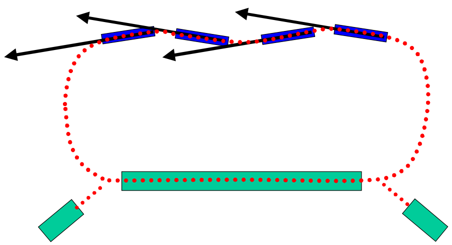

Energy Recovery Linac X-ray Opportunities

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Exciting Science! What ERL Parameters Needed?

Adjustable Parameters (Though not all independently adjustable parameters!)

Machine current: 1 to 100 mA
Gun emittance: 0.2 to 2 microns at 0 to 100 mA (scaled from Jlab experience)
Full transverse coherence when emittance < $\lambda/4\pi$, i.e., 0.01 nm-rad for 8 keV (1.5 Å)
Bunch length: 100 fs to 10 psec
Bunch rep rate: 1 MHz to 1.3 GHz
Inside undulators:
a) Electron beam size: 3 to 40 μm sigma (x or y)   Electron beam shape: Flat or round
b) X-ray beam divergence: 3 to 10 microradians

Assuming

Machine energy: 5 to 7 GeV, energy spread < 0.1%
Beam lifetime: continuous injection
ID gaps: > 2 mm
Undulator lengths: ≤ 25m
Bend magnet critical energy: 10 – 20 keV

Short period, small gap undulators

Undulator brilliance ~ N^x for $1 < x < 2$

Undulator flux ~ N, # of periods

$\lambda(A) = 13.056 * \lambda_u(cm) * (1 + K^2)/E^2$ (GeV)

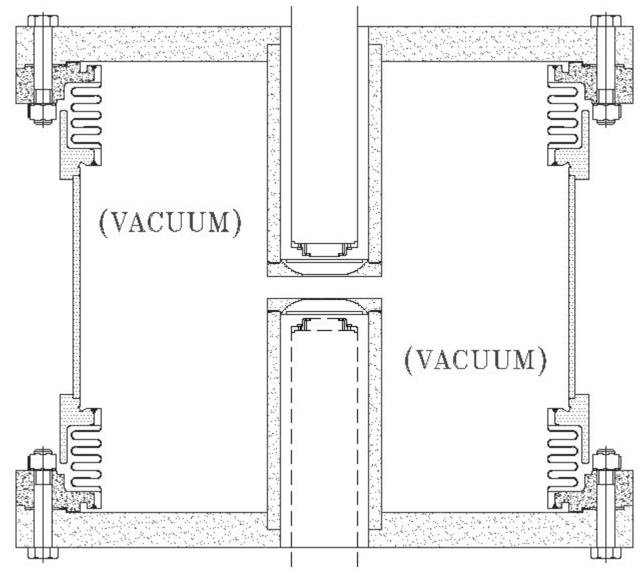
K = deflection parameter, E = machine energy

Spectral bandwidth $\Delta\lambda/\lambda = 1/(nN)$

For λ = 1.5 Angstrom, K=1, n=1, L=25 m undulator

for E=7 Gev, λ_u(cm) = 3.75 cm, N = 667 periods

for E=3.5 Gev, λ_u(cm) = 0.93 cm, 2668 periods

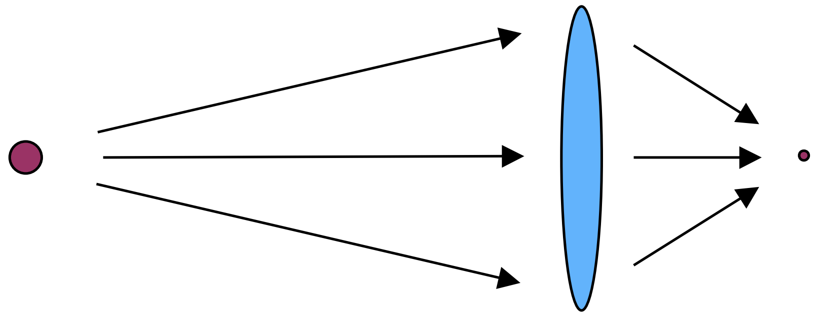


Stefan et.al. BNL/Spring-8
Prototype small gap und.
3.3 mm gap, 1.1 cm period

for comparison, silicon 111 monochromator has $\Delta\lambda/\lambda = 1.4x^{-4}$ or 1 / 7100

