

Tutorial on FEL

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FEL = Free Electron Laser

As opposed to bound electrons

?
Light Amplification by
Synchronised Electron
Retardation

Basics

Energy exchange: light \leftrightarrow e⁻



Bunching



Radiation

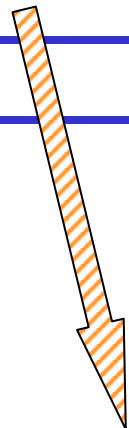


Amplification



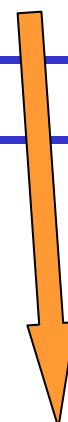
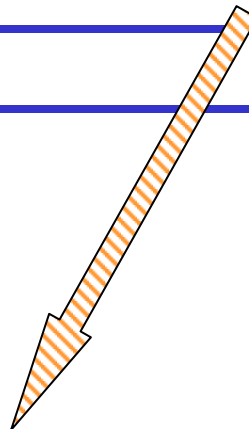
CHG

Coherent Harmonic
Generation



HGHG

High Gain Harmonic
Generation



SASE

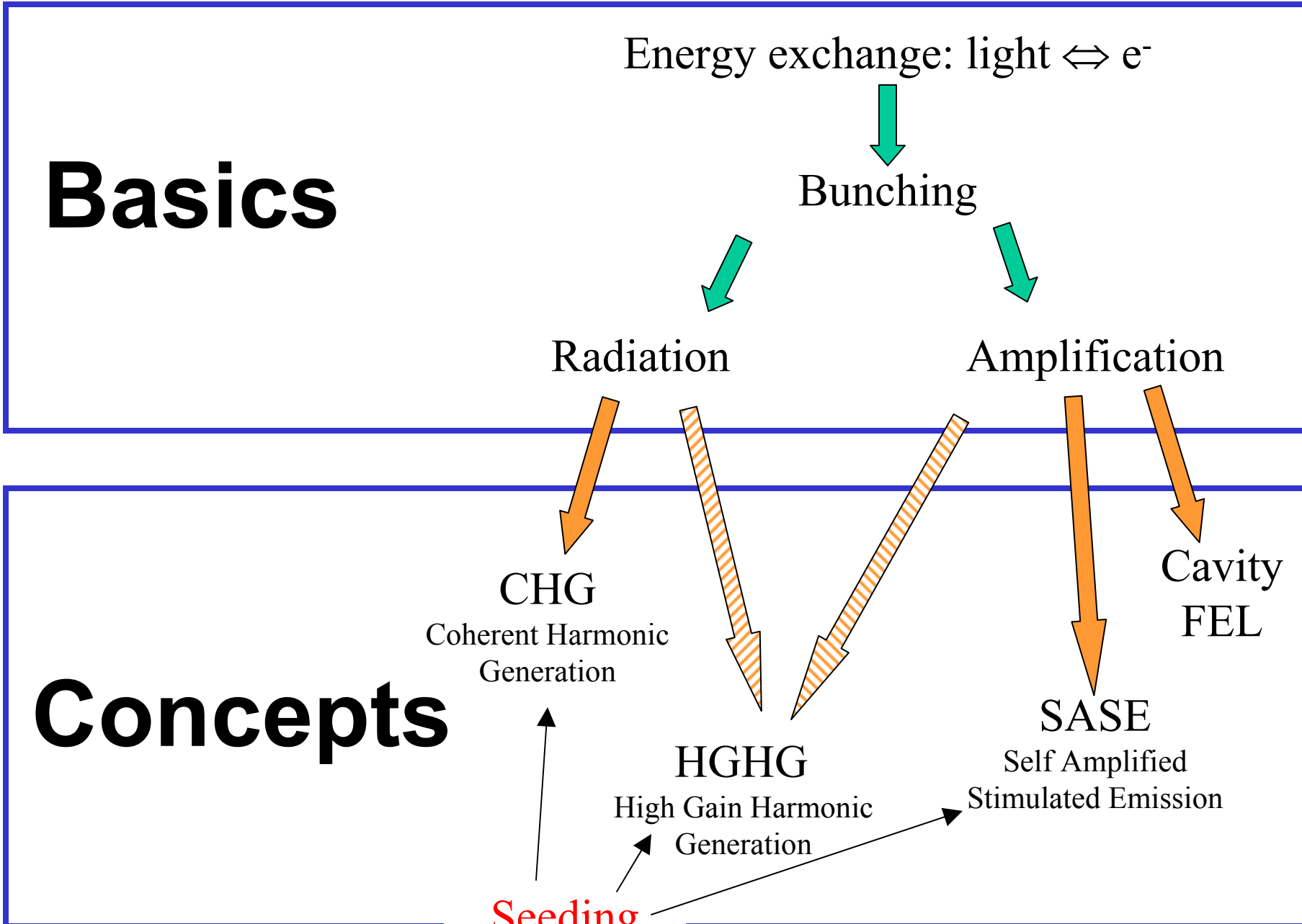
