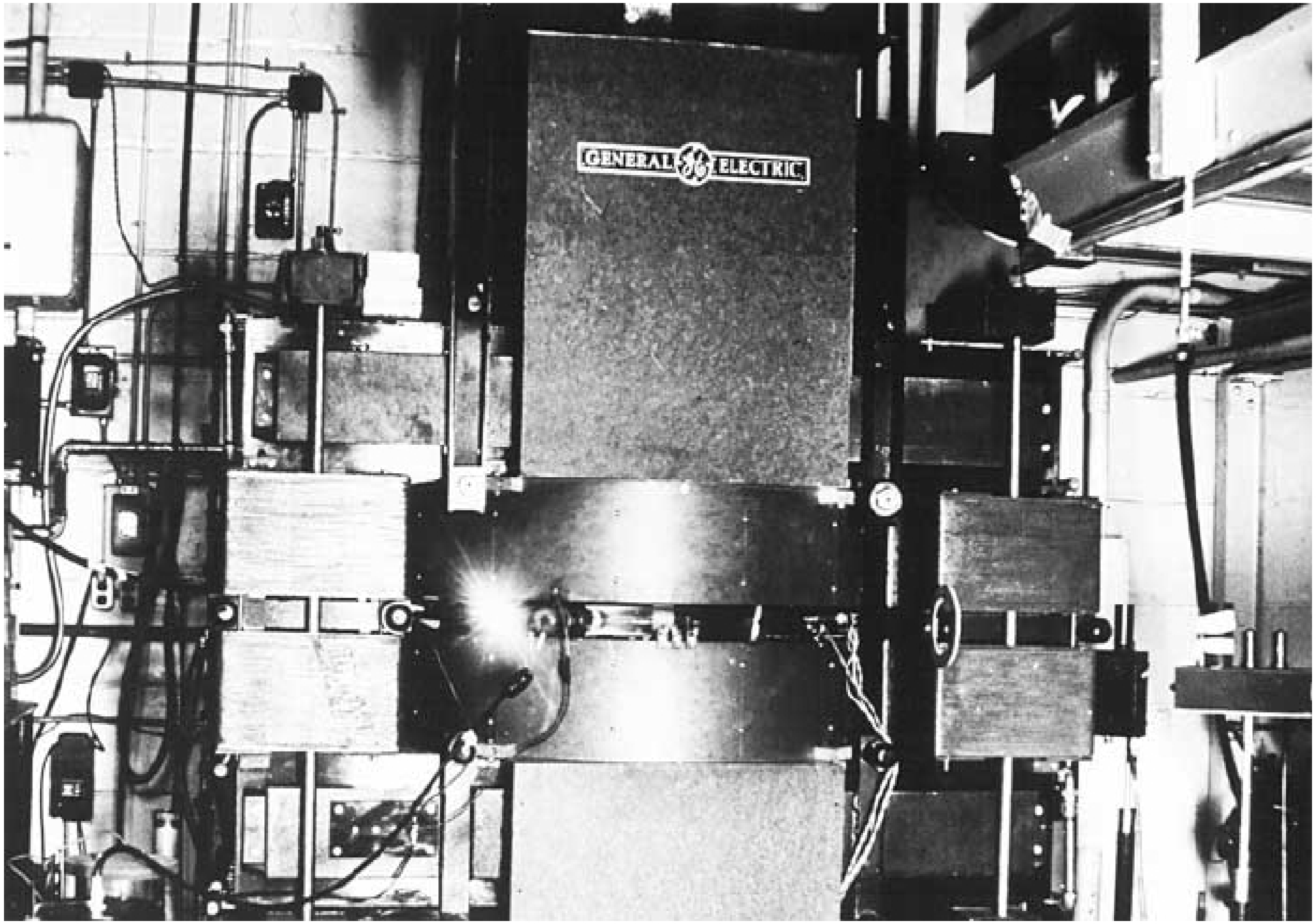
LIGHT SOURCES



High energy electron accelerators are used as extreme brightness sources of UV- to X-rays

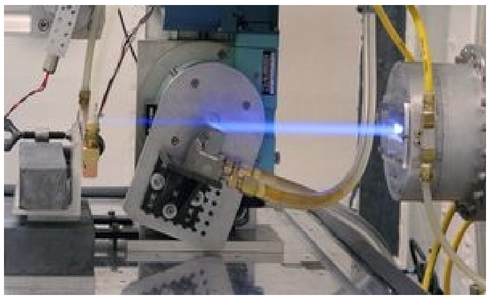
Latest developments : 4th generation light sources / Short pulse FELs on Linacs / ERLs

