
4th Generation Light Source Alignment Issues

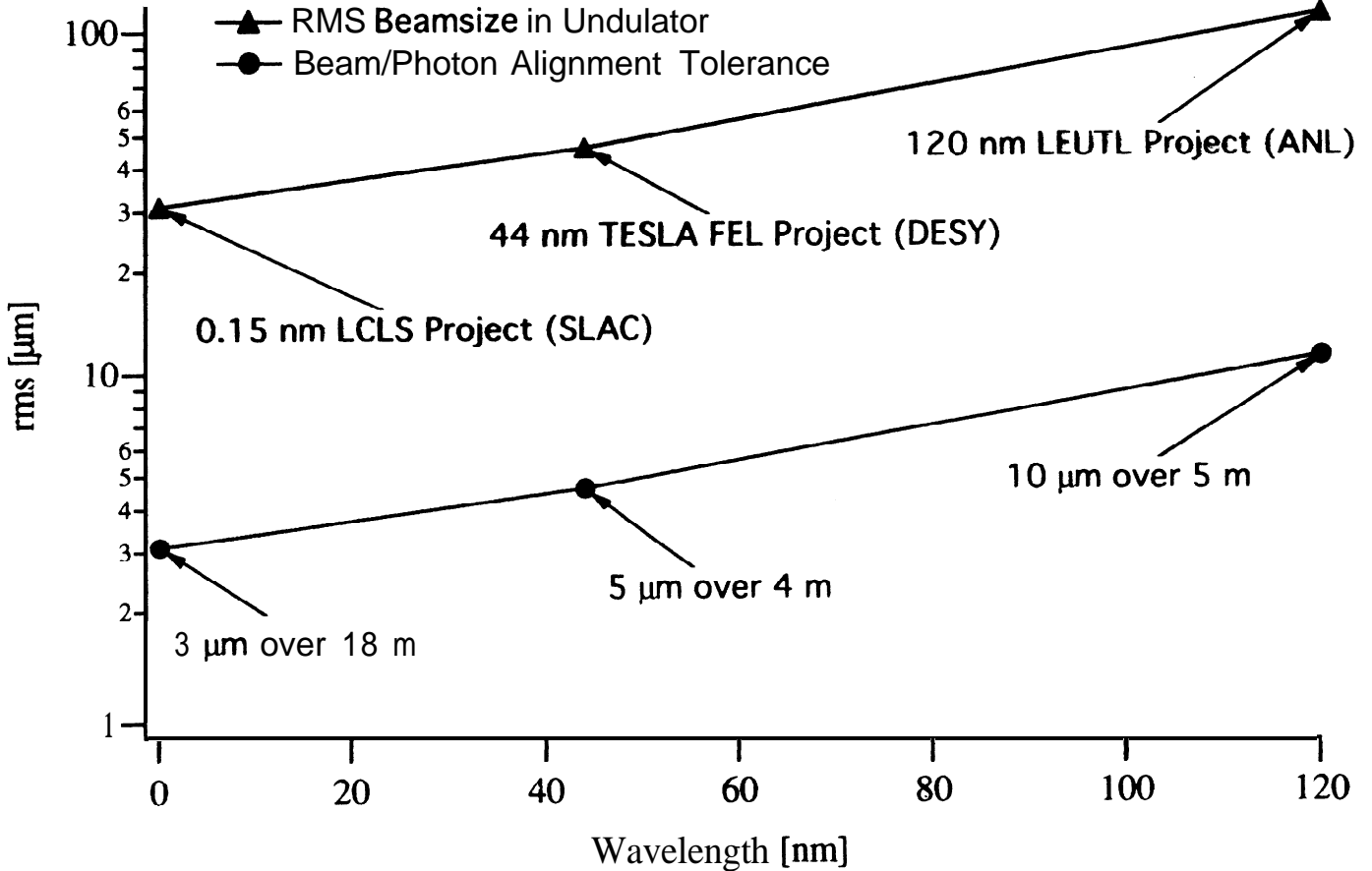
Stephen Milton

Argonne National Laboratory, Advanced Photon Source

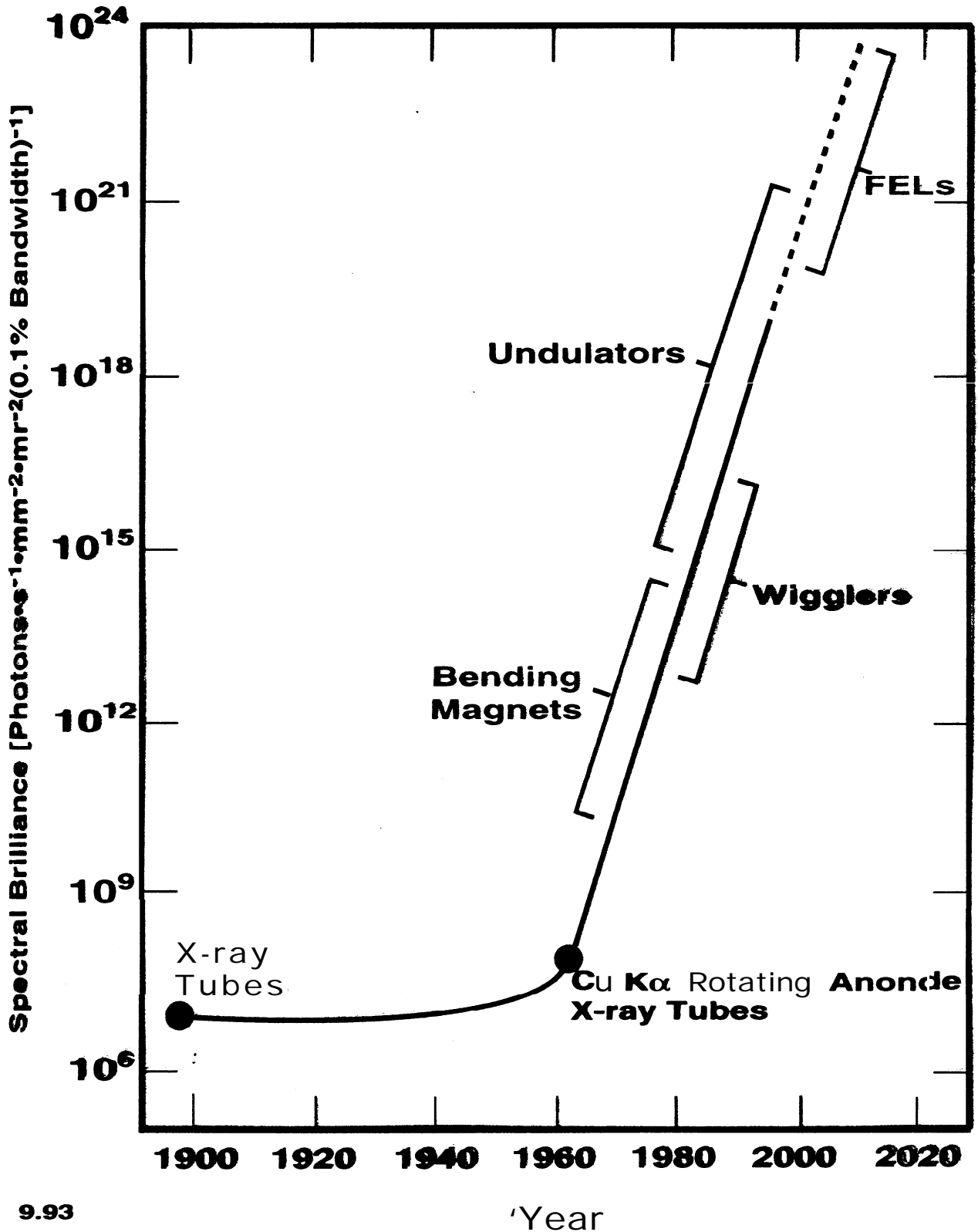
- **OUTLINE**
 - Synchrotron Radiation Historical Background
 - 4th Generation Description
 - FEL Operation Requirements
 - Methods of Measurement
 - Alignment Requirements