Self Amplified
Stimulated Emission



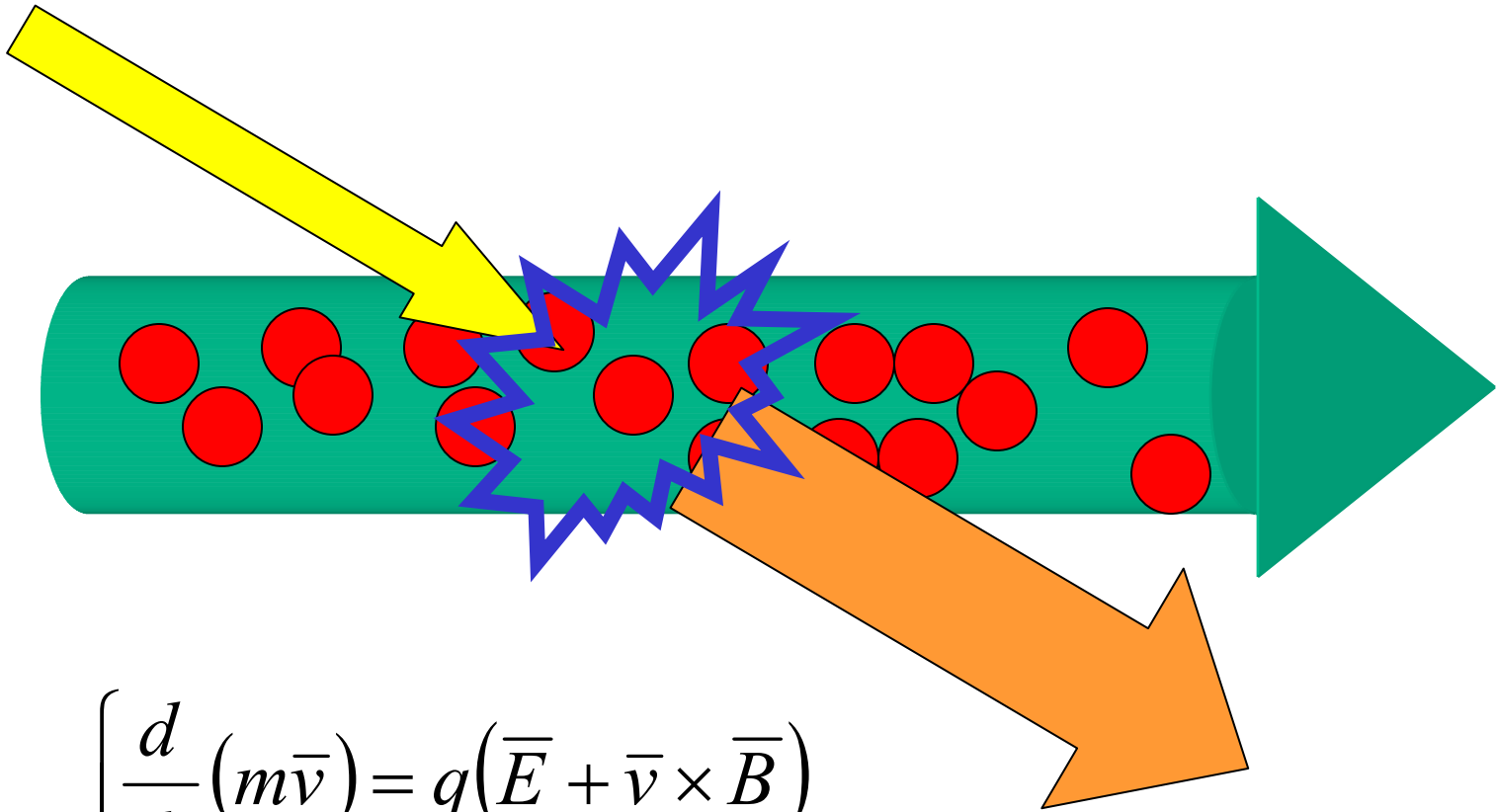
Cavity
FEL

Concepts

Seeding

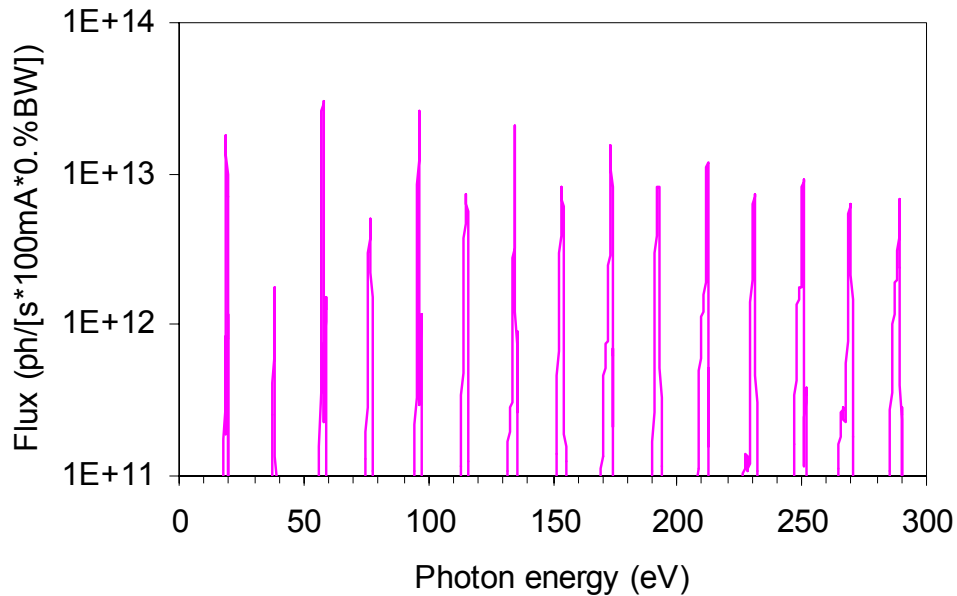
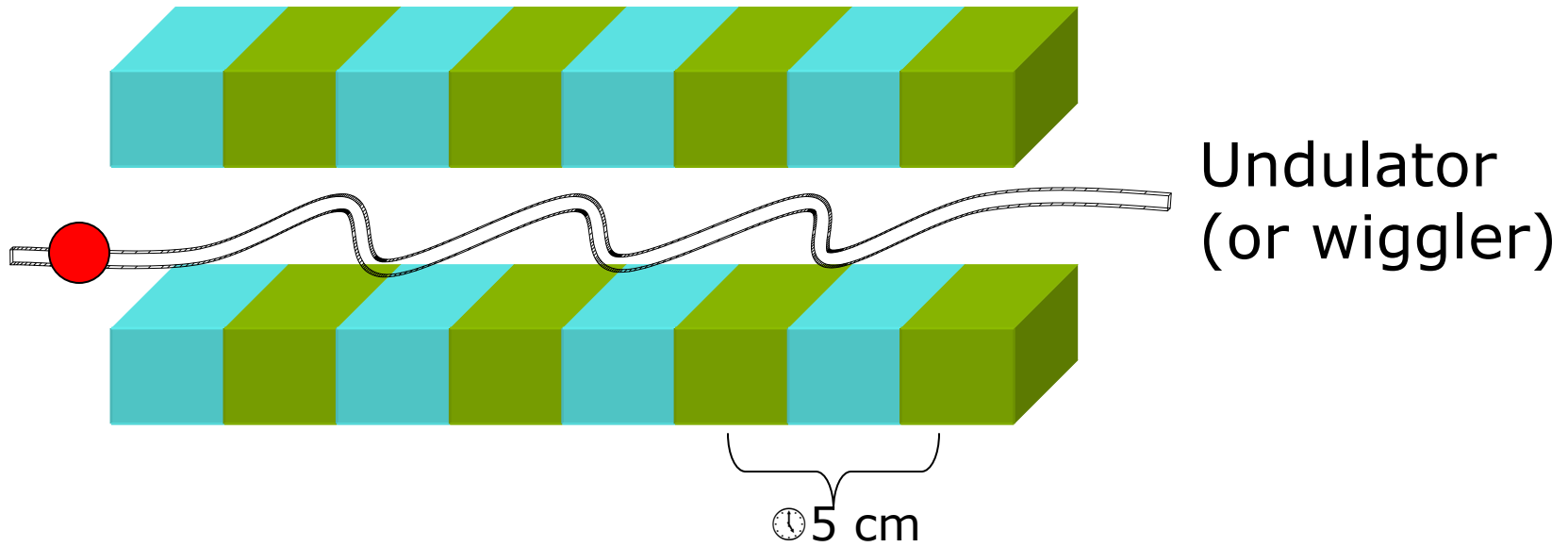


Light interacting with an electron beam



$$\left\{ \begin{array}{l} \frac{d}{dt}(m\bar{v}) = q(\bar{E} + \bar{v} \times \bar{B}) \\ \frac{d}{dt}(mc^2) = q\bar{E}\bar{v} \end{array} \right.$$

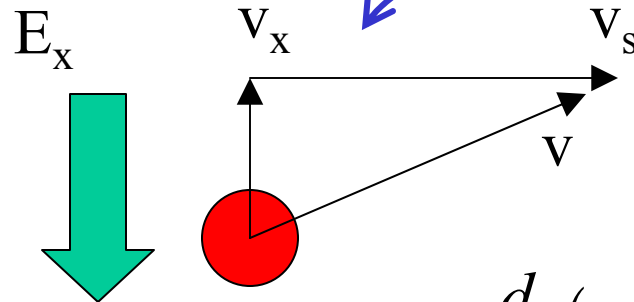
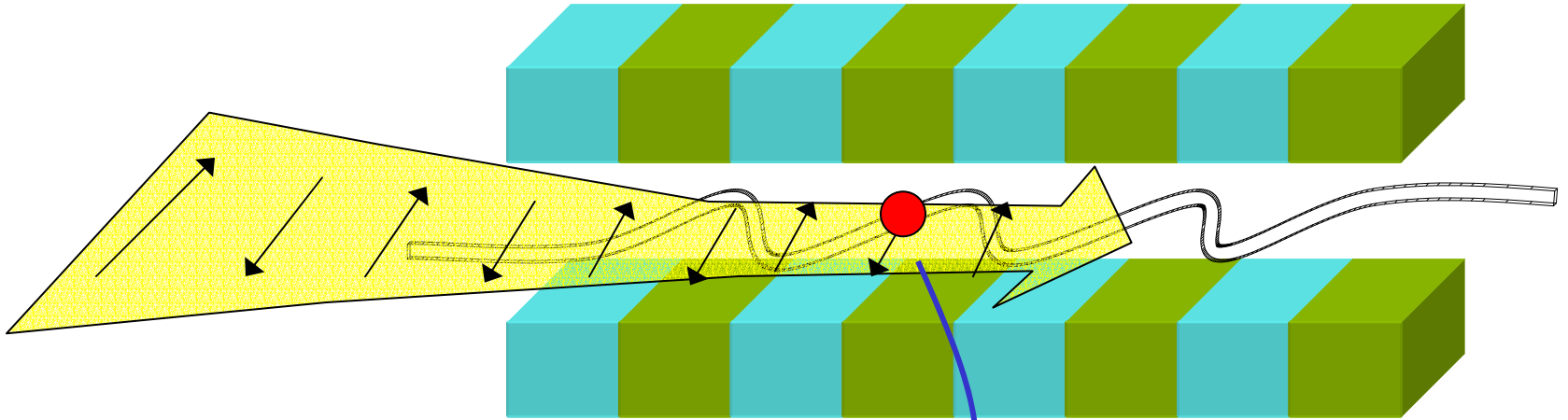
Making \vec{E} and \vec{v} parallel