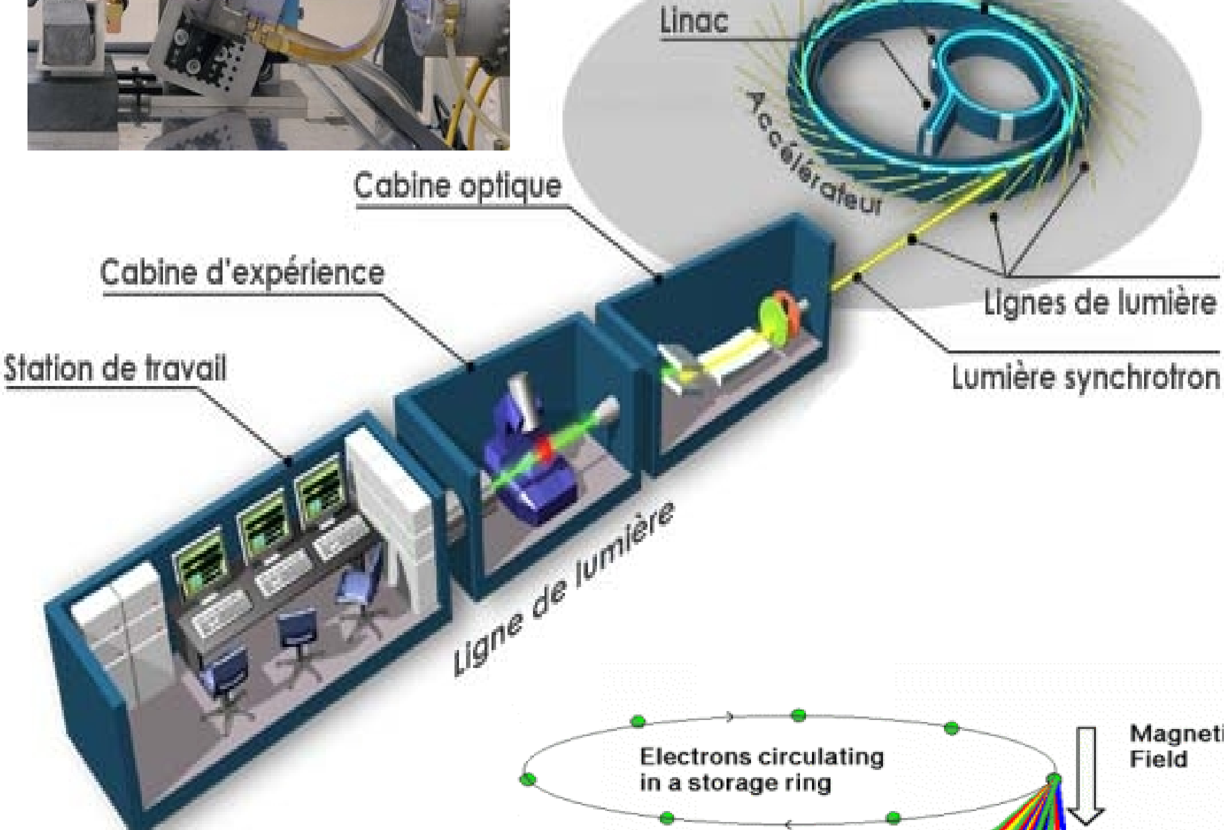
How this started

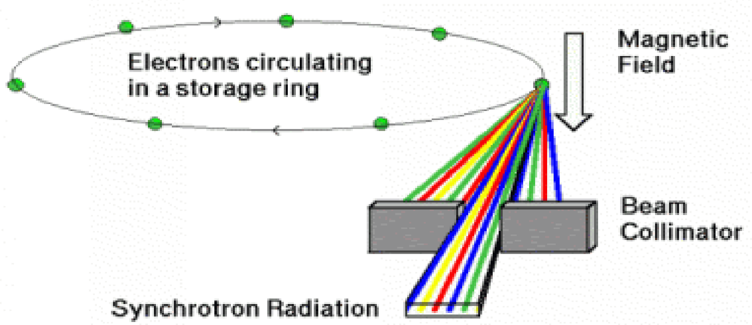


The 300 MeV electron synchrotron built at General Electric Co. in 1940s. The photograph shows the synchrotron radiation emitted from the accelerator.

Principle of an SR source







SOLEIL:

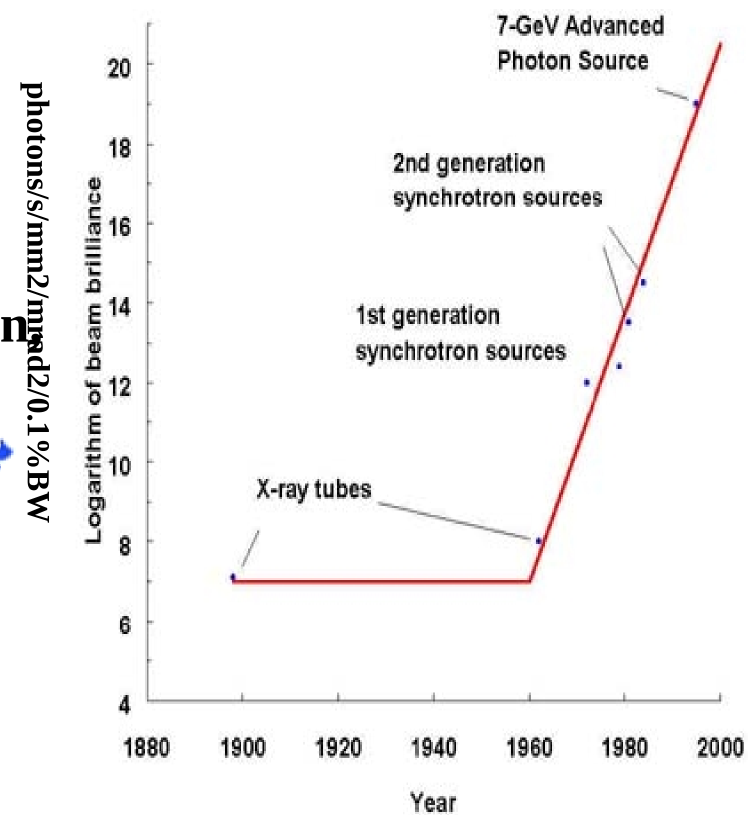
Energy	2.75 GeV
Regular e-synchrotron size :	
Circumference	354 m
# straight sections	4x12m/12x7m/8x3.5 m
Very small size e-beam (high brilliance) :	
Emittance H	3.7 nm.rad
Emittance V	37 pm.rad
High e-beam intensity (high brightness) :	
Current / lifetime :	
- multi-bunch mode	500 mA / 15 h
- 8-bunch mode	80 mA / 21 h
Time structure :	
typical bunch length	25 ps

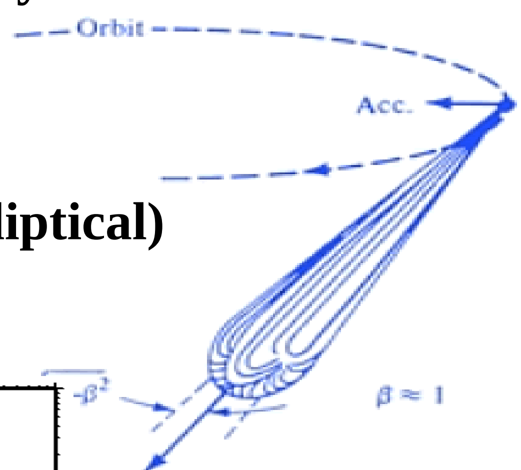
Characteristics of SR

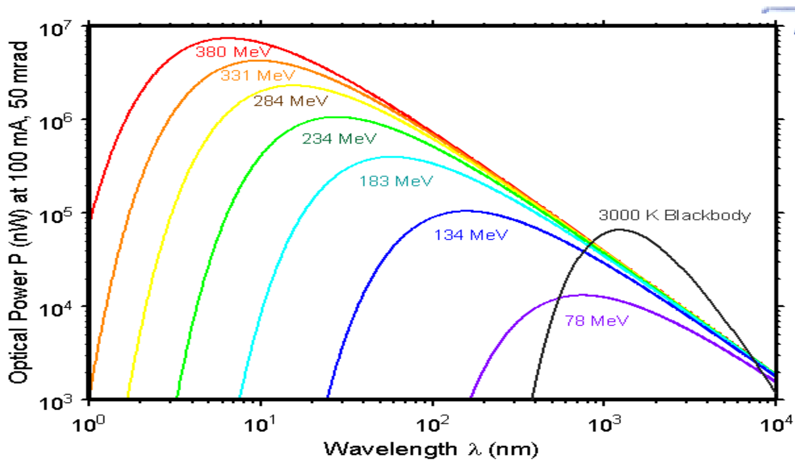
Radiated energy by an electron ~ E^4/ρ

High brightness and high intensity, many orders of magnitude more than from conventional X-ray tubes

