Dottorato in Fisica degli Acceleratori: Incontri con gli studenti del I anno

Plasma Driven Free Electron Lasers

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Università degli Studi "La Sapienza", Roma – October 13th, 2017

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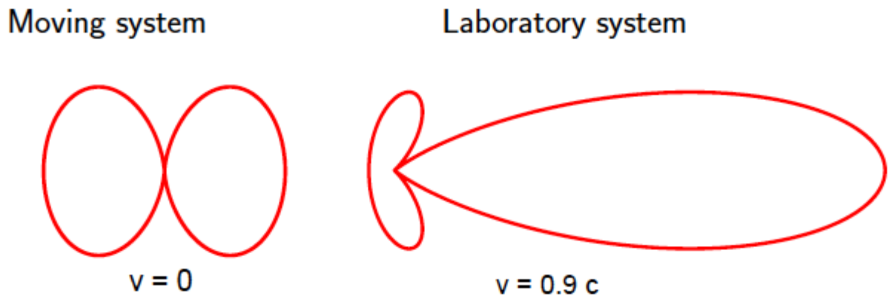
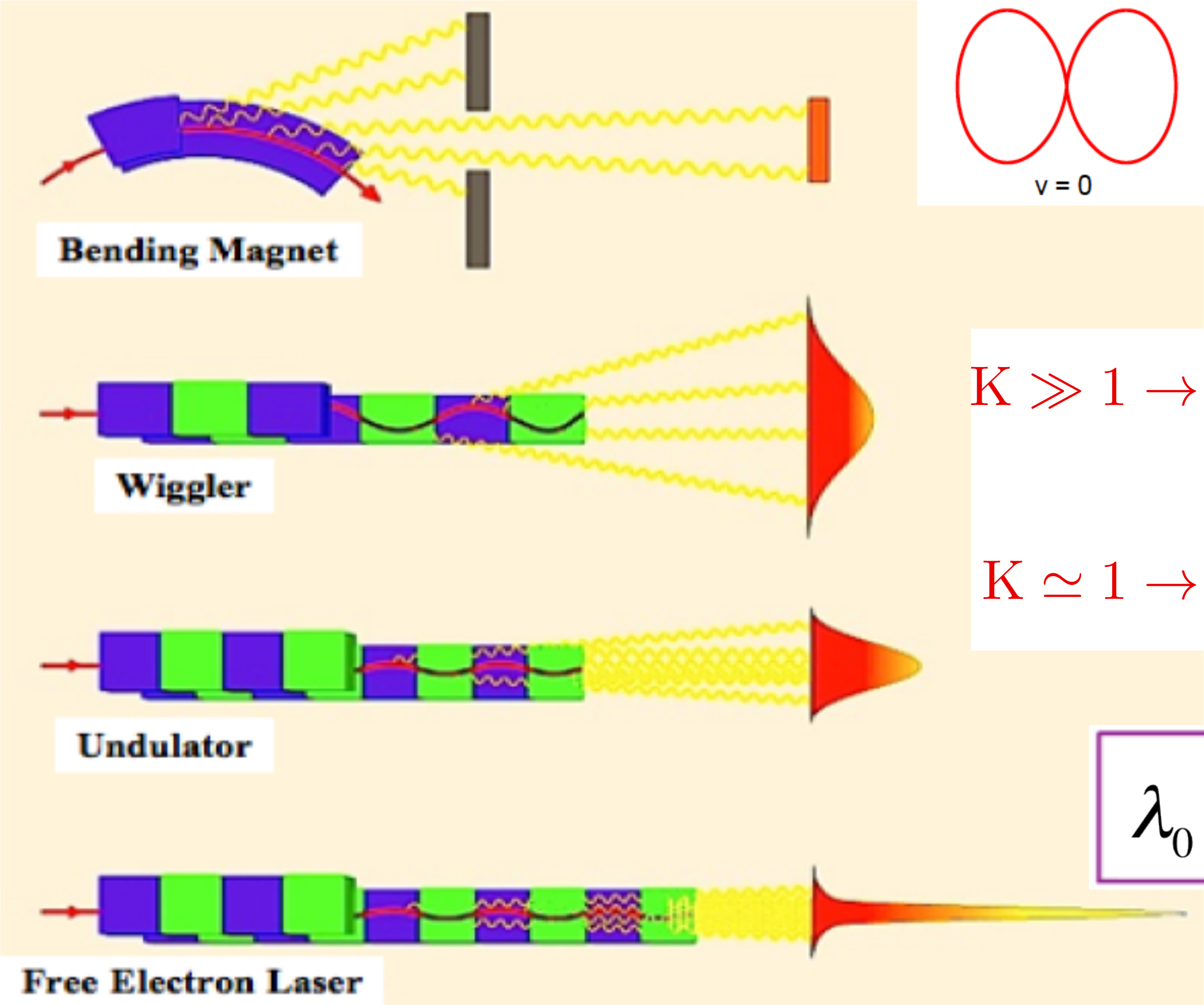
From synchrotron to FEL radiation