* SR in harmonics

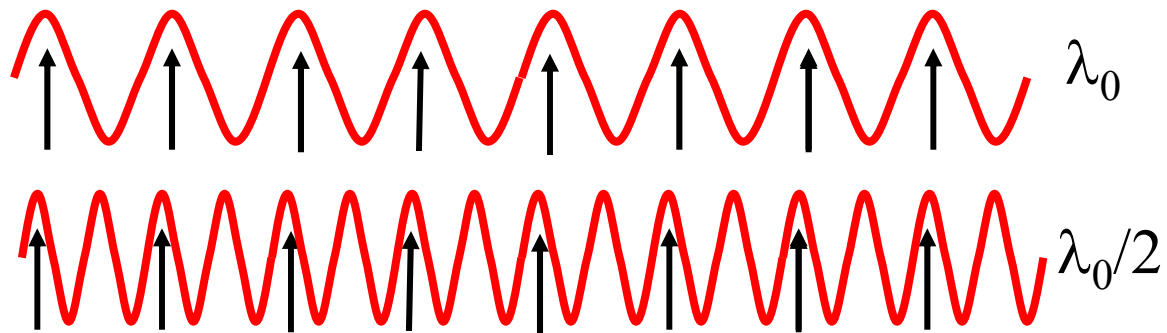
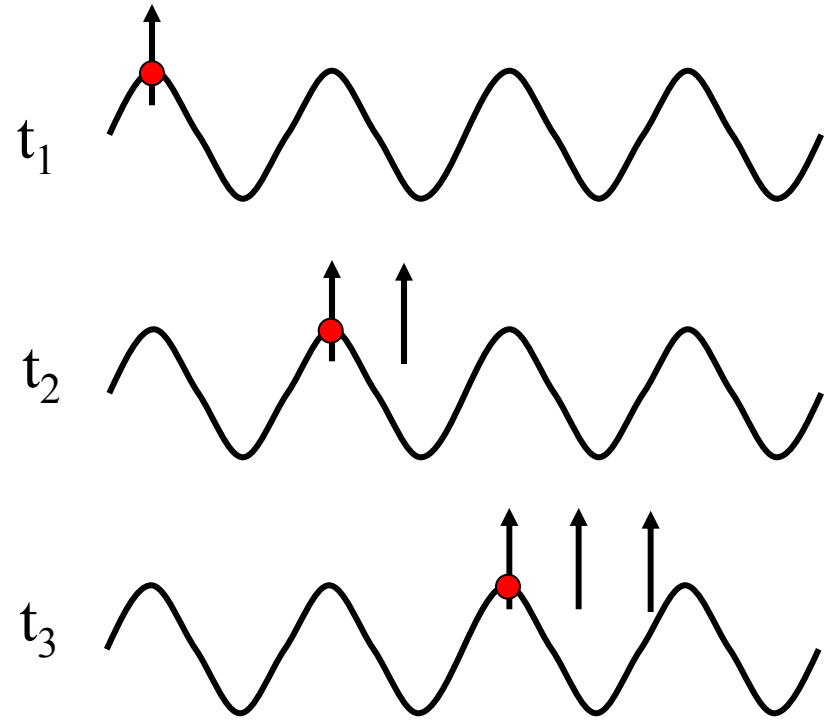
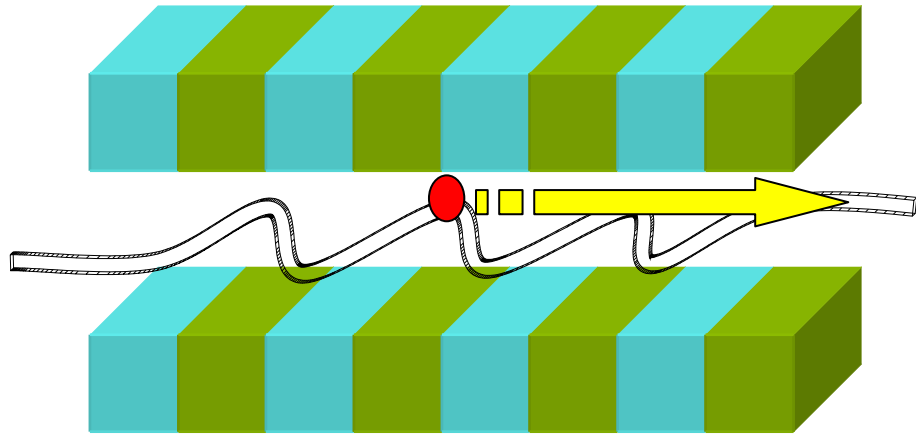
* Velocity γ s

Mixing light, e- and undulator

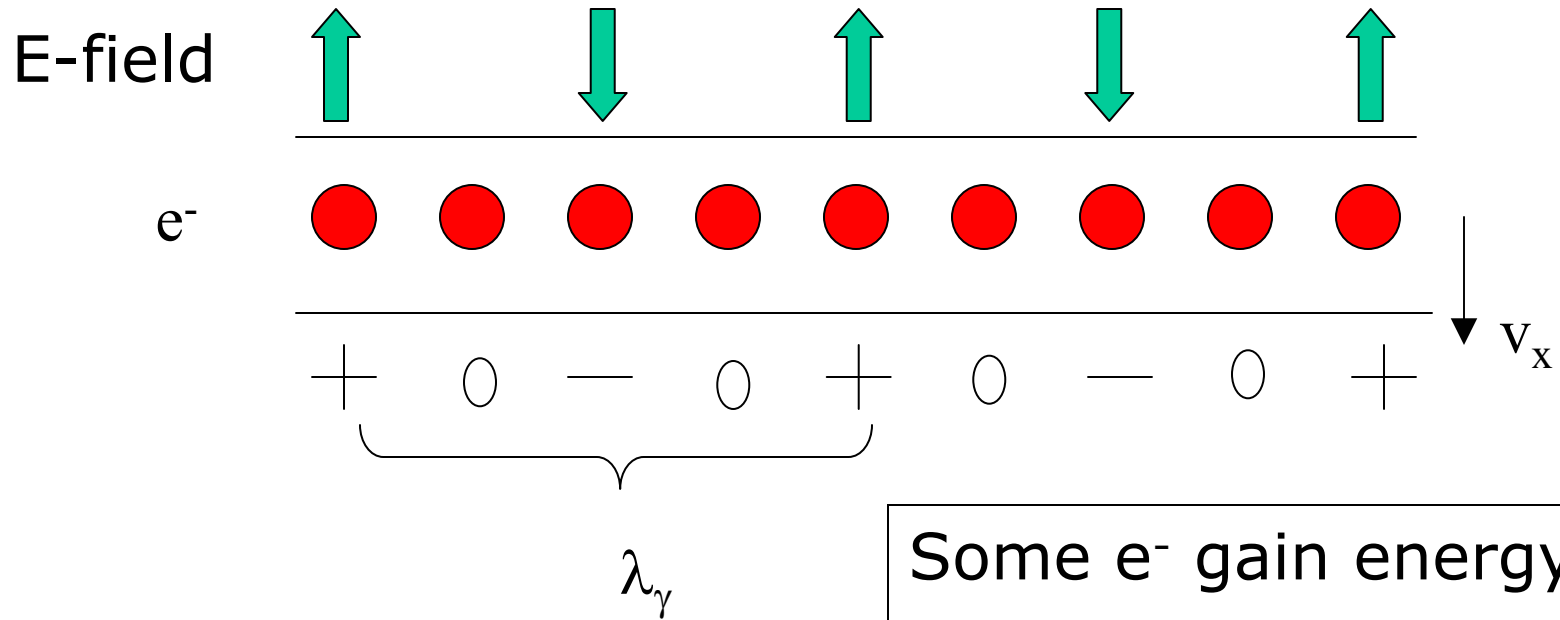


$$\frac{d}{dt}(mc^2) = -ev_x E_x \neq 0$$

Undulator radiation



Energy exchange

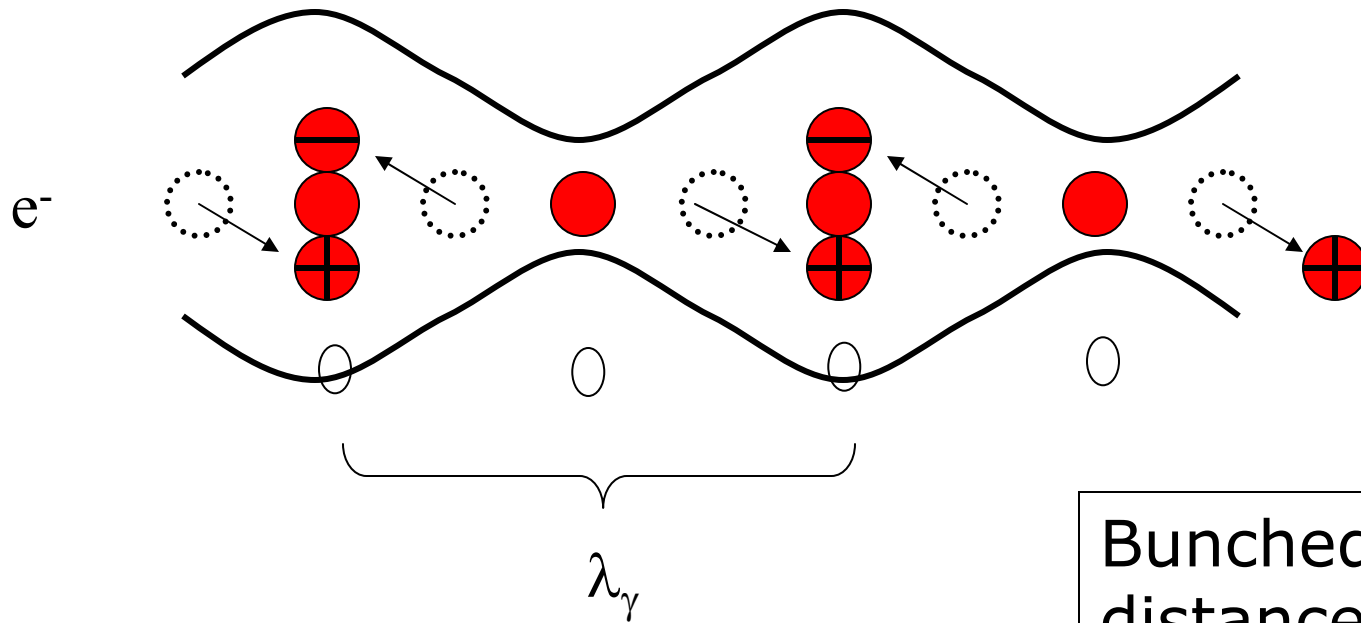
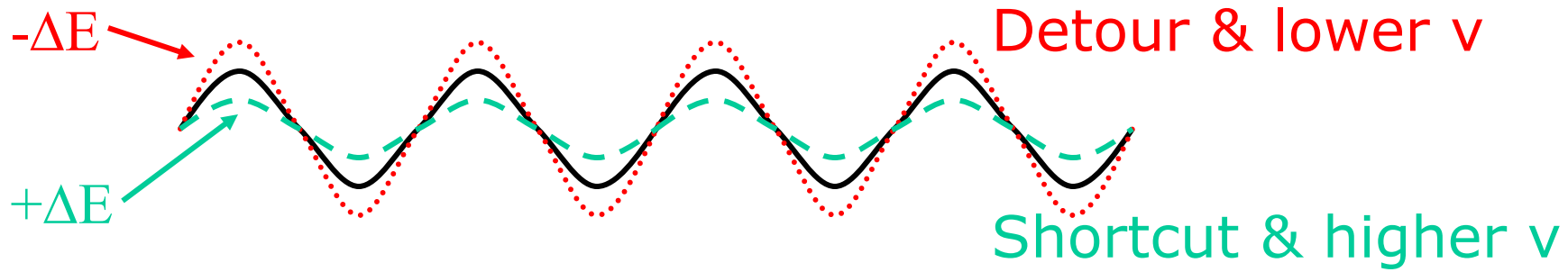


