4th Generation Light Source Alignment Issues

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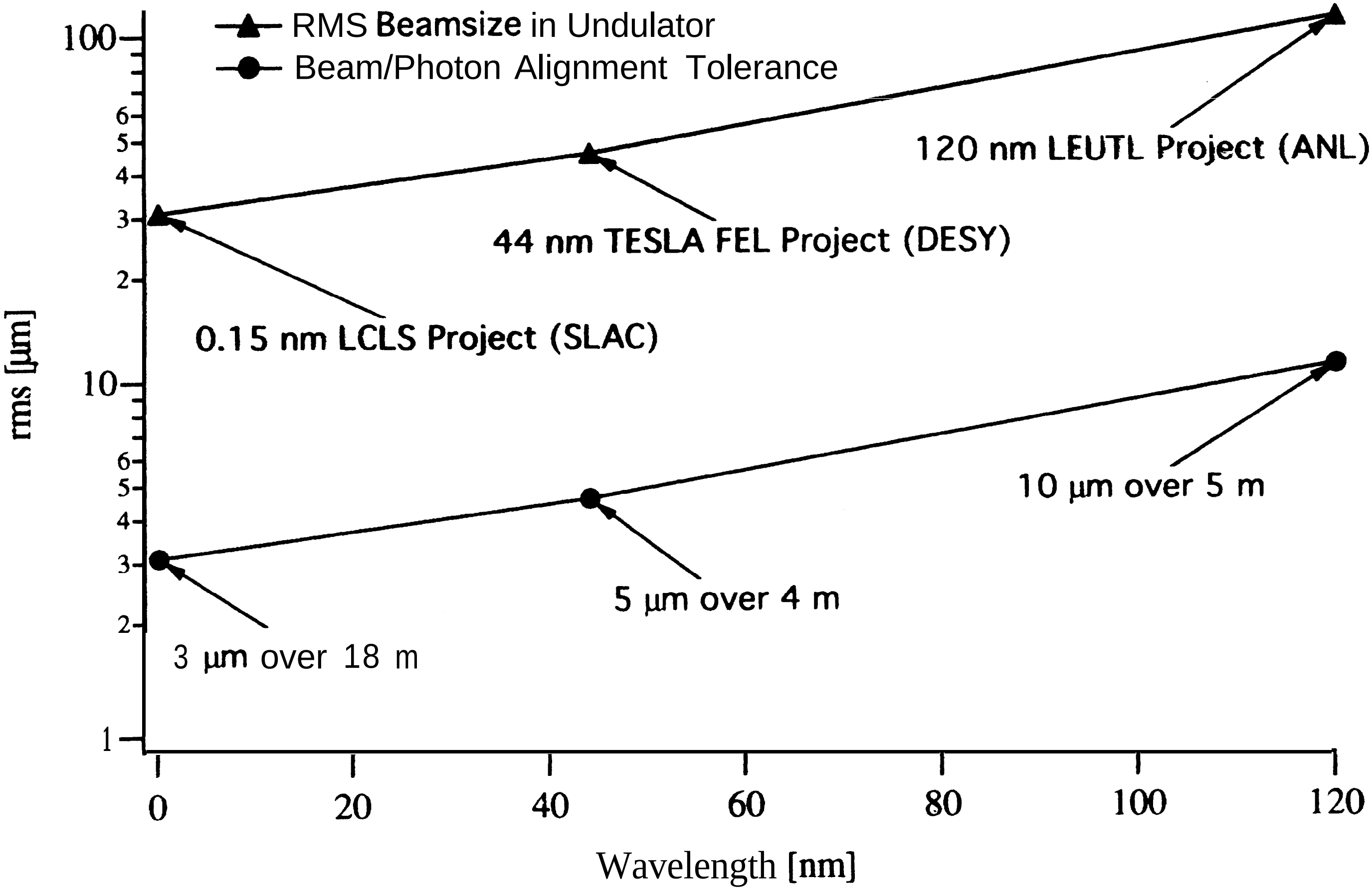
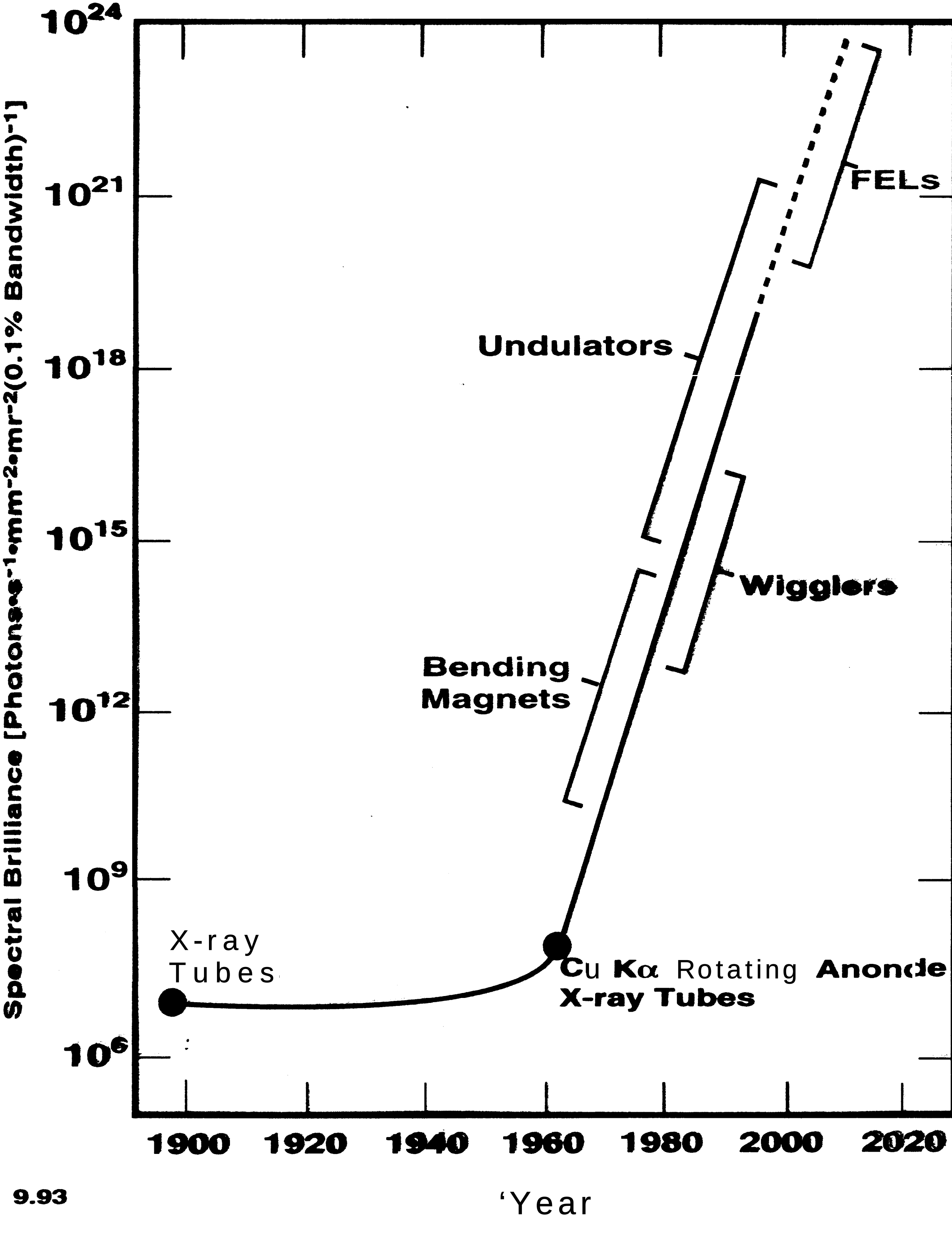
- **OUTLINE**
  - Synchrotron Radiation Historical Background
  - 4th Generation Description
  - FEL Operation Requirements
  - Methods of Measurement
  - Alignment Requirements