ADVANCED PHOTON SOURCE

ALIGNMENT TOLERANCE vs. WAVELENGTH



Average Spectral Brilliance - Real & Projected



Alignment Technique

- A PILOT'S PERSPECTIVE
 - **Dead Reckoning**
 - + **This is what the alignment/survey team provides.**
 - + Needs **to be good** enough for the **diagnostics to** work.
 - Navigational Aids
 - + Beam and photon diagnostics
 - Pilotage (Beamage?)
 - + Feedback systems

Progression of X-Ray Sources

- **The Big Step Beyond X-Ray Tubes**

Synchrotron Radiation

- **Further Improvements in Synchrotron Radiation**

1) Magnet Technology

- **Wiggler/Undulator Magnets**
- Permanent **Magnet Materials**
- **Superconducting Magnets**

2) Particle Beam Quality and Control

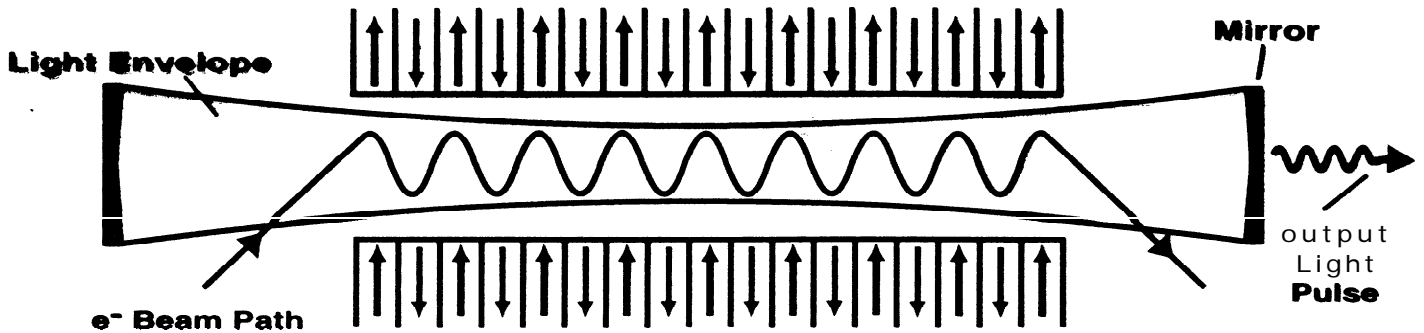
- Lower **Emittance**
- Lower Energy Spread
- Higher Average Current
- Higher Peak Current
- High Resolution and Precision **Diagnostics**
- Feedback Systems

