Argonne NATIONAL LABORATORY

... for a brighter future

Concepts and performance for a next-generation storage ring hard x-ray source

Michael Borland
Argonne National Laboratory
Advanced Photon Source
Accelerator Systems Division
October 1, 2009

U.S. Department of Energy

THE UNIVERSITY OF CHICAGO

Office of Science
U.S. DEPARTMENT OF ENERGY

Outline

- Introduction
- An Ultimate Storage Ring design
- Operations issues
- Outlook and conclusion

Demonstrated Strengths of Storage Rings[1]

- High brightness and flux
  - >100 mA is typical
  - Low emittance (1~10 nm)
- Highly stable
  - Excellent position and angle stability
  - Top-up mode improves optics stability
- ~98% availability and ~100 hour MTBFs
- Many independent, simultaneous users
- Well developed technology
  - Extensive R&D not required
  - New rings commission very quickly
- Safety issues well understood and controlled
- Other sources don't share all these features

[1] L. Emery, "Overview of SR Upgrade Options," APS MAC Review, 11/15/06.

Can Storage Rings Compete with ERLs?

- Major weakness: difficulty of improving emittance

$$\epsilon_o \sim \frac{E^2}{N_d^3}$$

- Possible approach[1,2,3]
  - Build a “large” ring
  - Multi-bend achromats instead of double-bend[4]
  - Use damping wigglers
- A multi-kilometer ring could be several orders of magnitude better than APS
- Could compete with an ERL, but
  - Much less risk
  - Much less R&D.

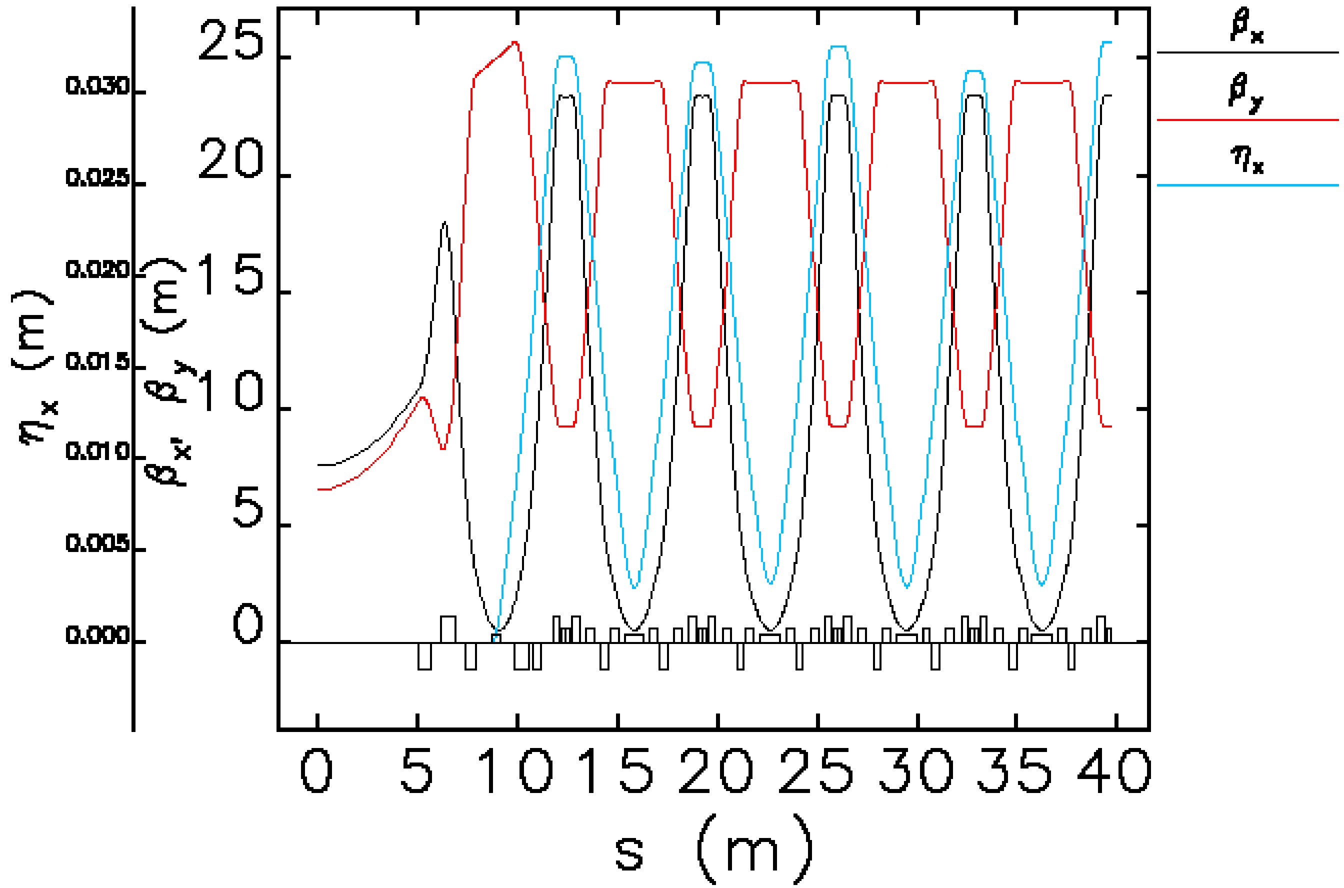
[1]A. Ropert, “Towards the ultimate storage-ring based light source,” EPAC 2000, www.jacow.org.
[2]M. Borland, “A super-bright storage ring alternative to an energy recovery linac,” NIM A 557 (2006) 230-235.
[3]K. Tsumaki and N. Kumagai, “Very low emittance light source storage ring,” NIM A 565 (2006), p. 394
[4]D. Einfeld *et al.*, “A Lattice Design to Reach the Theoretical Minimum Emittance for a Storage Ring,” EPAC 96, www.jacow.org.

