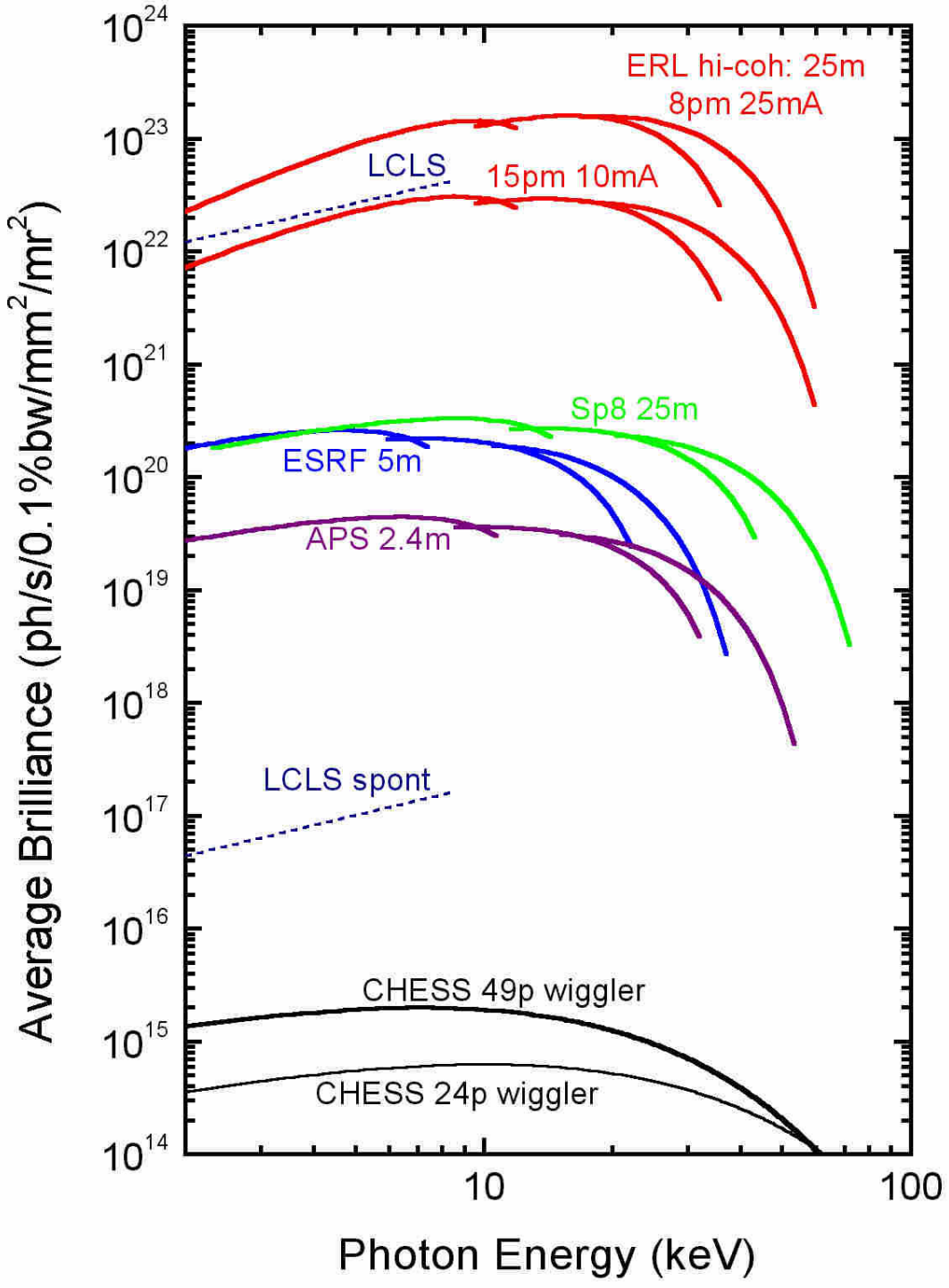
Expected Performance of the Proposed Cornell ERL X-ray Source