3) Coherence

- **Free Electron Lasers (FEL)**

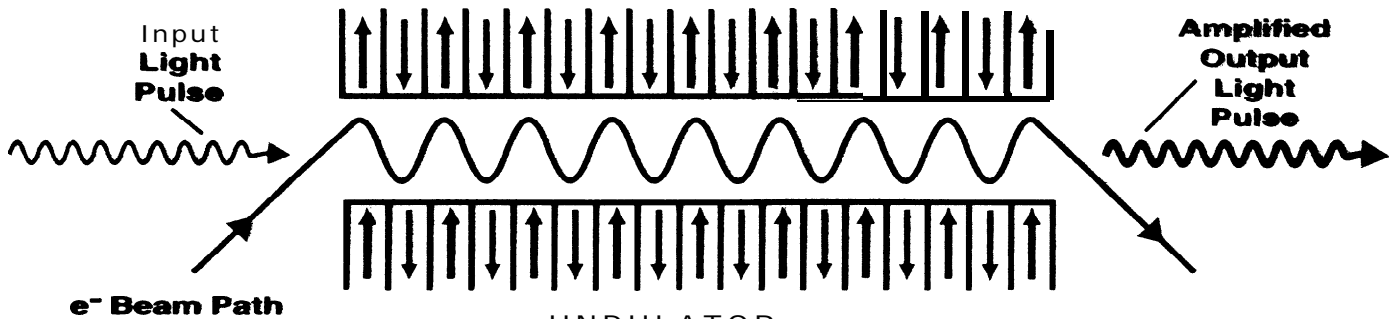
FEL Systems

FEL Oscillator



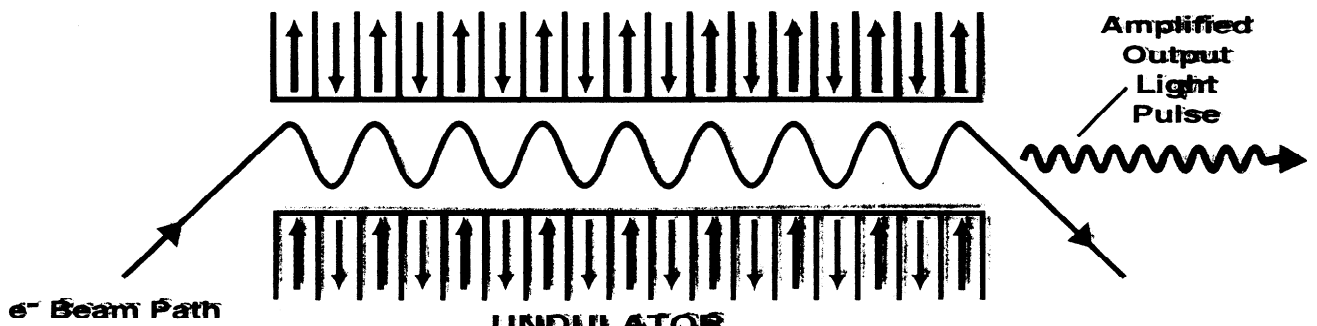
UNDULATOR
NOTE: Requires Mirrors

Seeded (Amplifier) FEL



UNDULATOR
NOTE: Requires an Input Light Laser
of Proper Wavelength

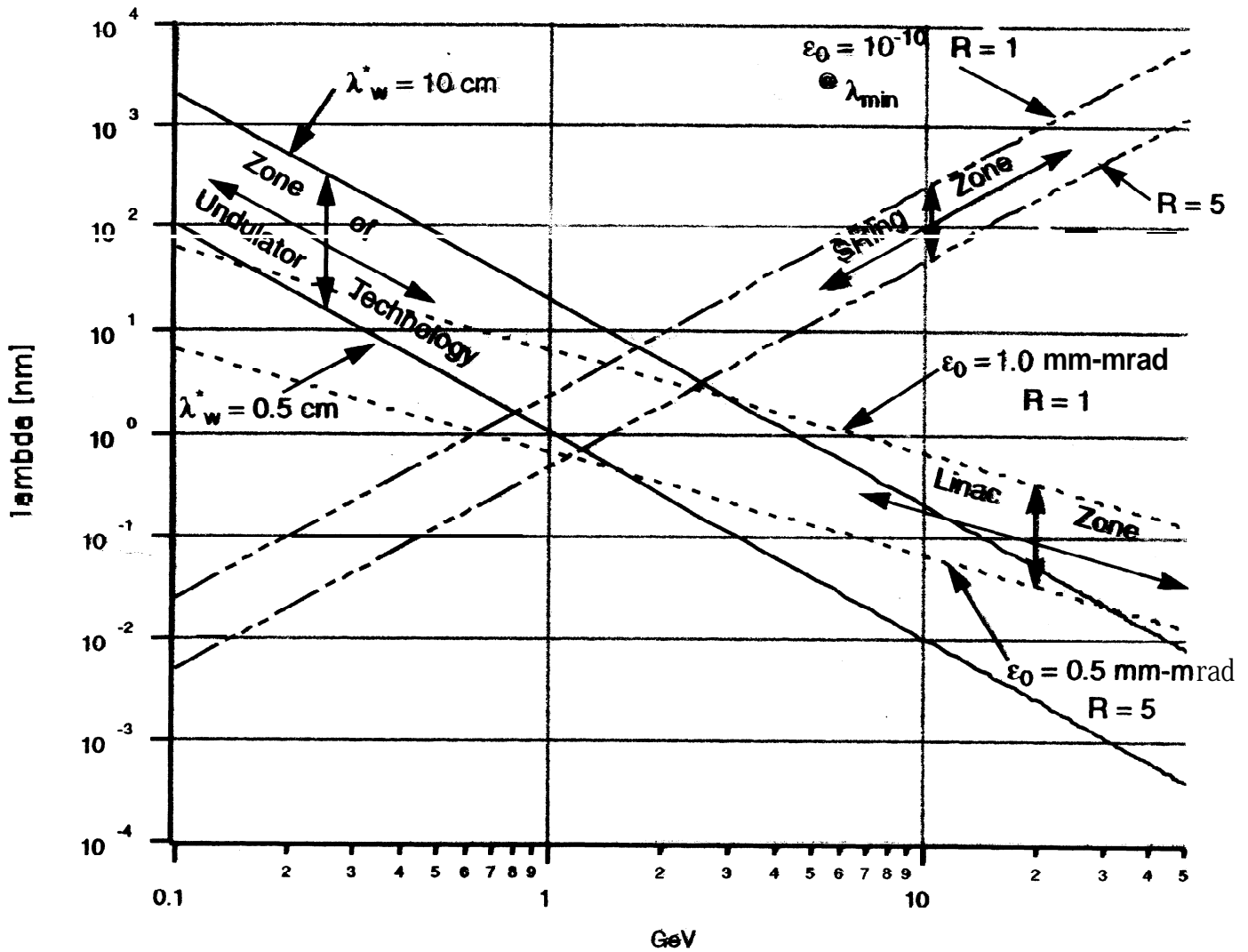
Self-Amplified-Spontaneous-Emission (SASE) FEL



UNDULATOR
NOTE: DOES NOT Require Mirrors
or Seed Pulse

ADVANCED PHOTON SOURCE

Storage Ring vs. Linac Comparison



Emittance Scaling

$$\lambda_L = \frac{\lambda_w^*}{2\gamma^2} = \frac{\lambda_w}{2\gamma^2} \left(1 + \frac{k^2}{2}\right)$$