- **High collimation of the beam**
- **Widely tunable in wavelength by monochromatization from sub eV up to MeV**
- **High polarization (linear or elliptical)**

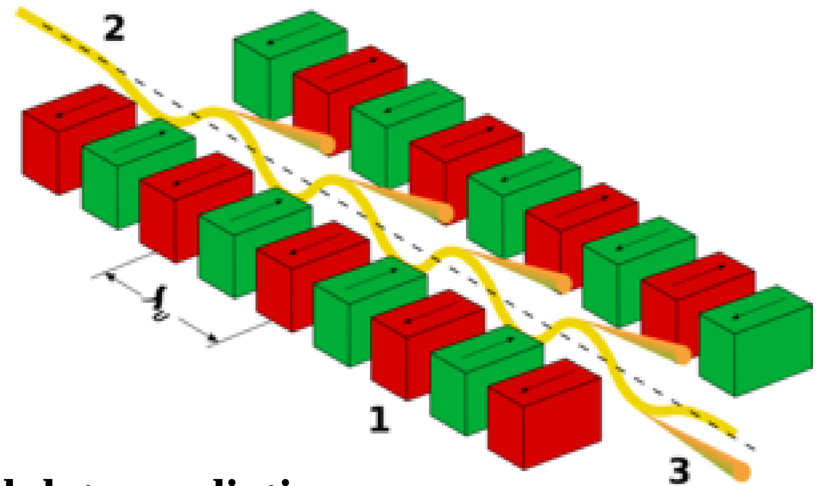


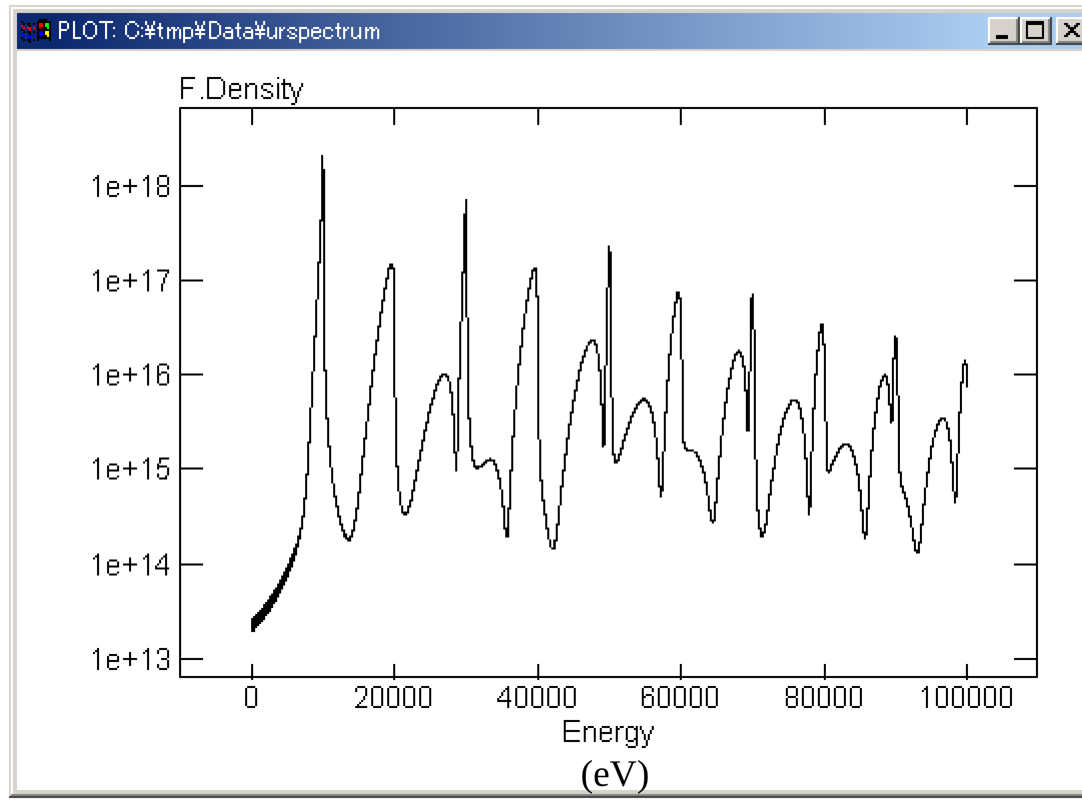




- **First generation light sources : high energy physics accelerators, used in a "parasitic mode".**
- **Second generation : dedicated SR rings**
- **Third generation SR rings : undulator insertions**

“Insertion devices”





Undulator radiation :

- sine-like field motion x(t). In the electron frame : Lorentz contracted, t -> t/γ

Radiation back in Lab: again, Lorentz contracted, t -> t/γ²

- narrow spectrum (Fourier transform of a sine-like E(t) impulse)

Wiggler magnet / radiation :