USR7: A 7-GeV Ultimate Storage Ring

- MBA-based with 10 dipoles per sector
- 40 sectors
- 8 m insertion devices
- 30 pm natural emittance

Quantity	Value	Unit
Energy	7	GeV
Circumference	3.16	km
Natural emittance	0.030	nm
Energy spread	0.079	%
Maximum ID length	8	m
Number of dipoles	10	per sector
Horizontal/vertical tune	183.1/36.1	
Horizontal/vertical chromaticity	-495/-166	
Energy loss	3.6	MeV/turn
Beta functions (x/y) at ID	7.58/6.56	m

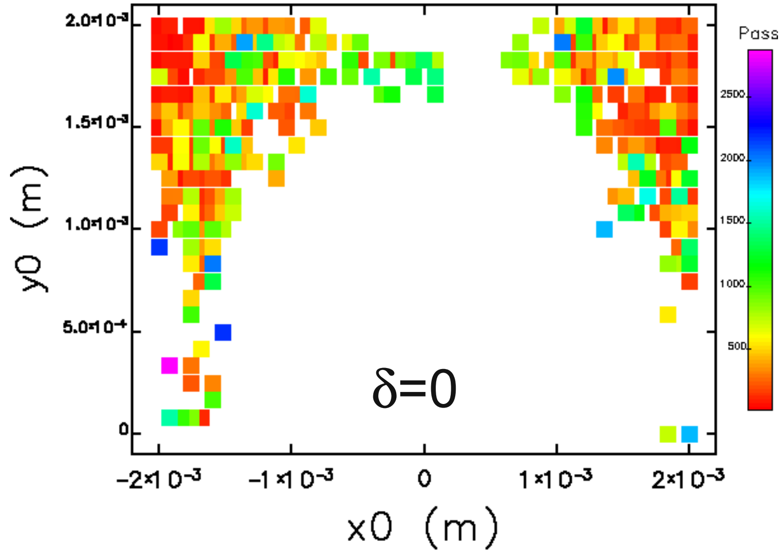
Lattice Functions (half sector)