Some e⁻ gain energy

Some e⁻ lose energy

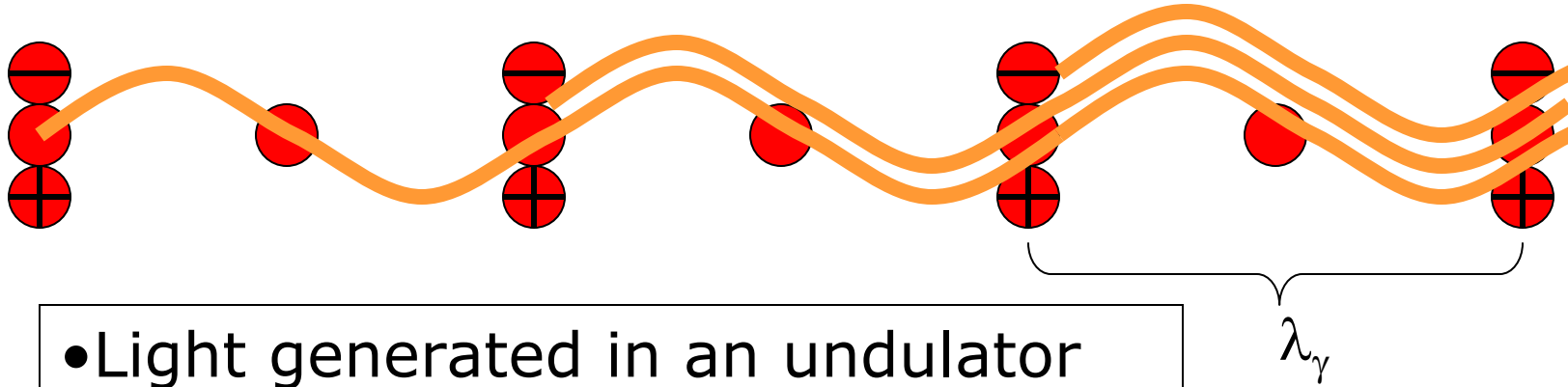
$$\Sigma = 0$$

Bunching

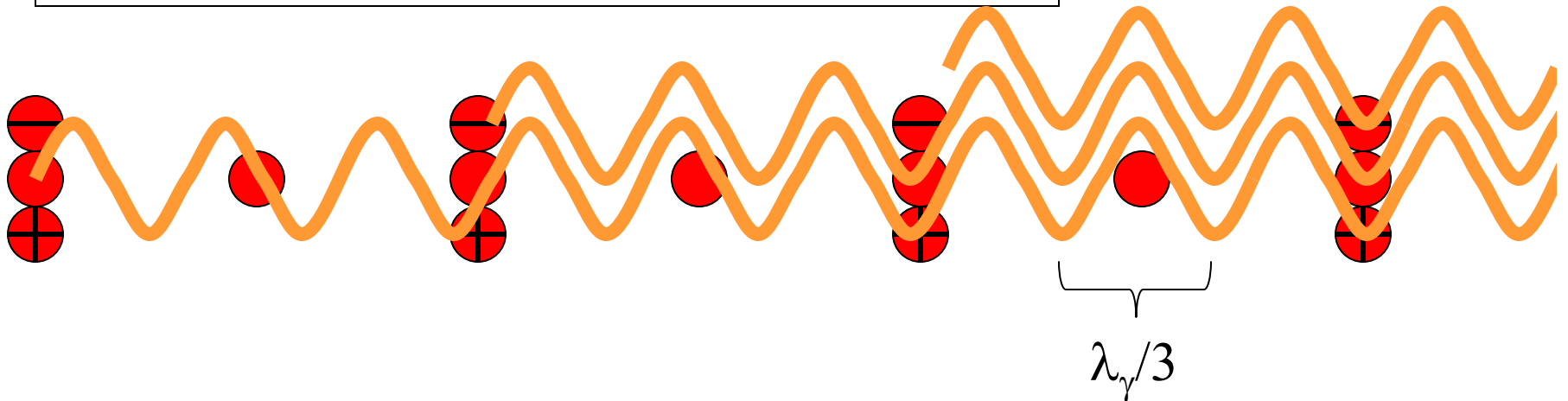


Bunched e^- with distance of light wavelength

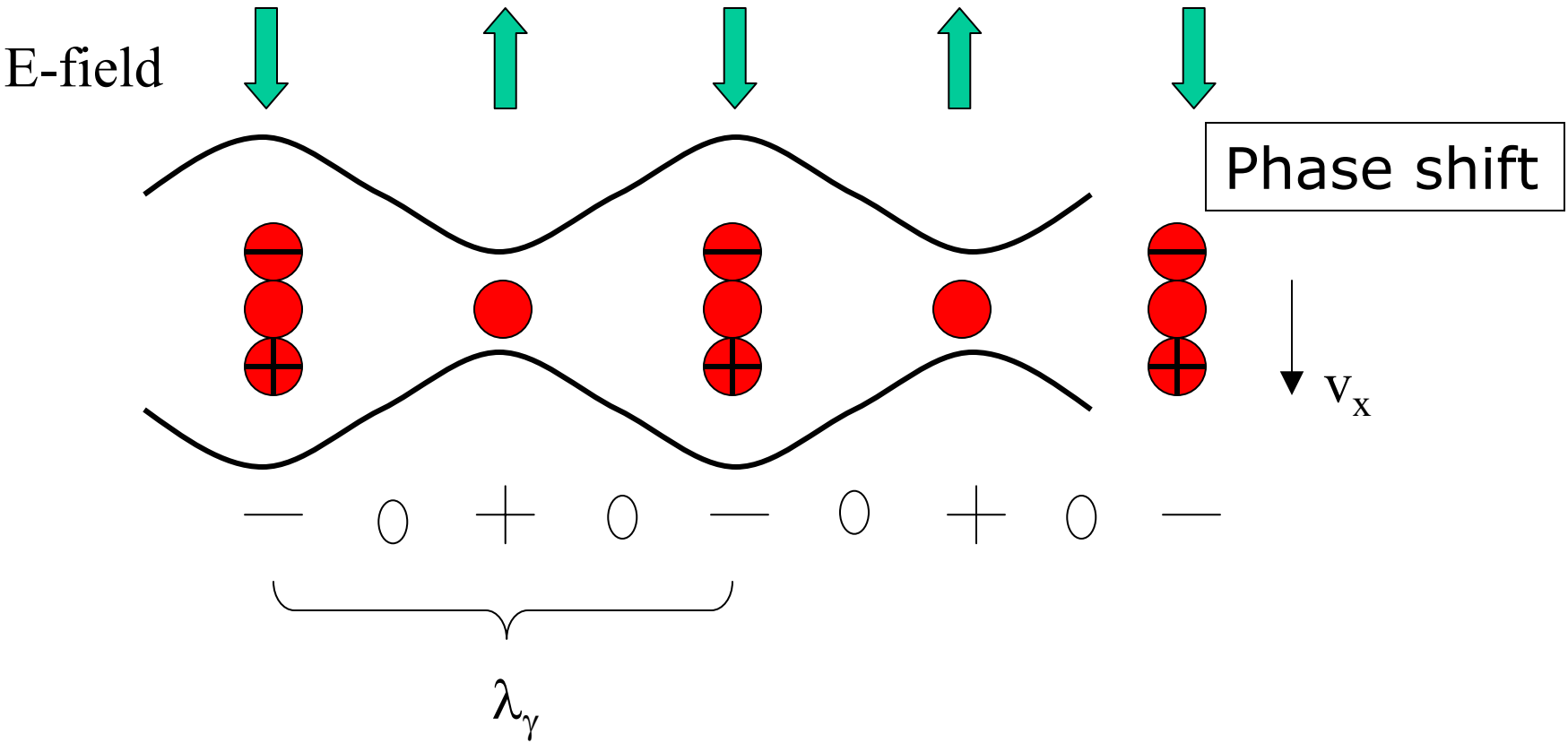
Radiator



- Light generated in an undulator
- Coherent
- With harmonics

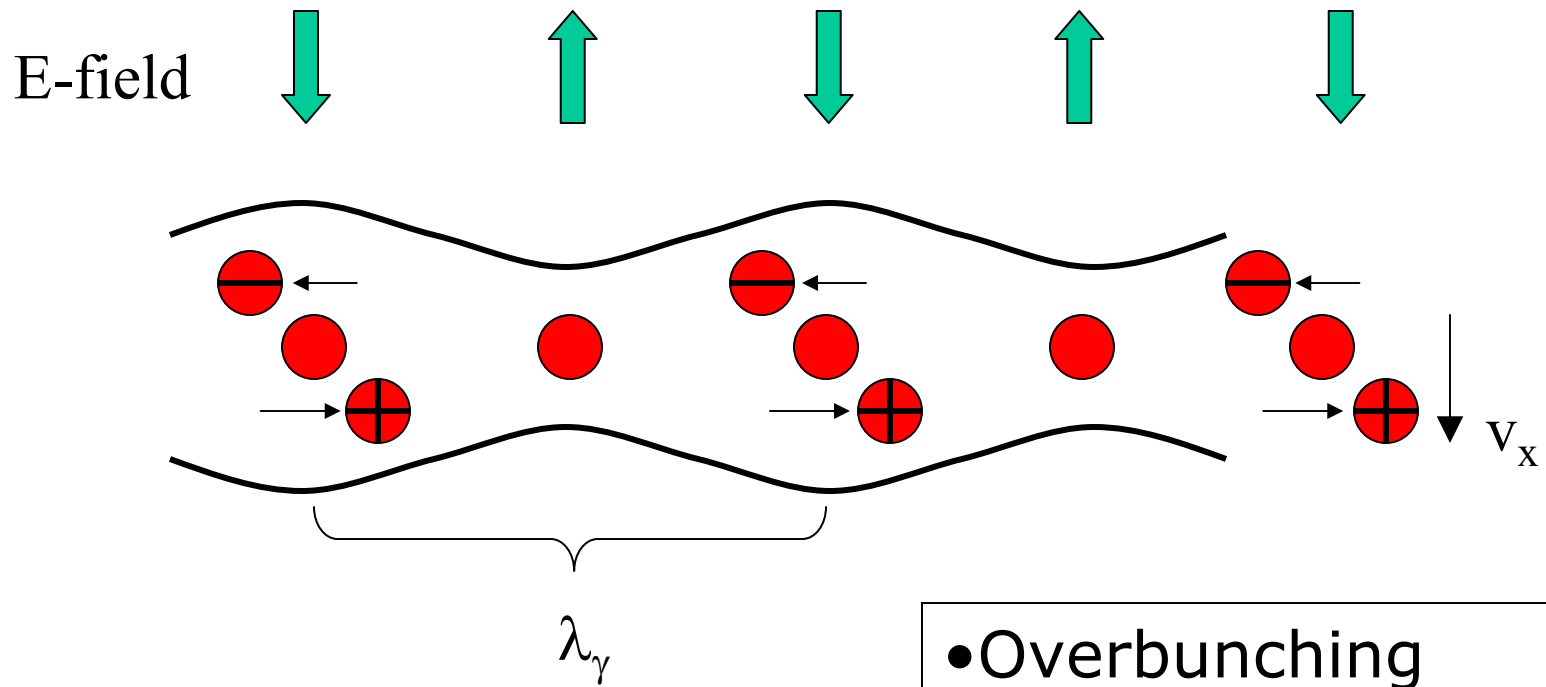


Amplification