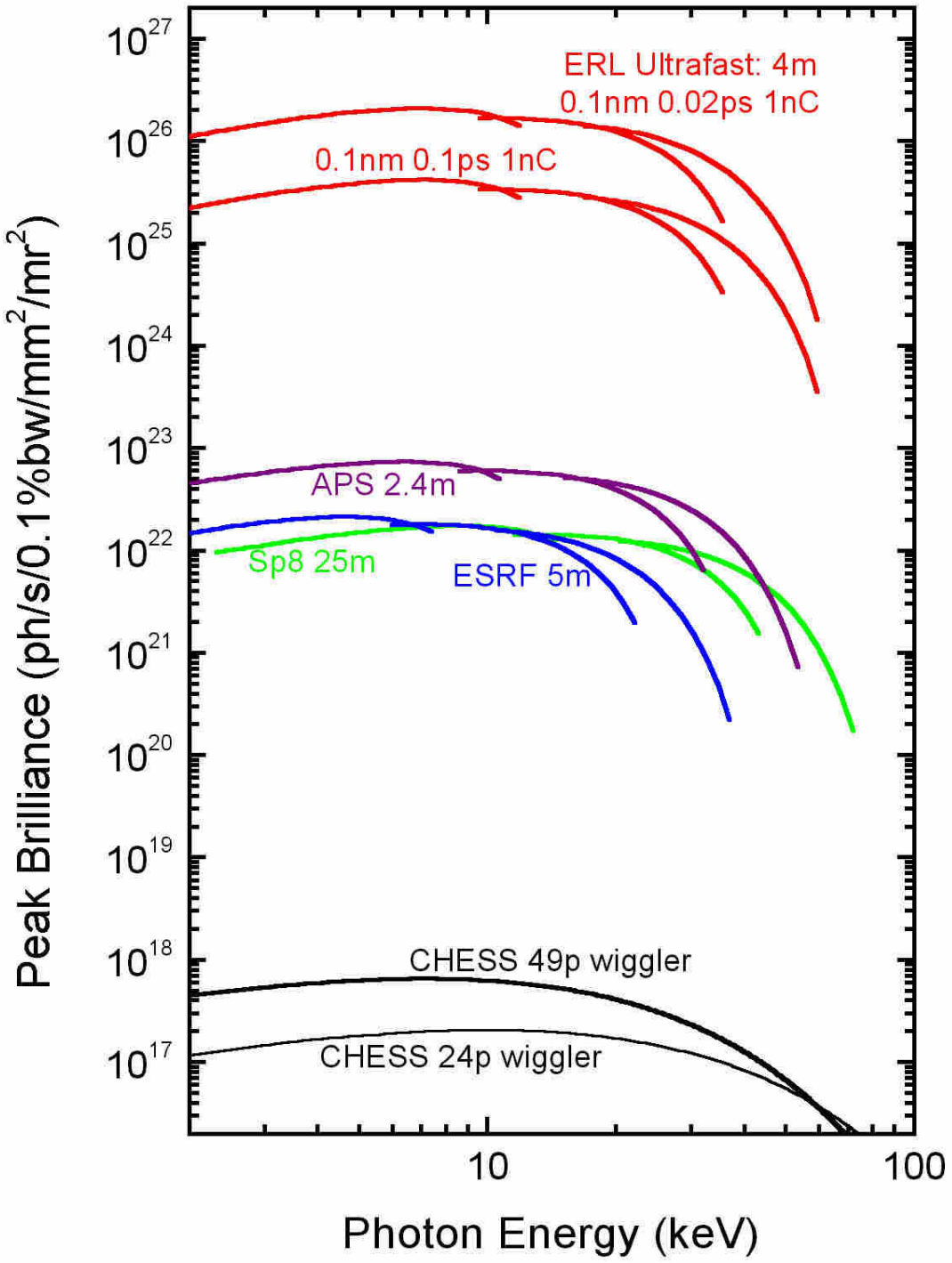
Qun Shen (CHESS)
April 14, 2004

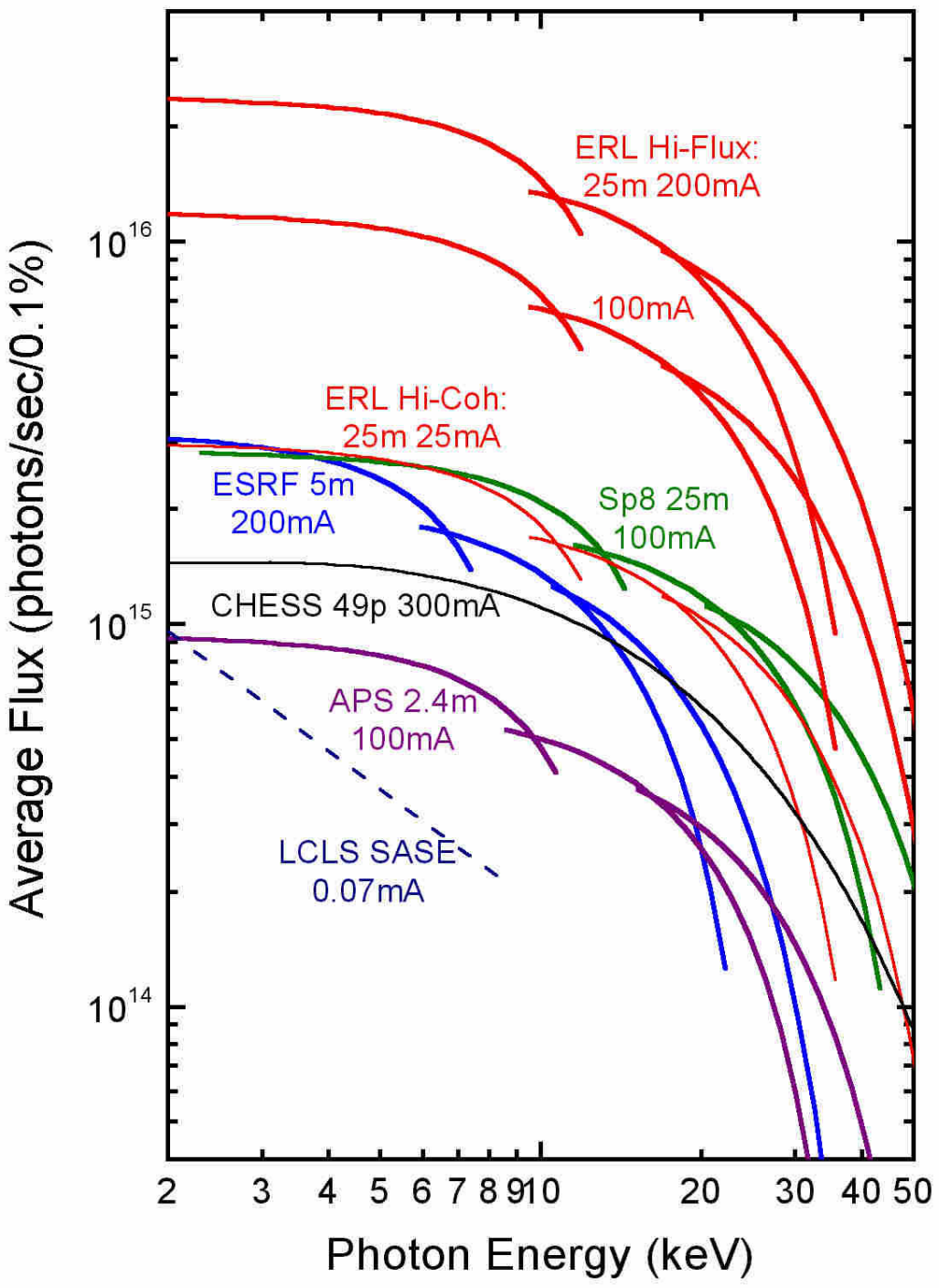
The following ERL performance numbers are based on extensive studies by Ivan Bazarov, Georg Hoffstaetter, and Charles Sinclair at Cornell, with computer simulations and proper scaling procedures. The terminology used here refers the prototype as ERL Phase-I and the initial X-ray ERL as Phase-II. Phase-IIa represents a list of numbers that may be achievable after multiple years of successful R&D using the Phase-II X-ray source.