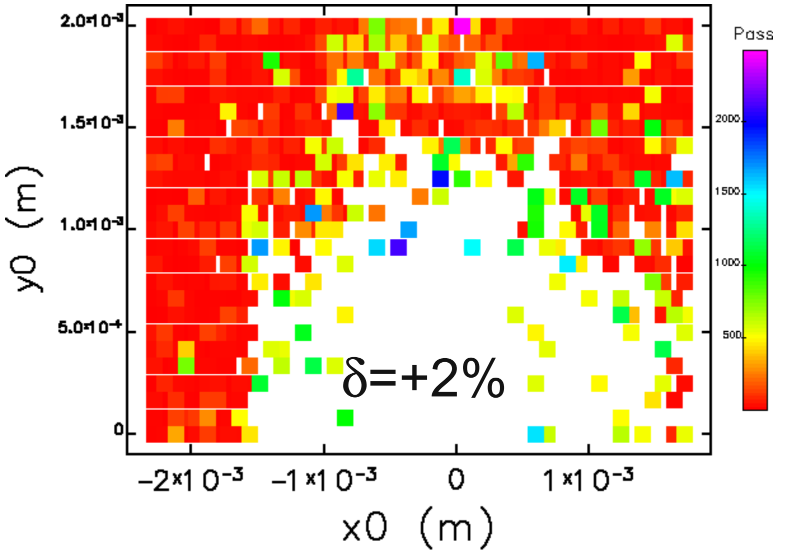


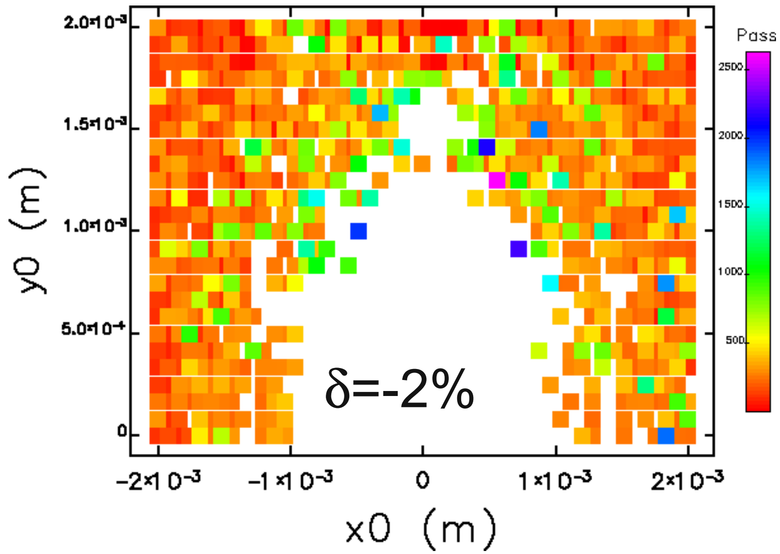
- Uses conventional magnets with workable strengths assuming reasonable 20mm bore radius

Lattice designed with **elegant** (M. Borland, *et al.*)

