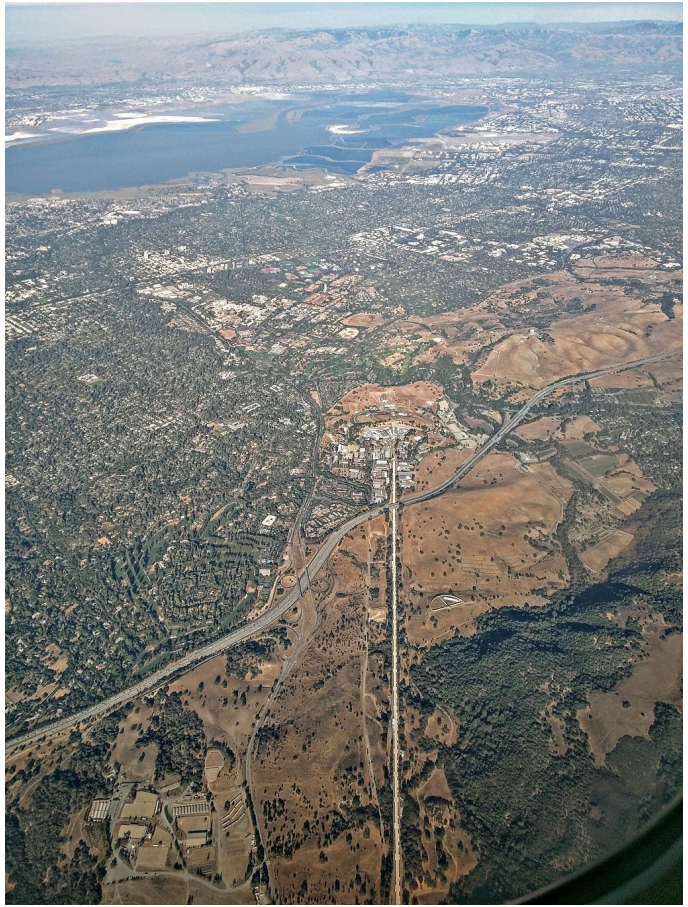
The UH FEL and what will happen next?

Siqi Li

Colloquium 9/26/2024

Fermilab
Lee Teng internship



SLAC

The Linac Coherent Light Source (LCLS) at SLAC

The UH FEL

John M.J. Madey
Inventor of the FEL

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 074901 (2014)

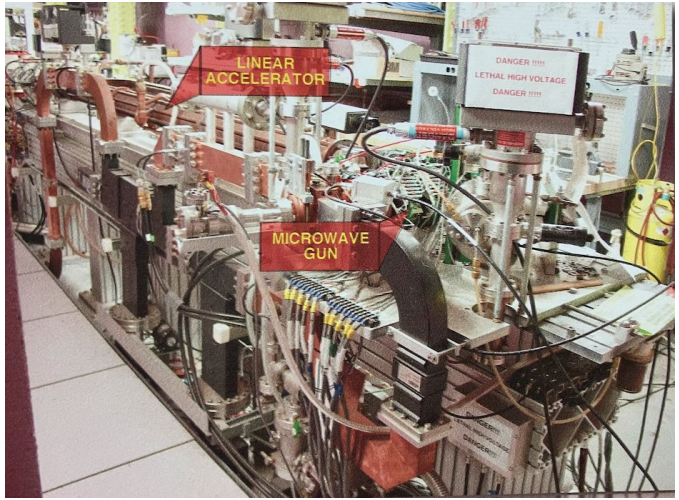
Wilson Prize article: From vacuum tubes to lasers and back again[1]

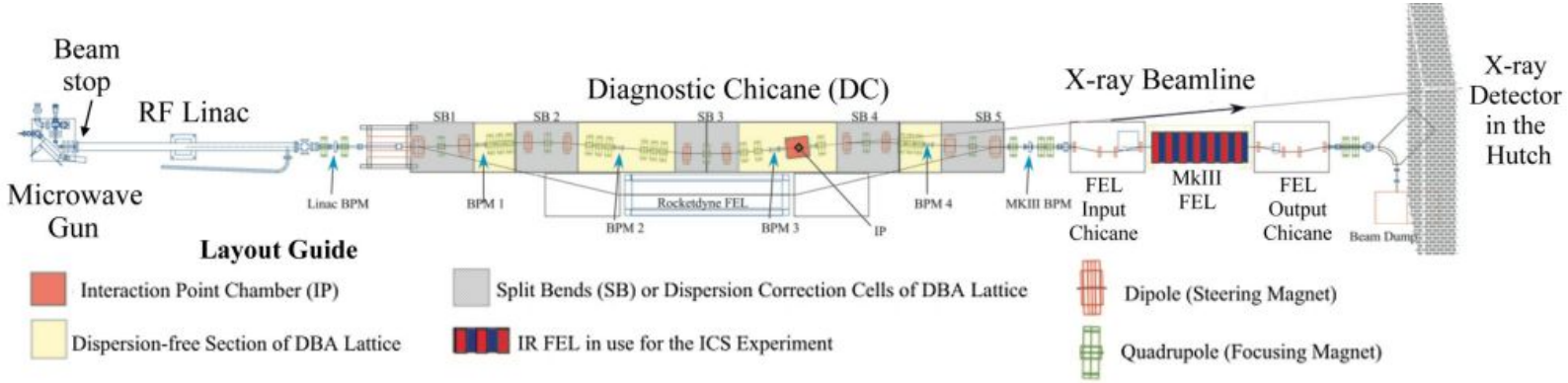
John M. J. Madey*
Department of Physics and Astronomy, University of Hawai'i at Manoa, Honolulu, Hawaii 96822, USA
(Received 5 May 2014; published 16 July 2014)

The first demonstration of an optical-wavelength laser by Theodore Maiman in 1960 had a transformational impact on the paths that would be blazed to advance the state of the art of short wavelength coherent electron beam-based radiation sources. Free electron lasers (FELs) emerged from these efforts as the electron beam-based realization of the pioneering model of atom-based "optical masers" by Schawlow and Townes, but with far greater potential for tunable operation at high power and very short wavelengths. Further opportunities for yet greater capabilities may be inherent in our still growing understanding of the underlying physics. This article focuses on the FEL efforts in which the author was directly and personally involved.

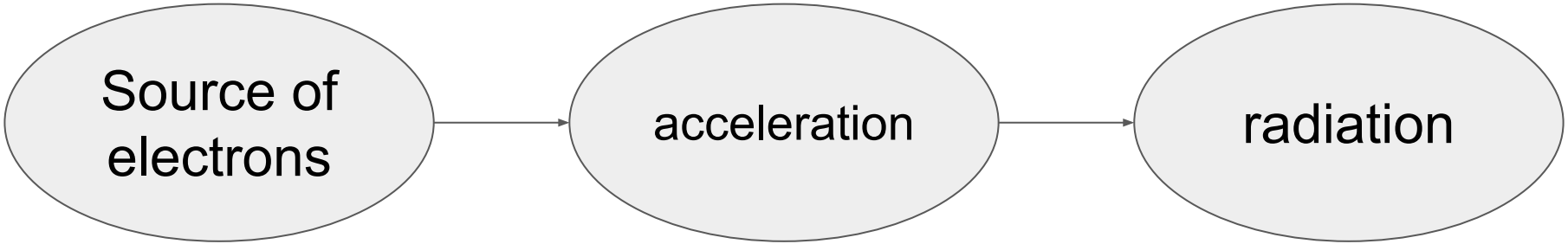
DOI: 10.1103/PhysRevSTAB.17.074901 PACS numbers: 41.60.Cr, 01.60.+q, 03.50.De, 12.20.−m

The UH FEL

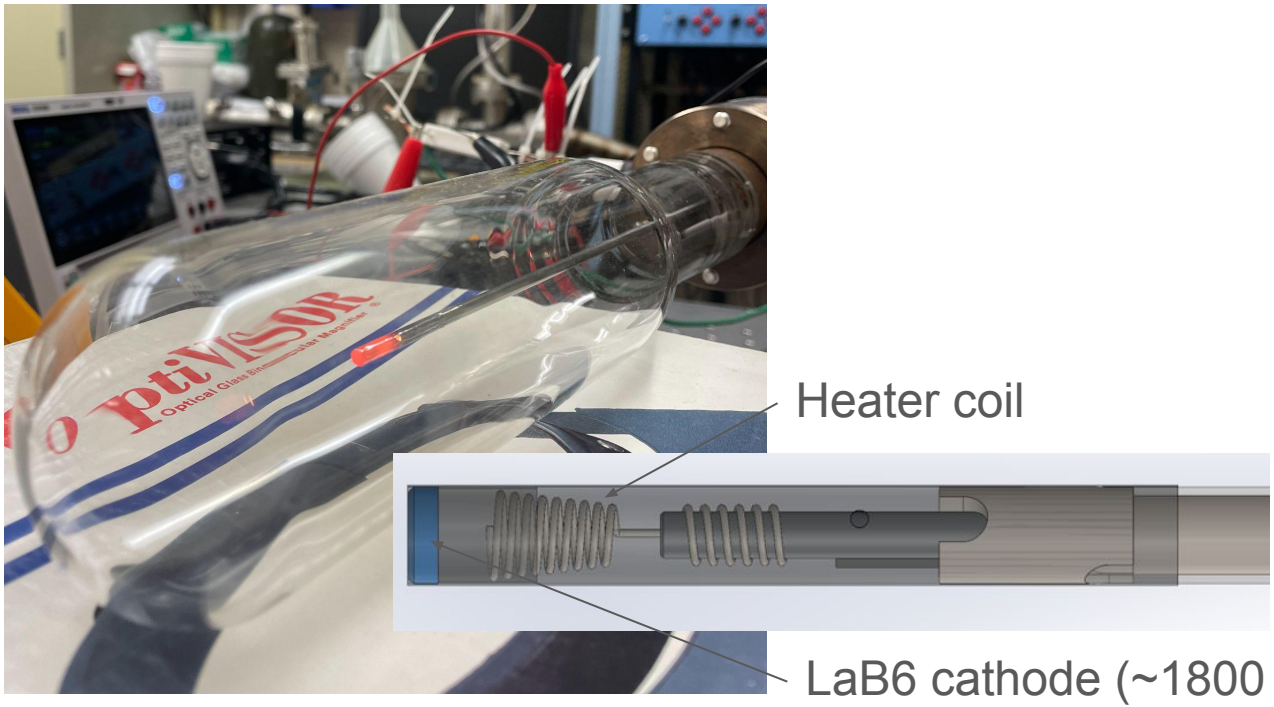

LINEAR ACCELERATOR
DANGER !!!!!
LETHAL HIGH VOLTAGE
DANGER !!!!!
MICROWAVE GUN


Beam stop
RF Linac
Microwave Gun
Linac BPM
Diagnostic Chicane (DC)
SB1
SB 2
SB 3
SB 4
SB 5
BPM 1
BPM 2
BPM 3
BPM 4
Rocketdyne FEL
IP
X-ray Beamline
MKIII BPM
FEL Input Chicane
MkIII FEL
FEL Output Chicane
Beam Dump
X-ray Detector in the Hutch
Layout Guide
Interaction Point Chamber (IP)
Split Bends (SB) or Dispersion Correction Cells of DBA Lattice
Dipole (Steering Magnet)
Dispersion-free Section of DBA Lattice
IR FEL in use for the ICS Experiment
Quadrupole (Focusing Magnet)