Idea: you might be able to run with no monochromator with enough poles

Great Source for Microfocusing & Diffraction

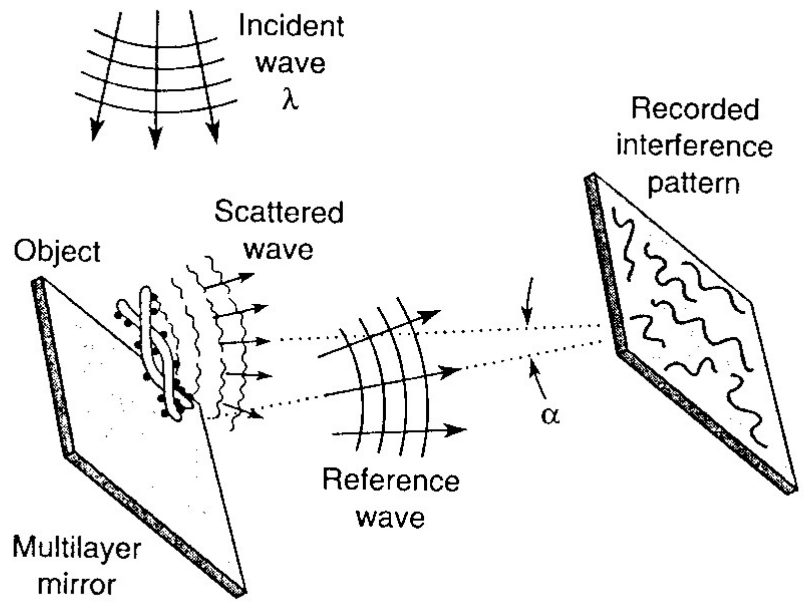


Emittance Mode	Undulator 1 L=2 m, β=1 m		Undulator 2 L=25 m, β=12 m	
	σ_x (μm)	$\sigma_{x'}$ (μrad)	σ_x (μm)	$\sigma_{x'}$ (μrad)
0.15 nm-rad (large)	12	15	42	4.3
0.01 nm-rad (small)	3.2	8.7	12	2.7

Note: σ includes radiative terms

↑ **Demagnify by 100 to 1000 times to reach 3 to 30 nm probe sizes**

Holography and Speckle

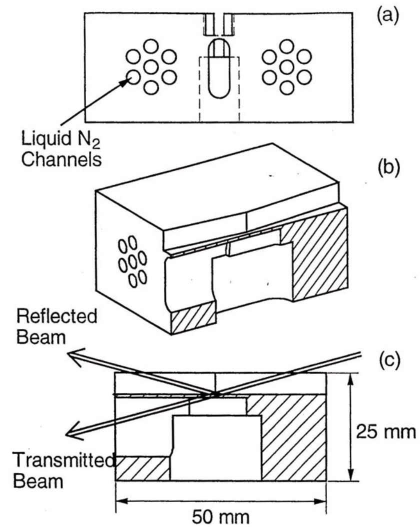


From D. Attwood (1999)

Emittance Mode	Machine & Undulator	Coherent Below (keV)	FWHM @ 40 m microns	8 keV Coherent flux in x-rays/sec/0.1% bw
0.15 nm-rad (large)	7 GeV, 100 mA, K=1 667 periods of 3.75 cm (L=25m)	0.65	410	2E14 through 290 μm pinhole
0.01 nm-rad (small)	7 GeV, 10 mA, K=1 1470 periods of 1.7 cm (L=25m)	9.5	250	2E15

Conclusion: ERL very good coherent source of x-rays

Heat load on x-ray optics & front end



Rogers and Mills APS crogenically cooled Si mono.