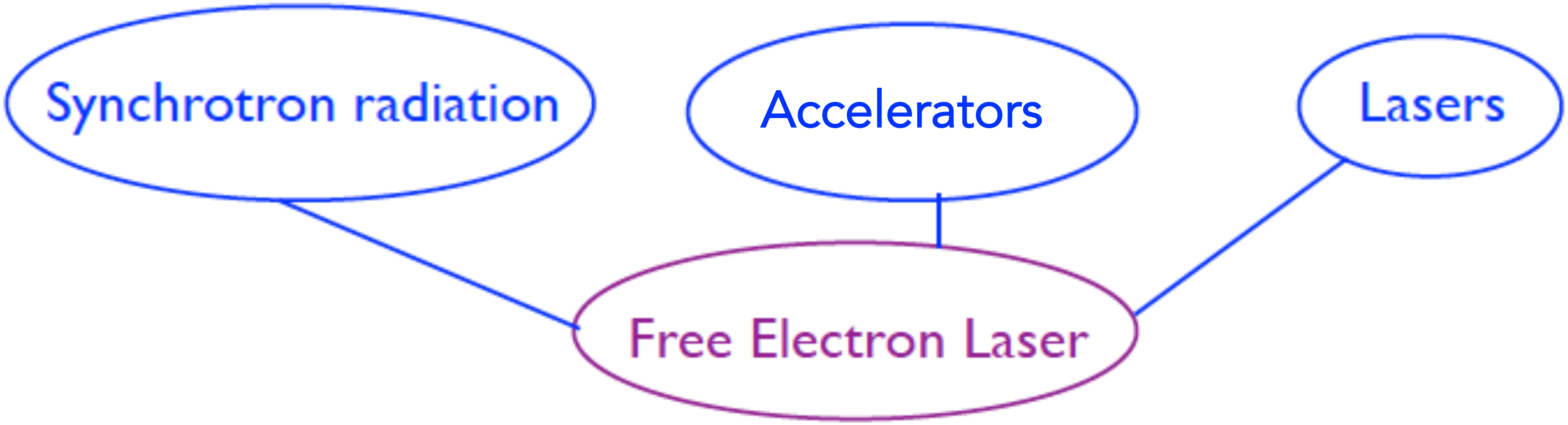


$$\mathrm{K} \gg 1 \rightarrow \text{wiggler}: \ \text{also} \ \theta \gtrsim \frac{1}{\gamma}$$

$$\mathrm{K} \simeq 1 \rightarrow \text{undulator}: \ \theta \ll \frac{1}{\gamma}$$

$$\lambda_0 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K_u^2}{2} + \gamma^2\theta^2\right)$$