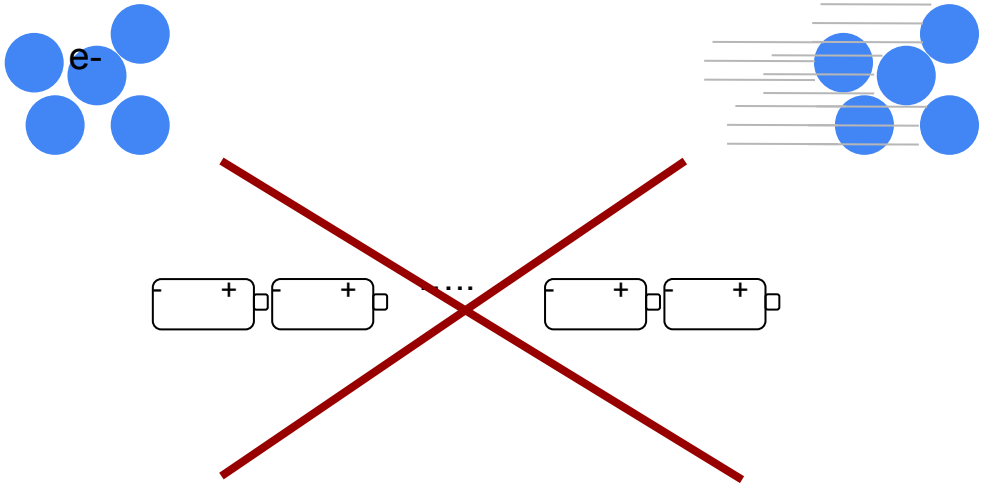
Free-electron laser



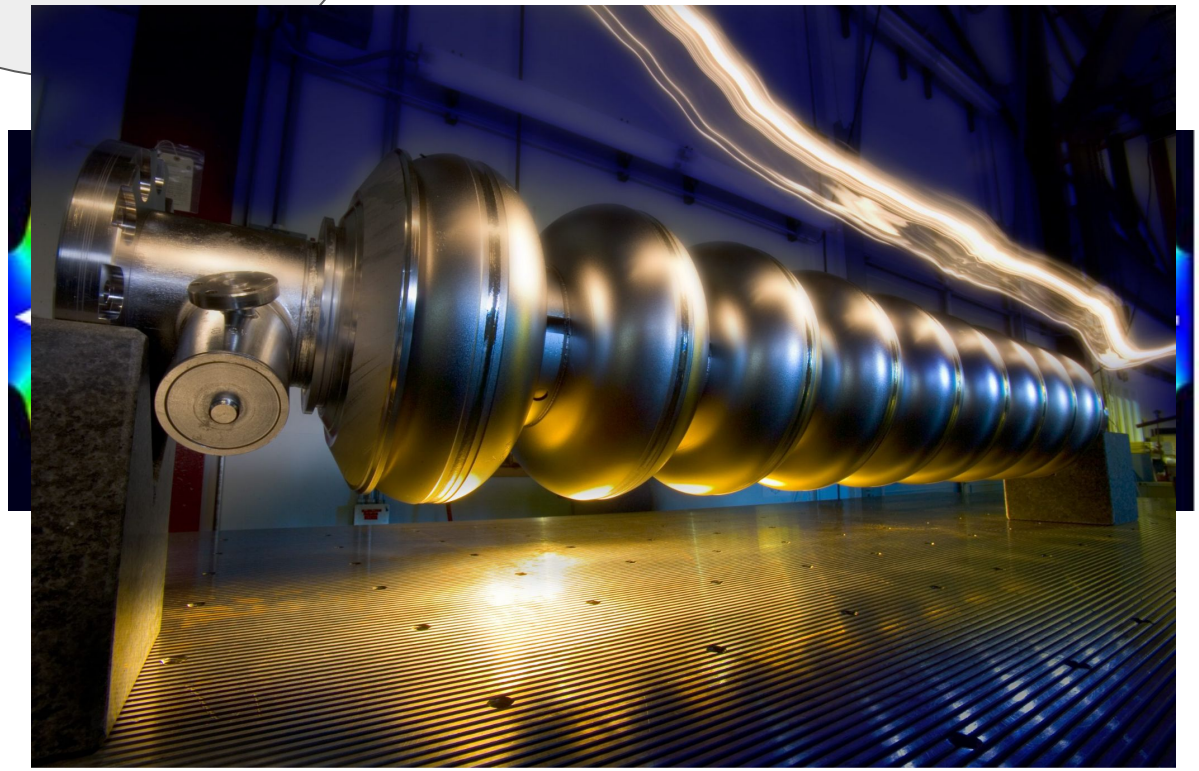
Source of electrons



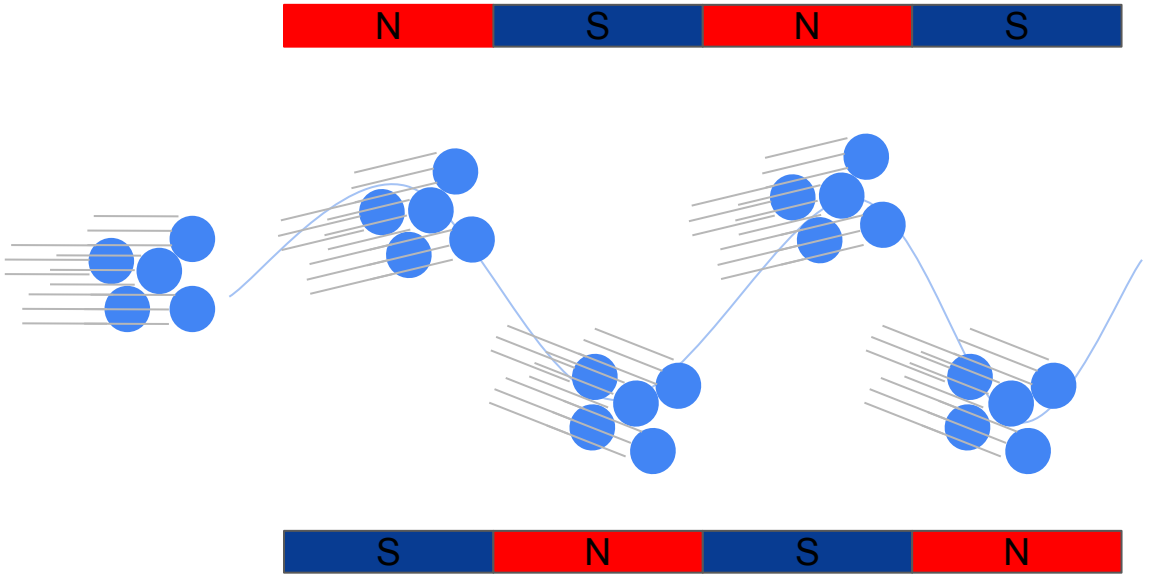
acceleration



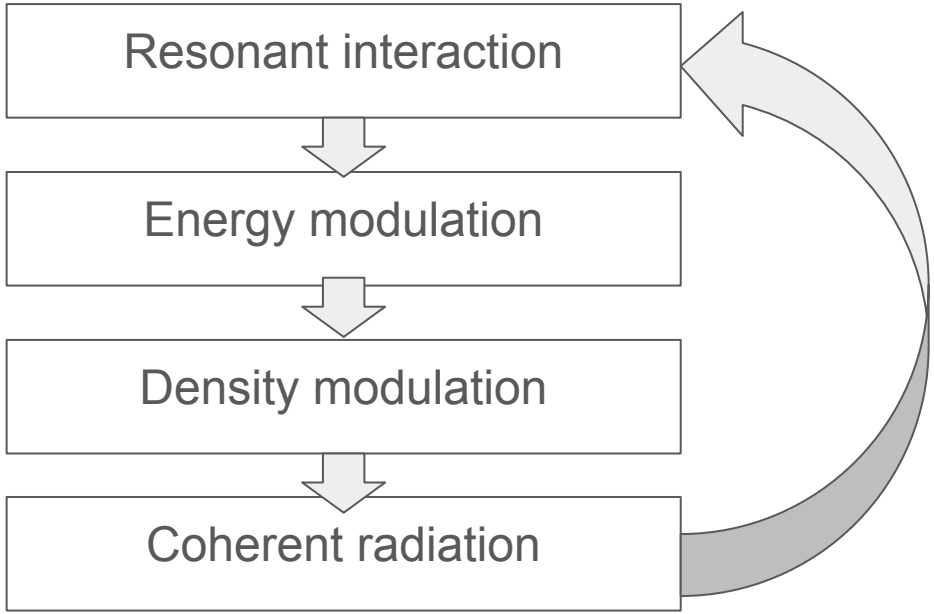
acceleration



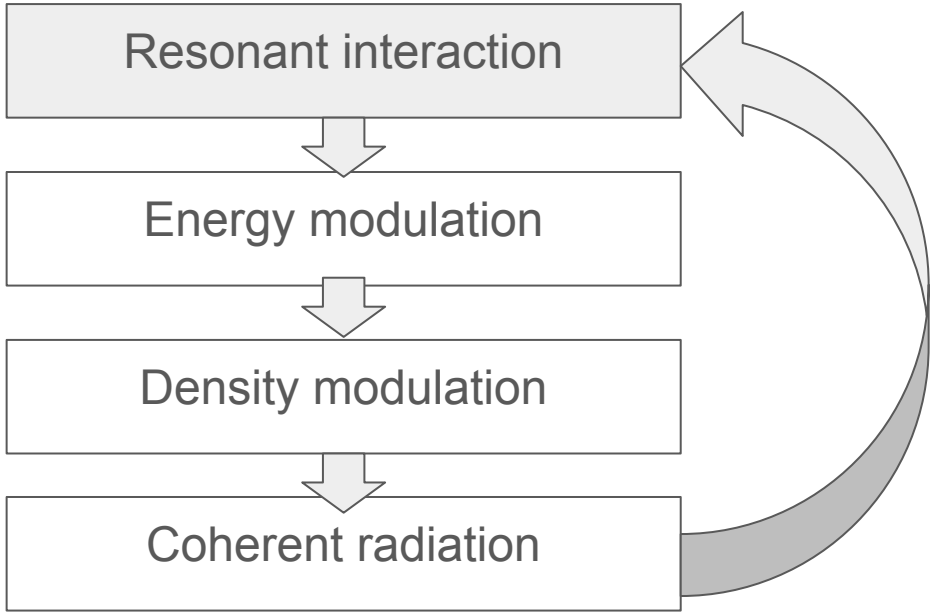
radiation



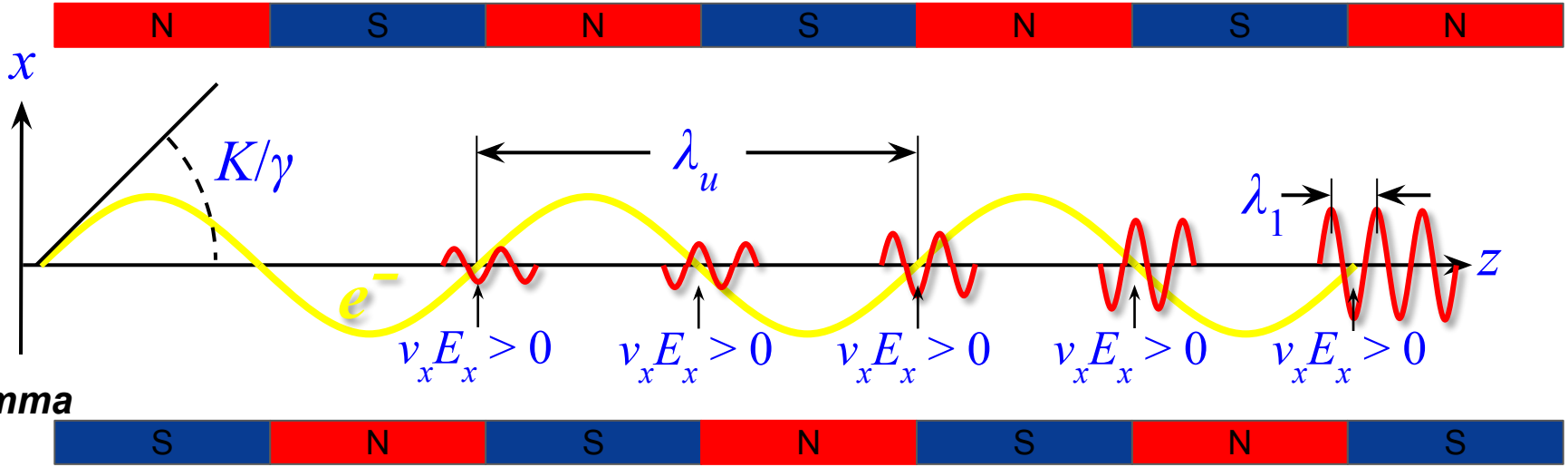
radiation


Resonant interaction
Energy modulation
Density modulation
Coherent radiation