Dynamic Aperture with Errors



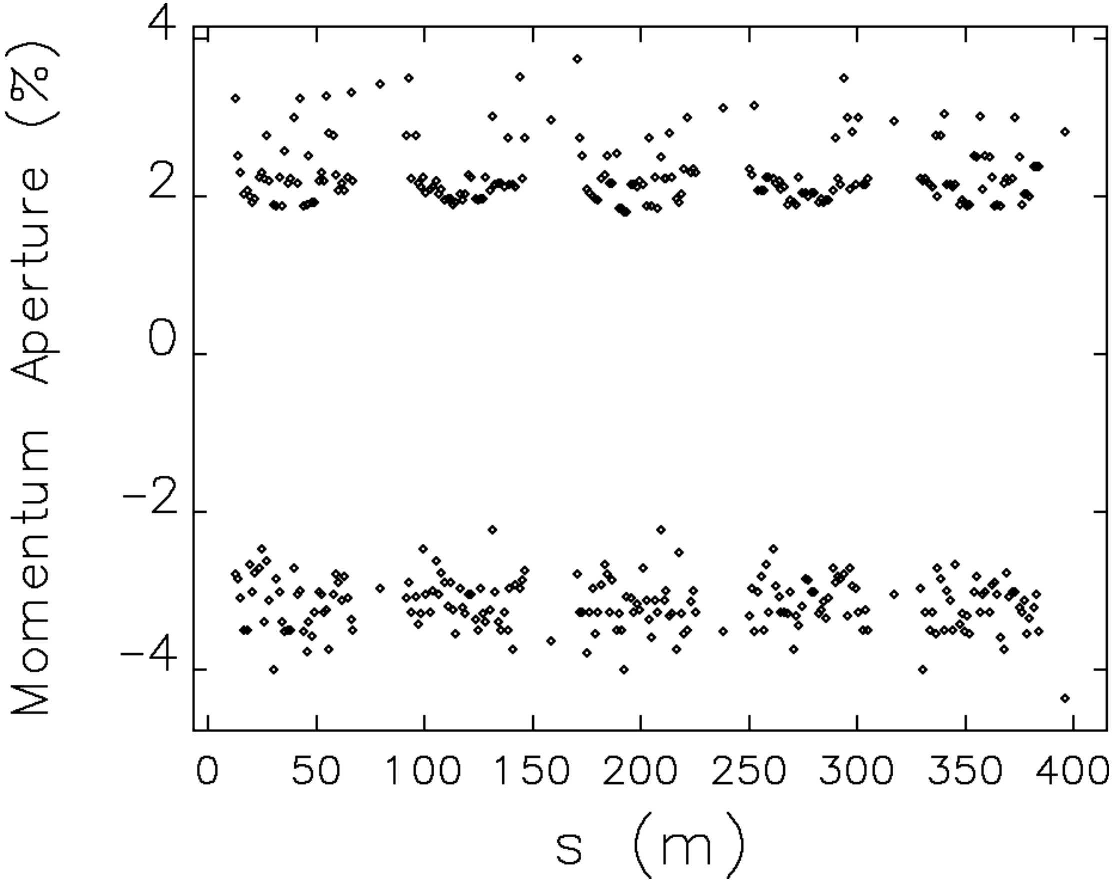




- Nonlinear elements tuned using genetic optimization technique
- 4000-turn tracking with damping and synchrotron oscillations
- Dynamic aperture is small, but very large compared to ~10 μm rms beam size

Modeled with **elegant** (M. Borland, *et al.*)