FEL: laser from an e-beam in a magnetic field

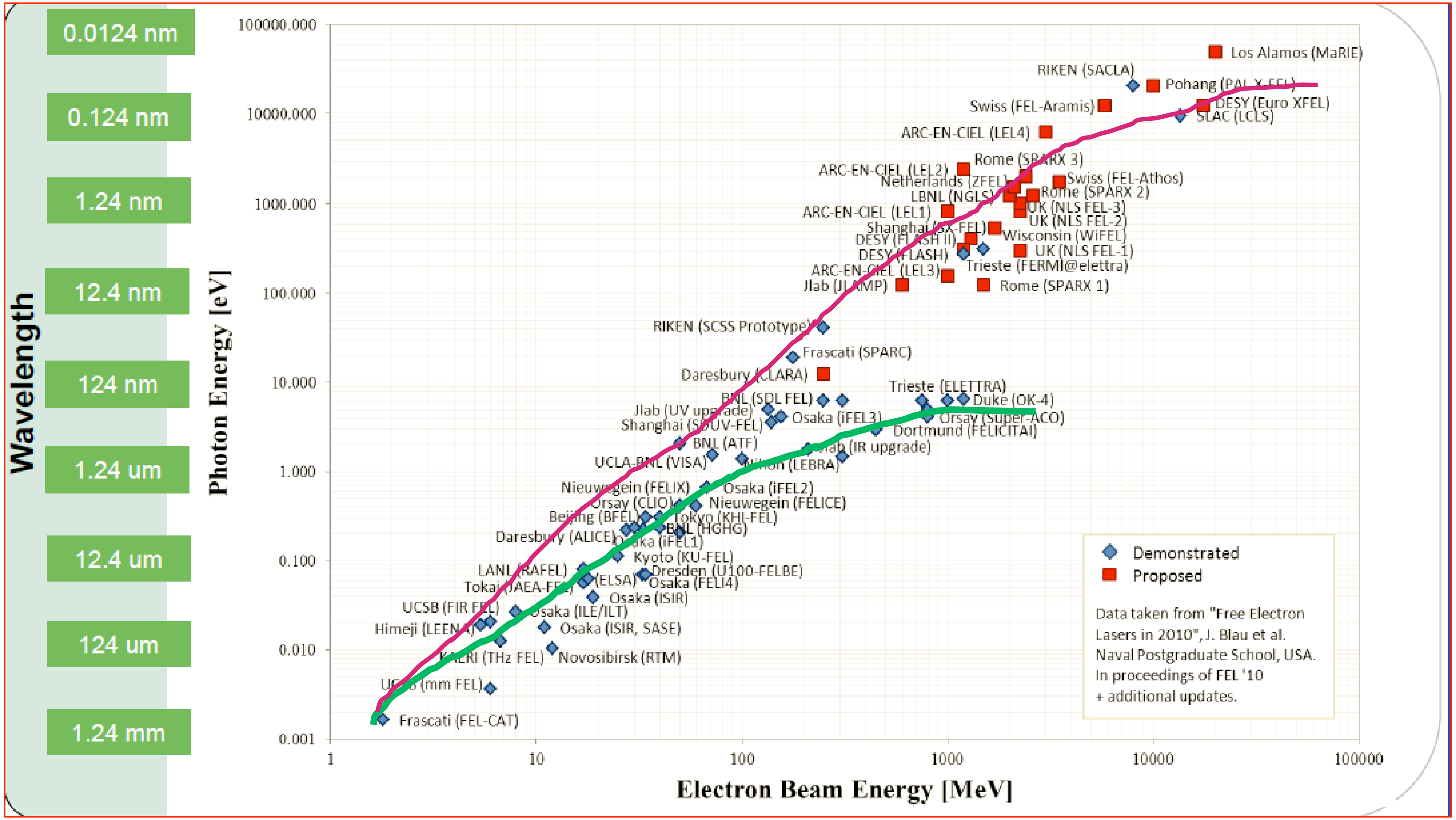


free electrons
bound electrons in atoms and molecules : vibrate at specific frequencies

- broad wavelength tunability (vibration frequency can be adjusted by changing the magnetic field or the speed of the electrons)
- excellent optical beam quality
- high power

$$K_u = \frac{eB_u\lambda_u}{2\pi m_o c}$$

Letardi FEL Chart: beam energy vs. γ wavelength



We observe sort of saturation of photon energy with the *e*-beam energy ➔ novel acceleration technologies (see M.Ferrario)

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Reasons to go beyond state of the art