radiation


Resonant interaction
Energy modulation
Density modulation
Coherent radiation

Resonant interaction



P. Emma

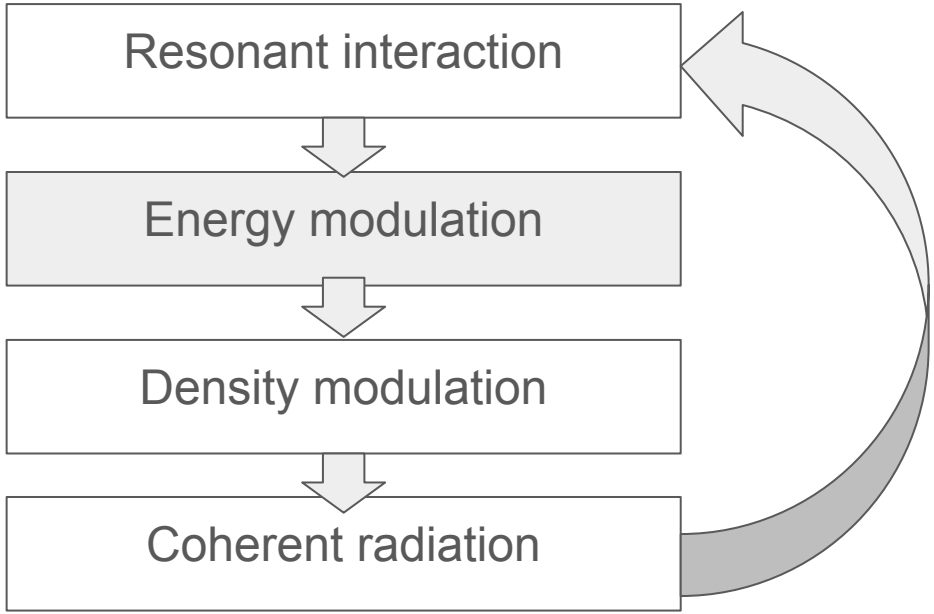
$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

Resonant interaction

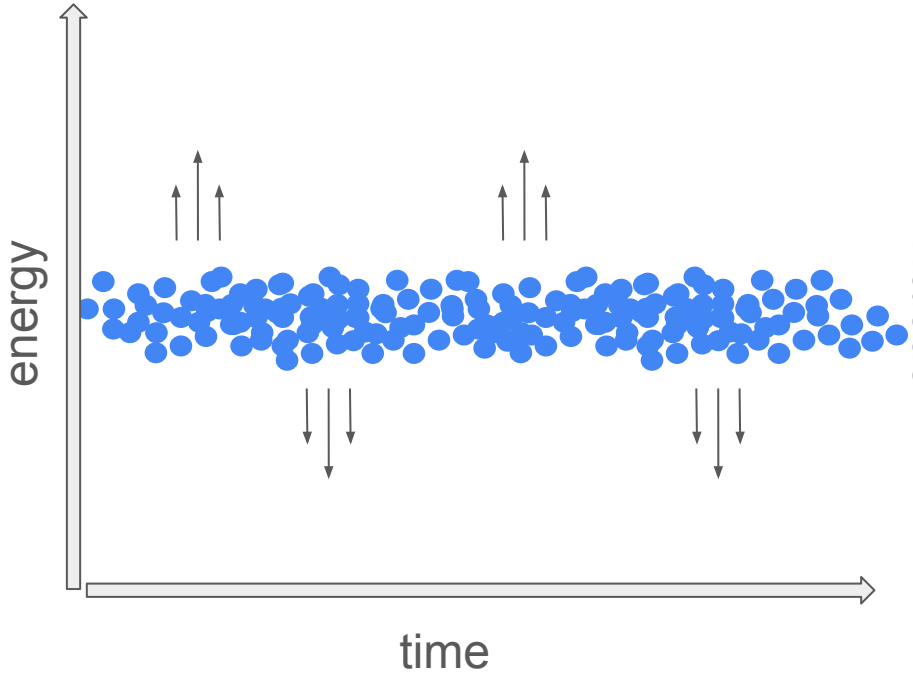
$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

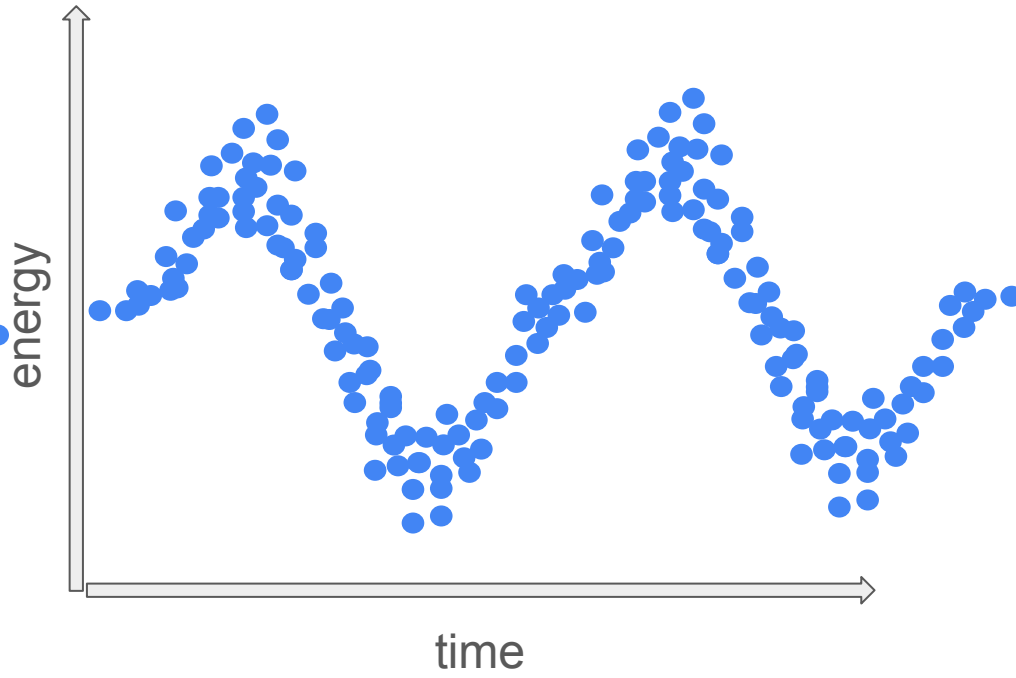
Radiation slips ahead of the e- by λ_1 per λ_u.