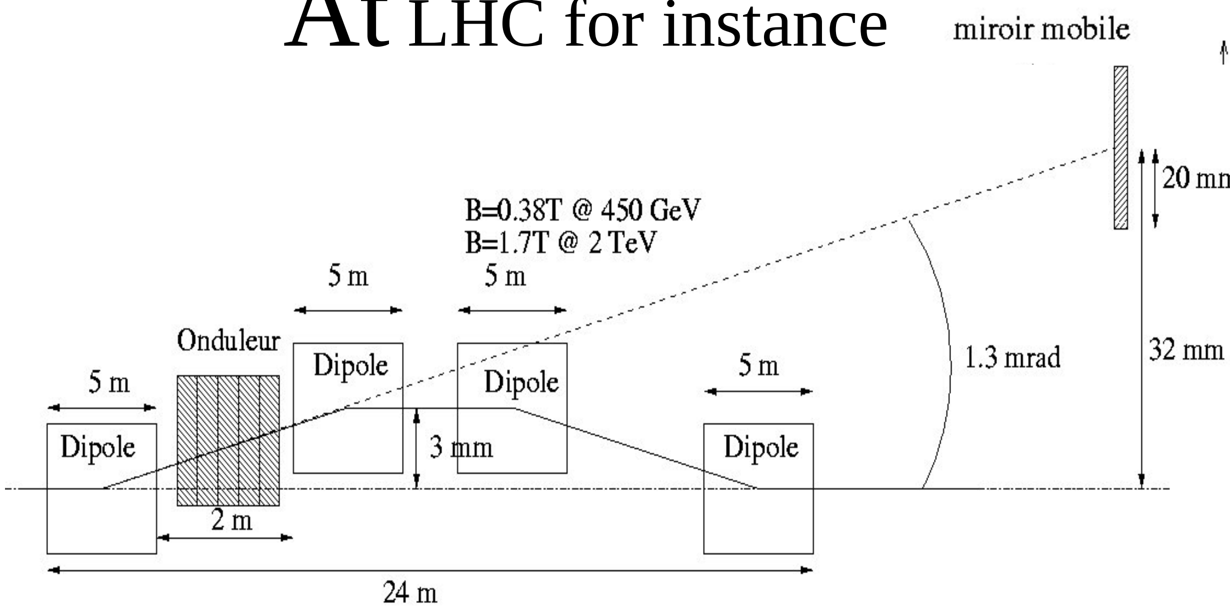
larger e-beam deflection, sharp spike, broad spectrum

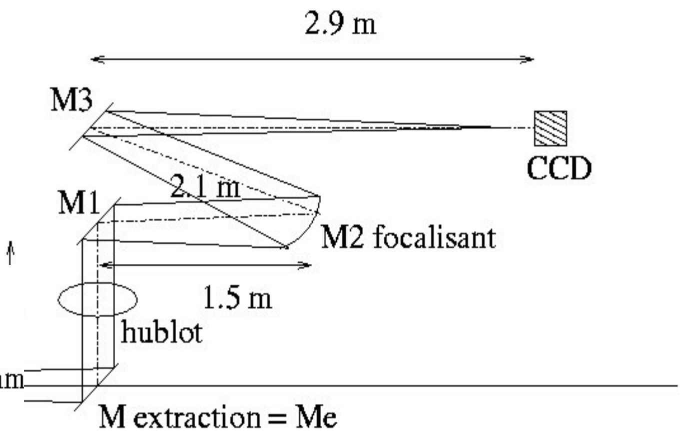
Example : B = 0.25 T, period = 3.2 cm, K = 0.76

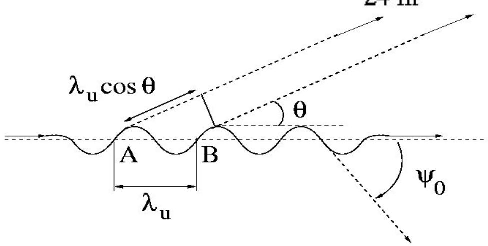
$$\lambda = \lambda_u / 2\gamma^2 (1 + \theta^2\gamma^2 + K^2/2)$$