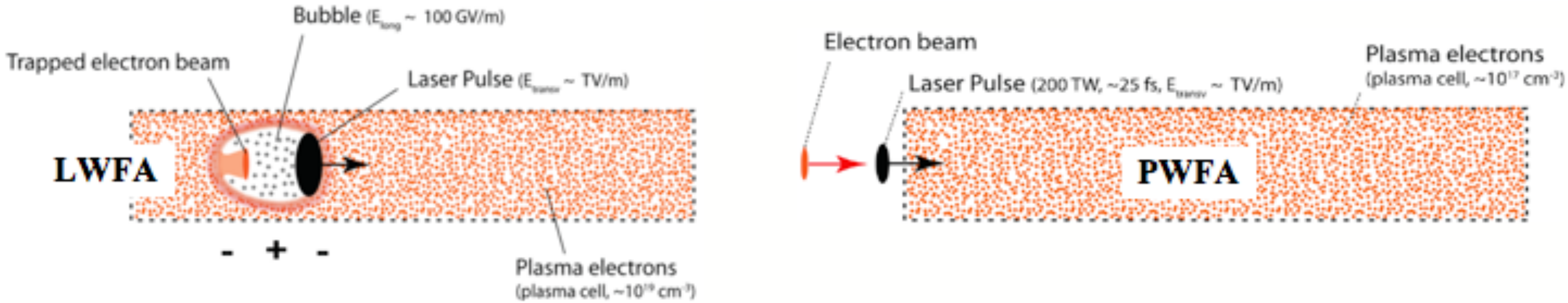
FEL size and cost

Wavelength	Energy	Size [m]	Cost [M$]
IR 2-10 μm	10-40 MeV	3-10	1-5
EUV 13.5 nm	0.5-1 GeV	40	30-50
X 0.15 nm	15 GeV	500-1000	1000

A) reduce the size of the accelerator using different accelerating schemes (see M.Ferrario) (High gradient, Plasma accelerators,…)

B) reduce the undulator length using novel technologies (Superconducting, Cryogenic Permanent Magnet, R.F. Undulators,….)

First stage of this Thesis subject



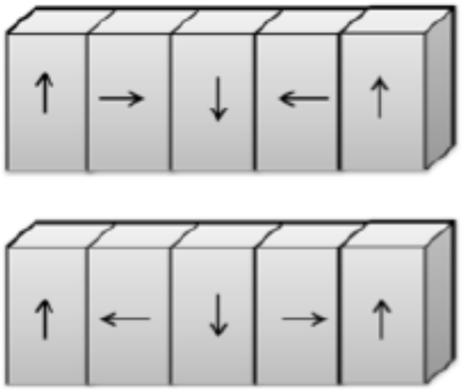
a) Study and define scaling laws describing the qualities of the e-beam accelerated through the plasma sections

b) Matching out of plasma with beam size ~ 1 μm, all the way down to the undulator entrance with 1 μm accuracy ➔ control of energy spread $\Delta\gamma/\gamma$ and emittance growth

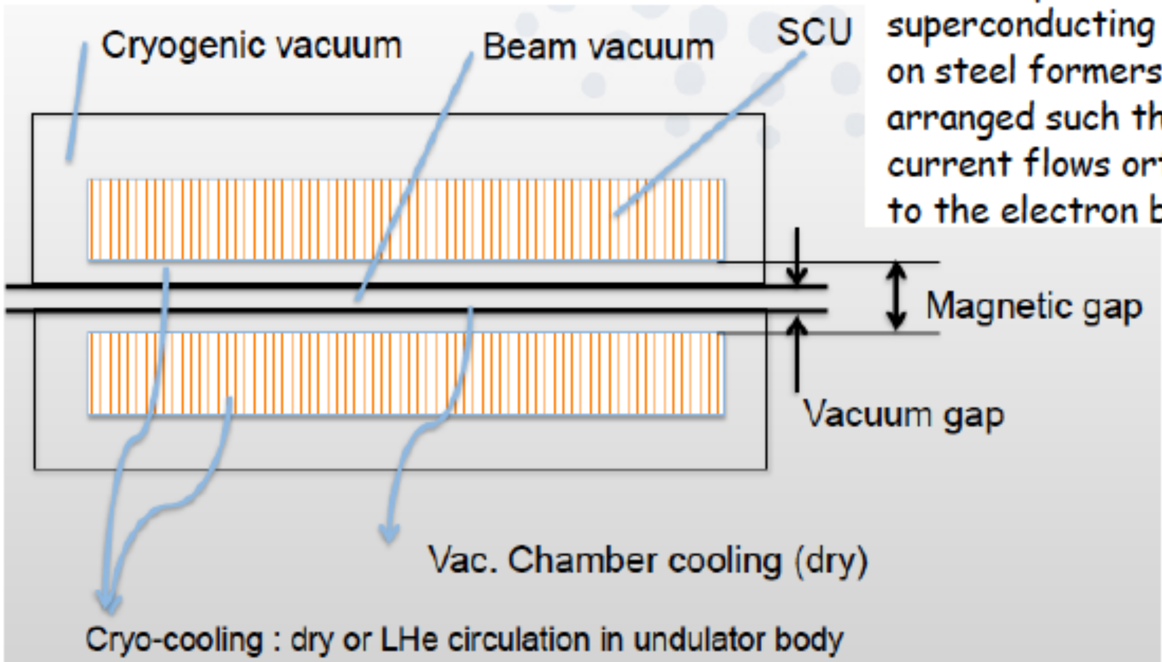
c) Scrutinize (with experim. input) the back-ups for coping with large $\Delta\gamma/\gamma$:

- Lengthening the outcoming bunch over the slice that lases, to reduce $\Delta\gamma/\gamma$
- Transverse gradient undulators with a dispersive chicane

Undulator technologies: PPMU, SCU, CPMU



pure permanent magnet in
Hallbach configuration



Two independent sets of superconducting windings on steel formers are arranged such that the current flows orthogonal to the electron beam

Cryogenic cooling of permanent magnet arrays:

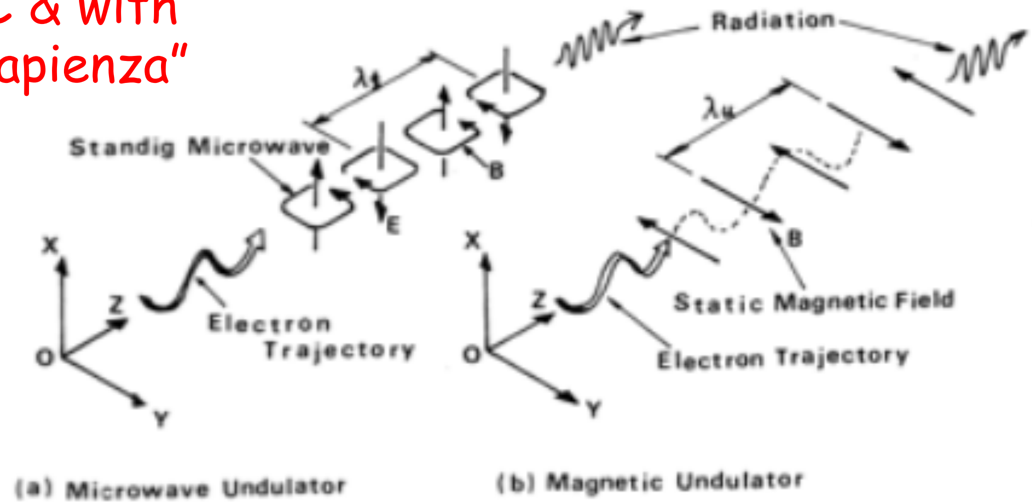
- ✓ ~ 40-50 % gain in peak field compared with standard PM undulators
- ✓ better vacuum performance because cold, and better radiation damage resistance

➤ Present limitations for SCUs:

1) gap can't be squeezed because of the vacuum chamber
2) very sensitive to synchrotron and wakefield radiations

Novel undulators: cost reduction

Activity in collaboration with SLAC & with the SBAI Department, Univ. "La Sapienza"