radiation

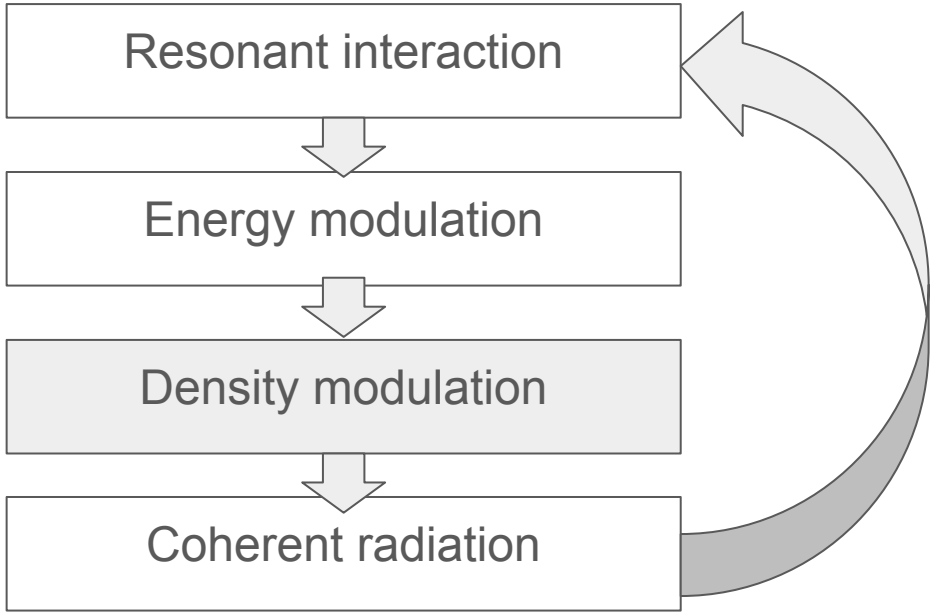

Resonant interaction
Energy modulation
Density modulation
Coherent radiation

Energy modulation

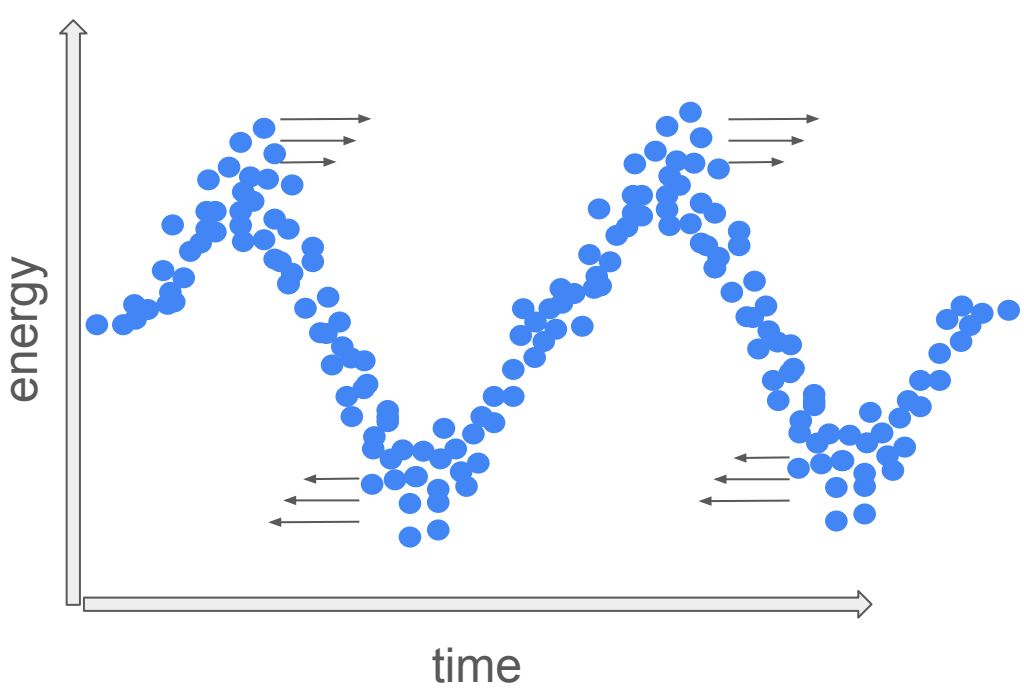


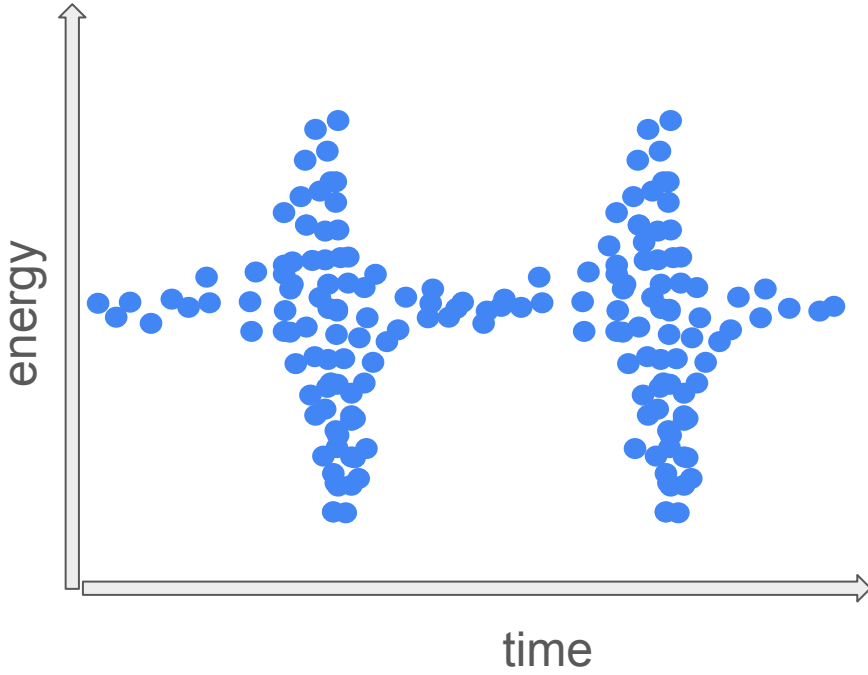


radiation

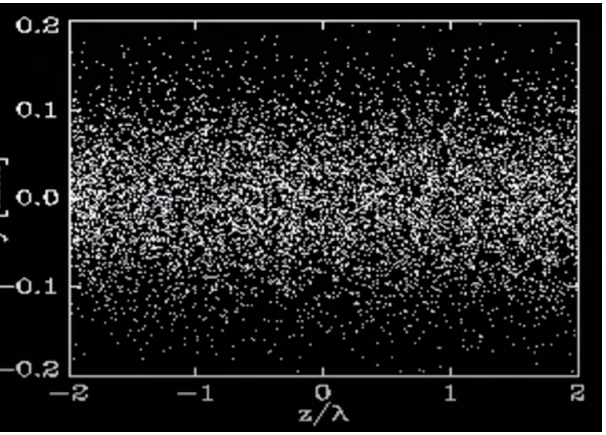

Resonant interaction
Energy modulation
Density modulation
Coherent radiation

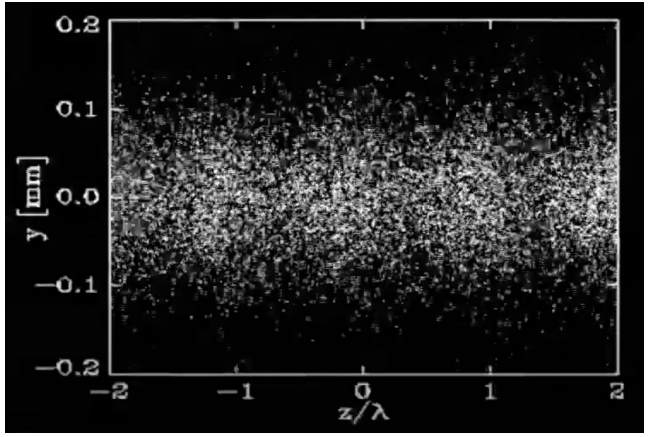
Density modulation

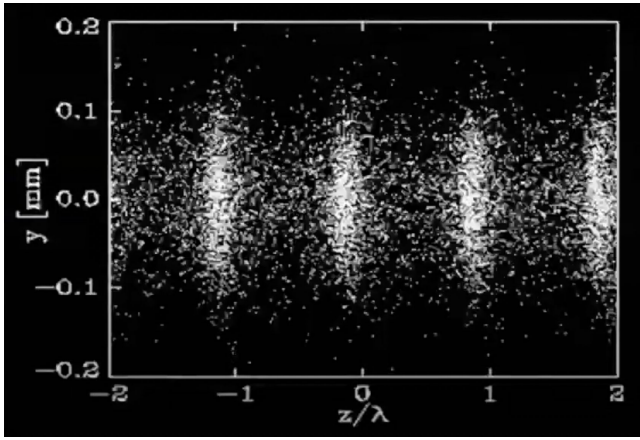




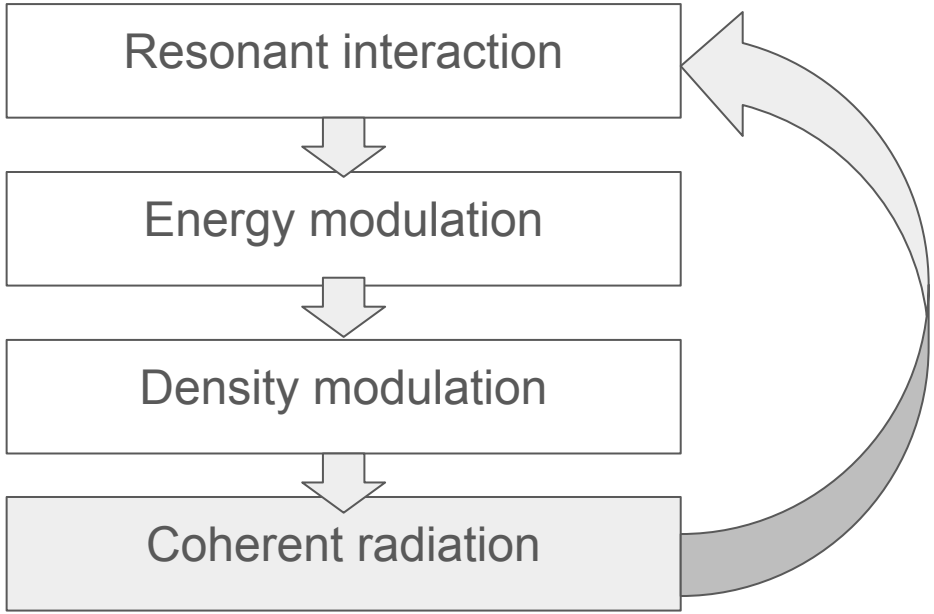