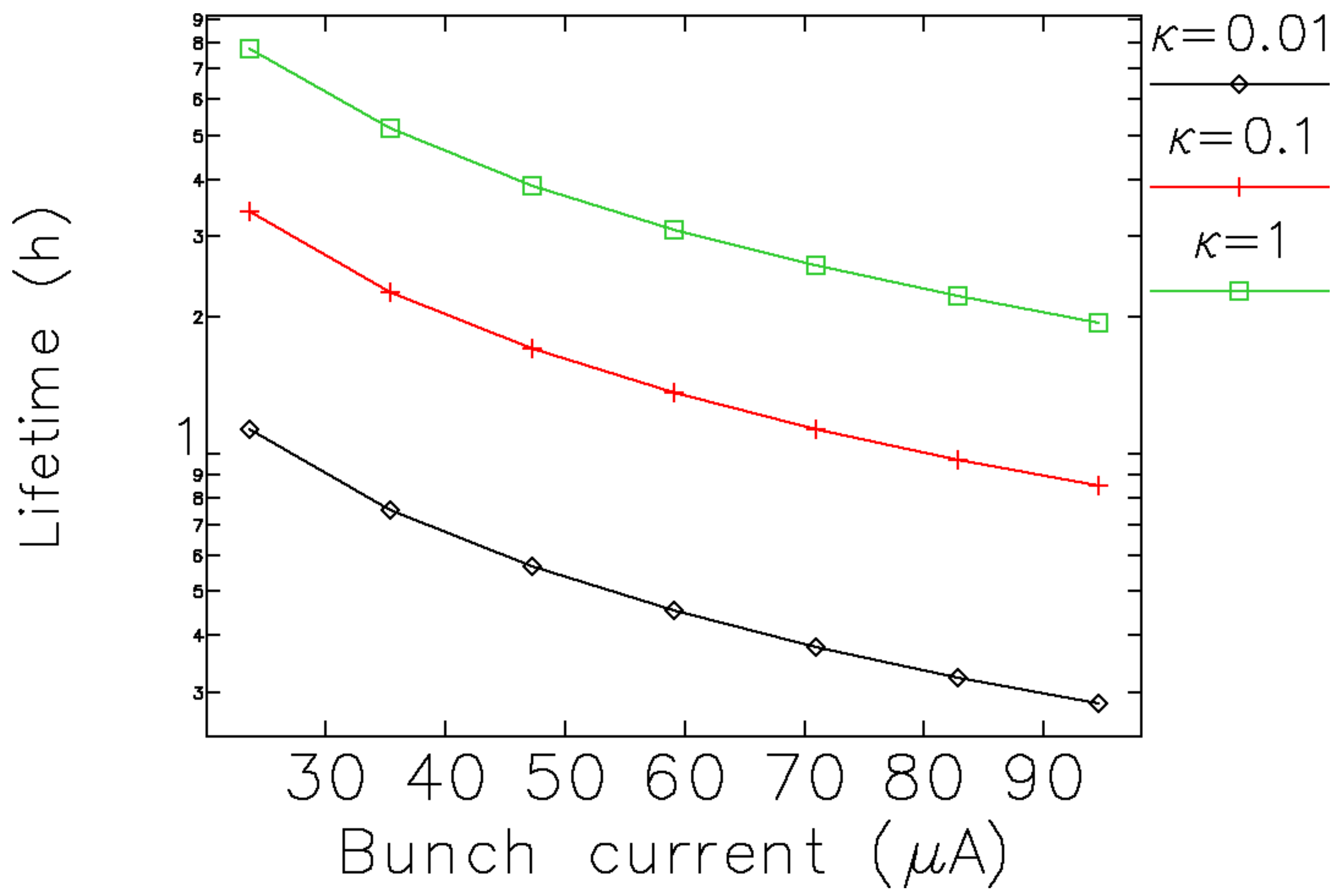
Momentum Aperture with Errors



- Large momentum aperture is important for Touschek lifetime
- We computed momentum aperture at exit of sextupoles for first five sectors

Modeled with **elegant** (M. Borland, *et al.*)