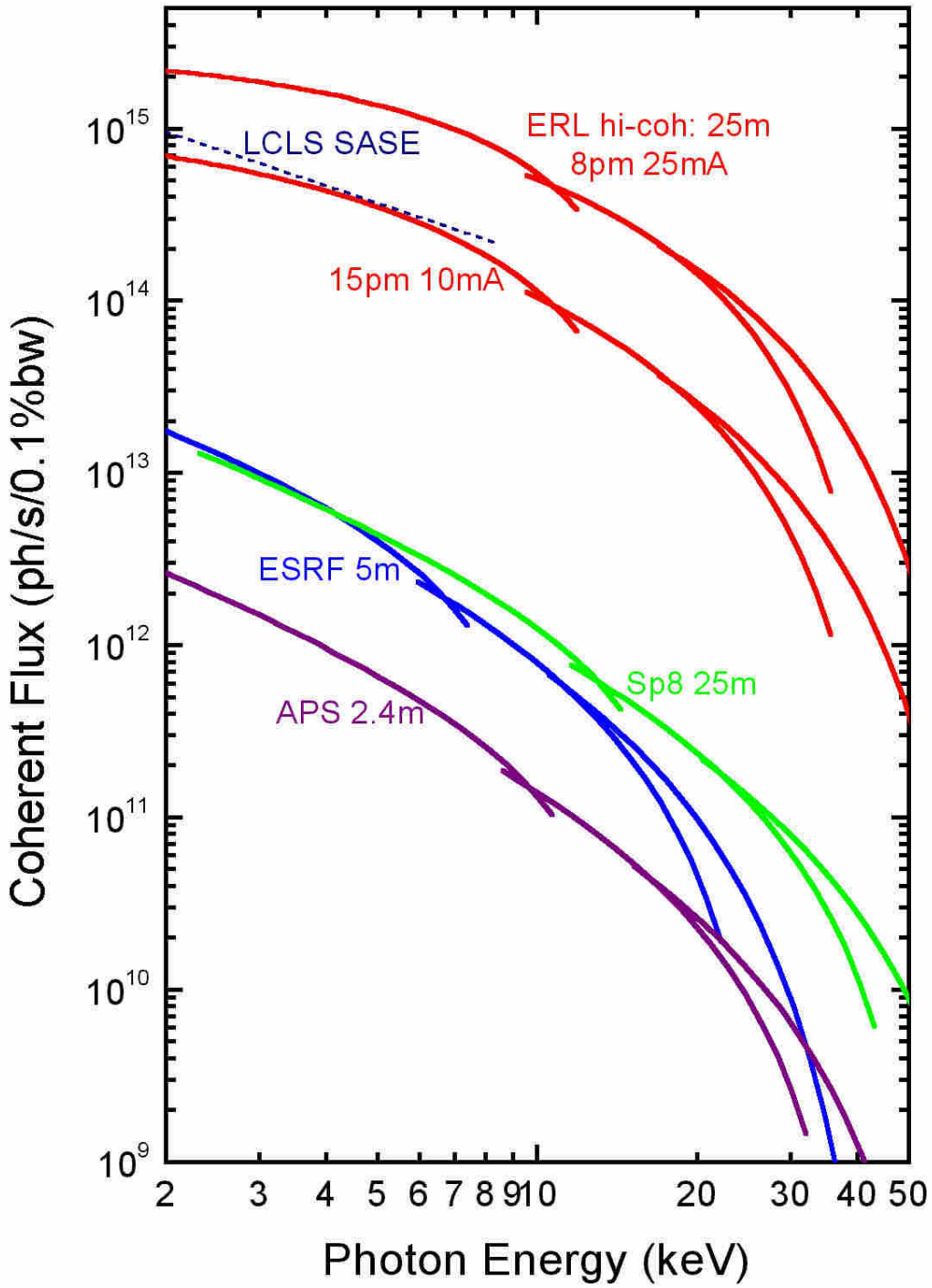
	Cornell ERL-II			Cornell ERL-IIa		
Mode of operation	Hi-flux	Hi-coh	Ultrafast	Hi-flux	Hi-coh	Ultrafast
Machine energy E (GeV)	5.3	5.3	5.3	5.3	5.3	5.3
Charge per bunch q (nC)	0.077	0.008	1	0.154	0.0192	1
Repetition rate f (MHz)	1300	1300	1	1300	1300	10
Machine current I (mA)	100	10	1	200	25	10
Horizontal emittance ε_x (nm-rad)	0.1	0.015	0.1	0.1	0.008	0.1
Vertical emittance ε_y (nm-rad)	0.1	0.015	0.1	0.1	0.008	0.1
Rms bunch length σ_t (ps)	3.0	3.0	0.1	2.0	2.0	0.02
Energy spread σ_E/E	0.0004	0.0004	0.0027	0.0002	0.0002	0.0027
Undulator length L (m)	25	25	4.1	25	25	4.1
Number of periods N_u	1470	1470	240	1470	1470	240
Deflection parameter K	1.34	1.34	1.34	1.34	1.34	1.34
Fundamental energy E_1 (keV)	8.27	8.27	8.27	8.27	8.27	8.27
Average flux F_n (p/s/0.1%)	5.11E+15	5.31E+14	7.65E+12	1.76E+16	2.20E+15	7.65E+13
Average brilliance B_n (std units)	9.08E+21	1.86E+22	1.10E+19	3.13E+22	1.40E+23	1.10E+20
Peak flux F_p (p/s/0.1%)	4.91E+17	5.10E+16	2.86E+19	2.54E+18	3.16E+17	1.43E+20
Peak brilliance B_p (std units)	8.72E+23	1.78E+24	4.10E+25	4.51E+24	2.02E+25	2.05E+26
Photons per pulse n_p (p/0.1%)	3.93E+06	4.09E+05	7.65E+06	1.36E+07	1.69E+06	7.65E+06
Coherent flux F_c (p/s/0.1%)	5.10E+13	1.04E+14	6.15E+10	1.76E+14	8.20E+14	6.15E+11
Peak coherent flux F_{cp} (p/s/0.1%)	4.90E+15	1.00E+16	2.30E+17	2.53E+16	1.13E+17	1.15E+18
Coherent flux fraction p_c (%)	1.0	19.6	0.8	1.0	37.3	0.8
Photons per coherent volume δ_D	2	5	115	13	57	576
Total undulator output power P_0 (W)	31,679	3,291	51.7	63,358	7,899	517
On-axis power density @20m dP/dA (W/mm^2)	2,655	276	4.3	5,311	662	43
Peak coh. electric field @ exit E_c (V/m)	1.42E+06	4.56E+05	5.71E+04	2.00E+06	7.07E+05	1.81E+05