Density modulation





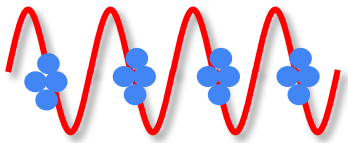


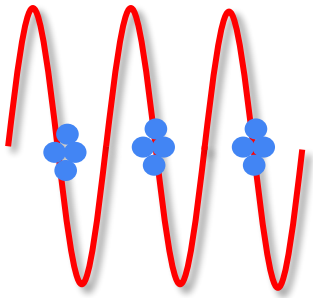
radiation


Resonant interaction
Energy modulation
Density modulation
Coherent radiation

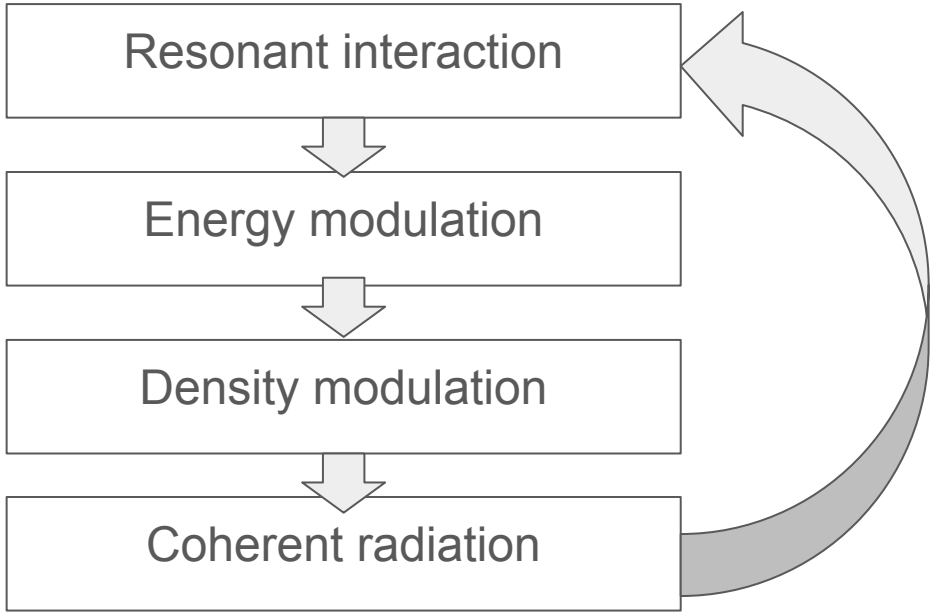
Coherent radiation

power $\propto N^2$



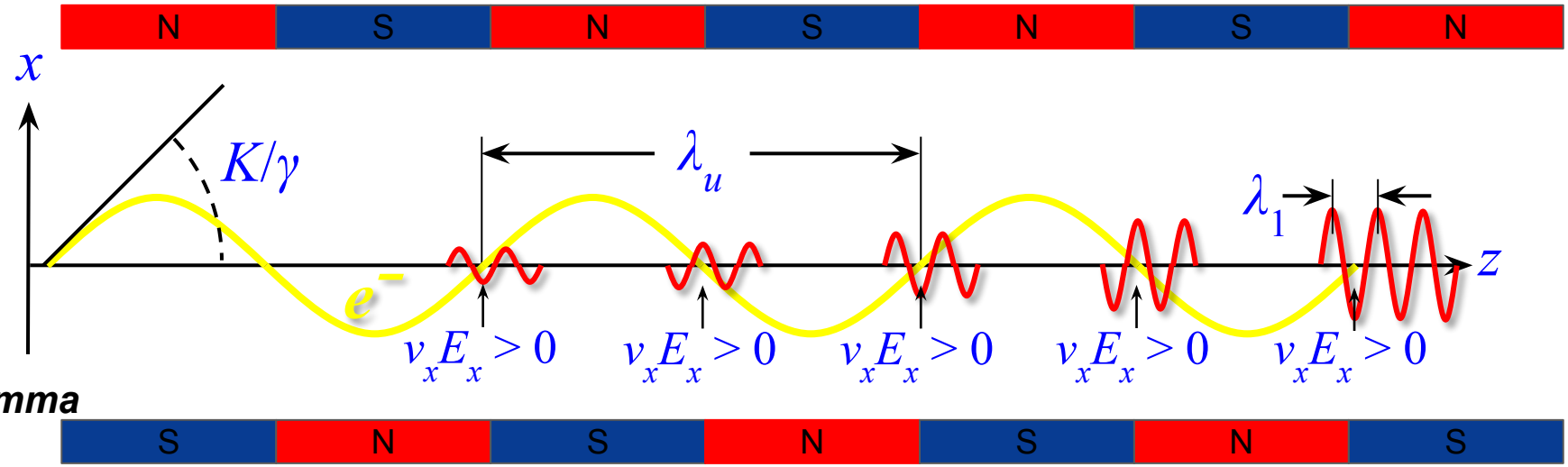


radiation


Resonant interaction
Energy modulation
Density modulation
Coherent radiation

Resonant interaction

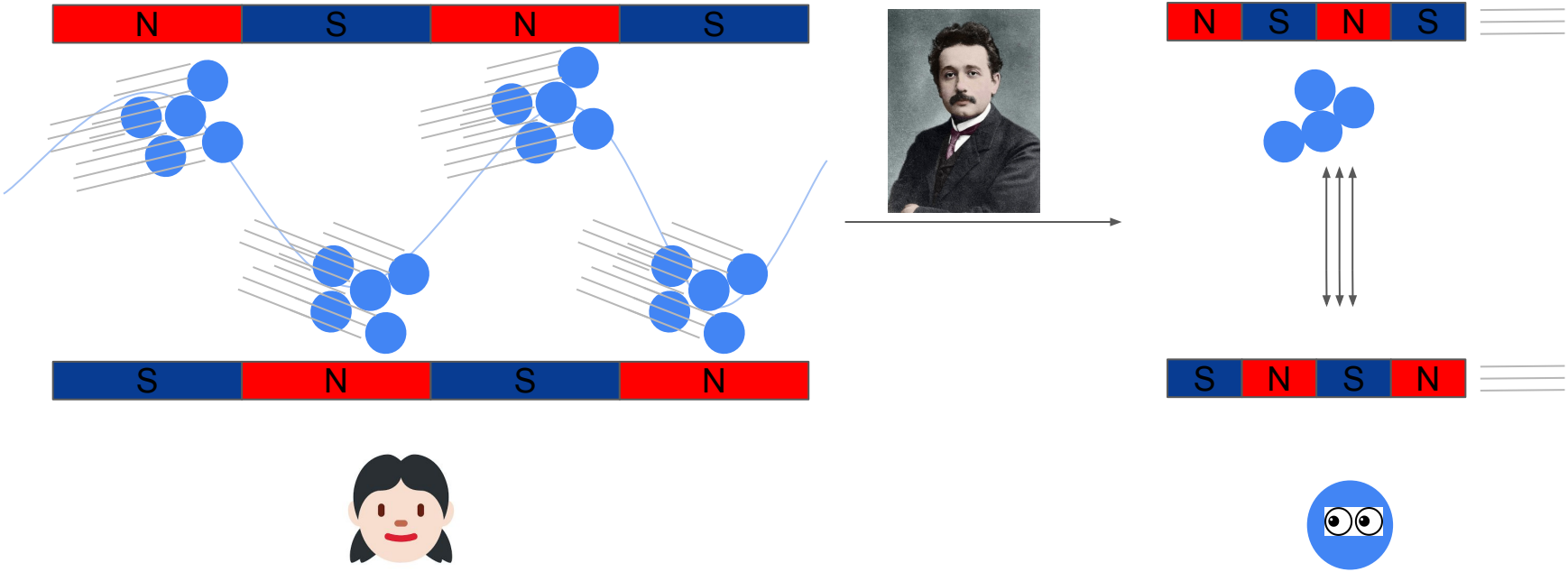
Radiation slips ahead of the e- by λ_1 per λ_u.