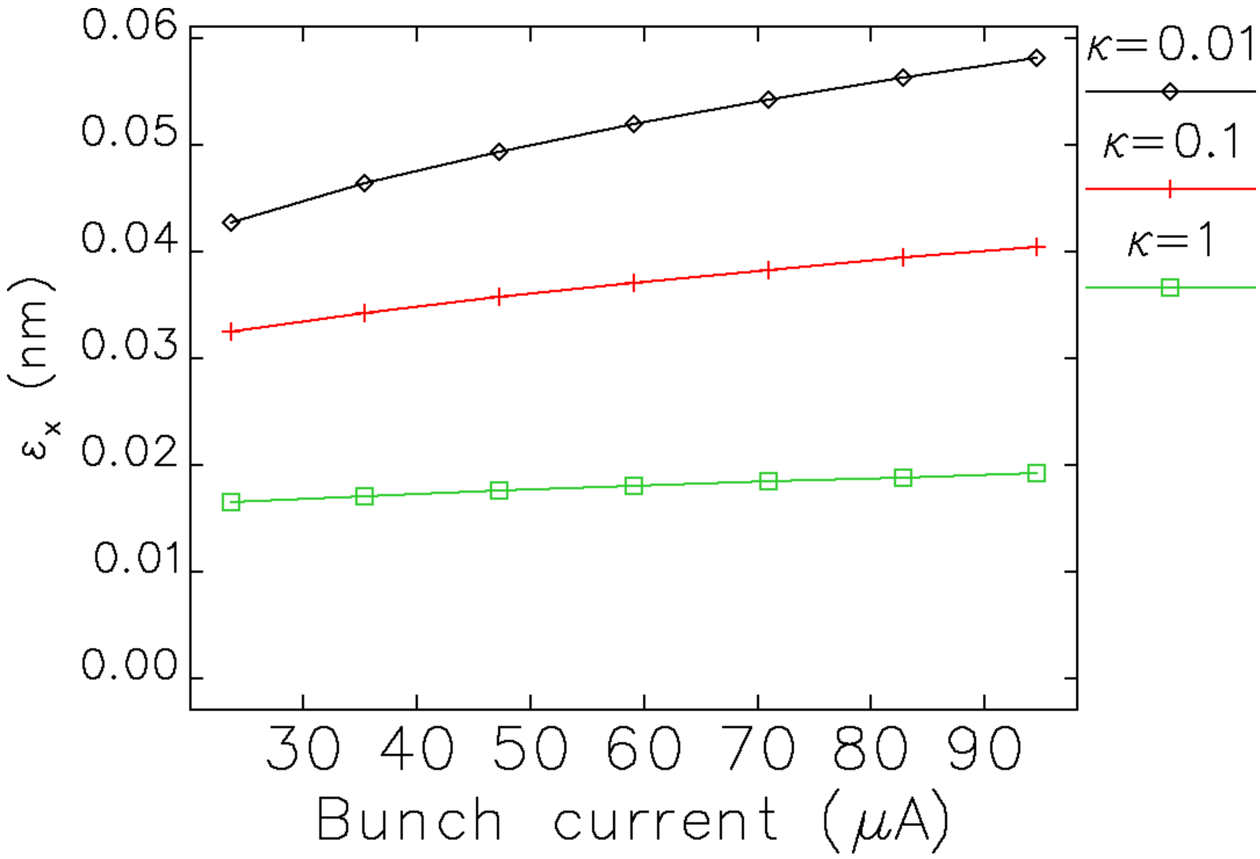
Touschek Lifetime Predictions



- Lifetime is a workable 4 hours for 50 µA/bunch and full coupling ($\epsilon_y = \epsilon_x$)

Computed with **touschekLifetime** (A. Xiao).