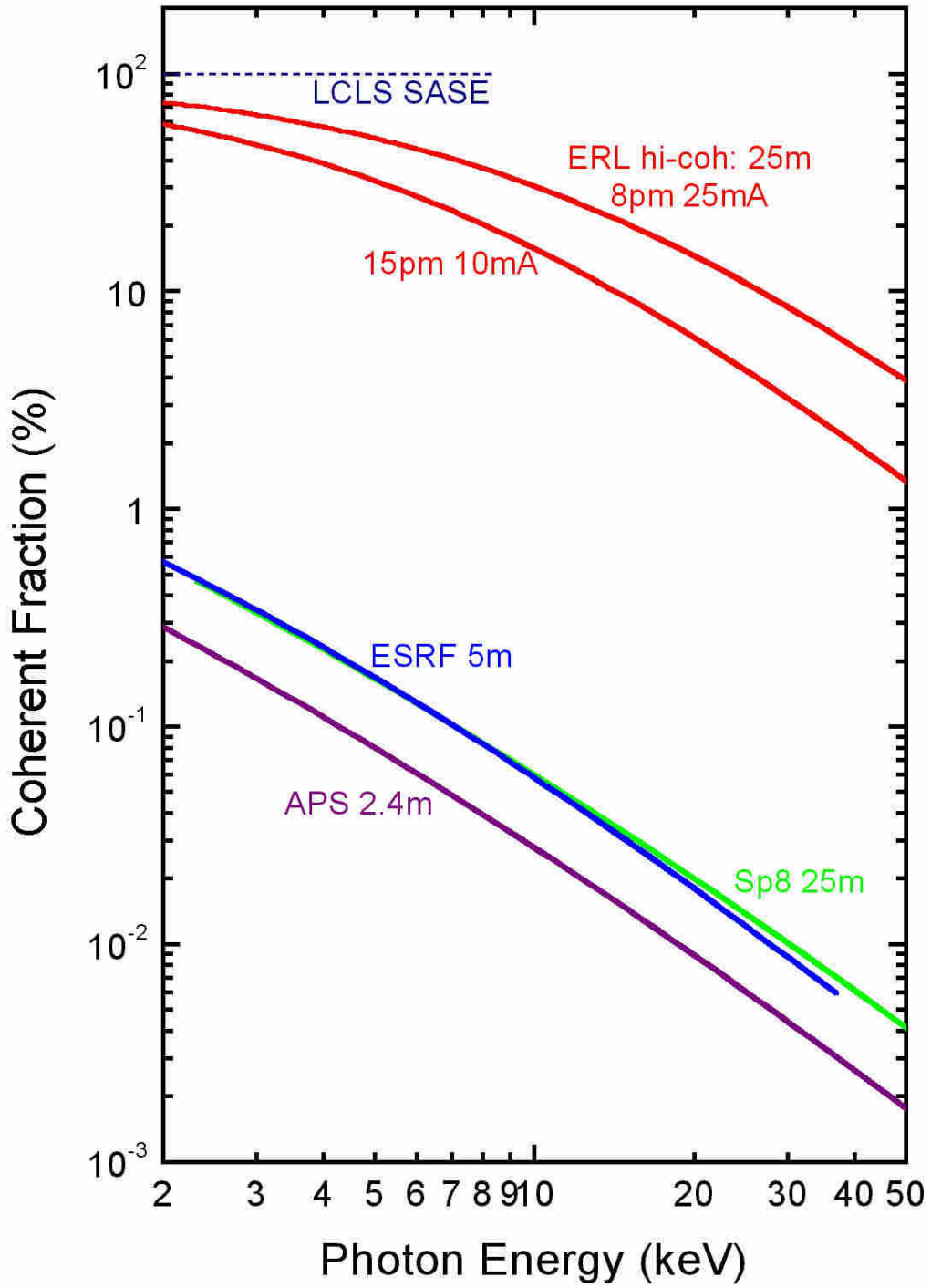
In the following pages, several figures are shown for the purpose of comparing ERL performance with existing and some of the proposed synchrotron x-ray sources. The number for other sources are based mostly on a CHESS Technical Memo 01-002 by Qun Shen (http://erl.chess.cornell.edu/papers/ERL_CHESS_memo_01_002.pdf), with recent updates obtained from APS, ESRF, and SPring-8 websites.