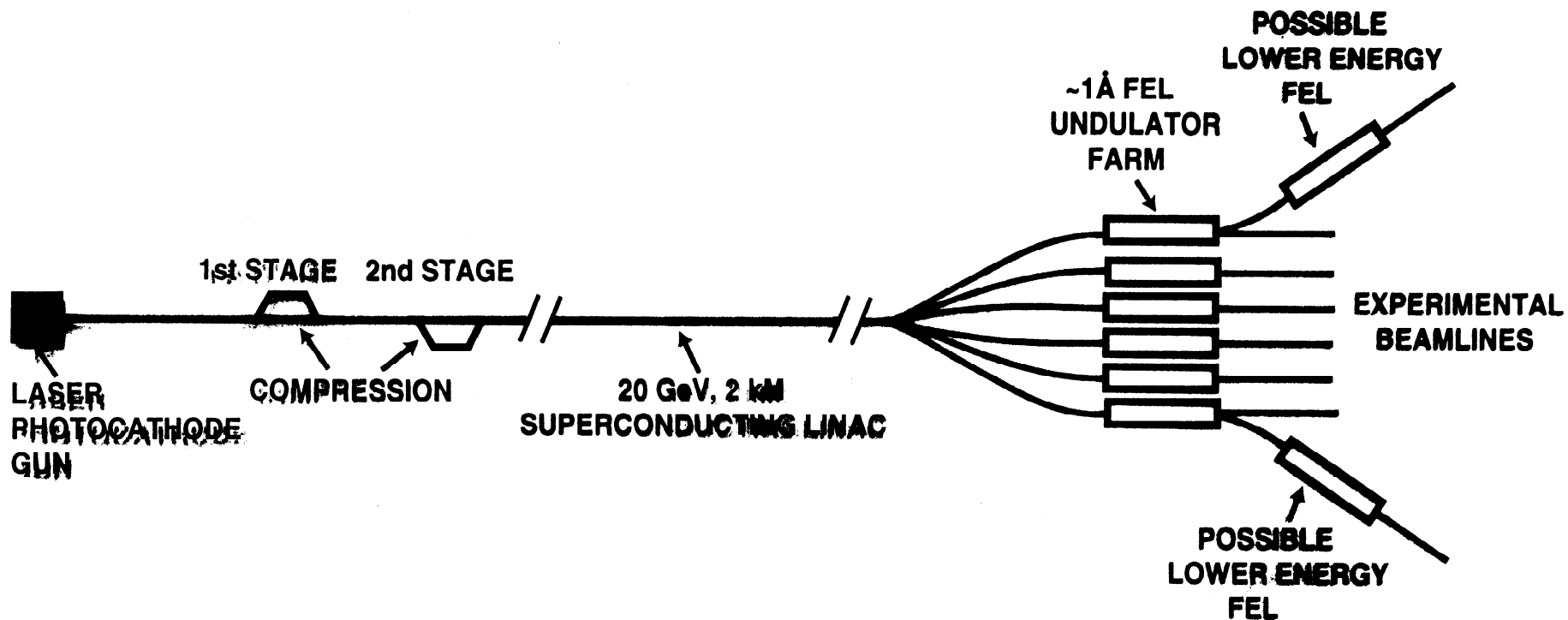
$$\lambda_L > \lambda_{diff} \equiv \frac{4\pi\epsilon}{R}$$