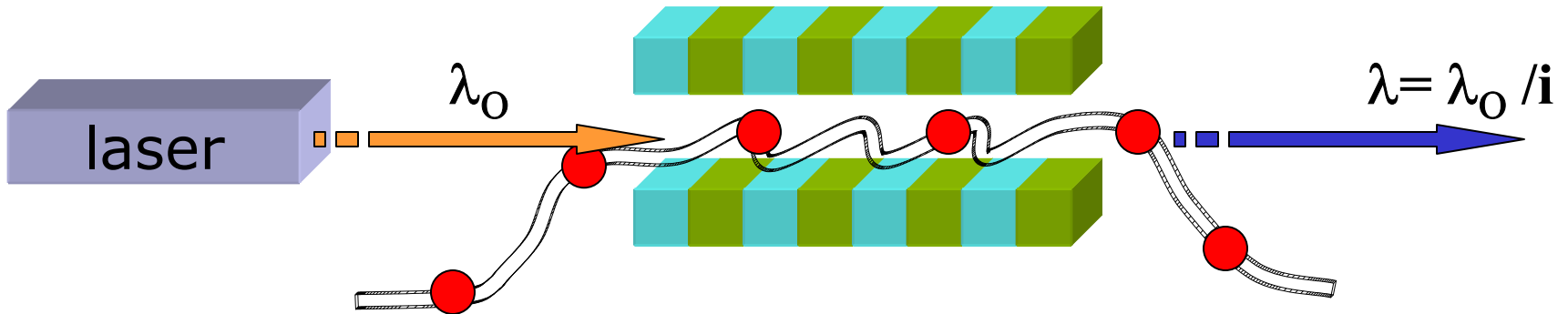
- All e⁻ loose energy
- E-field gains energy
- $\Sigma \text{ ⌚ } 0$

Saturation



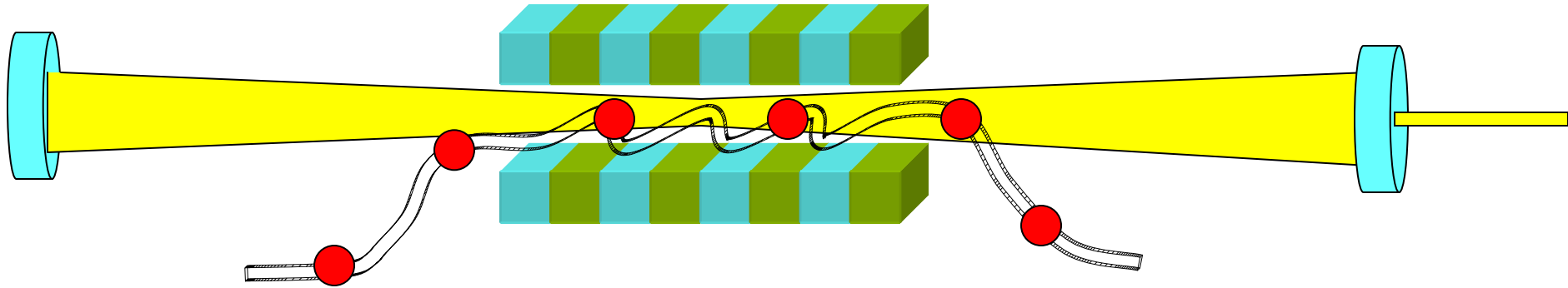
- Overbunching
- Amplification dies off

CHG - Coherent Harmonic Generation



- $i = 1, 3, 5, ?$
- $\lambda \approx 100 \text{ nm}$
- coherent

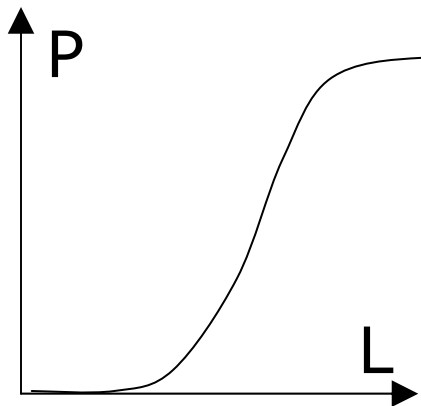
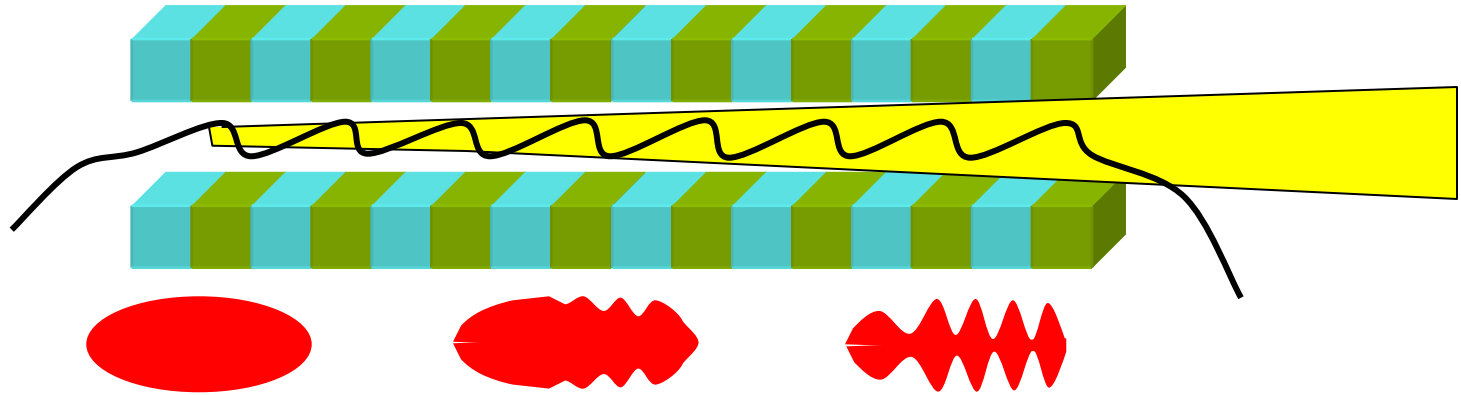
Resonator FEL