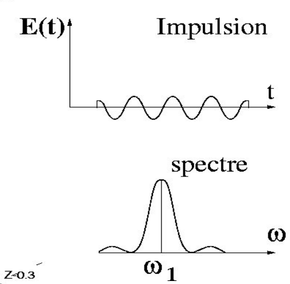
SR as beam diagnostics tool

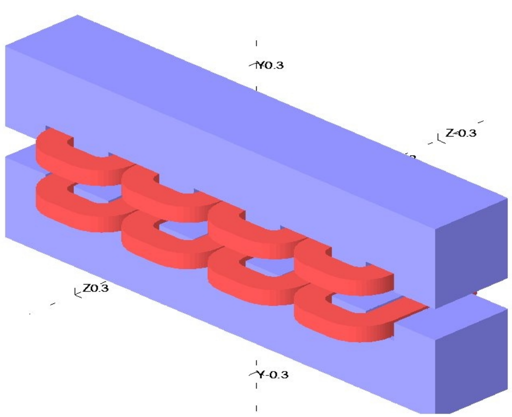
At LHC for instance

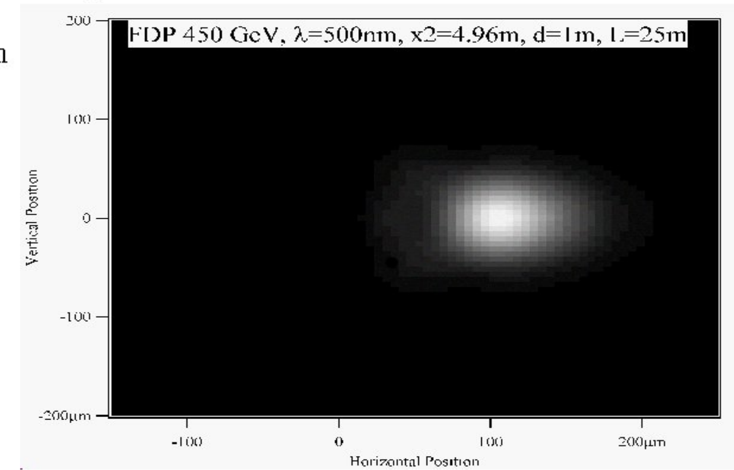


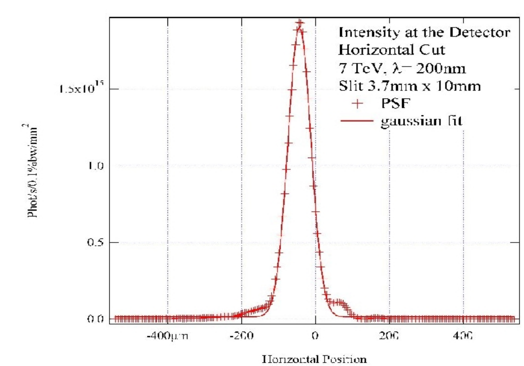










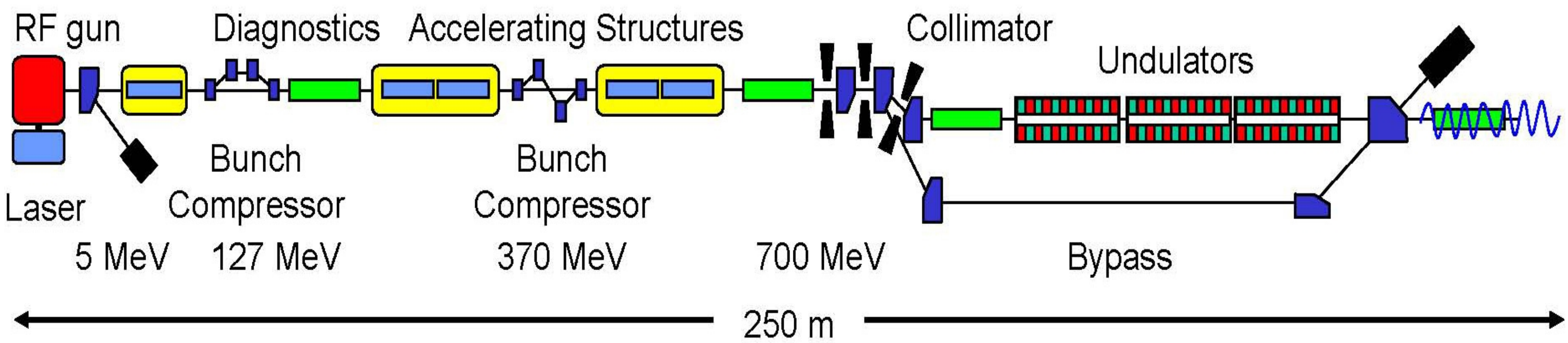


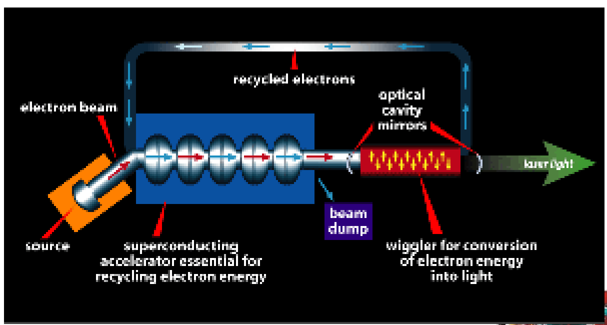
4^{th} Generation light sources

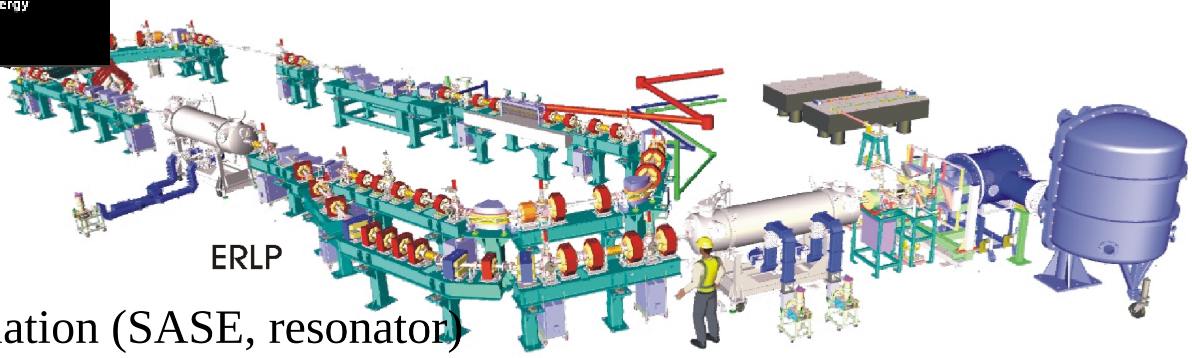
Laser-like X-photon beams

Potential for femto-second X-pulse

<u>SASE undulator on Linac :</u>







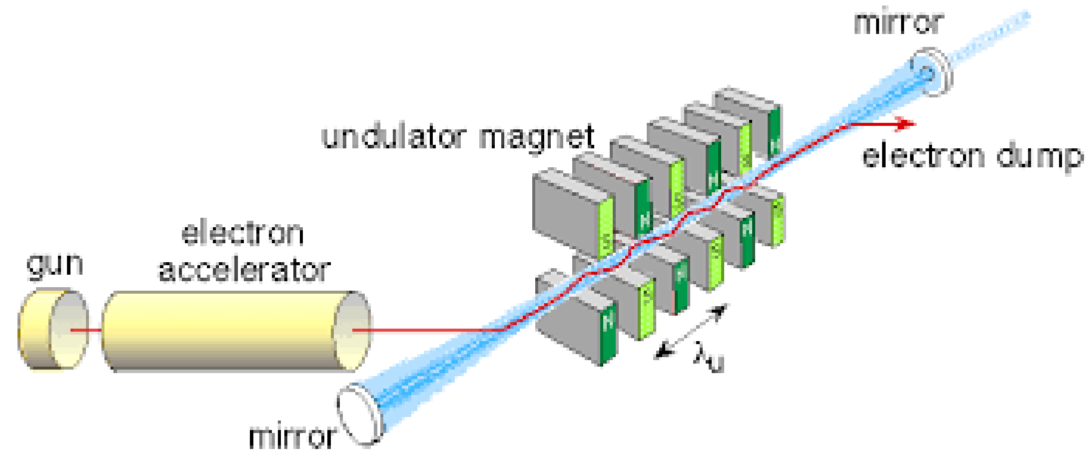
<u>FEL on ER-Linac :</u>

Two important concepts :

- coherent SR, allowed by e-beam modulation (SASE, resonator)

- femto-pulse radiation, allowed by linac-style of e-bunch.