Storage Ring

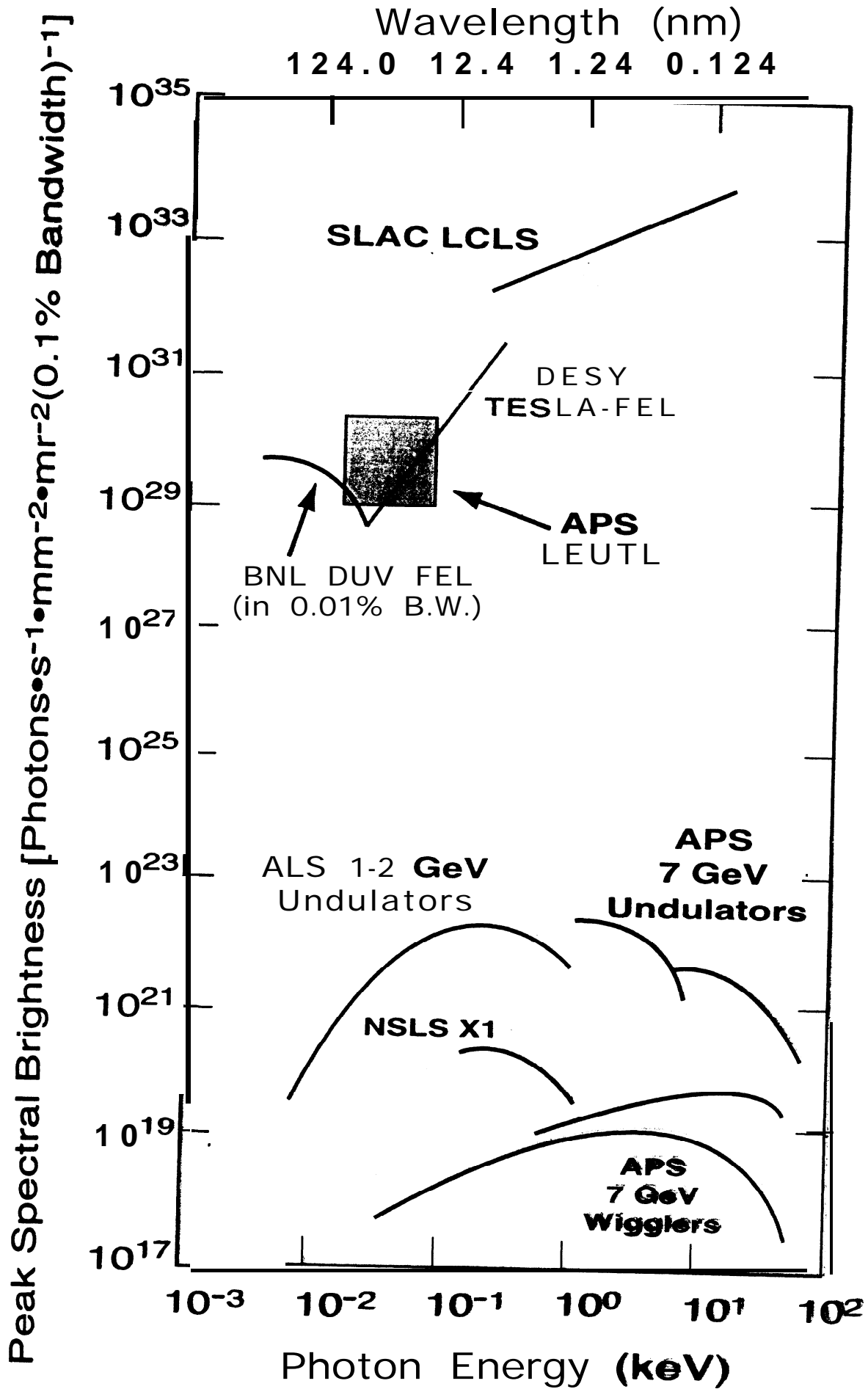
$$\epsilon \propto \gamma^2$$

Linac

$$\epsilon \propto \frac{1}{\gamma}$$



**POSSIBLE FOURTH-GENERATION SYNCHROTRON FACILITY
USING SELF-AMPLIFIED SPONTANEOUS EMISSION (SASE) FELS**

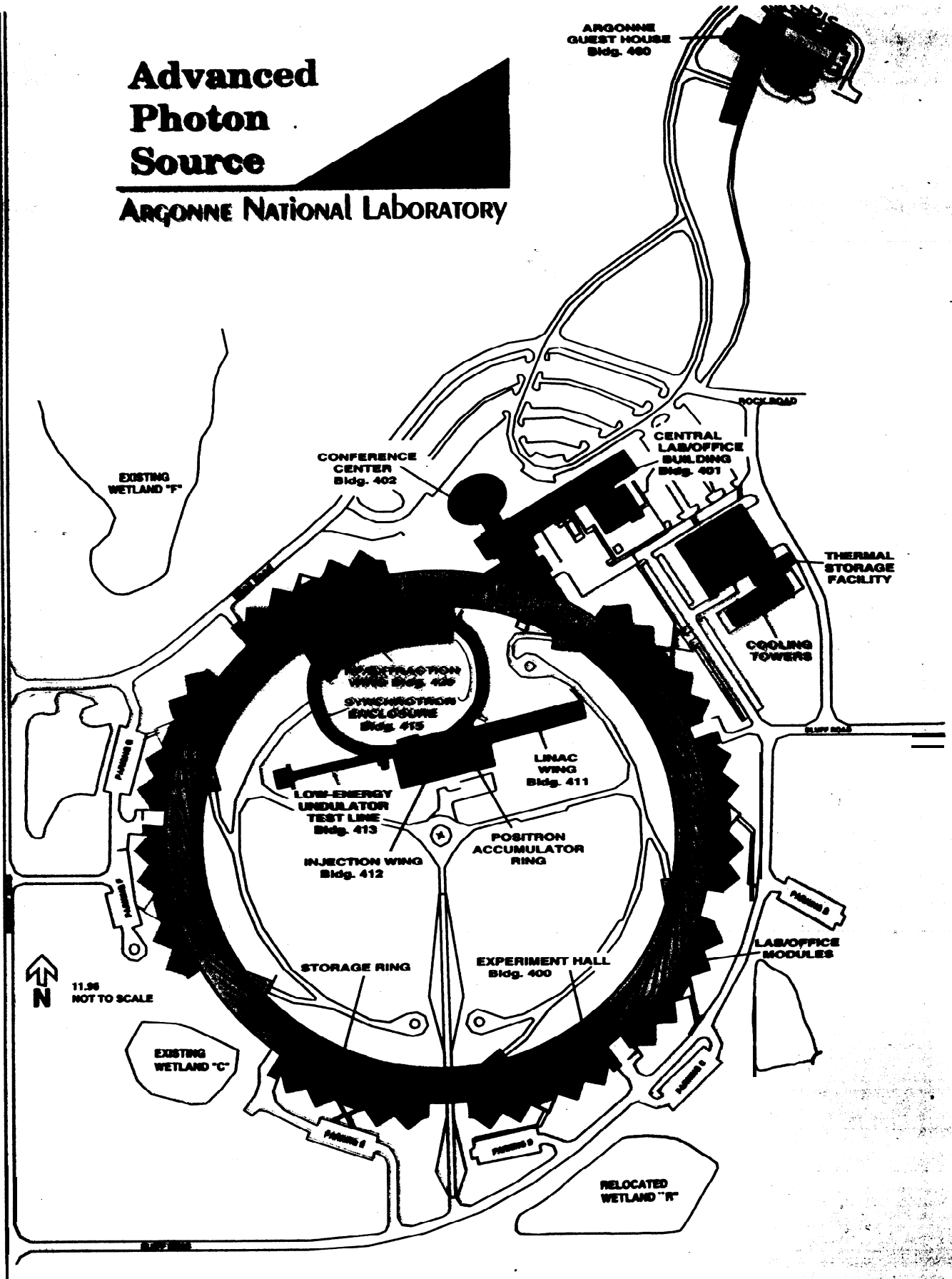


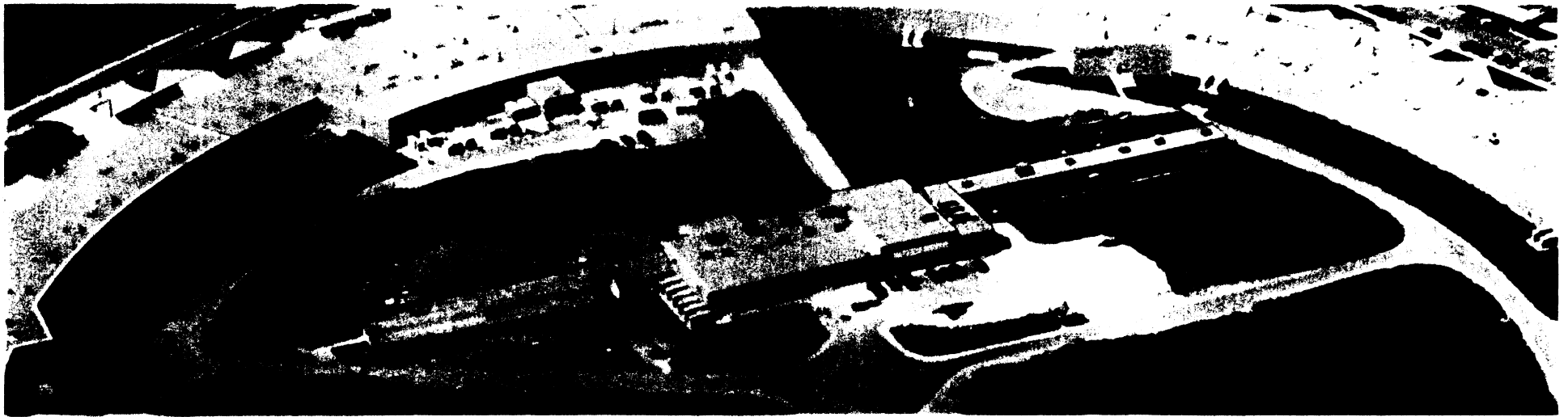
Parameters of the Short-Wavelength SASE FEL

Parameter	SLAC	DESY	ANL	BNL
Wavelength, nm	.15 - 4	6.4 - 72	120	1000
Electron Energy, GeV	15 - 7	1 - .3	.4	.23
Normalized Emittance, $\pi mm \cdot mrad$	1 - 3.5	2	5	6
Energy Spread, %	.02	.1 - .2	.1	.1
Peak Current, kA	5 - 2.5	2.5 - .5	.15	.15
Undulator Period, mm	30 - 83	27.3	27	38.9
Magnetic Field, T	1.3 - .76	.5	12.	.56
Undulator Gap, mm	6	12	5	14.4
Focusing	FDFD	FODO	Separated Quadrupoles	FOFO
Gain Length, m	6 - 2.5	1.1 - .6	15.	.67
Undulator Length, m	100 - 40	6 .4.8 - 3 .4.8	15 .2.5	10