ALIGNMENT TOLERANCE vs. WAVELENGTH



Average Spectral Brilliance - Real & Projected



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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

  <u>Synchrotron Radiation</u>

- **Further** Improvements in **Synchrotron** Radiation

  1) Magnet Technology

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

  2) Particle Beam Quality and Control

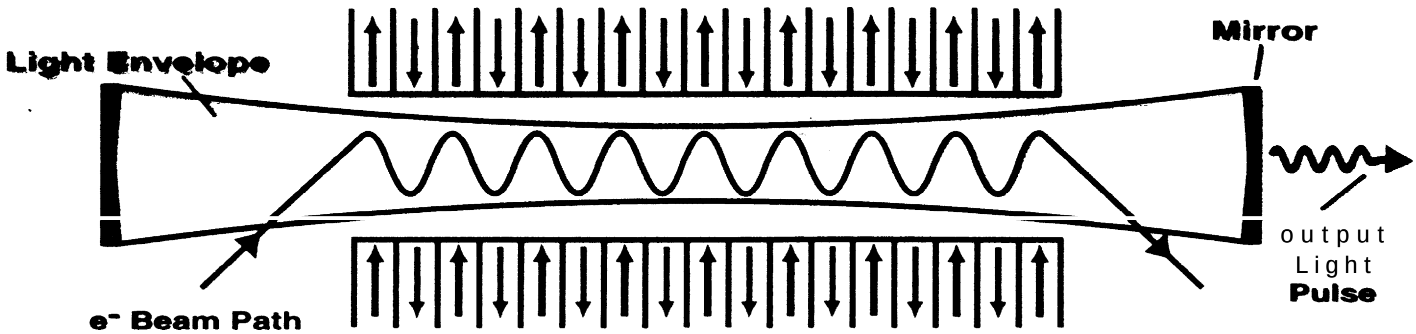
     - Lower **Emittance**
     - Lower Energy Spread
     - Higher Average Current
     - Higher Peak Current
     - High Resolution and Precision **Diagnostics**
     - Feedback Systems