Drawbacks of Static Undulators

1. Cannot control the polarization
2. Cannot change the undulator period
3. Vulnerable to X-ray radiation
4. High cost

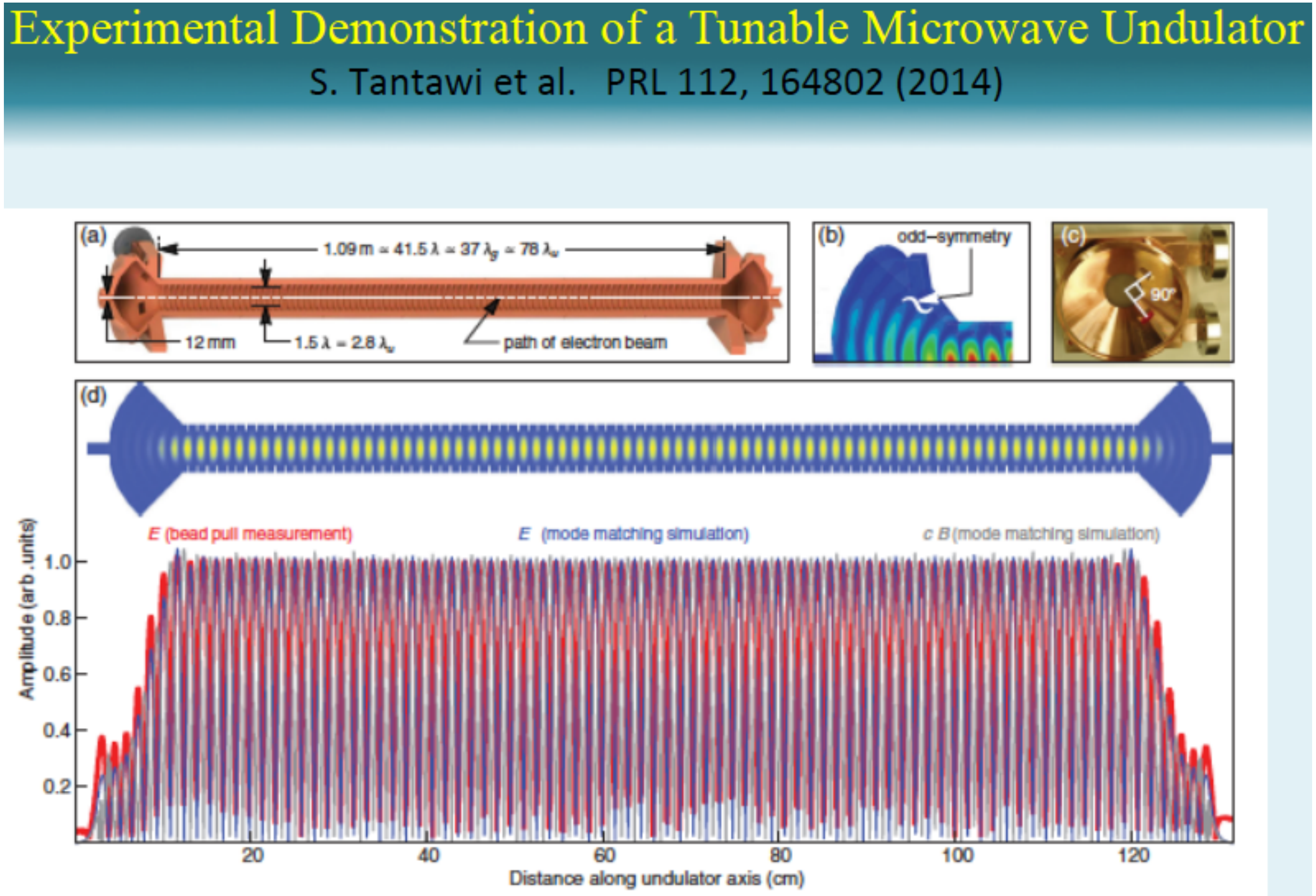
Advantages of RF undulators

1. Easy polarization control
2. Short undulator periods and large gaps.
3. Cheap in comparison with the Permanent Magnet Undulators

Drawbacks of RF Undulators

1. Realization of High-Power RF Sources with stable amplitude and phase
2. Complicate design and fabrication

RF undulators



We wish to address this technology

Further stages of this Thesis subject

a) Undulator choice to be deployed as a FEL driven by Plasma acceleration stages, a systematic comparison study among:

- Conventional undulators
- Superconducting undulators
- Cryogenic permanent magnet undulators

b) Research and development on innovative technologies such as RadioFrequency and Laser undulators

c) Making use of a broad tools range: from exact analytical and semi-analytical scaling laws through start-to-end simulations including the full transport chain and also realistic (higher order…) corrections