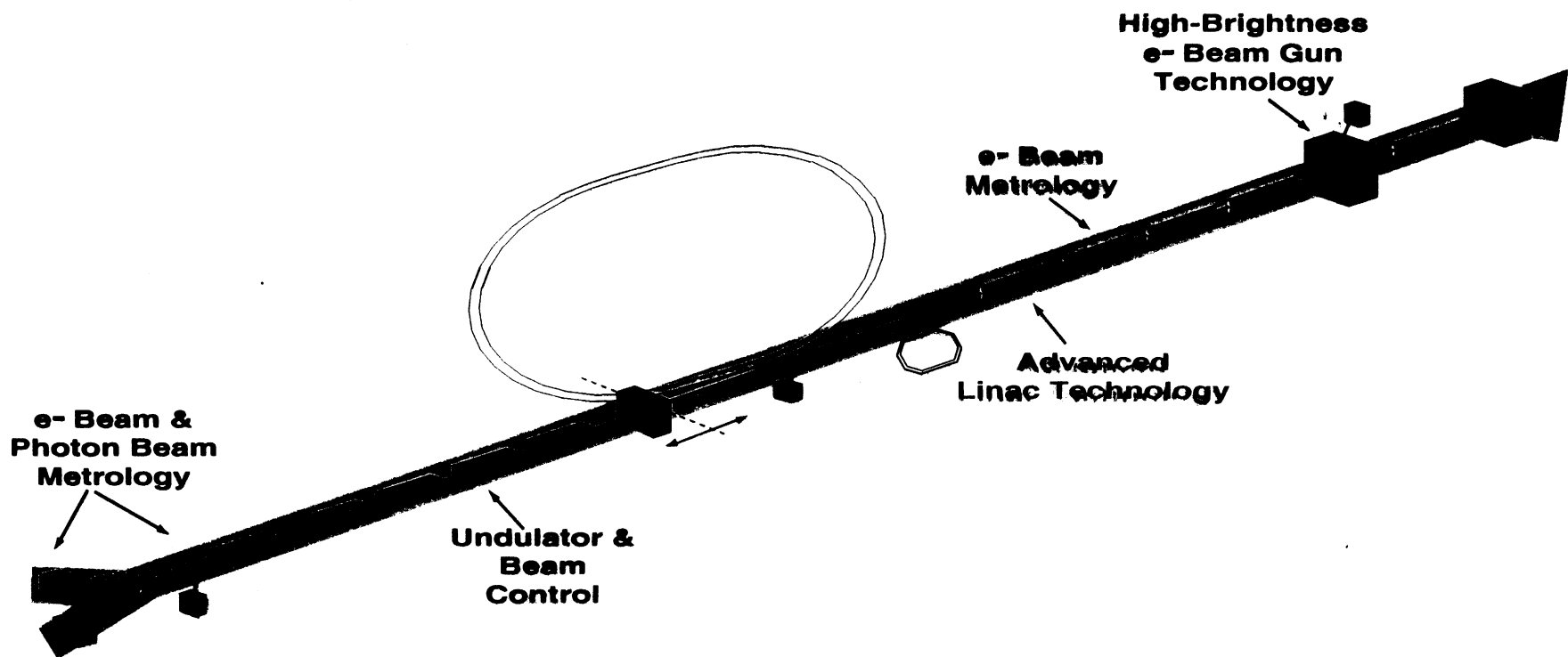
Advanced Photon Source

ARGONNE NATIONAL LABORATORY

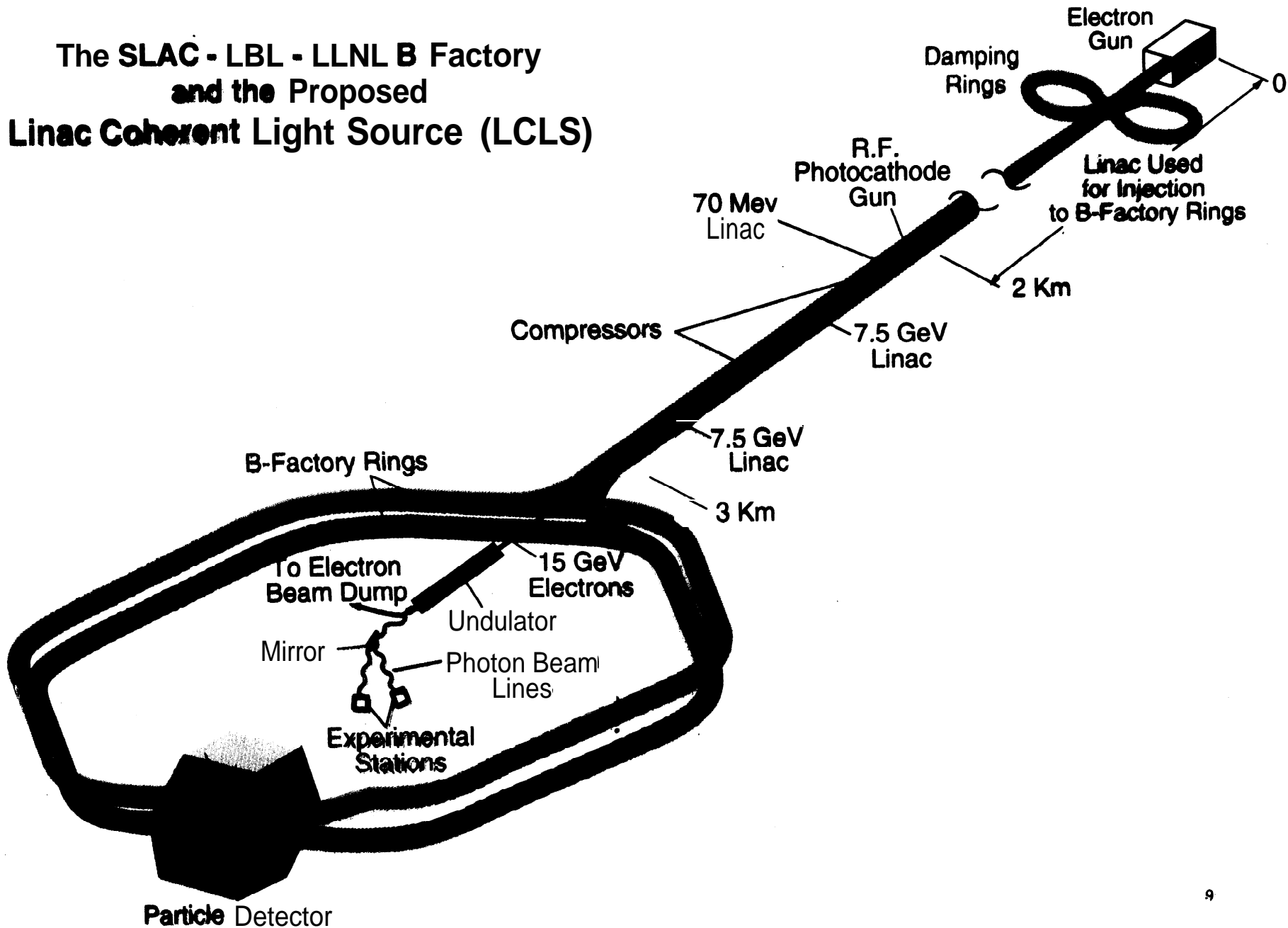




LOW ENERGY UNDULATOR TEST LINE System Layout



The SLAC - LBL - LLNL B Factory and the Proposed Linac Coherent Light Source (LCLS)



Parameters		Units
Electron beam energy	14.35	GeV
Emittance	1.5	π mm mrad, rms
Peak current	3,400	A
Energy spread (uncorrelated)	0.02	%, rms
Energy spread (correlated)	0.10	%, rms
Bunch length	100	fsec, rms
Undulator period	3	cm
Number of undulator periods	3,330	
Undulator length	100	m
Undulator field	1.32	Tesla
Undulator gap	6	mm
Undulator parameter, K	3.7	
FEL parameter, ρ	$4.7 \cdot 10^{-4}$	
Gain length	11	m
Repetition rate	120	Hz
Saturation peak power	10	GW
Peak brightness	$5.5 \cdot 10^{32} - 5.5 \cdot 10^{33}$	Photons/(s mm ² mrad ² 0.3% BW)
Average brightness	$5.5 \cdot 10^{21} - 5.5 \cdot 10^{22}$	Photons/(s mm ² mrad ² 0.1% BW)

Fig. 2 shows the peak and average brightness as a function of photon energy

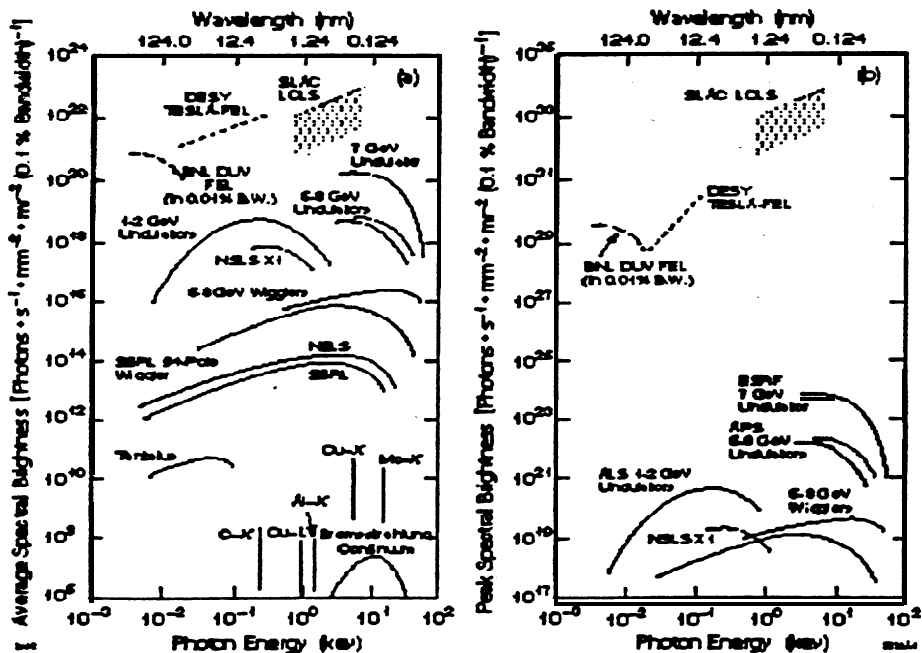


Figure 2: Average and peak brightness calculated for the LCLS, other planned FEL facilities and those obtained in some operating facilities.