  3) Coherence

     - **Free Electron Lasers (FEL)**

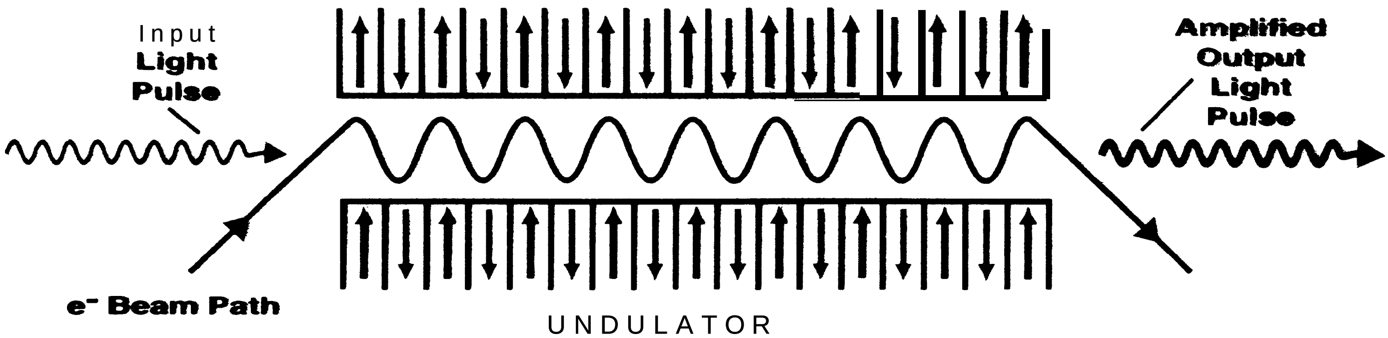
FEL Systems

FEL Oscillator



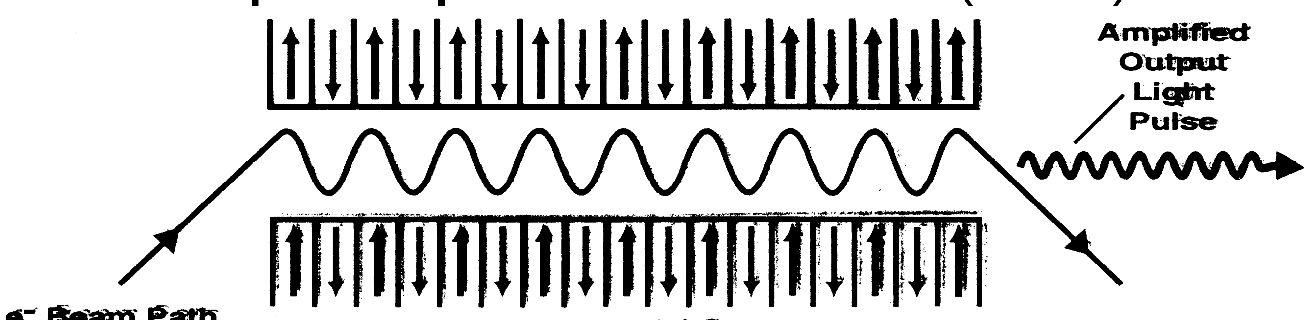
UNDULATOR
NOTE: Requires Mirrors

Seeded (Amplifier) FEL



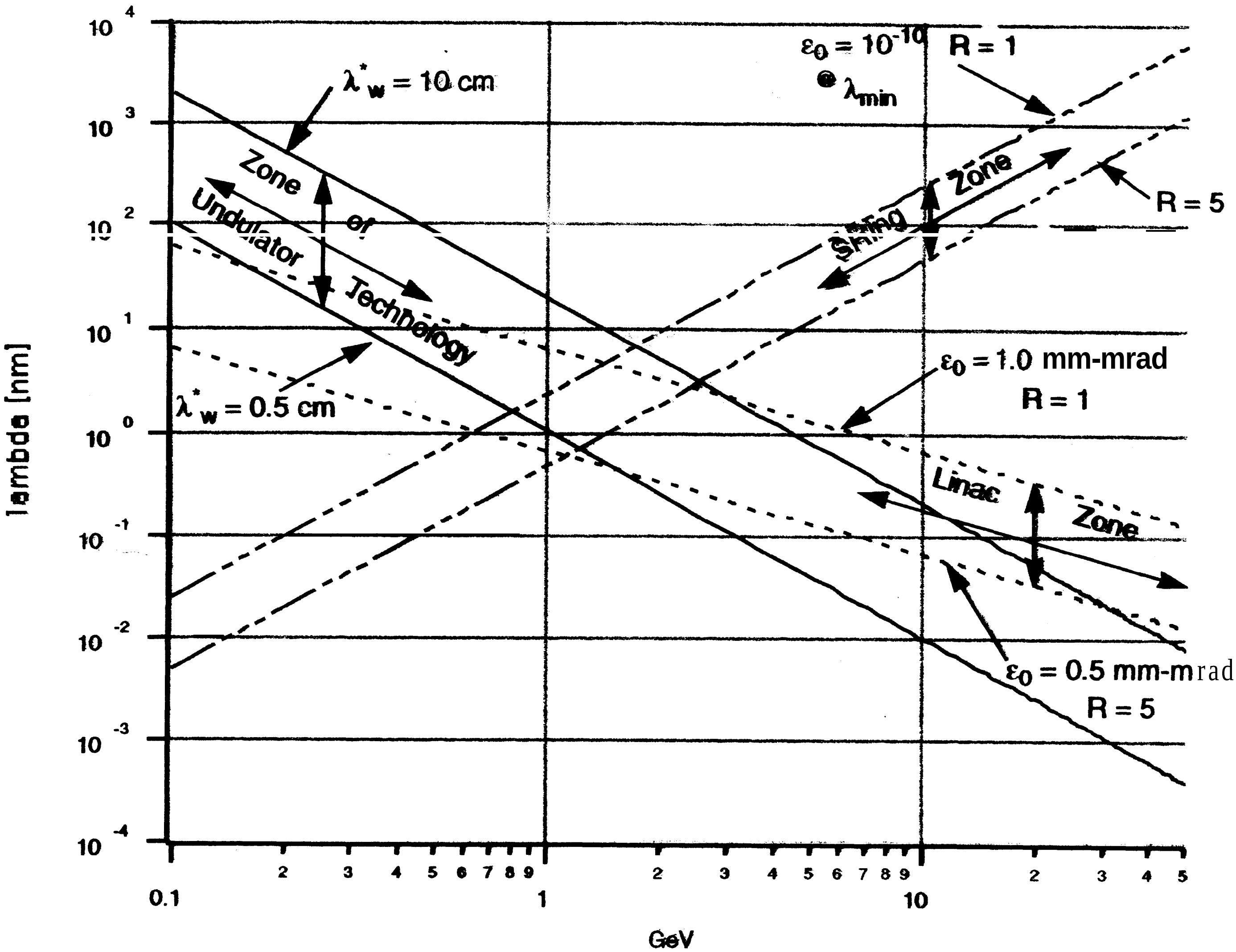
UNDULATOR
NOTE: Requires an Input Light Laser
of Proper Wavelength

Self-Amplified-Spontaneous-Emission (SASE) FEL



UNDULATOR
NOTE: DOES NOT Require Mirrors
or Seed Pulse

Storage Ring vs. Linac Comparison



Emittance Scaling

$$\lambda_L - \frac{\lambda^*_W}{2\gamma^2} = \frac{\lambda_W}{2\gamma^2}\left(1 + \frac{k^2}{2}\right)$$