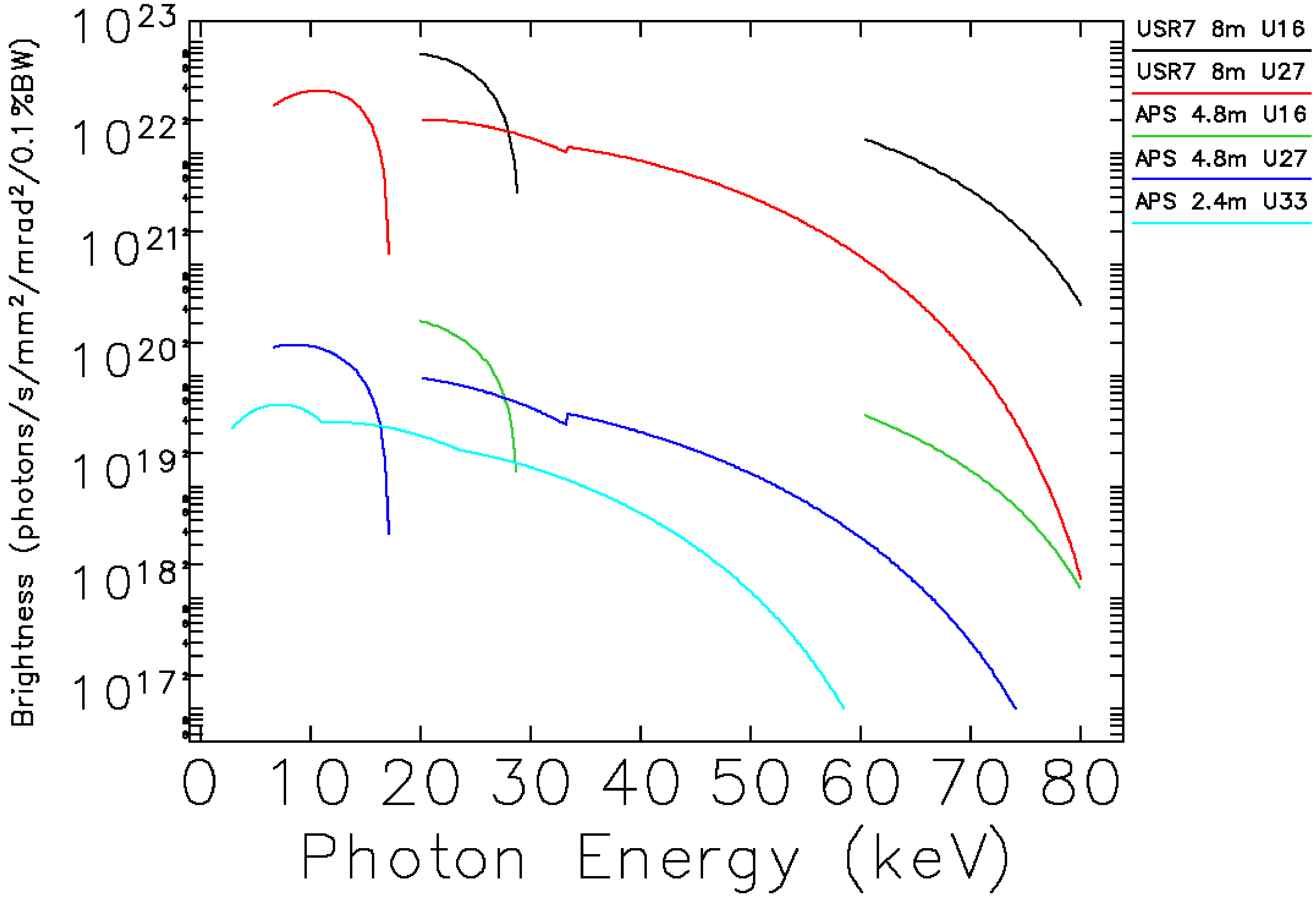
Intrabeam Scattering Impacts Emittance



- IBS effects greatly reduced for full coupling and low current/bunch
- For 200 mA, need 4000 bunches at 50 μA/bunch

Computed with **ibsEmittance** (L. Emery, A. Xiao, M. Borland)

Brightness Predictions Compared to APS



Computed with **sddsbrightness** (H. Shang, R. Dejus, M. Borland).

Can We Operate with Full Coupling?[1,2]

- Present-day rings all use accumulation
  - Requires large dynamic aperture (off-axis injection)
  - Prevents working on coupling resonance
  - Charge is added via repeated injections into each bucket
  - Top up replenishes the charge when it decays
- Need to abandon accumulation in favor of “swap-out”
  - Inject on-axis
  - Kick out depleted bunch or bunch train
  - Simultaneously kick in fresh bunch or bunch train
- Many benefits
  - Can tune for very low emittance
  - Provide round beams
  - Reduce intrabeam scattering and improve lifetime

[1] M. Borland, “Can APS Compete with the Next Generation?”, APS Strategic Retreat, May 2002.
[2] M. Borland, L. Emery,”Possible Long-term Improvements to the APS,” Proc. PAC 2003, 256-258 (2003).

Bunch Pattern and Fill Rate

- If we inject bunch trains, the fractional droop in intensity among trains is

$$D \approx \Delta T_{inj} N_{trains} \frac{1}{\tau}$$

- The required injector current is

$$I_{inj} \approx \frac{I_{ring} L_{ring}}{c \tau D}$$

- We probably want D<0.1
- For 4000-bunch beam, 20 bunches per train, and 4 hour lifetime
  - Replace a bunch train every 7.2 s
  - 1.5 nA average current from the injector (APS injector: 4 nA)
  - Each train has 11 nC (APS injector: 3 nC/bunch)
- Shorter lifetimes should be acceptable

Radiation Issues (For Example Parameters)

- We worry about radiation from two sources
  - Extracted beam
  - Losses in the ring
- The beam dump power is only ~20W for a 7 GeV beam
- The losses in the ring are ~1 W
  - In APS today, have 0.1 W
  - Can design a collimation system to intercept these losses

Outlook for Further Improvement

- Increase the beam current above 200 mA
  - Lifetime will drop as we can't easily have more bunches
  - Emittance will increase for same reason
  - Beamlines/front-ends may not be feasible
  - Need to evaluate beam instabilities
- Add damping wigglers
  - ~30% reduction in emittance from 10 DWs
- Decrease the beam energy
  - Only slight improvement at ~6 GeV
- Ring DA is ~20x larger than needed
  - Push lattice harder to get lower emittance
  - Adding geometric sextupoles will also help

Conclusion

- We've developed an ultimate storage ring design with ultra-low emittance
  - 7 GeV
  - 40-sector MBA lattice
  - 16 pm emittance in both planes
- Dynamic aperture and lifetime are workable
- Swap-out injection is key
  - Injector requirements not difficult
- Ultimate ring is very competitive with ERL
  - Modest risk and R&D
- May be possible to further increase brightness

Acknowledgements

- We appreciate valuable discussions with
  - Louis Emery (ANL)
  - Vadim Sajaev (ANL)
  - Aimin Xiao (ANL)