- IR 5-250 μm
- UV \approx 200 nm
- Tunable: magnet / e- energy
- Mirrors limit

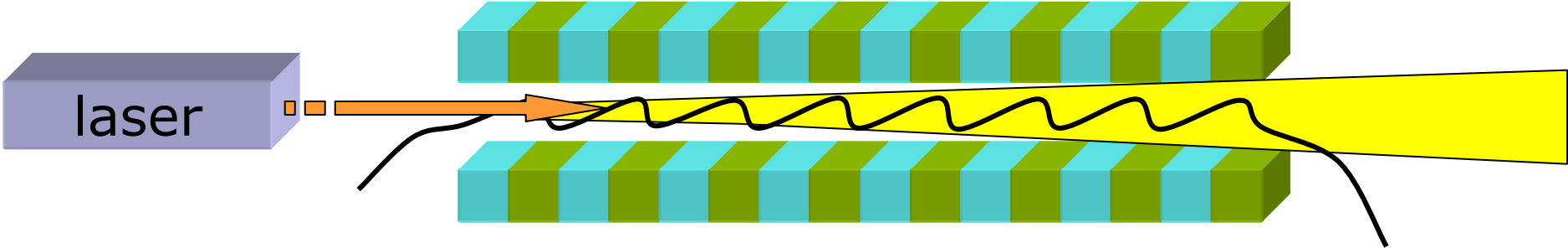
- **Storage ring**: high rep. Rate, "stable"
- **Linac**: high peak power, "unstable"

SASE (Self Amplified Stimulated Emission)



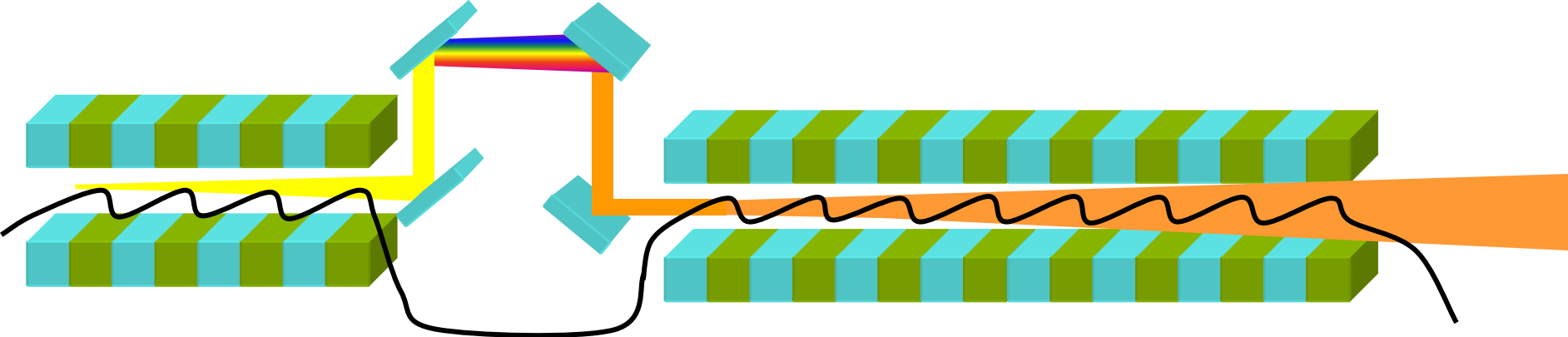
- From noise
- No mirrors (☹ X-rays)
- Tunable
- "Spiky" (t and λ)