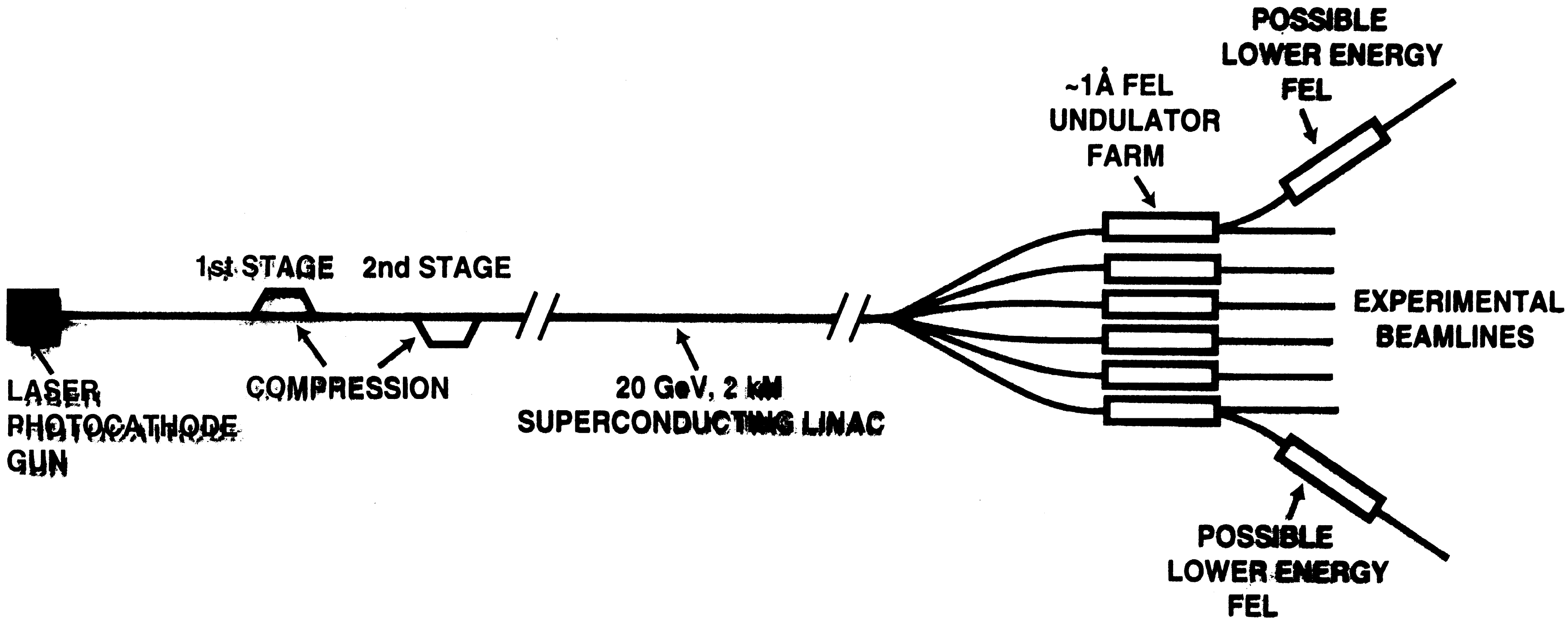
Storage Ring

$$\varepsilon \ \alpha \ \gamma^2$$

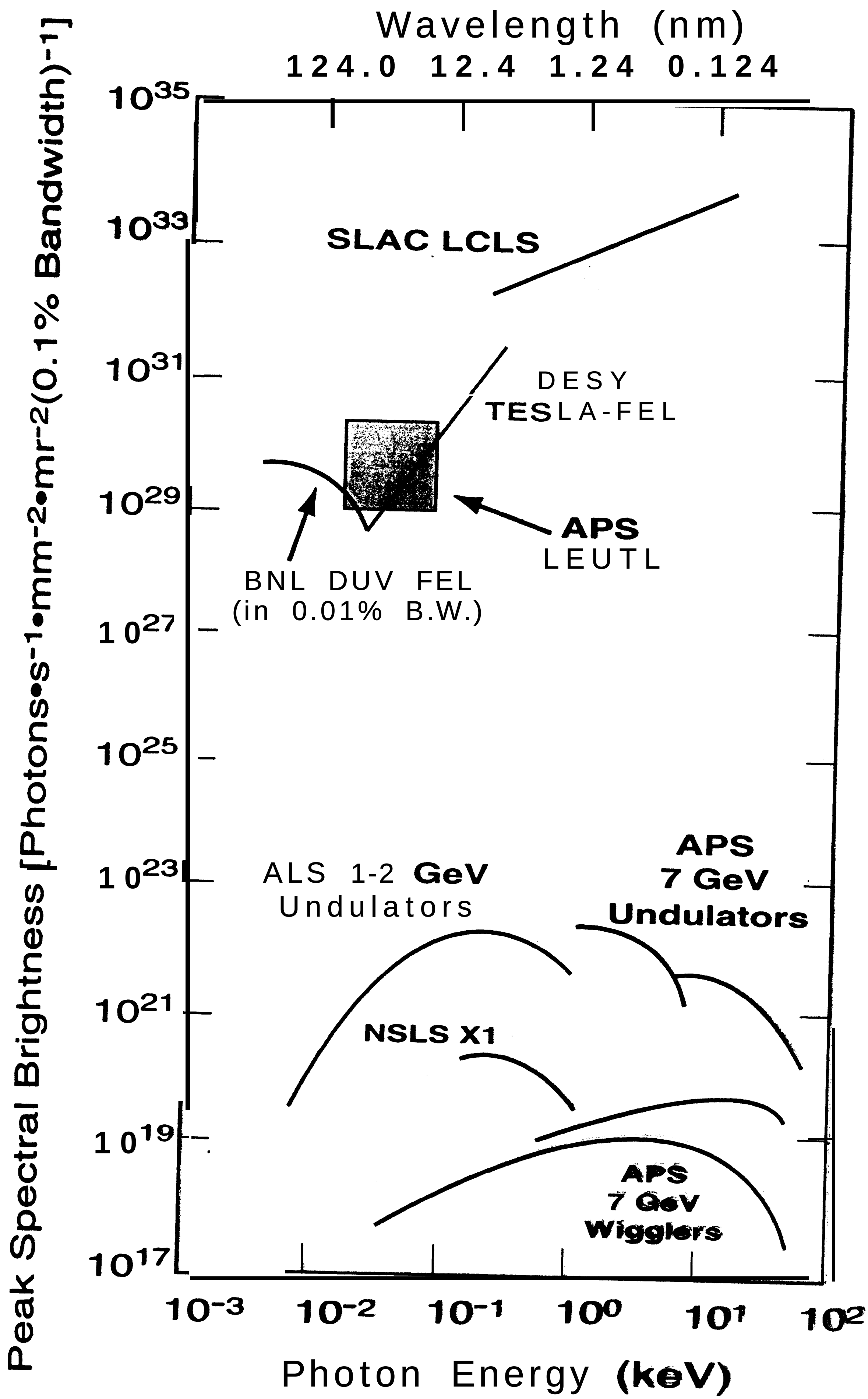
$$\lambda_L > \lambda_{diff} \equiv \frac{4\pi\varepsilon}{R}$$