The curves for the presently operating 3rd generation facilities indicate that the projected peak brightness of the LCLS would be about 8 orders of magnitude greater than currently achieved. Fig 3 shows the build up of the FEL radiation along the undulator length, computed with the code "GINGER". The power saturates, and reaches its maximum output value, at about 80 m along the undulator. A set of simulations takes into account the effect of magnetic imperfections.¹² This is

ADVANCED PHOTON SOURCE

FEL Operation Requirements

- SASE MODE: Basic Description**

Spontaneous emission + bunch irregularities



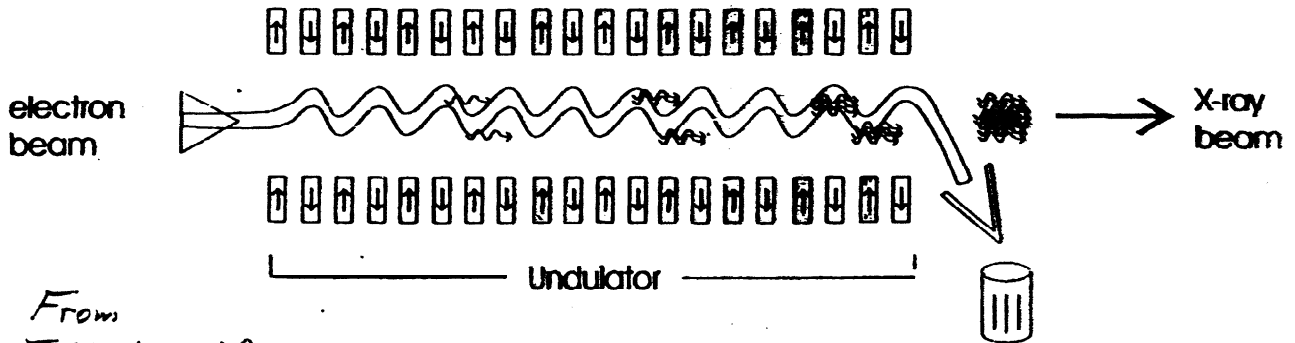
Bunching begins



Field strength increase

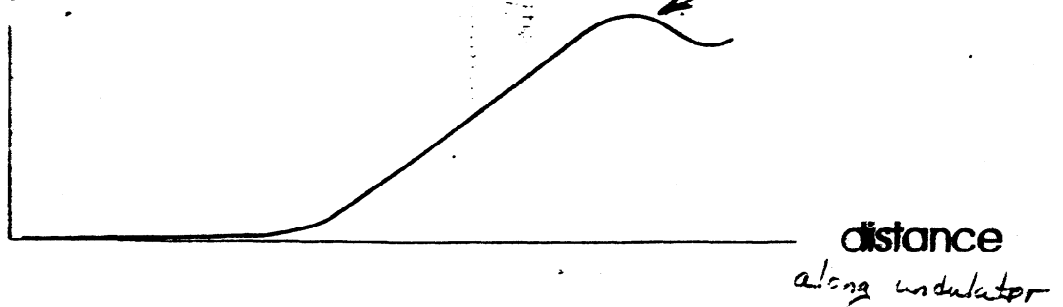


Exponential growth of coherent field



$\log(\text{radiation power})$

Saturation



Free Electron Laser in the Self Amplified Spontaneous Emission (SASE) mode

ADVANCED PHOTON SOURCE

- SASE PARAMETERIZATION

- The Pierce Parameter

$$\rho \propto \left[\frac{I_{peak} K^2 \lambda_w^2}{\sigma_{trans}^2 \gamma^3} \right]^{1/3} = \left[\frac{I_{peak}}{\sigma_{trans}^2} \frac{\lambda^2 \gamma K^2}{\left(1 + K^2/2\right)^2} \right]^{1/3}$$

- The Gain Length

$$L_{gain} = \frac{1}{1 + \eta} L_{gain}^{1-D} = \frac{1}{1 + \eta} \frac{\lambda_w}{4\pi\sqrt{3}\rho}$$

- Efficient Operation

$$\frac{4\pi\epsilon}{a_{light}} \leq 1 \quad \frac{L_{gain}}{L_R} \leq 1 \quad \frac{b_y}{\gamma} \leq \rho$$

- Quickly Summing Up

Make ρ as large as possible without violating conditions for efficient operation.

ADVANCEDPHOTONSOURCE

Length and Time Scales

- **LENGTH SCALES**
 - Transverse
 - + **Beam size i.e. beam emittance**
 - + Photon **wavelength i.e.** diffraction effects
 - **Longitudinal**
 - + **Interaction length i.e.** the gain length
 - + **Phase** errors

- **TIME SCALE**
 - DC Shifts
 - + Discreteness of the beam diagnostics
 - Slowly varying
 - + Averaging techniques
 - Shot-to-Shot
 - + Vibrations
 - + A **real** problem

ADVANCED PHOTON SOURCE

Conditions for Ignition

Conditions for Usable Light

- **ALIGNMENT RELATED**
 - **Overlap Condition**
 - + Keep e- beam overlapped with the photon beam to within 10% **of the e-** beam rms size over **a distance** of at least 3 **gain lengths**.
 - + To be done **with e-** and photon beam **position** monitors (as yet to be constructed).
 - **Phase Coherence**
 - + Keep e- beam “wiggle” phase properly aligned with the coherent photon beam phase.
 - + Longitudinal alignment

ADVANCED PHOTON SOURCE

Dead Reckoning

- TRAJECTORY AMBIGUITY
 - Finite number of beam position monitors