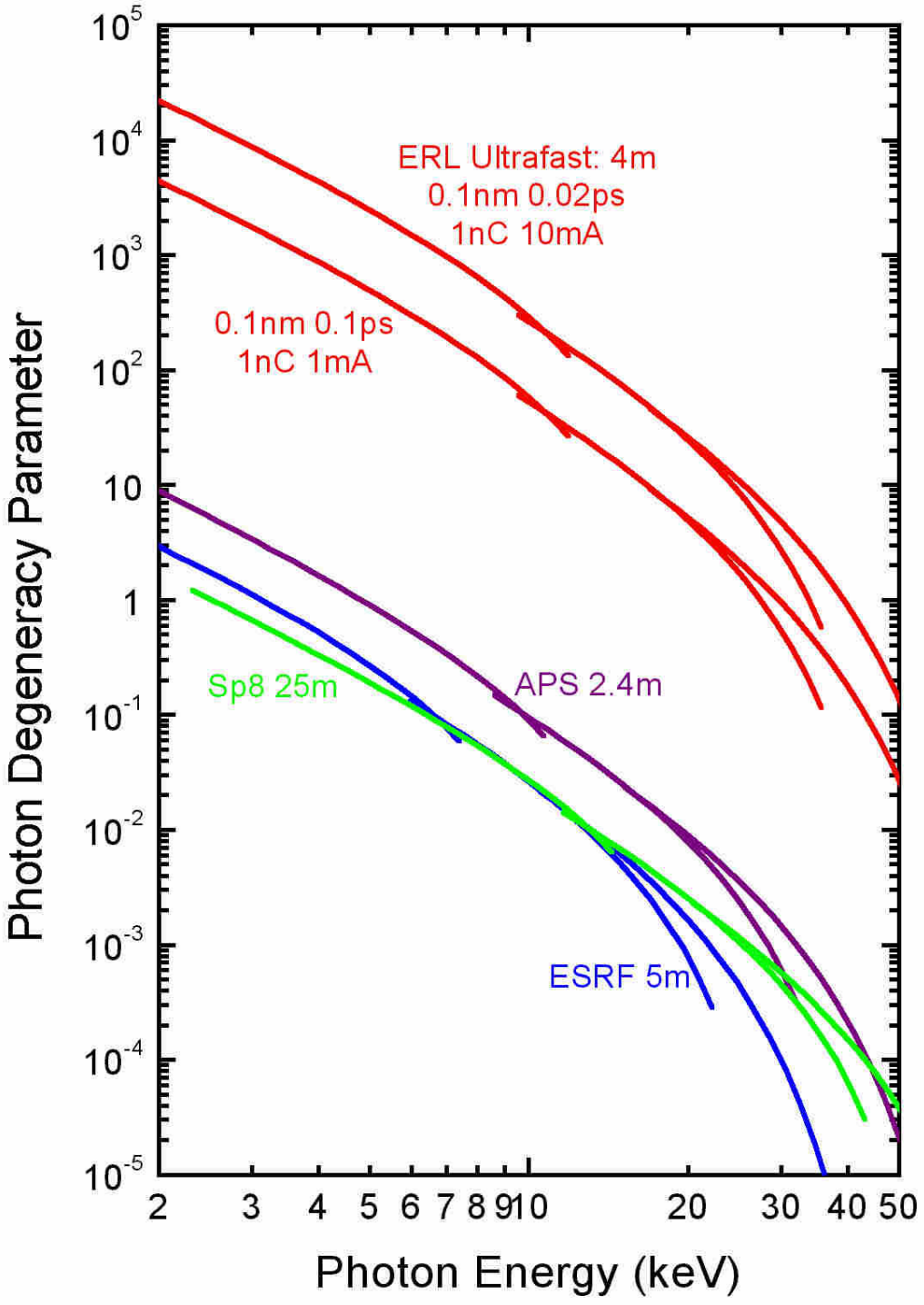

ERL hi-coh: 25m
8pm 25mA
LCLS
15pm 10mA
Sp8 25m
ESRF 5m
APS 2.4m
LCLS spont
CHESS 49p wiggler
CHESS 24p wiggler
Average Brilliance (ph/s/0.1%bw/mm²/mr²)
Photon Energy (keV)
10
100