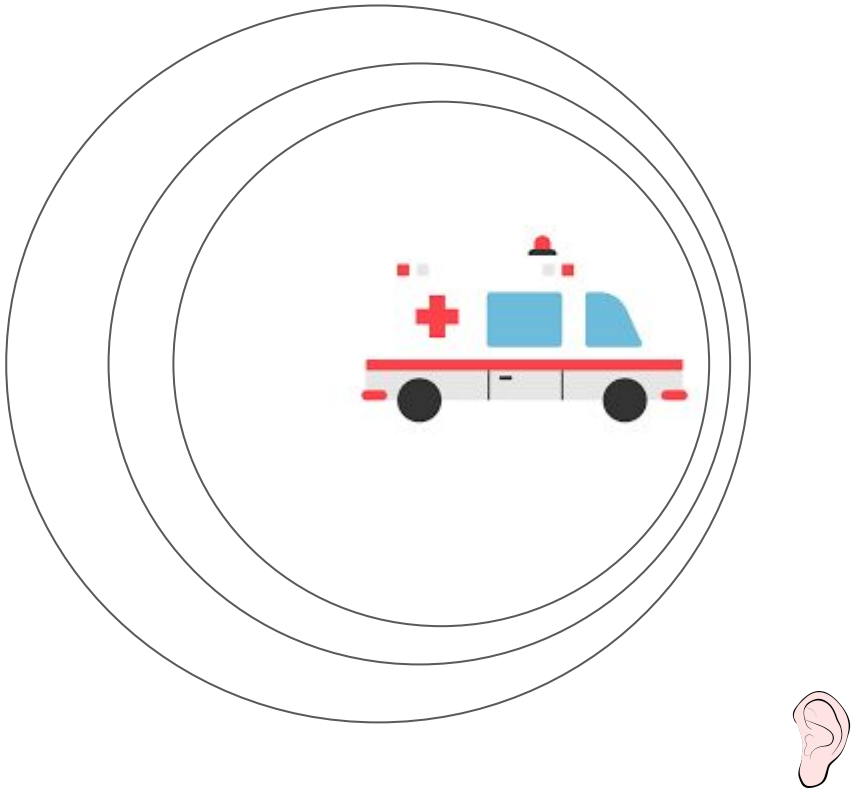
P. Emma

$$\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$

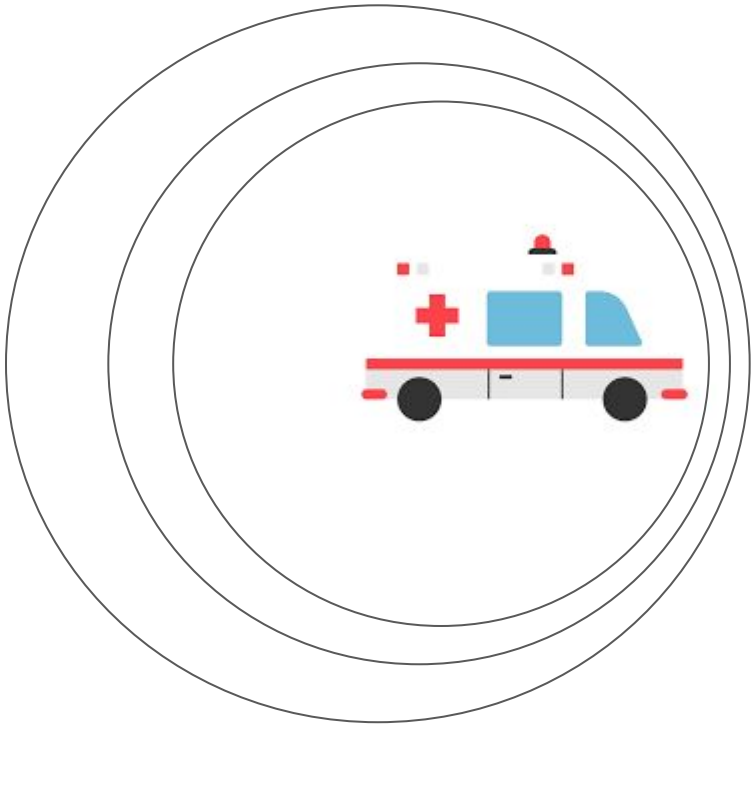
The first γ - special relativity



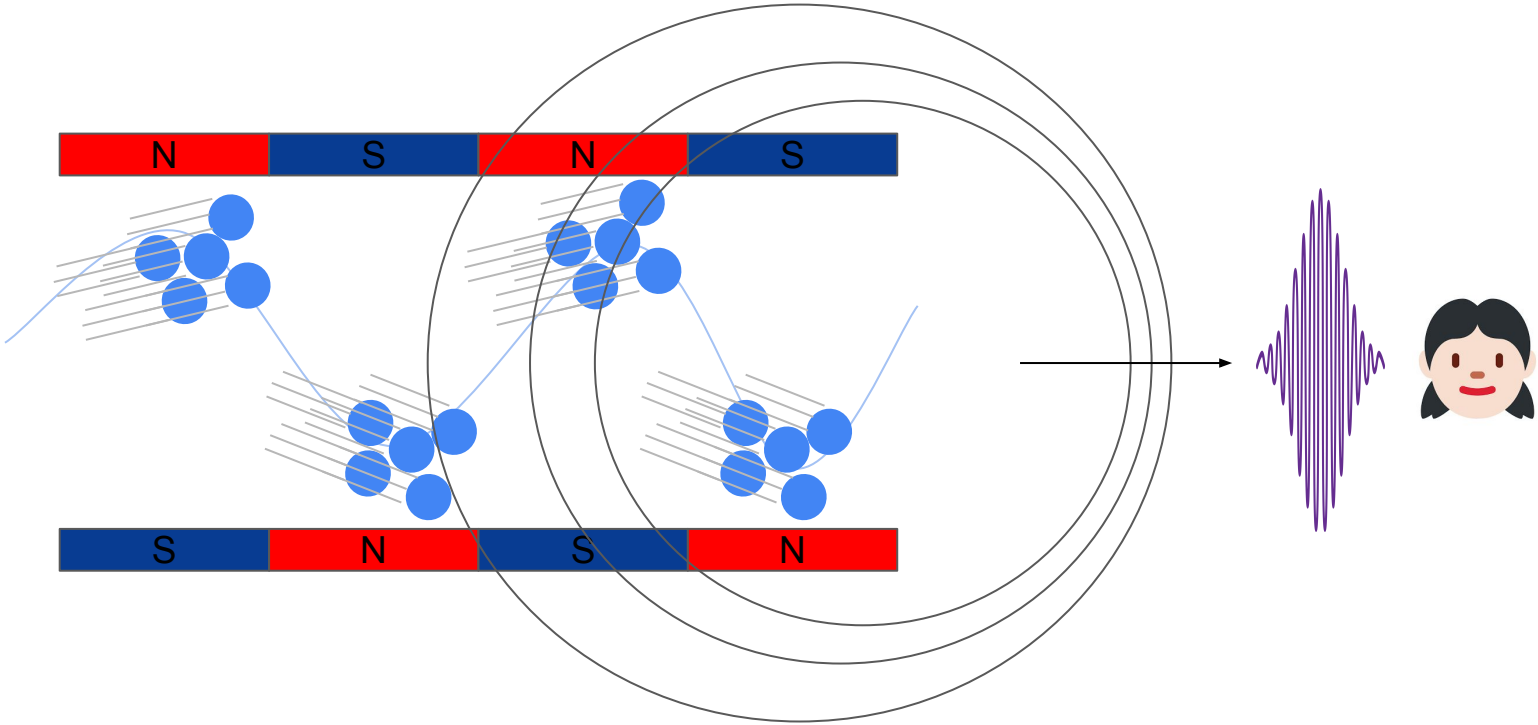
The second γ - the Doppler effect



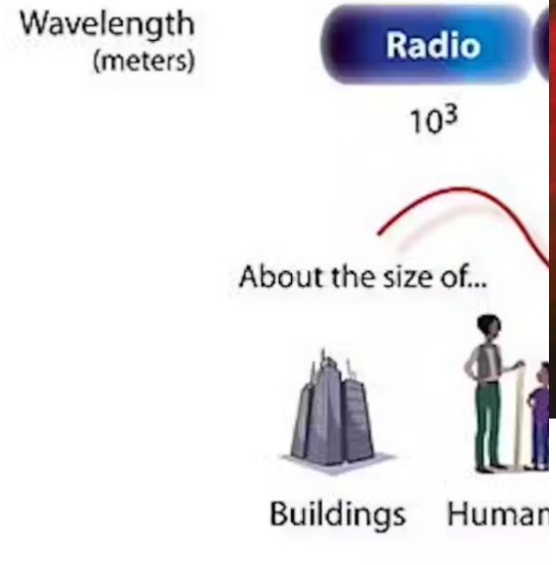
The second γ - the Doppler effect

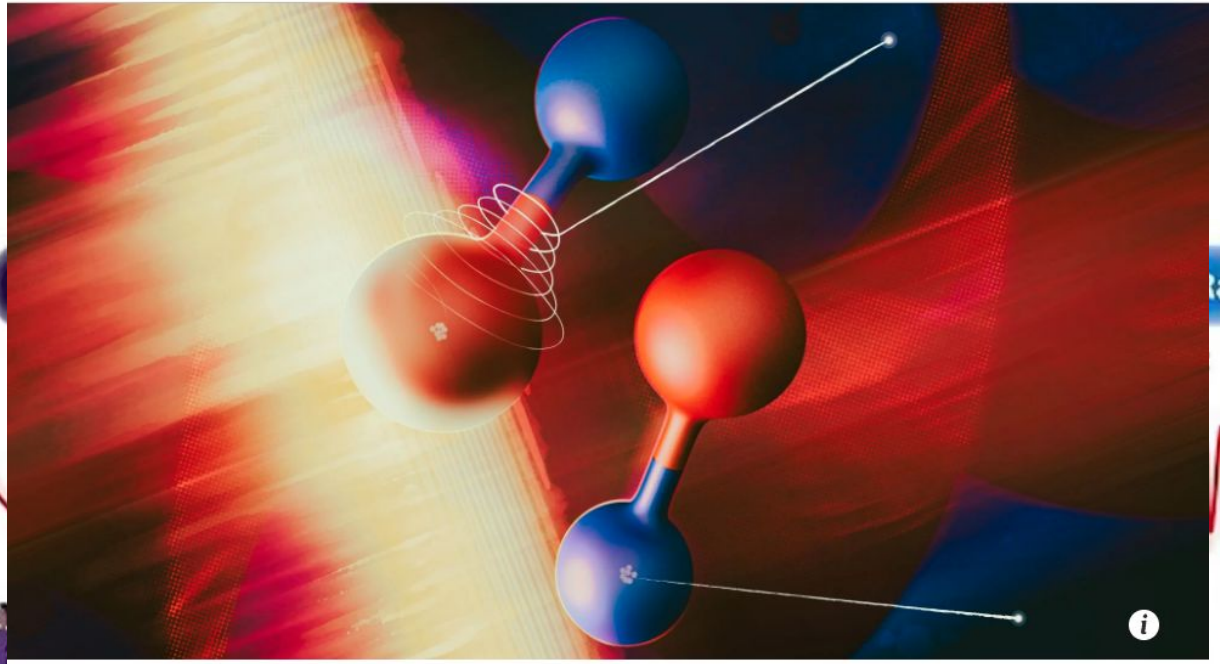


The second γ - the Doppler effect



$$\lambda_1 \propto \lambda_u / \gamma^2$$





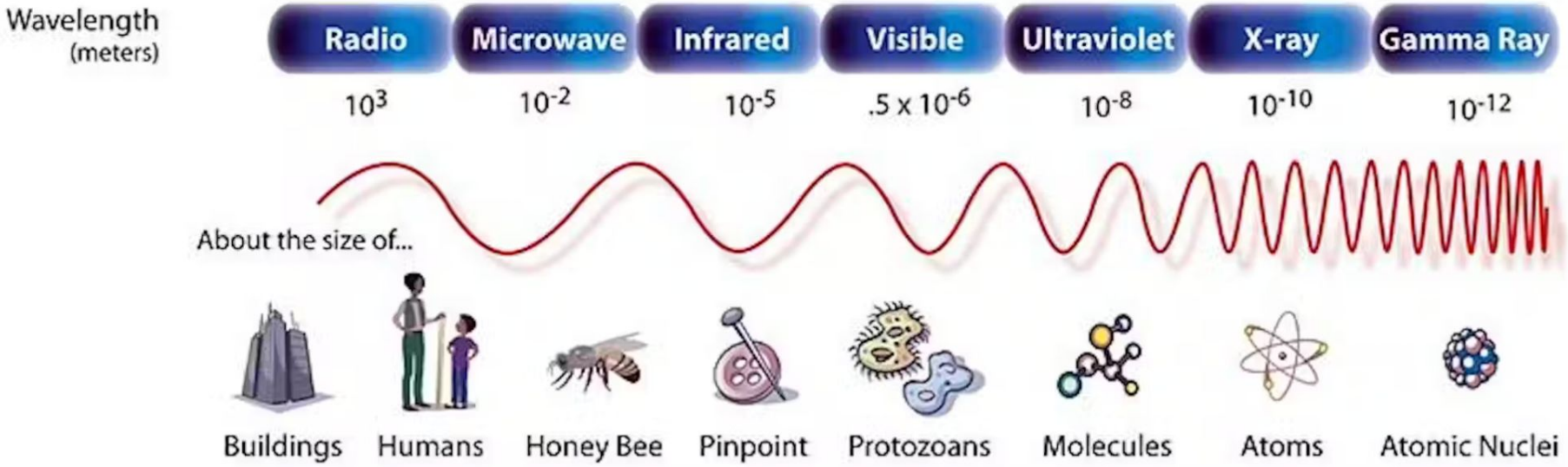
AUGUST 21, 2024

Scientists use attosecond X-ray pulses to shed new light on the photoelectric effect

$$\lambda_1 \propto \lambda_u / \gamma^2$$

UH FEL
40 MeV
γ ~1e2

LCLS
4-11 GeV
γ ~1e4



$$\lambda_1 \propto \lambda_u / \gamma^2$$

UH FEL

LCLS

PHYSICAL REVIEW ACCELERATORS AND BEAMS **22,** 040704 (2019)