SEEDING



- Remove instabilities
- CHG with gain HGHG

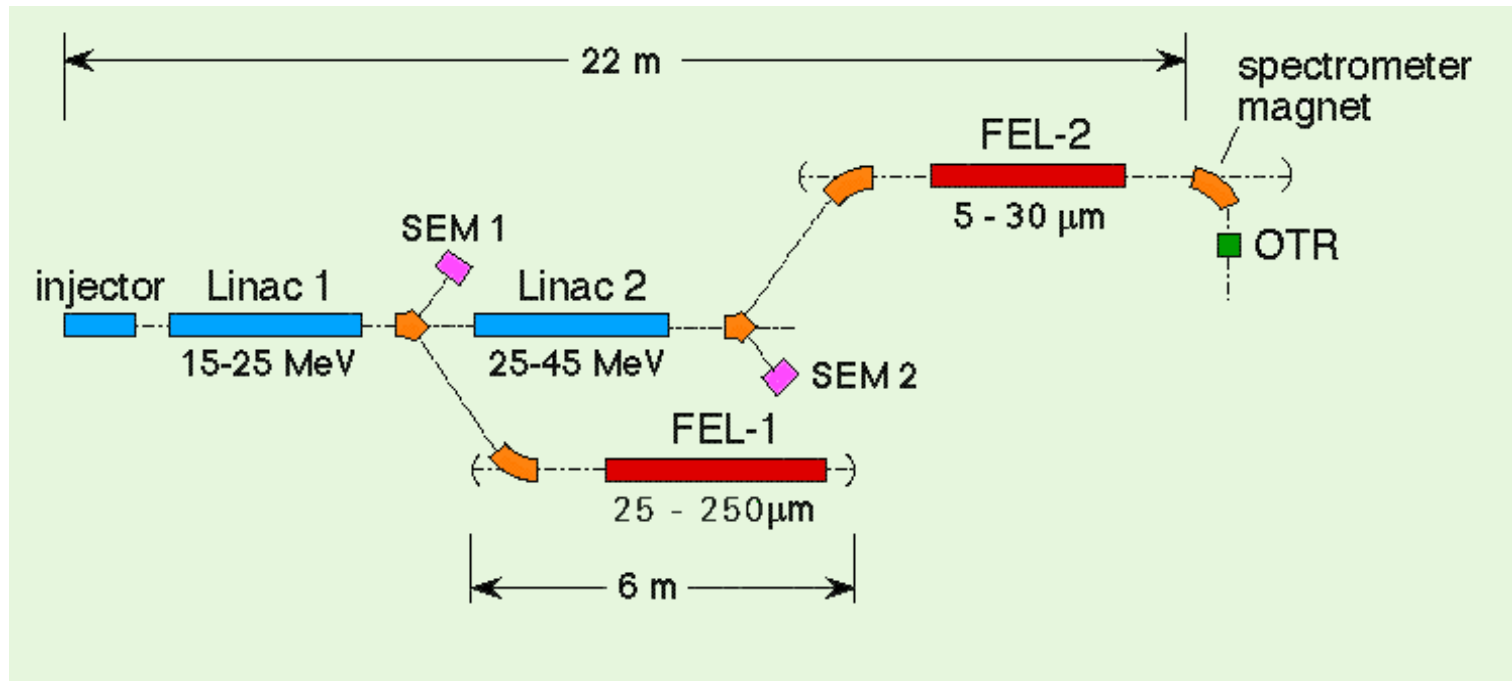
Monochromator



FELIX

Resonator IR- FEL

FOM, Holland

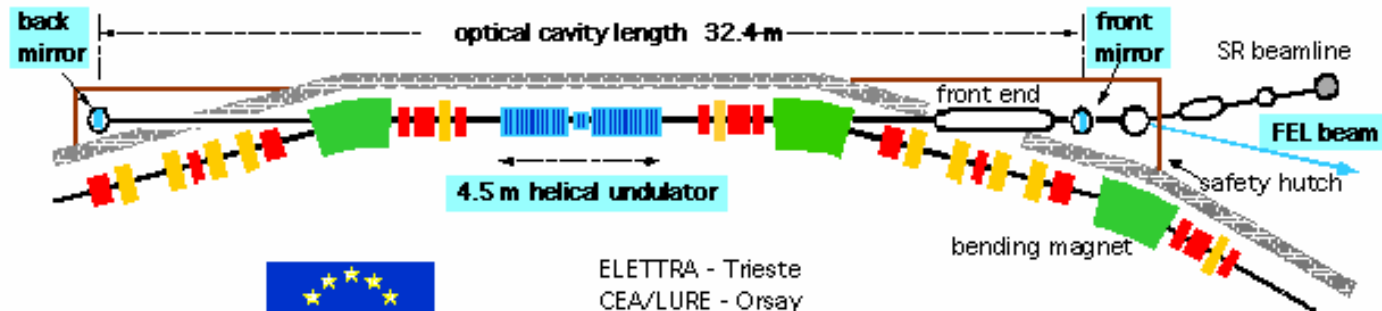


ELETTRA, Italy

Storage ring FEL

$$\lambda \geq 190 \text{ nm}$$

e- energy 1 GeV



EU Project N° FMGE-CT98-01 02

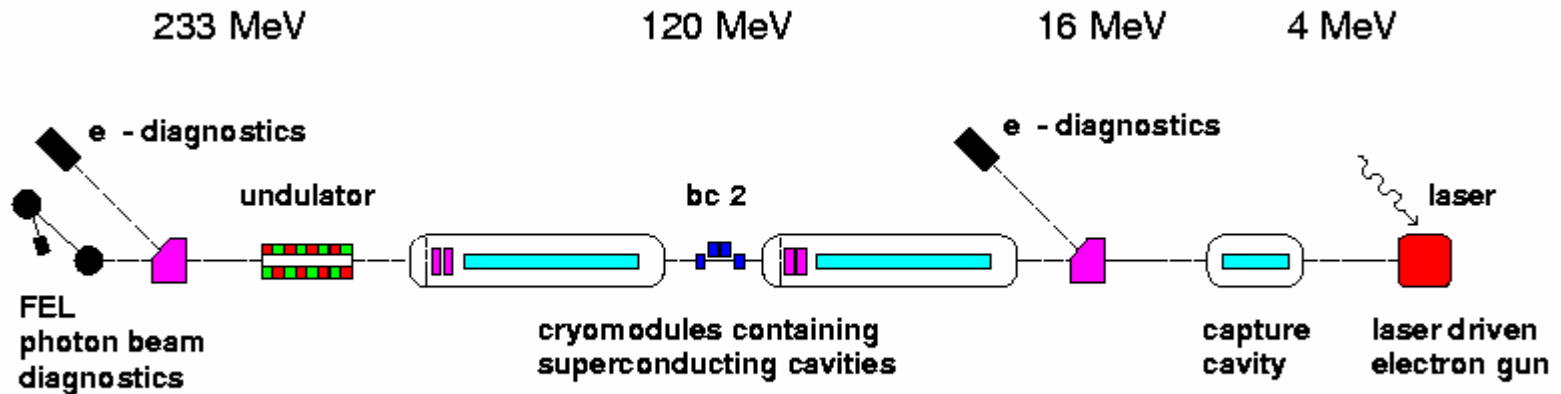
ELETTRA - Trieste
CEA/LURE - Orsay
DELTA - Dortmund
CLRC - Daresbury
ENEA - Frascati
MAX-LAB - Lund

TTF, Hamburg

Tesla Test Facility

$$\lambda = 109 \text{ nm}$$

SASE FEL



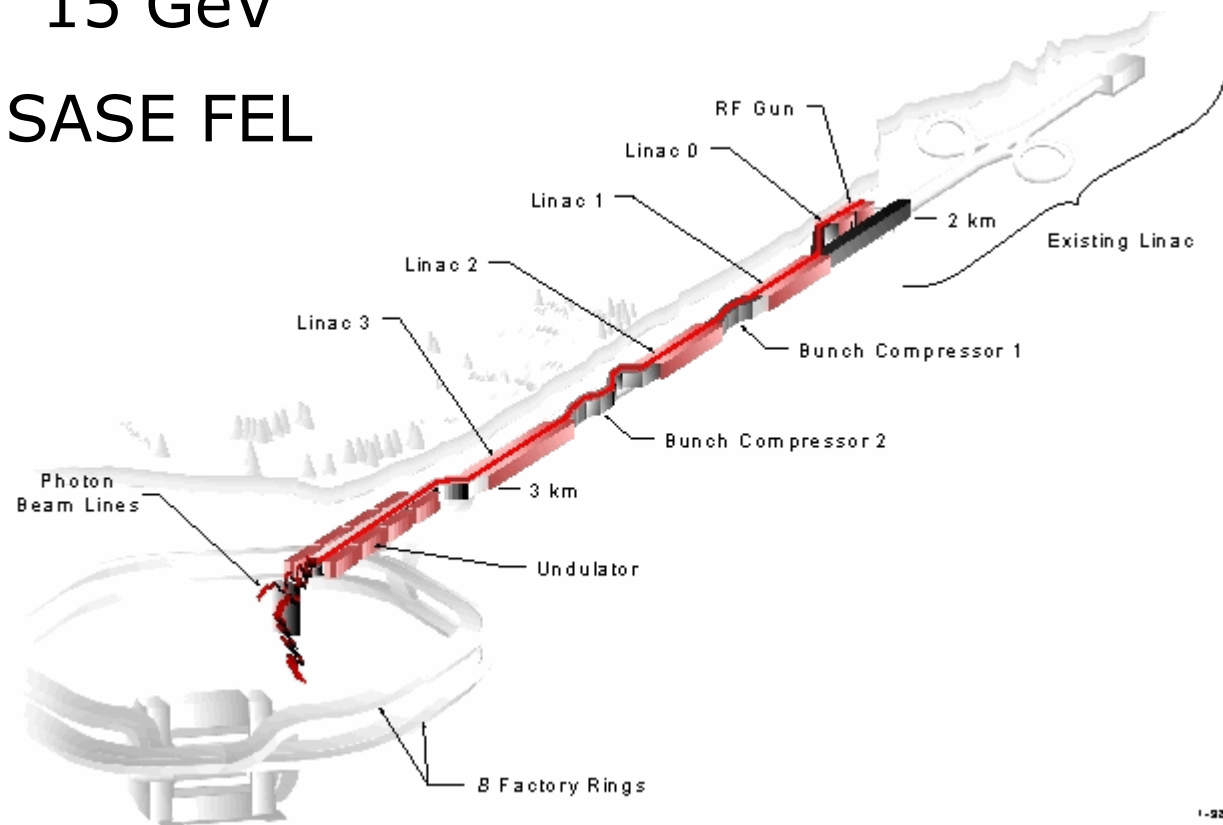
LCLS, Stanford

Linac Coherent Light Source

$$\lambda = 1-15 \text{ \AA}$$

15 GeV

SASE FEL





MAX-lab

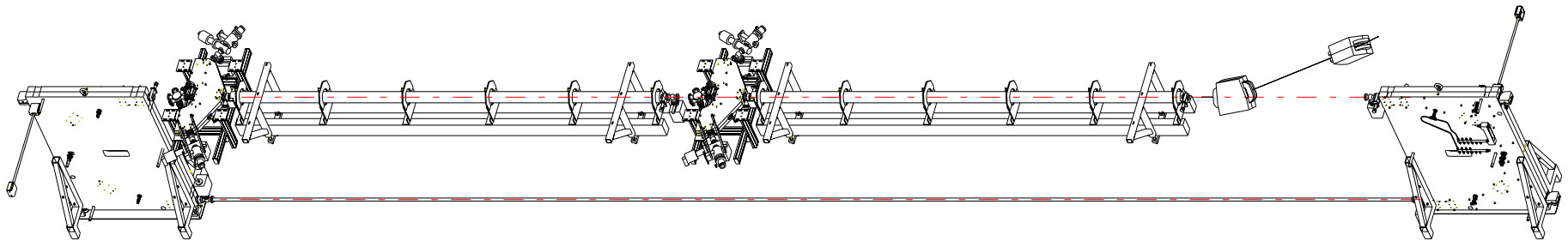
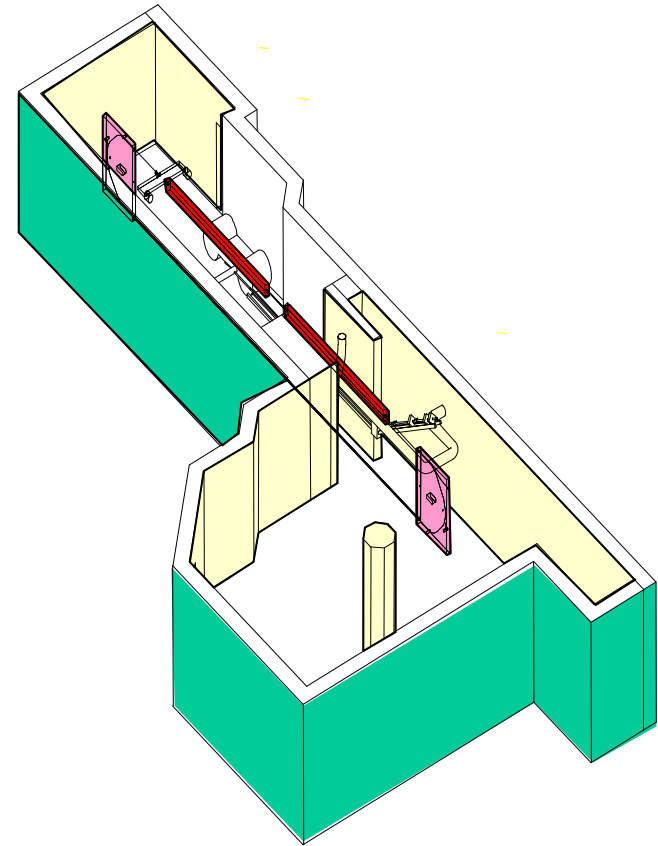
VUV FEL