FEL :



- **Tunable**
- **Wavelengths can be in microwave region, terahertz, infrared, visible spectrum, ultraviolet, X-ray**

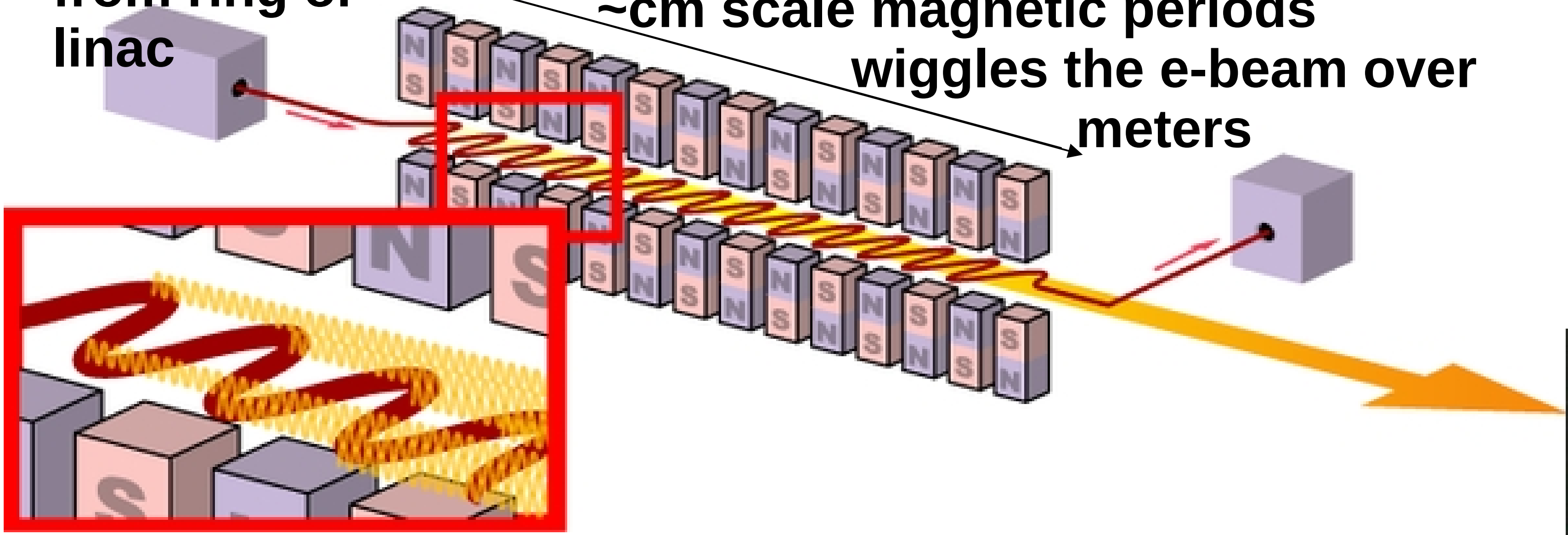
depending on electron beam energies

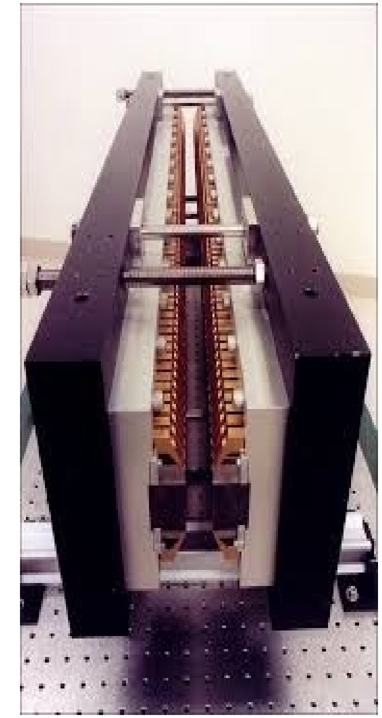
- **Invented by John Madey, Stanford University, 1971. Used a 43-MeV electron beam and 5 m long wiggler to amplify a signal**
- **based on undulator technology developed by Motz et al. in 1953, for a 43 MeV beam**

Principle of FEL

Electron beam, from ring or linac

A long string (meters) of ~cm scale magnetic periods wiggles the e-beam over meters

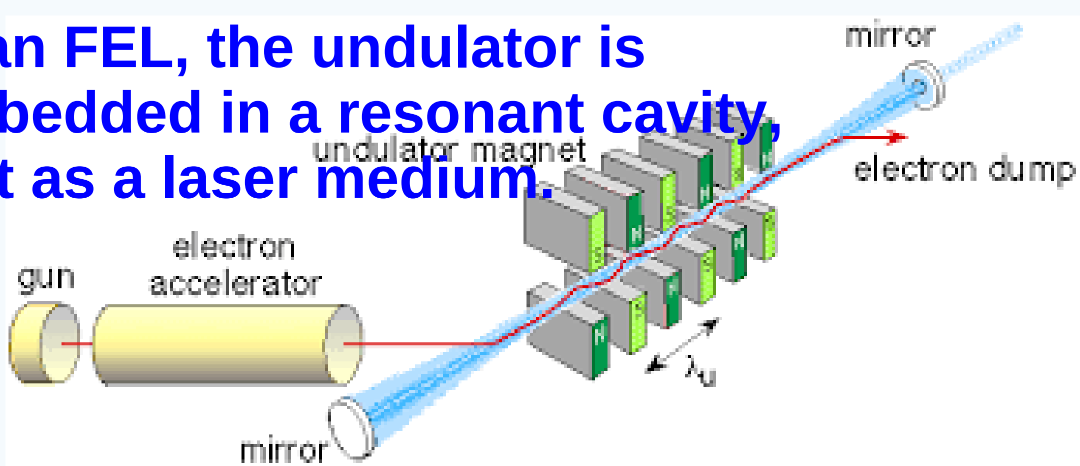




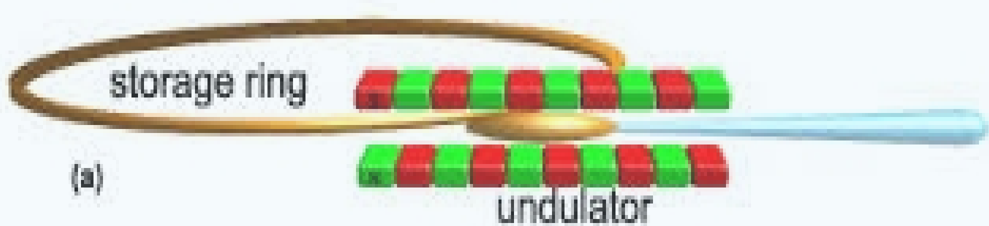
Monochromatic light spot

$$\lambda(\theta) = \lambda_u/(2\gamma^2)\ (1+\gamma^2\theta^2+K^2/2)$$

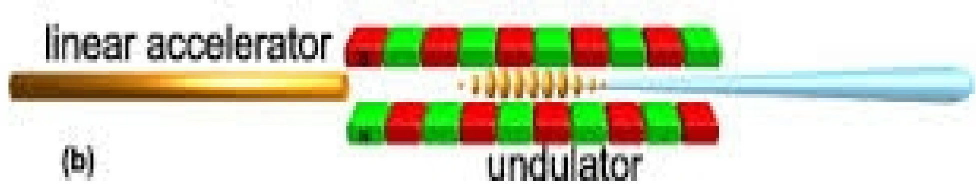
In an FEL, the undulator is embedded in a resonant cavity, just as a laser medium.