Linac

$$\varepsilon \ \alpha \ \frac{1}{\gamma}$$



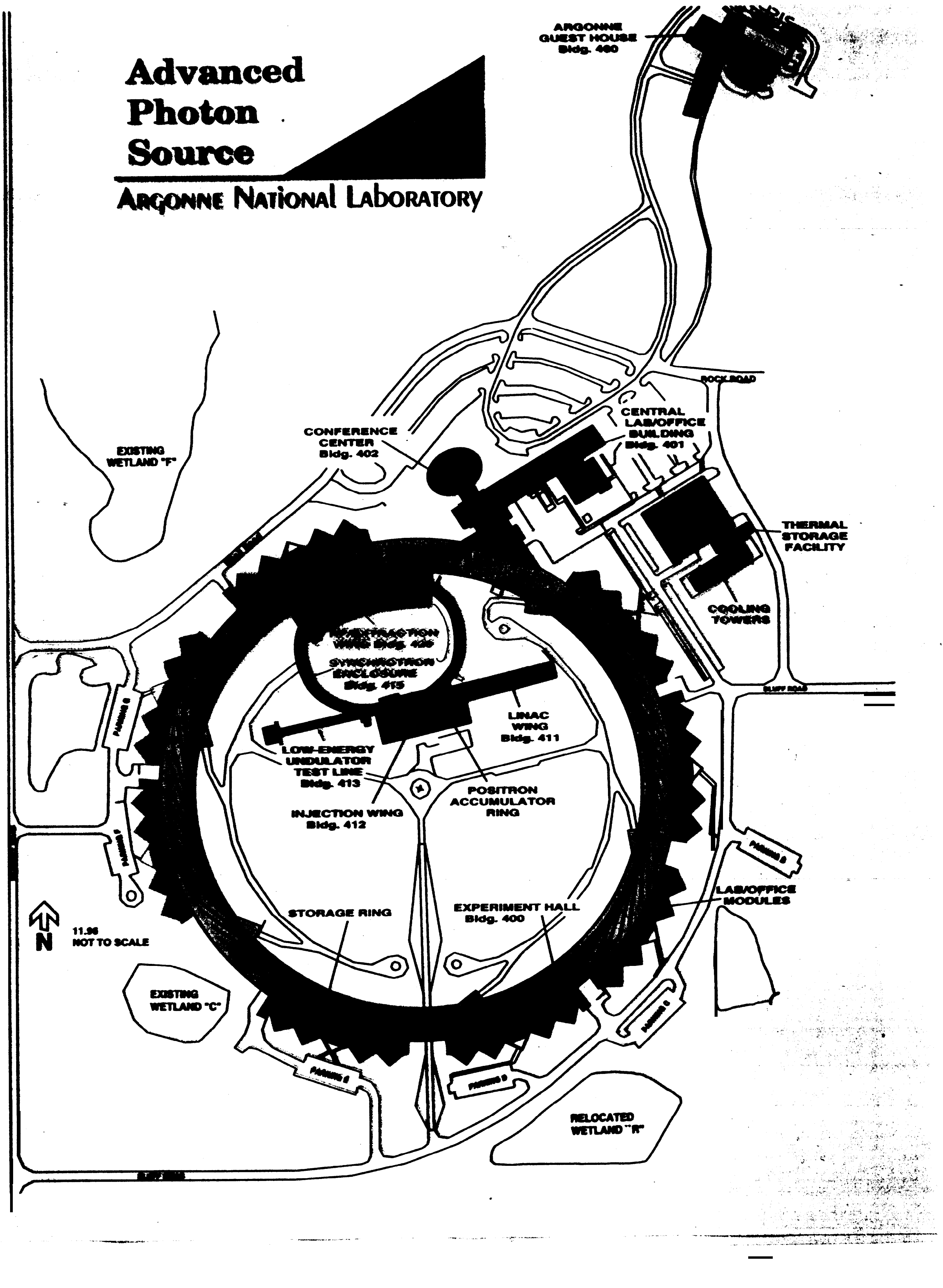
POSSIBLE FOURTH-GENERATION SYNCHROTRON FACILITY USING SELF-AMPLIFIED SPONTANEOUS EMISSION (SASE) FELS

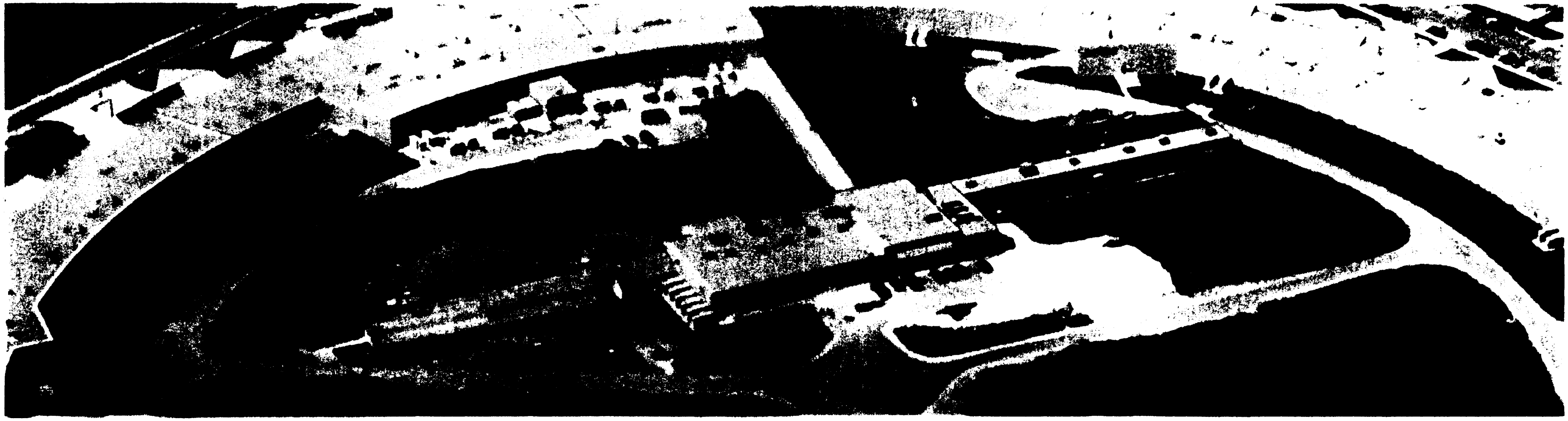


Wavelength (nm)
124.0 12.4 1.24 0.124
Peak Spectral Brightness [Photons•s-1•mm-2•mr-2(0.1% Bandwidth)-1]
10^35
10^33
10^31
10^29
10^27
10^25
10^23
10^21
10^19
10^17
SLAC LCLS
DESY
TESLA-FEL
APS
LEUTL
BNL DUV FEL
(in 0.01% B.W.)
ALS 1-2 GeV
Undulators
APS
7 GeV
Undulators
NSLS X1
APS
7 GeV
Wigglers
10-3 10-2 10-1 100 101 102
Photon Energy (keV)