Seeded SASE FEL

$\lambda = 100\text{-}400\text{ nm}$

500 MeV

300-400 undulator periods



TESLA, Hamburg

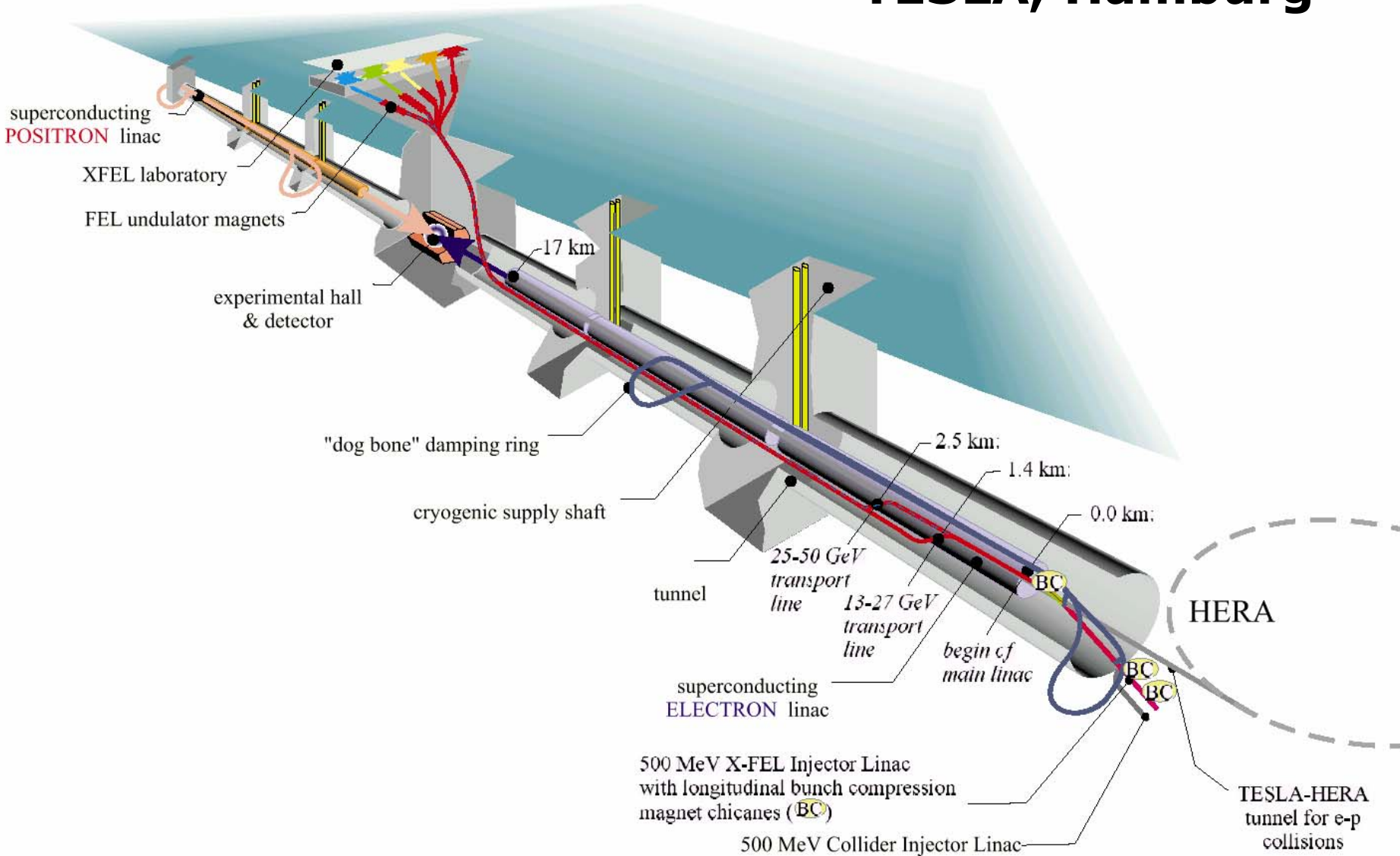


Figure 1.0.4.: Schematic presentation of the whole TESLA facility.

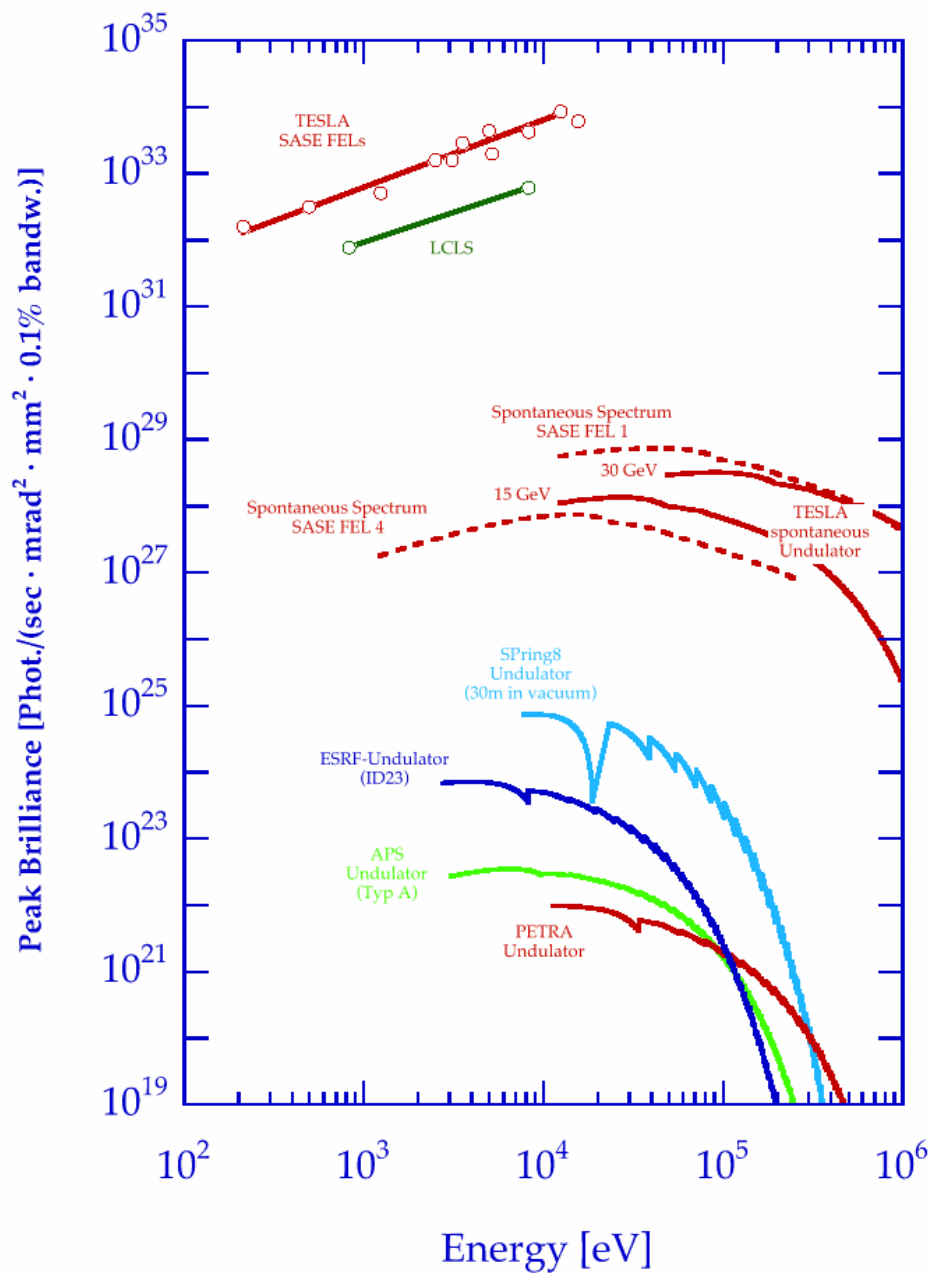


Figure 1.0.3.: Peak brilliance of the TESLA XFEL devices in comparison to third generation storage ring insertion devices. Red open circles: calculated values for the TESLA XFELs. Note that the photon energy E is related to the wavelength by $\lambda[\text{\AA}] = 12.4/E[\text{keV}]$.