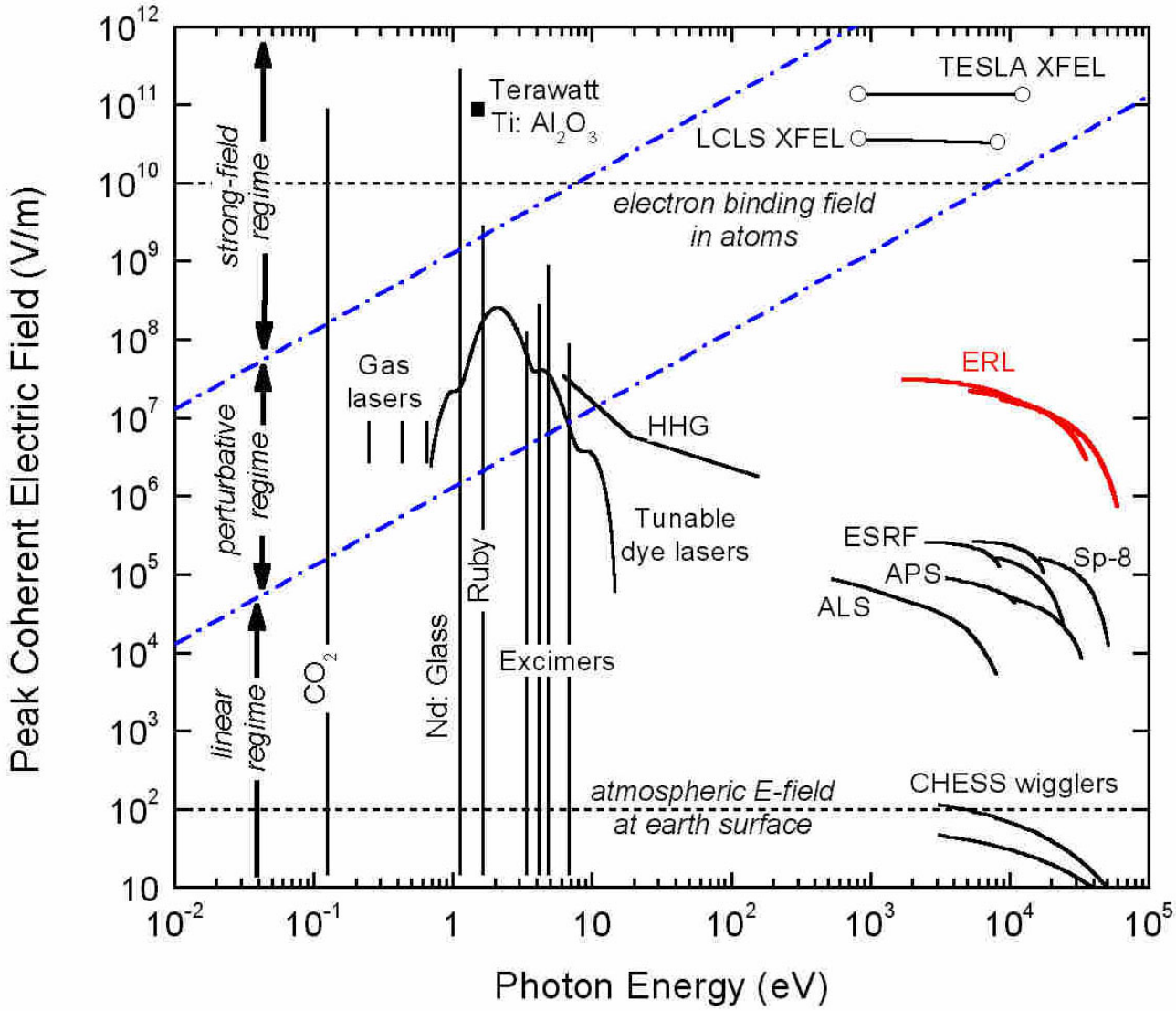

ERL Ultrafast: 4m
0.1nm 0.02ps 1nC
0.1nm 0.1ps 1nC
APS 2.4m
Sp8 25m
ESRF 5m
CHESS 49p wiggler
CHESS 24p wiggler
Peak Brilliance (ph/s/0.1%bw/mm²/mr²)
Photon Energy (keV)
10
100