Parameters of the Short-Wavelength SASE FEL

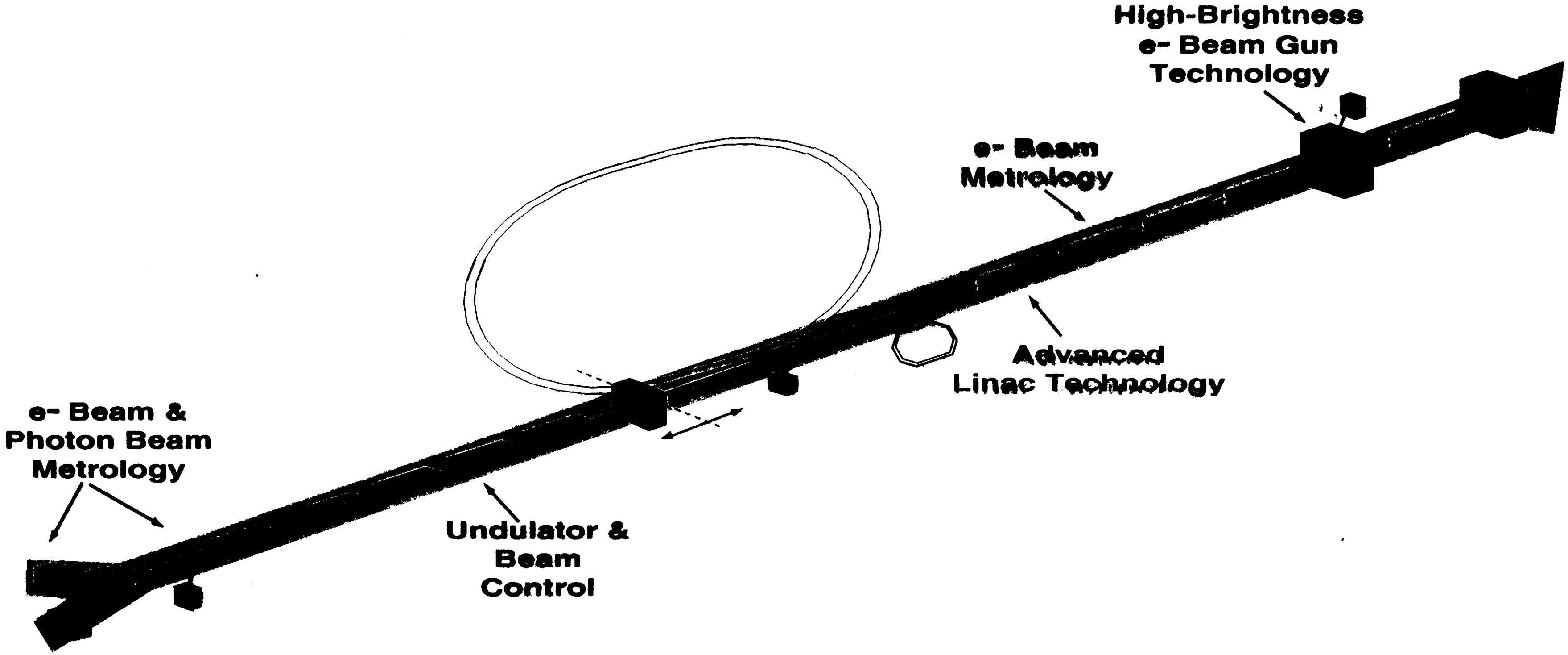
Parameter	SLAC	DESY	ANL	BNL
Wavelength, *nm*	.15 - 4	6.4 - 72	120	1000
Electron Energy, *GeV*	15 - 7	1 - .3	.4	.23
Normalized Emittance, π *mm·mrad*	1 - 3.5	2	5	6
Energy Spread, %	.02	.1 - .2	.1	.1
Peak Current, *kA*	5 - 2.5	2.5 - .5	.15	.15
Undulator Period, *mm*	30 - 83	27.3	27	38.9
Magnetic Field, *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
ARGONNE
GUEST HOUSE
Bldg. 460
ROCK ROAD
CENTRAL
LAB/OFFICE
BUILDING
Bldg. 401
CONFERENCE
CENTER
Bldg. 402
EXISTING
WETLAND "F"
THERMAL
STORAGE
FACILITY
COOLING
TOWERS
SYNCHROTRON
ENCLOSURE
Bldg. 415
LINAC
WING
Bldg. 411
LOW-ENERGY
UNDULATOR
TEST LINE
Bldg. 413
POSITRON
ACCUMULATOR
RING
INJECTION WING
Bldg. 412
LAB/OFFICE
MODULES
STORAGE RING
EXPERIMENT HALL
Bldg. 400
N
11.96
NOT TO SCALE
EXISTING
WETLAND "C"
RELOCATED
WETLAND "R"