The accelerator in that application can be **a ring**, or **a linac**.
That depends on the type of application, on desired photon properties.

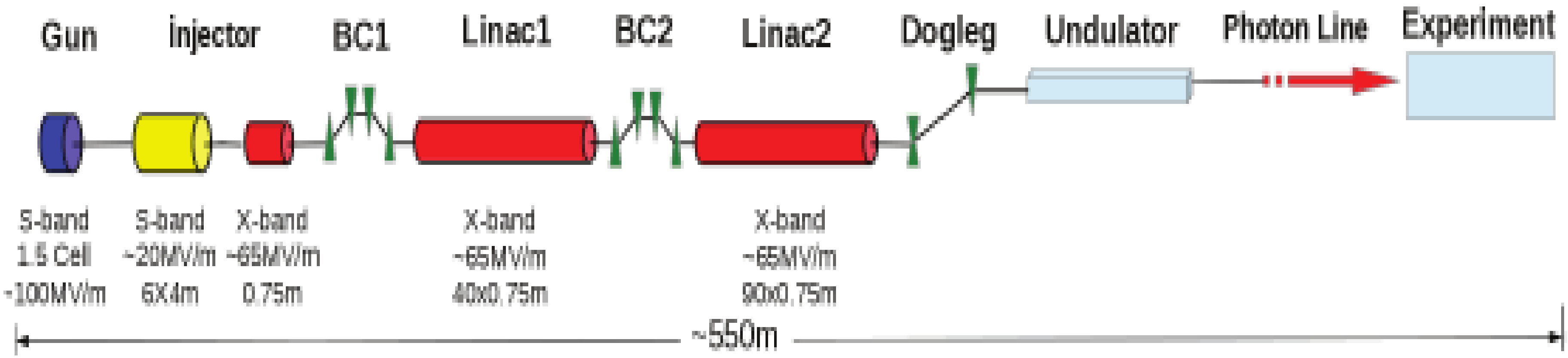


We'll be back to ring light sources, later in the tour...



Linac FEL

- **Principle layout of the FEL installation**



- **The linac sections in that installation :**

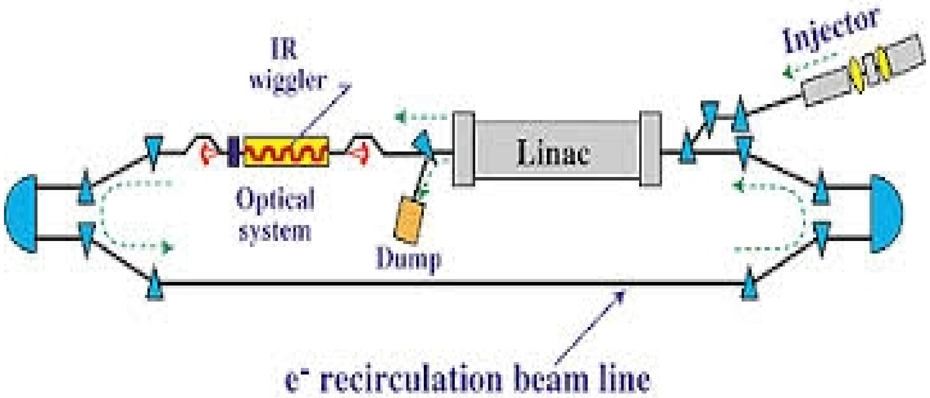
- a string of accelerating cavities,

- aligned in cryostats

FLASH SC linac, at DESY, Hamburg, Germany.

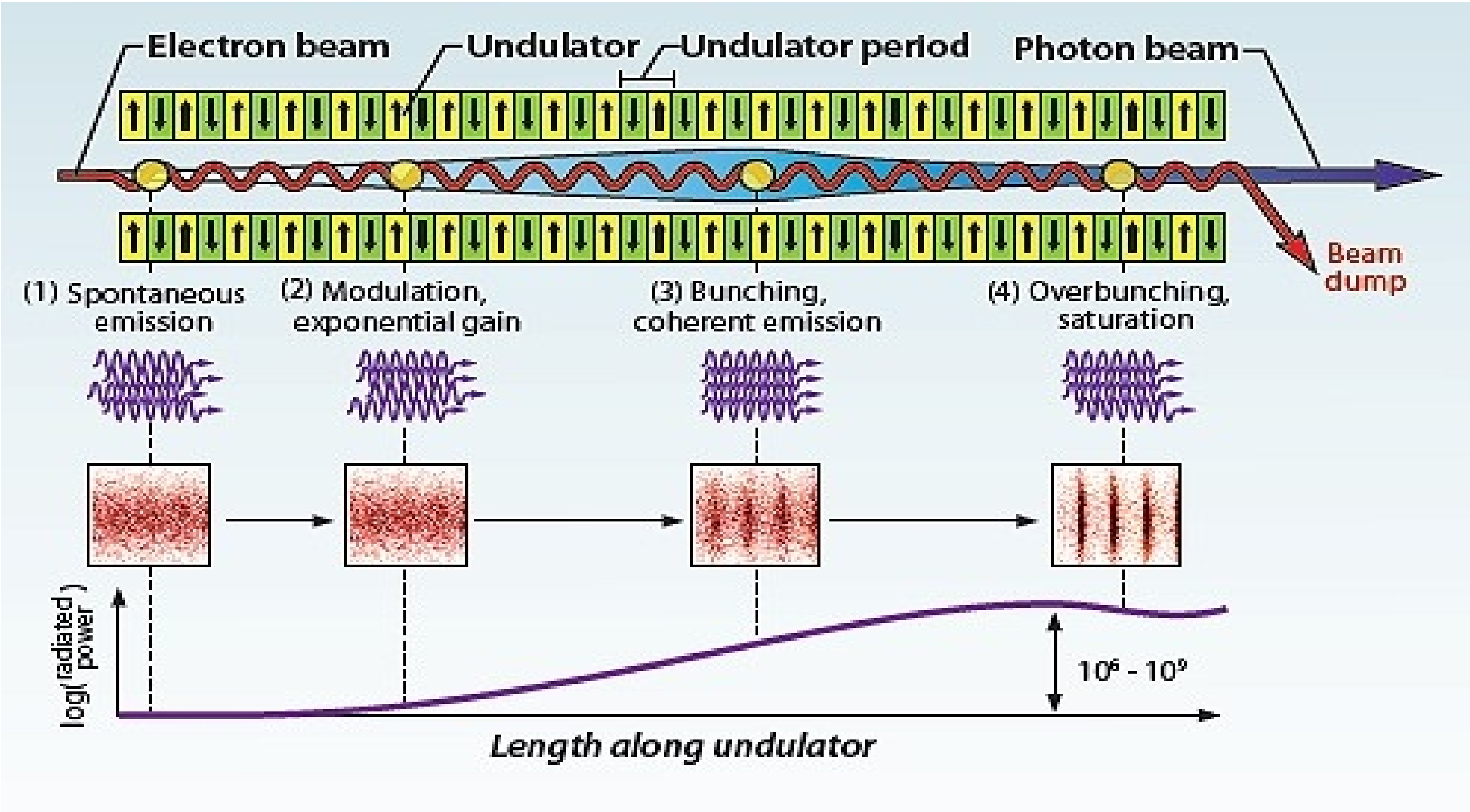
The linac can be a *re-circulating linac*, moreover with *energy recovery, “ERL”*...