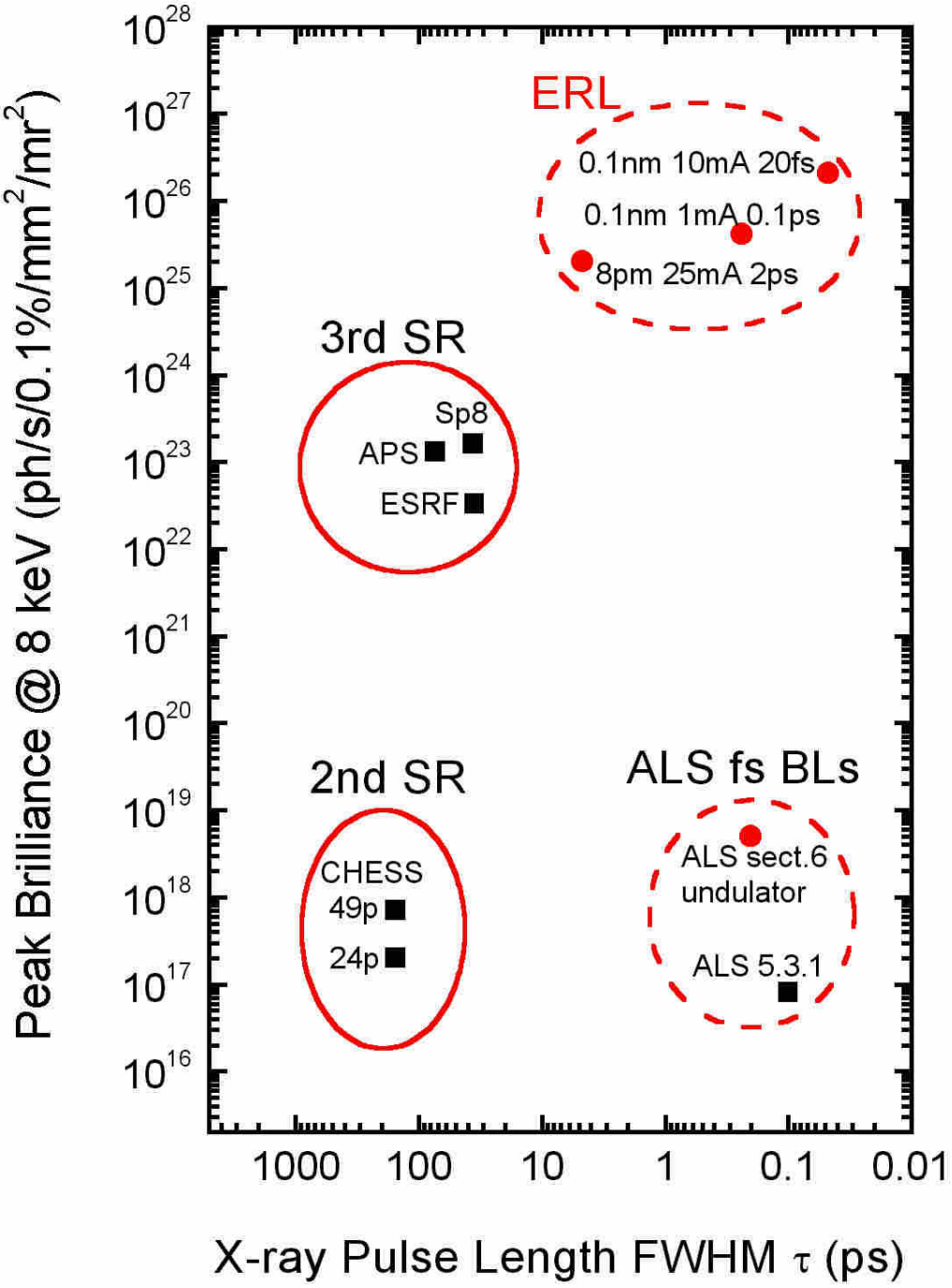

ERL Hi-Flux:
25m 200mA
100mA
ERL Hi-Coh:
25m 25mA
ESRF 5m
200mA
Sp8 25m
100mA
CHESS 49p 300mA
APS 2.4m
100mA
LCLS SASE
0.07mA
Average Flux (photons/sec/0.1%)
10^{16}
10^{15}
10^{14}
2
3
4
5
6
7
8
9
10
20
30
40
50
Photon Energy (keV)

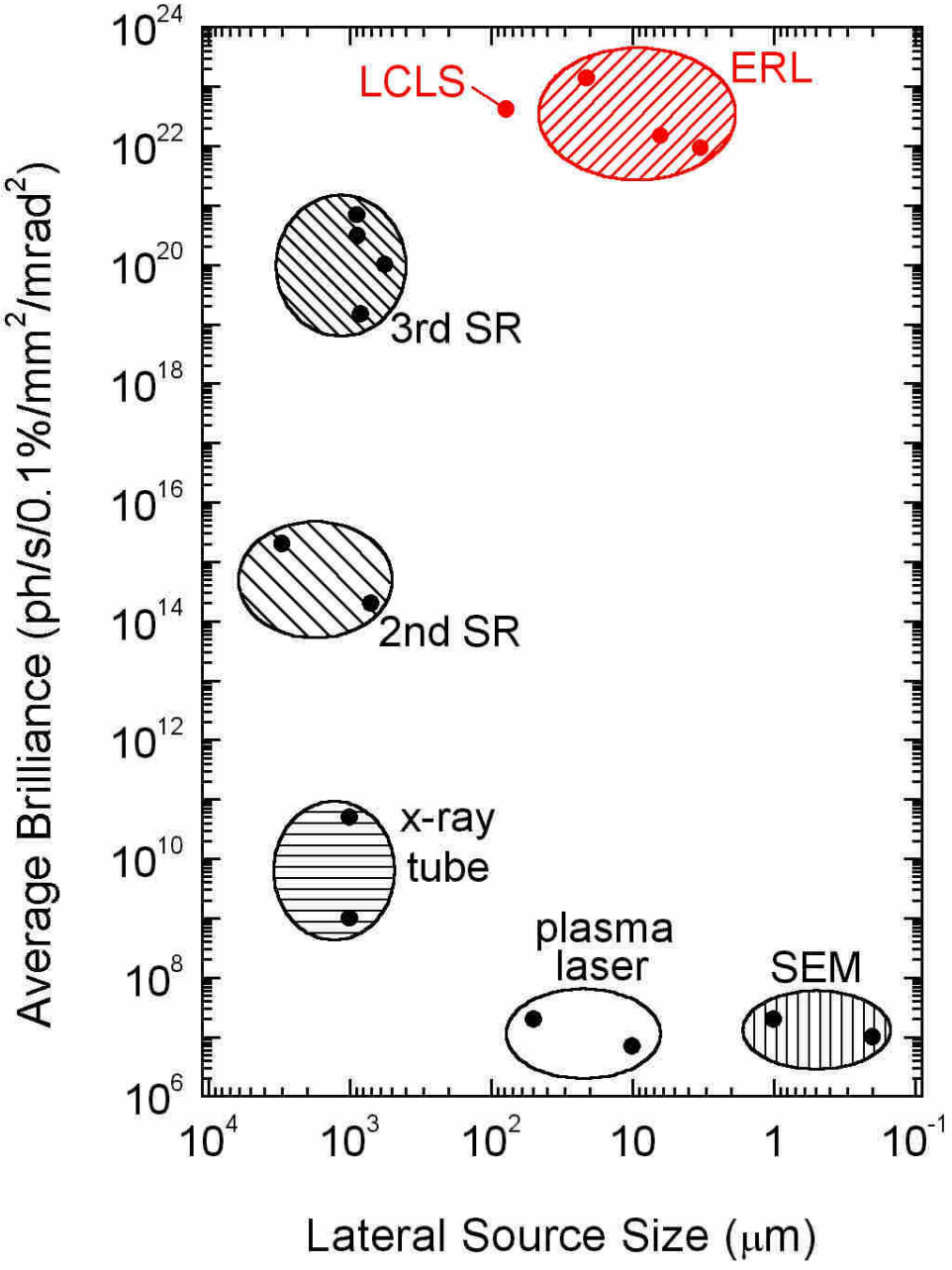

Coherent Flux (ph/s/0.1%bw)
Photon Energy (keV)
LCLS SASE
ERL hi-coh: 25m
8pm 25mA
15pm 10mA
ESRF 5m
Sp8 25m
APS 2.4m