Power (kW)=0.633*(7 GeV)**2 * (.29 T) **2 * (25 m) * (.1 A) = 6.5 kW

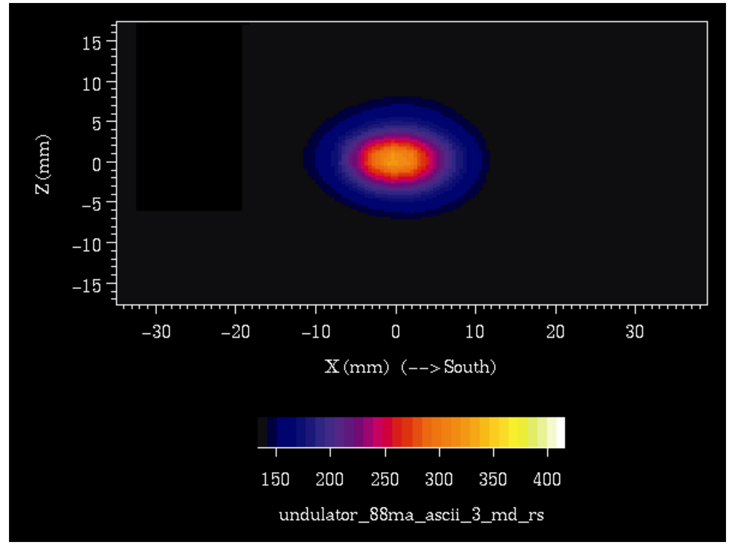
for K=1, 3.75 cm period undulator, 667 poles, 25 m long & front end + optics @ 20 m

On-axis power density of ~1200 w/mm^2

This will be require care in engineering front end,

cryogenic silicon or diamond optics, etc.

‘Hot’ Monochromatic Beam



IR camera view of Si monochromator ‘hot spot’ from prior APS/CHESS undulator run

Example from ‘white paper’ for 10 to 20 keV x-rays:

F=1x10^{16} x-rays/sec/0.1% bw for 7 GeV, 100 mA, 1.65 cm period, L=20 m undulator

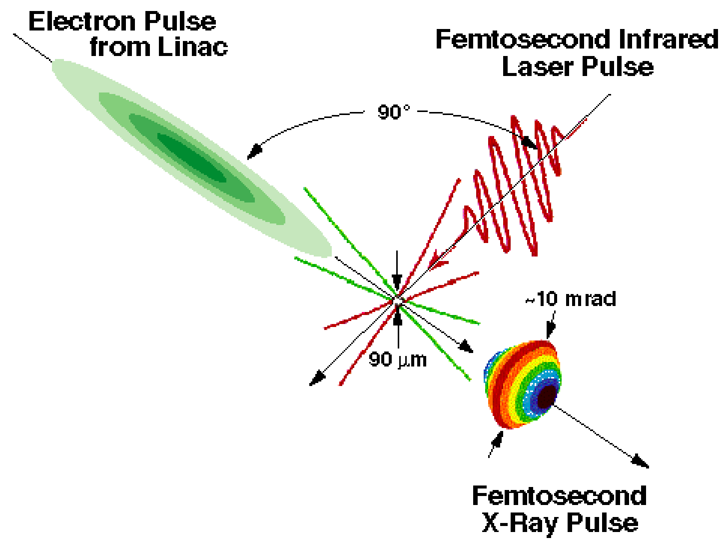
Hence, F(Si 111) ~ 1x10^{15} x-rays/sec ~ 1.6 watts in size of order 400 μm FWHM at 40 meters

F(1% multilayer) ~ 70x Si(111) ~ 7x10^{16} ~ 100 watts

Conclusion: This is a very ‘hot’ monochromatic beam!

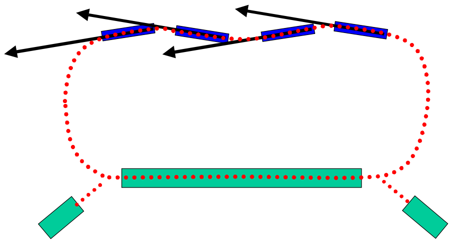
Pump and Probe on 100 fs Time Scale

- Chemical reactions
- Phase Transitions
- Surface Processes
- Atomic vibrational period ~ 100 fs



Conclusion: ERL with 100 fs x-rays will be very well matched for repetitive pump & probe experiments

Schoenlein & Leemans, et.al.
Center for Beam Physics Test Facility
ALS Linac, .4 A x-rays, 300 fs



Very Flexible Operations of ERL

- ERL more flexible than a Storage Ring source of x-rays
- Tradeoff emittance for current
- Adjustable bunch lengths and timing patterns
- Beam lasts as long as you want it
- Tolerates very low gap Insertion Devices
- Can make round or flat beams
- Able to serve a wide variety of x-ray user needs

Conclusion: ERL will be a great machine for experimentation!