Principle of an ERL



JLab ERL-FEL Specifications	
Wavelength range (IR)	1-14μm
Energy/pulse	120 μJ
Pulse repetition frequency	Up to 75 MHz
Pulse length	500-1700 fs FWHM
Maximum average power	>10 kW
Wavelength range (UV/VIS)	250-1000 nm
Energy/pulse	20 μJ
Pulse repetition frequency	Up to 75 MHz
Pulse length	300-1700 fs FWHM
Maximum average power	>1 kW

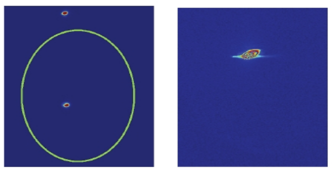
Self-Amplified Spontaneous Emisson "SASE-FEL"



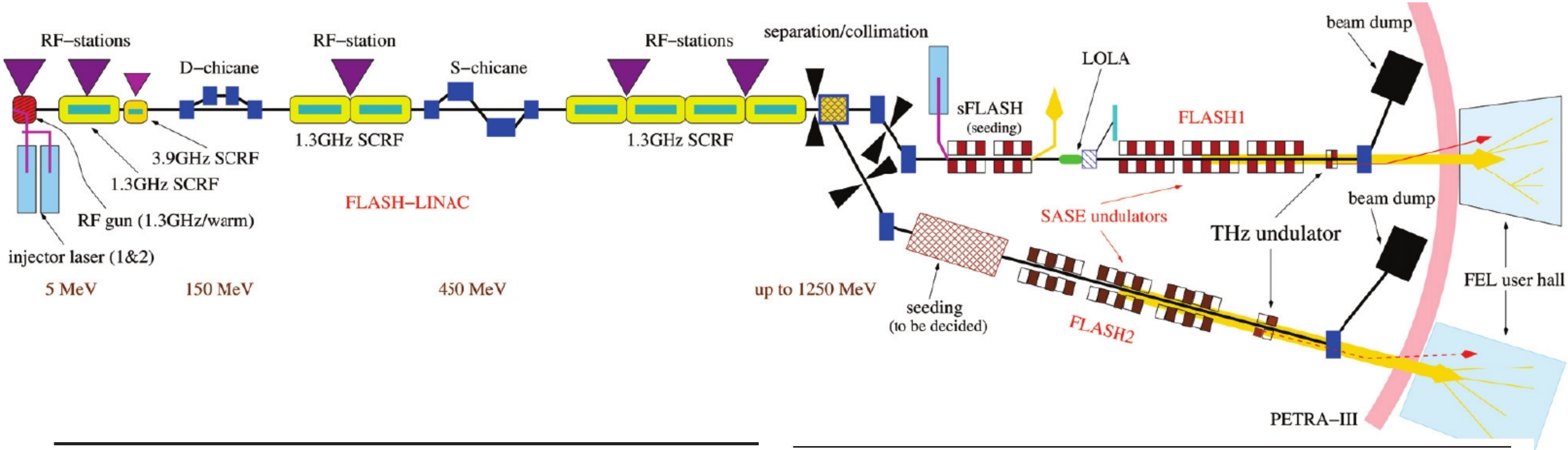
- **Principle : the e-beam density modulates into short bunches, l~λ.**

- **Thus : coherent radiation,**
power~$(Ne)^2$ rather than (incoherent) power~N e^2,
i.e., high brightness highly collimated femtosecond X-ray pulses.
Can make life science X-movies !

FLASH SASE-FEL installation, Hamburg



150 m



e^- :			
emittance	$\beta\gamma\varepsilon_{x,y}$		
(1 nC, on-crest, 90% rms)		1.4	mm mrad
charge		0.08 - 1.0	nC
peak current		0.8 - 2.0	kA
beam energy		380 - 1250	MeV
bunches / train		1 - 450	
bunch spacing		1 - 25	μs
train repetition frequency		10	Hz

γ (FLASH1):		
wavelength (fundamental)	4.2 - 45	nm
average single pulse energy	10 - 540	μJ
pulse duration (fwhm)	<30 - 200	fs
spectral width (fwhm)	0.7 - 2.0	%
peak power	1 - 3	GW
peak brilliance	10^{29} - 10^{31}	(+)
average brilliance	10^{17} - 10^{21}	(+)

(+) : photons/(s mm^2 mrad^2 0.1%bw)

What are the plans with FELs ?

Cutting edge research, with a new tool:

An instance, from FEIS-2 conference web site :

- **Femtosecond Electron Imaging and Spectroscopy**
- **Structure and spectroscopy of matter with atomistic space and femtosecond time resolution, enabled by the development of extremely bright radiation sources, such as high-brightness X-ray and electron beam systems. The capabilities of generating ultrabright sources and very high level of control in delivering intense electron beams through tuning of source geometry, pulse shaping, laser-electron pulse synchronization, and understanding of space-charge effects are now synergistically enabling ultrabright electron microscopes and electron microdiffraction systems for femtosecond imaging and spectroscopy.**
- **FEIS-2 will bring together leaders engaged in cutting edge development of high-brightness electron and X-ray beam systems and their applications to frontier science problems, in order to showcase recent progress and discuss future directions and opportunities. It will also attempt to draw comparisons to other recently emerging approaches to ultrafast observation. The workshop will build on the potential synergy between related technology developments and various emerging scientific opportunities.**