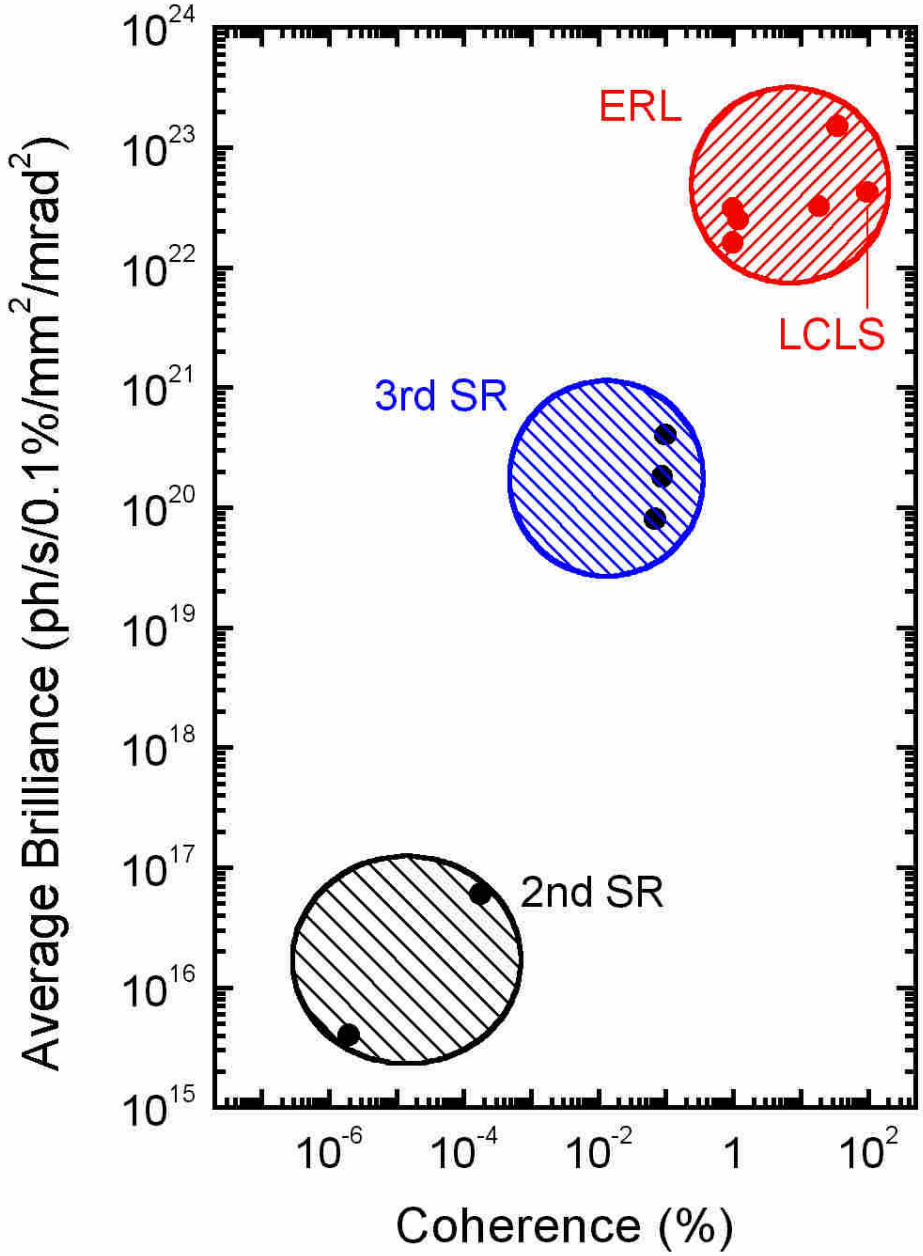

LCLS SASE
ERL hi-coh: 25m
8pm 25mA
15pm 10mA
ESRF 5m
APS 2.4m
Sp8 25m
Coherent Fraction (%)
Photon Energy (keV)
10^2
10
1
10^-1
10^-2
10^-3
2
3
4
5
6
7
8
9
10
20
30
40
50


ERL Ultrafast: 4m
0.1nm 0.02ps
1nC 10mA
0.1nm 0.1ps
1nC 1mA
APS 2.4m
Sp8 25m
ESRF 5m
Photon Degeneracy Parameter
Photon Energy (keV)
10^5
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
2 3 4 5 6 7 8 9 10 20 30 40 50


Peak Coherent Electric Field (V/m)
Photon Energy (eV)
strong-field regime
perturbative regime
linear regime
Terawatt
Ti: Al2O3
TESLA XFEL
LCLS XFEL
electron binding field in atoms
Gas lasers
HHG
ERL
Tunable dye lasers
ESRF
APS
ALS
Sp-8
CO2
Nd: Glass
Ruby
Excimers
atmospheric E-field at earth surface
CHESS wigglers


ERL
0.1nm 10mA 20fs
0.1nm 1mA 0.1ps
8pm 25mA 2ps
3rd SR
Sp8
APS
ESRF
2nd SR
CHESS
49p
24p
ALS fs BLs
ALS sect.6
undulator
ALS 5.3.1
Peak Brilliance @ 8 keV (ph/s/0.1%/mm²/mr²)
X-ray Pulse Length FWHM τ (ps)
10^28
10^27
10^26
10^25
10^24
10^23
10^22
10^21
10^20
10^19
10^18
10^17
10^16
1000
100
10
1
0.1
0.01


LCLS
ERL
3rd SR
2nd SR
x-ray
tube
plasma
laser
SEM
Average Brilliance (ph/s/0.1%/mm²/mrad²)
Lateral Source Size (μm)
10^24
10^22
10^20
10^18
10^16
10^14
10^12
10^10
10^8
10^6
10^4
10^3
10^2
10
1
10^-1


ERL
LCLS
3rd SR
2nd SR
Average Brilliance (ph/s/0.1%/mm²/mrad²)
Coherence (%)
10^24
10^23
10^22
10^21
10^20
10^19
10^18
10^17
10^16
10^15
10^-6
10^-4
10^-2
1
10^2