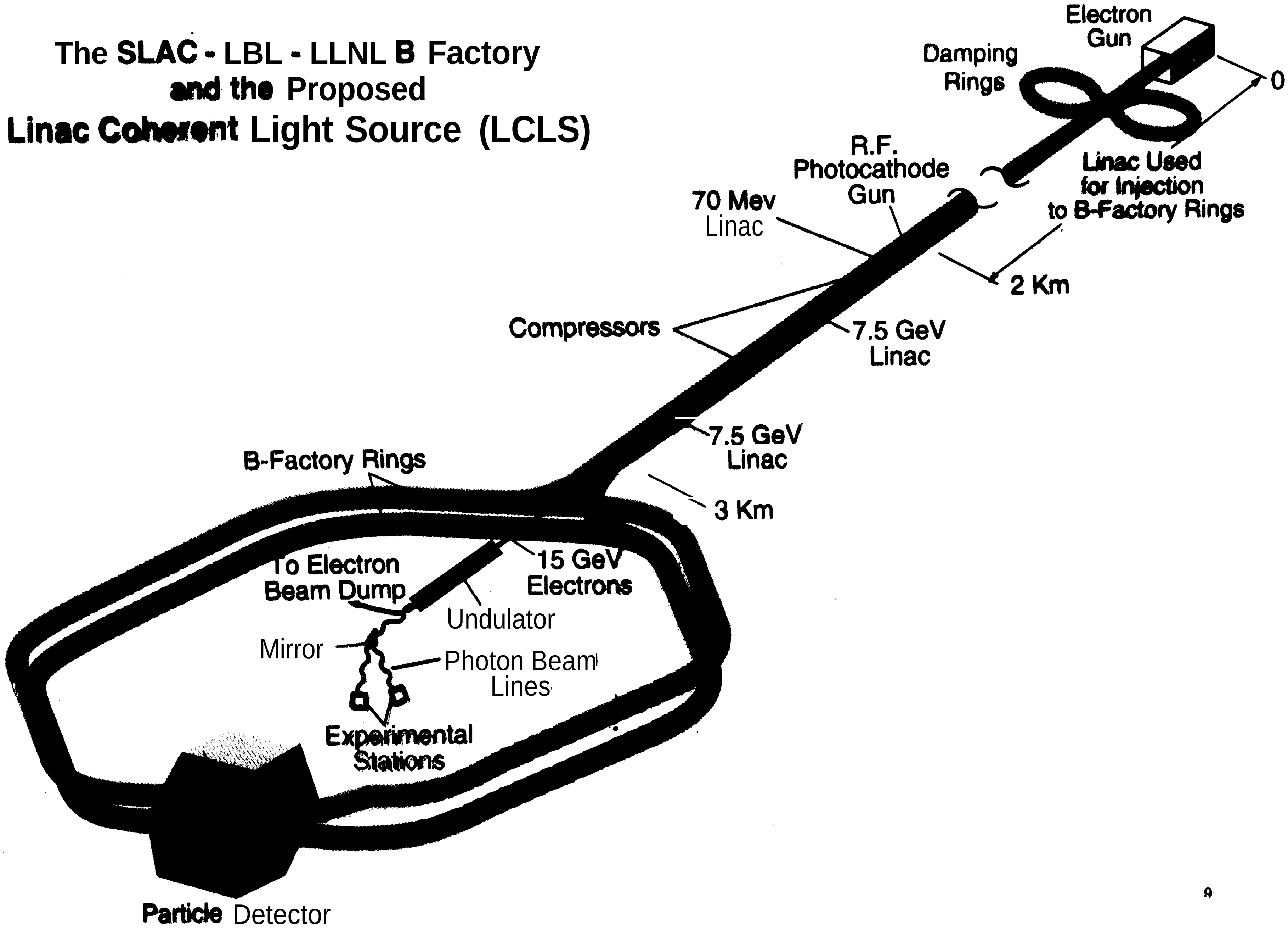


LOW ENERGY UNDULATOR TEST LINE

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 10^{-4}	
Gain length	11	m
Repetition rate	120	HZ
Saturation peak power	10	GW
Peak brightness	$5.5\cdot10^{32}$-$5.5\cdot10^{33}$	Photons/(s mm^2 mrad^2 0.3% BW)
Average brightness	$5.5\cdot10^{21}-5.5\cdot10^{22}$	Photons/(s mm^2 mrad^2 0.1%BW)

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

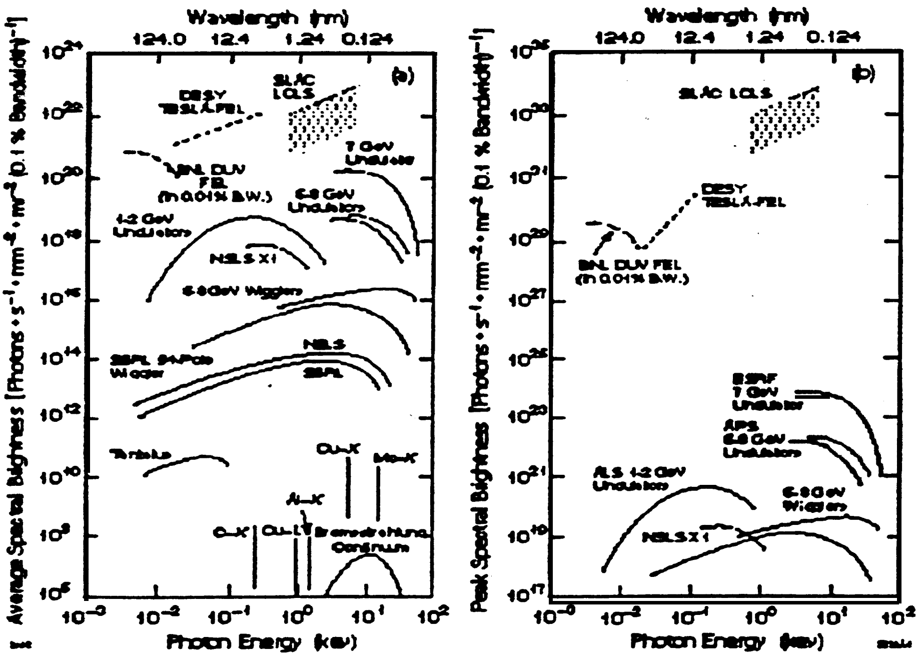


Figure 2: Average and peak brightness calculated for the LCLS, other planned FEL facilities and those obtained in some operating facilities.

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 tbe 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 tbe effect of magnetic imperfections.[12] This is