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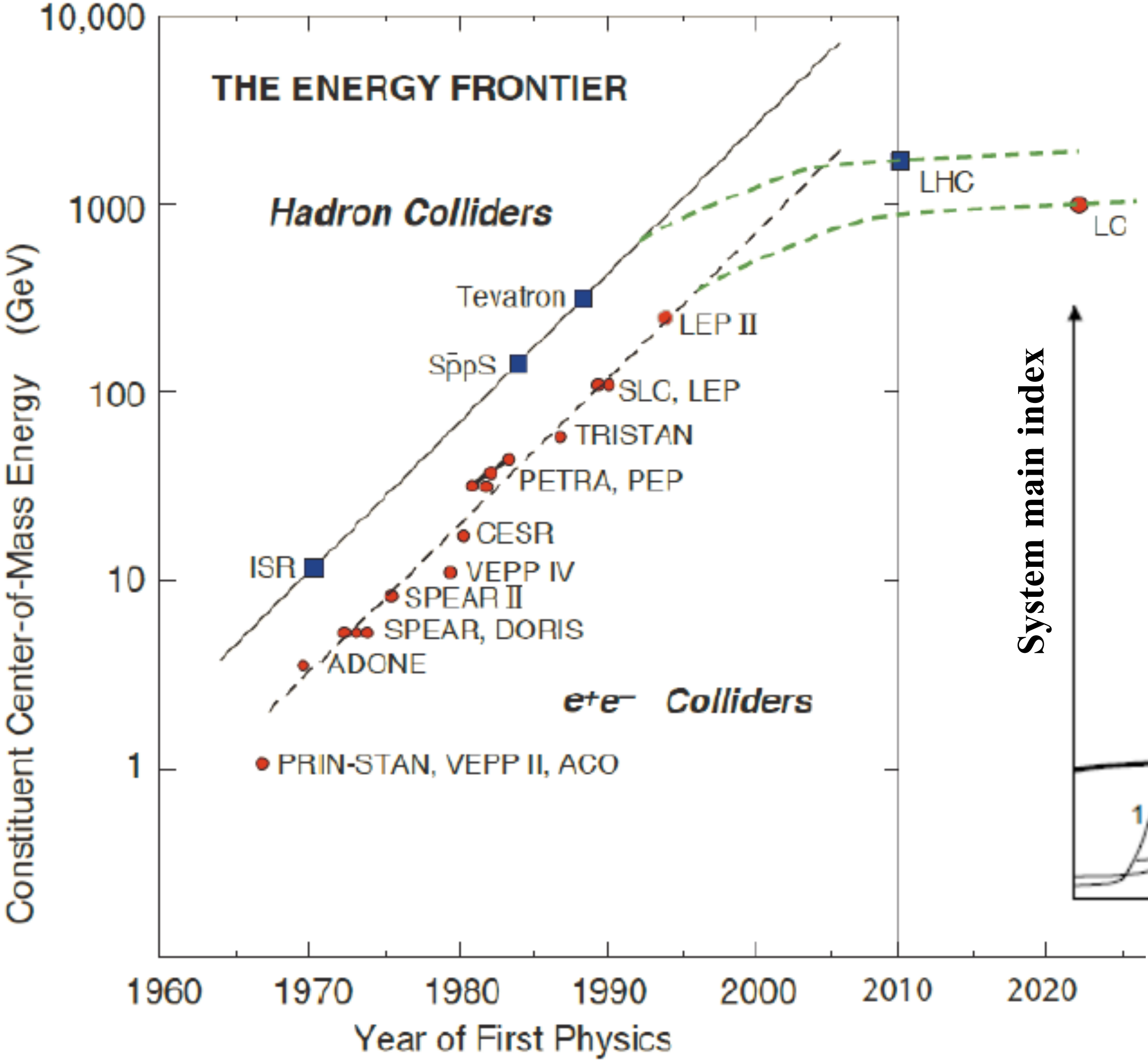
Livingston Chart: new technologies' need



Subsequent replacements of old for new systems according to an ideal Growth Law