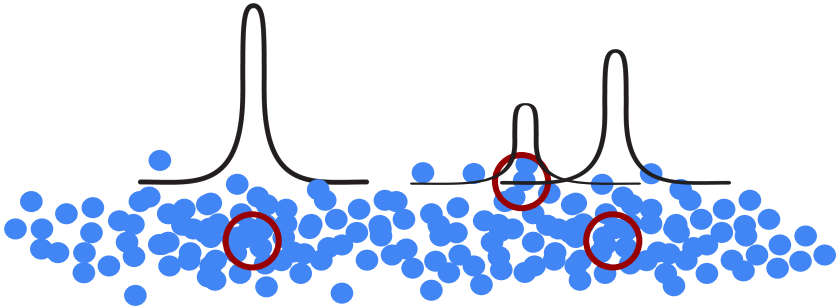
Free-electron laser inverse-Compton interaction x-ray source

Pardis Niknejadi,[1,*] Jeremy M. D. Kowalczyk,[1,†] Michael R. Hadmack,[1,2] Bryce T. Jacobson,[1,3] Ian Howe,[1] Shidong Kan,[1] Steven Smith,[1] Eric B. Szarmes,[1] Gary Varner,[1] and John M. J. Madey[1,‡]

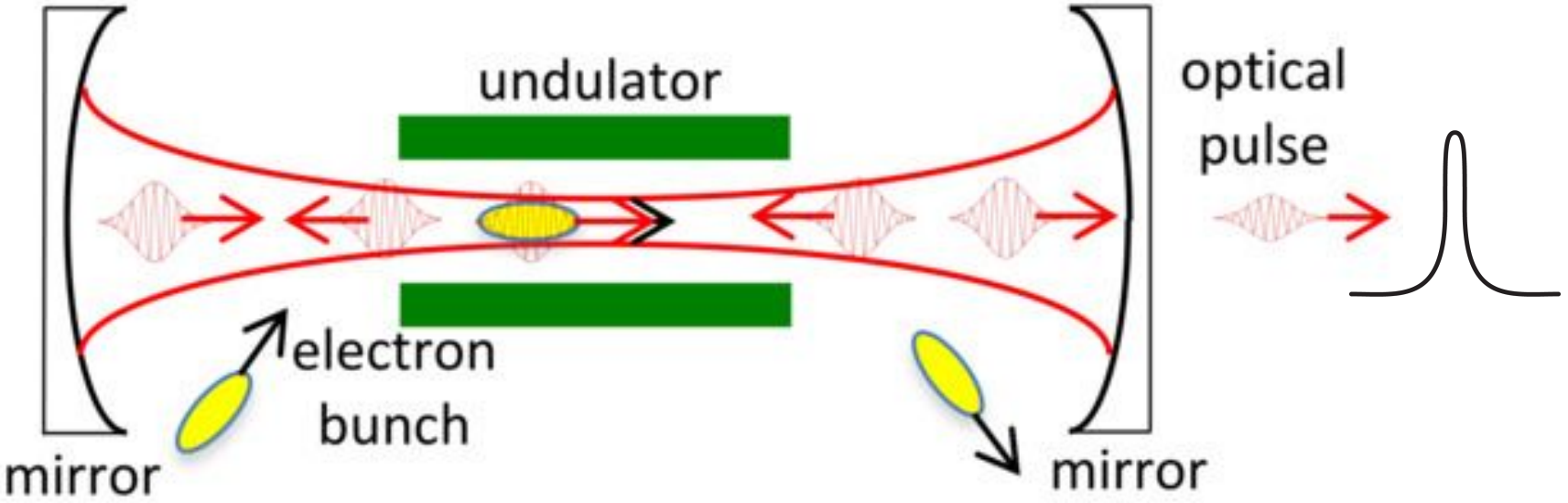
[1]*University of Hawai'i at Mānoa, Department of Physics and Astronomy, Honolulu, Hawaii 96822, USA*
[2]*Oceanit, 828 Fort Street Mall, Honolulu, Hawaii 96813, USA*
[3]*SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, California 94025, USA*

(Received 11 February 2019; published 29 April 2019)

FEL starts from shot noise - a stochastic process

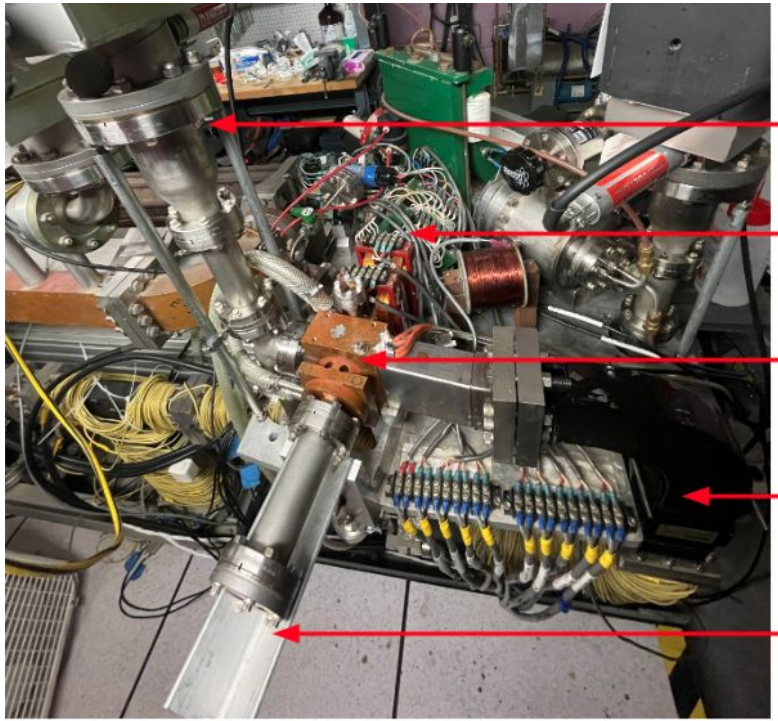


FEL oscillator



Research projects:

- Switch on the accelerator!
  - Vacuum checks
  - Replace and repair



4th step, leak on the vacuum column:
Ion Pumps = 2.5 mA -> 5 mA

3rd step, leak near Gun Toroid1:
Ion Pumps = 2.5 mA -> 3 mA

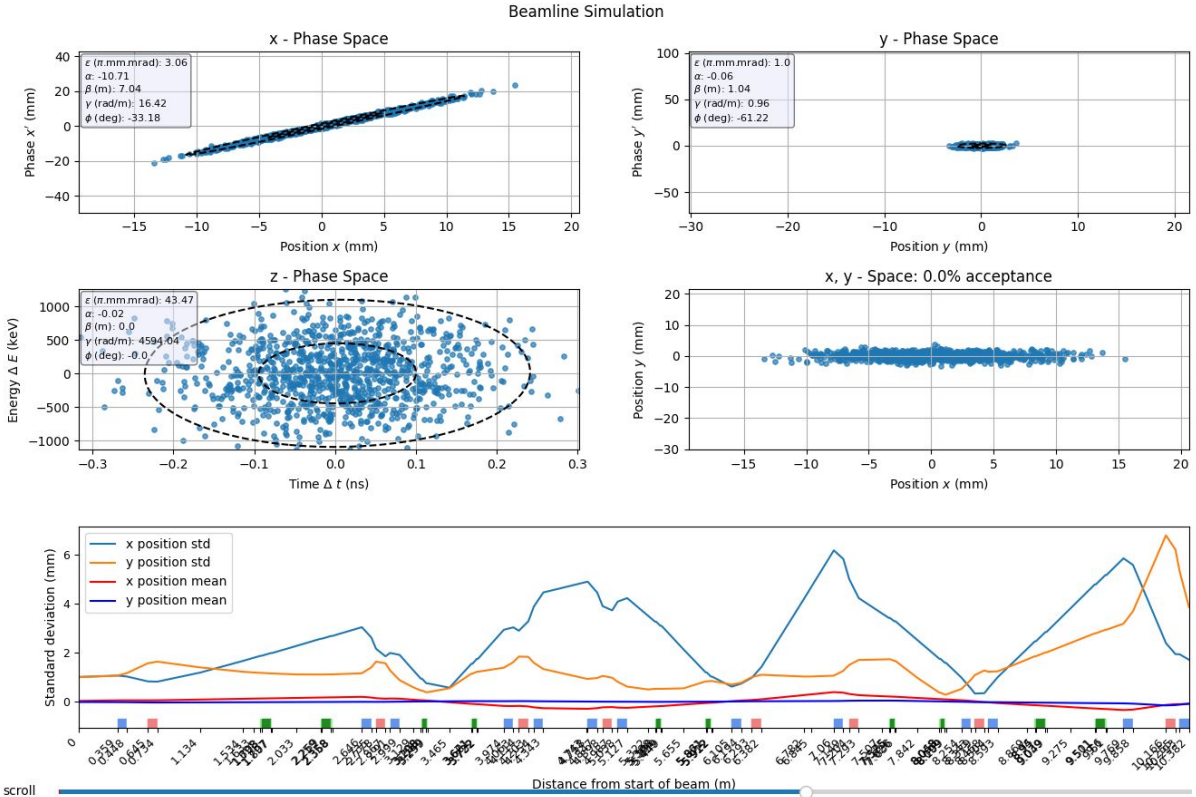
2nd step, bake-out:
Ion Pumps = 150 uA -> 2.2 mA

