Talk given to an ASD general audience in Feb. 1996 as part of a series by APS participants to the 4th generatation light source workshop at ESRF (ICFA 1996, January 21-26).

Diffraction-Limited Storage Ring Source

- **Goal:** Maximize photon beam brightness by reducing electron beam size.
- Diffraction limit is reached for a photon of wavelength λ:

$$\epsilon_{\rm el} < \lambda/4\pi \tag{1}$$

Required beam emittances for diffraction-limited photons.

$E_{\rm ph}$ (kV)	λ (nm)	$\epsilon_{\rm el}$ (nm-rad)
1.0 kV (soft X-ray)	1.2	0.2
10.0 kV (hard X-ray)	0.12	0.02
APS ring at 7 GeV		8.0

A Factor of 400 to go!

Going to Lower Emittances

- Emittance at low current per bunch is determined by two processes:
$$\epsilon = \frac{Q}{D} \tag{2}$$
where Q is the quantum excitation term, D is the damping term. Most efforts has to do with reducing Q.
- Lower the beam energy. ($Q \sim \gamma^2$)
- Make shorter cells. ($Q \sim \phi^3$)
- Have larger circumference. ($Q \sim \phi^3$)
- Modify cell structure for lower Q. (i.e. combination of TME cells and DBA cells)

Problems

- Lower Touchek lifetime, because of denser beam. Becomes irrelevant with top-up injection.
- Intra-beam scattering spoils the emittance at high current per bunch because:

$$\epsilon = \frac{Q + IBS(\epsilon)}{D} \tag{3}$$

$$IBS(\epsilon) \sim \frac{I_{\mathrm{b}}}{\epsilon_x \epsilon_y \sigma_{\Delta p/p} \sigma_z \gamma^4} \tag{4}$$

  - the damping D ($\sim E^3/C\rho$) for low energy and large circumference machines is much less.
- Limit of stable particle motion (dynamic acceptance) is drastically reduced because:
  - the chromaticity sextupoles need to be much stronger because of:
    * stronger focusing (to reduce terms in Q) increases chromaticity, and
    * lower dispersion (to reduce terms in Q) decreases chromaticity-correcting effect of sextupoles.
- Need $\sigma_{\Delta p/p} < 10^{-3}$ for preserving the low undulator $\Delta\lambda/\lambda$ of future long wigglers.

Thesis Damping Ring Parameters

Main parameters of ring.

Energy (GeV)	4.0
Circumference (m)	2229.
Emittance at 4 GeV (m-rad)	2.5×10^{-11}
Emittance at 4 GeV (nm-rad)	0.025
Emittance for I=0.3 mA/bunch (m-rad)	5×10^{-11}
Emittance for I=0.3 mA/bunch (nm-rad)	0.05
Horizontal damping time at 4 GeV (msec)	13.5
Horizontal and vertical tunes	61.74/62.84
Number of superperiods	12
Energy loss per turn at 4 GeV (MeV)	4.4
Fractional momentum spread at 4 GeV	9×10^{-4}
Momentum compaction factor α_c	2.9×10^{-4}

Wiggler parameters.

Total length (m)	360.
Number	12
Maximum field for 4 GeV operation (kG)	10.7
Minimum bending radius (m)	12.5
Wiggler period (cm)	12.0
Full gap width (mm)	25.6

Radiation-related quantities for the calculation of equilibrium emittance.

Arc quantum excitation term (m^{-1})	5.6×10^{-7}
Wiggler quantum excitation term (m^{-1})	7.4×10^{-7}
Arc damping term (m^{-1})	3.8×10^{-2}
Wiggler damping term (m^{-1})	1.2×10^{0}
Emittance at 4 GeV (m-rad)	2.5×10^{-11}
Emittance at 4 GeV (nm-rad)	0.025
Emittance without wiggler term at 4 GeV (m-rad)	3.4×10^{-10}
Emittance without wiggler term at 4 GeV (nm-rad)	0.34

Note the ratio of wiggler damping term to arc damping term: 30 !

Damping Wigglers in APS

- As an exercise, put half of above damping wigglers into APS at 4 GeV.
- No change to DBA cells. Expect same dynamic aperture (not including wiggler non-linear fields).
- 30×6 m of wigglers. Ok, so there's practically no room for anything else.
- Emittance at 4 GeV with and without wigglers:

$$\epsilon_0 = 3.8 \times 10^{-13} \gamma^2 \frac{Q_{DBA}}{D_{DBA}} \quad (5)$$

$$\epsilon_W = 3.8 \times 10^{-13} \gamma^2 \frac{Q_{DBA} + Q_W}{D_{DBA} + D_W} \quad (6)$$

Q_{DBA} (m^{-1})	1.7×10^{-6}
Q_W (m^{-1})	2.8×10^{-7}
D_{DBA} (m^{-1})	1.6×10^{-2}
D_W (m^{-1})	5.8×10^{-1}
ϵ_0 (m-rad)	2.6×10^{-9}
ϵ_0 (nm-rad)	2.6
ϵ_W (m-rad)	8.2×10^{-11}
ϵ_W (nm-rad)	0.08

Note the ratio $D_W/D_{DBA} = 35$!

- IBS was not calculated but the strong damping term will help.