FEL Operation Requirements

- **SASE MODE: Basic Description**

Spontaneous emission + bunch irregularities

↓

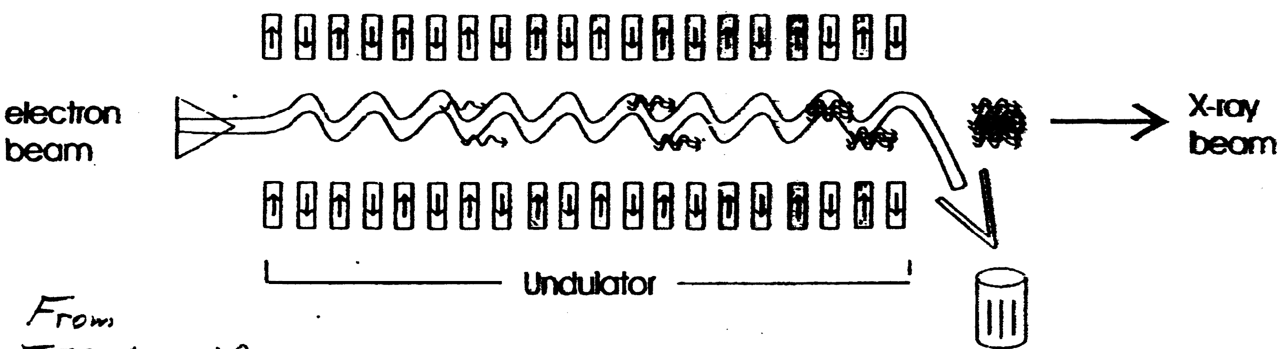
Bunching begins

↓

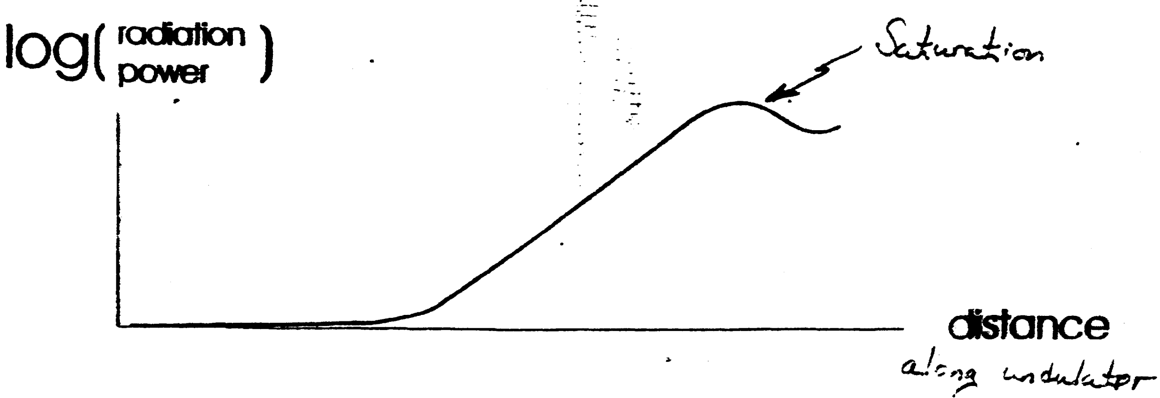
Field strength increase

↓

Exponential growth of coherent field



From TESLA CDR



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

$$\frac{4\pi\varepsilon}{a_{light}} \le 1 \qquad \frac{L_{gain}}{L_R} \le 1 \qquad \frac{b\,y}{\gamma} \le \rho$$

  - Quickly Summing Up

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

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

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).

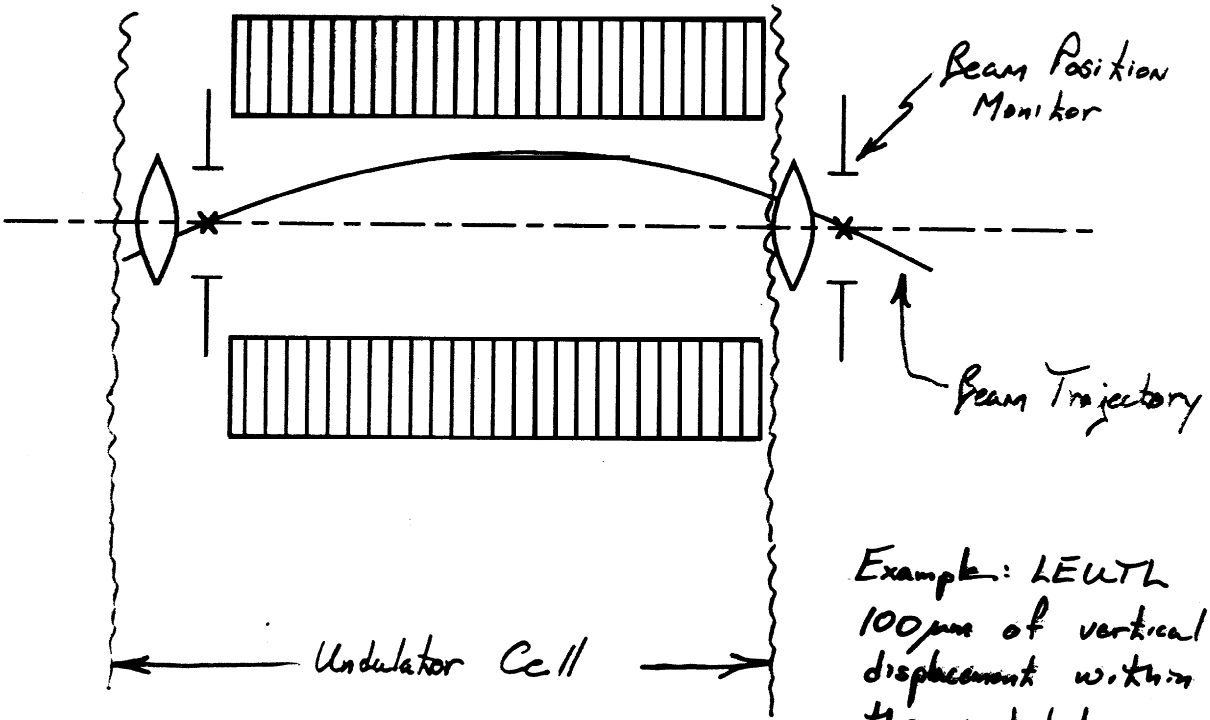
  – Phase Coherence

    + Keep e- beam “wiggle” phase properly aligned with the coherent photon beam phase.

    + Longitudinal alignment

Dead Reckoning

- **TRAJECTORY AMBIGUITY**
  - Finite number of beam position monitors



Example: LEUTL
100 μm of vertical
displacement within
the undulator produces
a 15 μm uncertainty.

Dead Reckoning

- **SOME NUMBERS (LEUTL ONLY)**
  - Transverse
    - + Undulator vertical: **100 µm over 5 m**
    - + Quadrupoles: **100 µm over 5 m**
    - + Beam Position Monitors: **50 µm over 5 m**
  - Longitudinal (Phase to within **5°** over the entire length)
    - + Undulator Cell-to-Cell: 30 µm over 5 m

- **SO WHY THE WORRY?**