Leak detected on the Waveguide

1st step, cathode removal:
Ion Pumps = 120 uA -> 130 uA

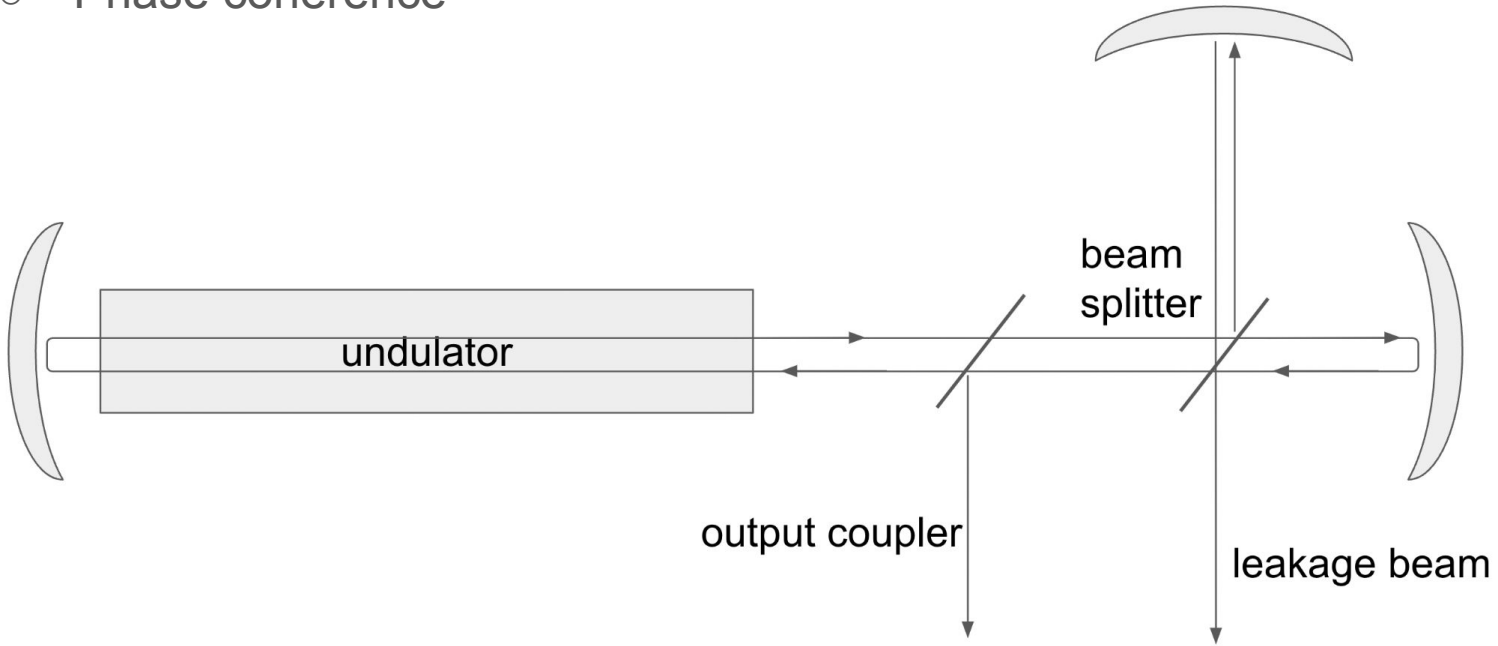
Research projects:

- Beam simulation



Research projects:

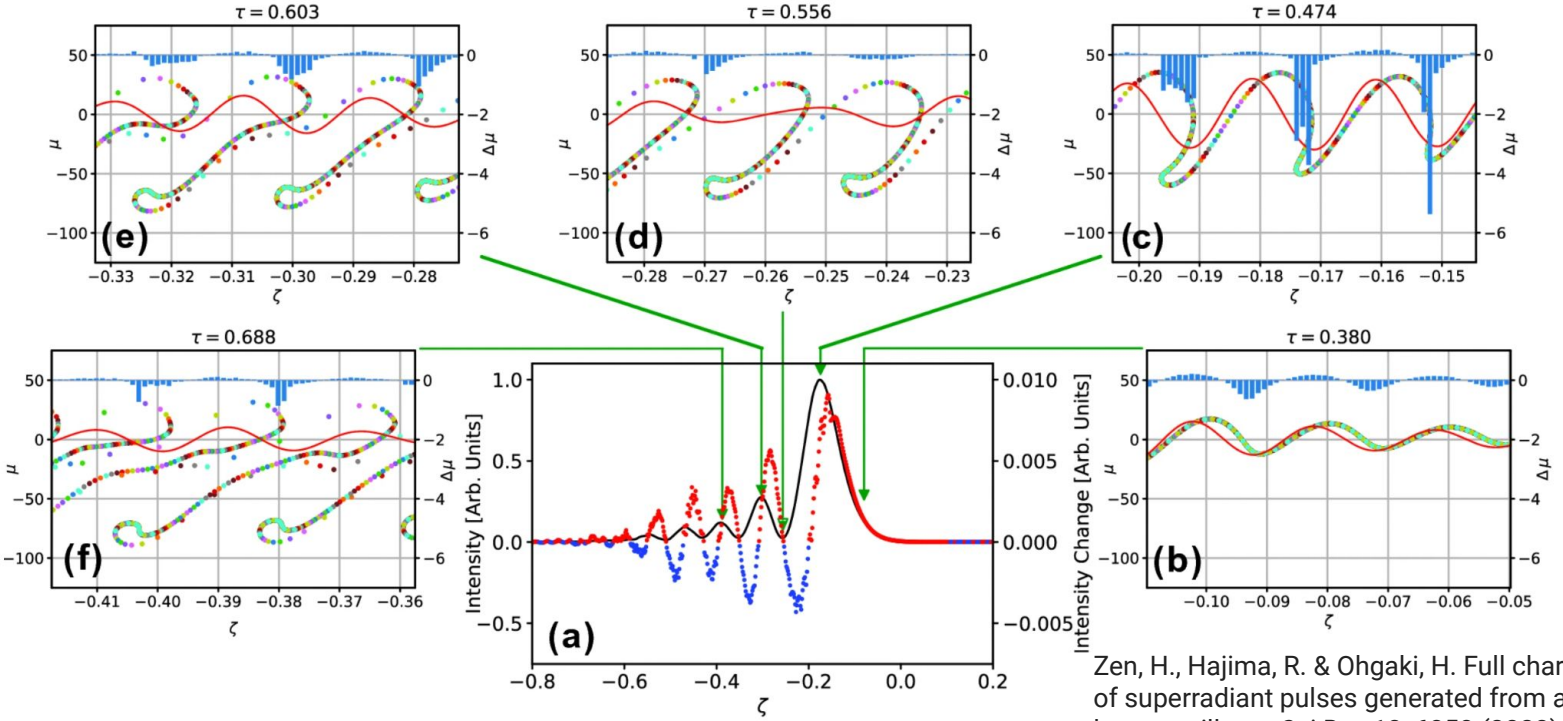
- 3D simulation of the FEL oscillator
  - Phase coherence



Szarmes, Eric B., Stephen V. Benson, and John MJ Badey. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 296.1-3 (1990): 98-109.

Research projects:

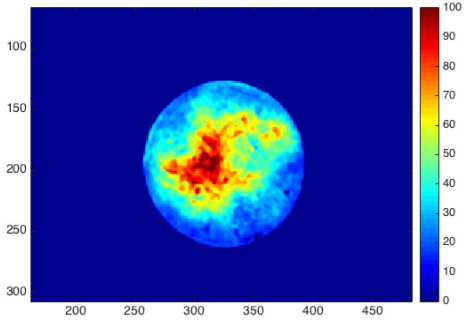
- 3D simulation of the FEL oscillator
  - superradiance



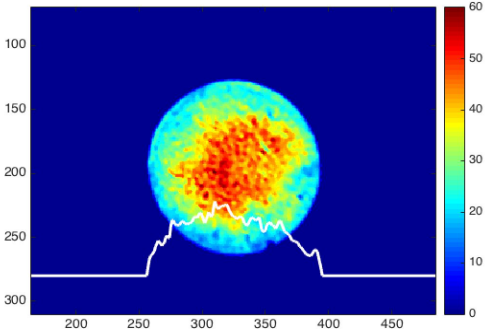
Zen, H., Hajima, R. & Ohgaki, H. Full characterization of superradiant pulses generated from a free-electron laser oscillator. *Sci Rep* 13, 6350 (2023).

Research projects:

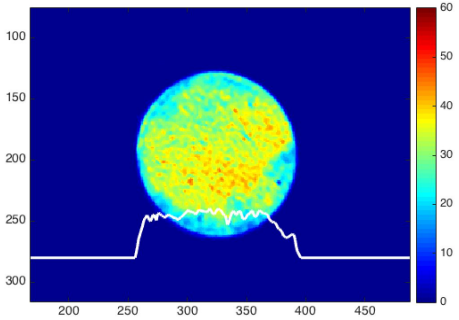
- Beam shaping



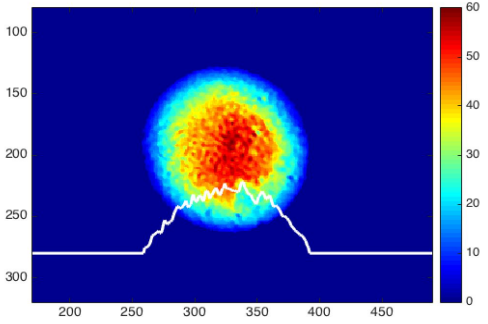
original



cut-gaussian



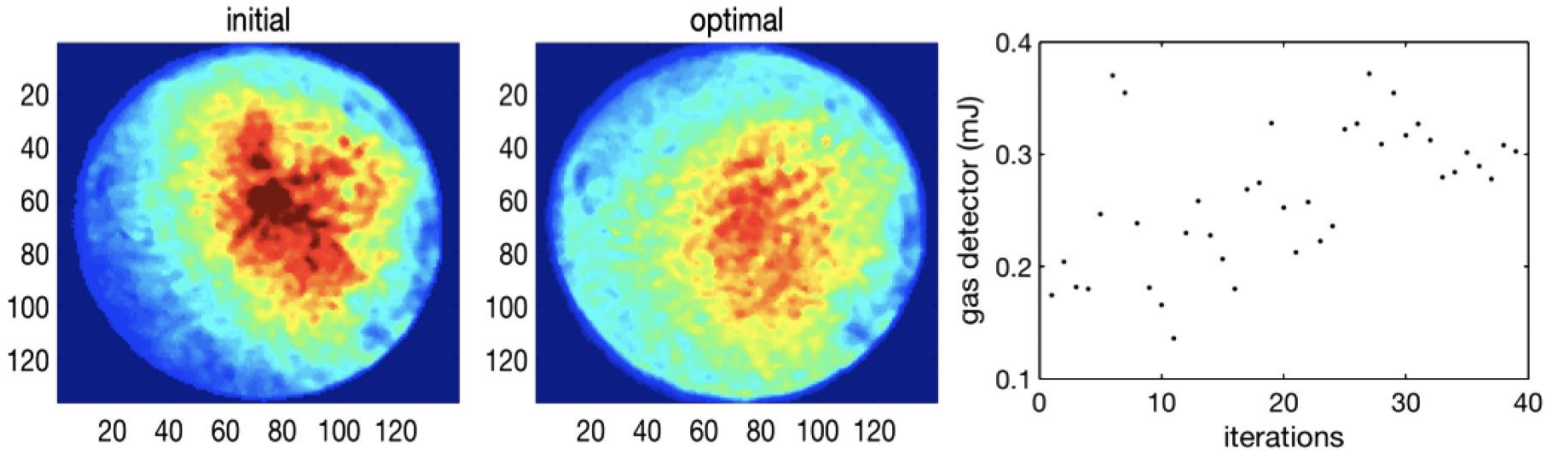
flat top



parabolic

Research projects:

- Controls upgrade
- AI/ML



Li, S., et al. "Ultraviolet laser transverse profile shaping for improving x-ray free electron laser performance." *Physical Review Accelerators and Beams* 20.8 (2017): 080704.

Resources

- Possible course on accelerator physics Fall 2025.
- USPAS, every winter and summer
- Lee Teng undergraduate internship
- Contact us for tour

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