Argonne NATIONAL LABORATORY

Possible Accelerator Upgrades

Michael Borland
Accelerator Systems Division
Advanced Photon Source
August 10, 2006

THE UNIVERSITY OF CHICAGO
Office of Science U.S. DEPARTMENT OF ENERGY
A U.S. Department of Energy laboratory managed by The University of Chicago

Boundary Conditions

- Use existing storage ring tunnel
- All beamlines (sectors 1~35) will be preserved
  - Can continue operation with no change in performance if so desired
  - Bending magnet beamlines (sectors 1~35) may require realignment
- 7 GeV is target, 6 GeV is minimum energy
- Existing beam stability will be maintained
- Existing bunch patterns will be maintained
  - E.g., 24 bunch, 1296, hybrid mode
- Single bunch current limit will be maintained
  - E.g., 16 mA in hybrid mode.

Goal for the Upgrade

- Provide upgraded experimental capabilities on multiple fronts
  - Support for time-resolved studies requiring picosecond pulses
  - Improved transverse coherence
    - *E.g., coherent diffraction studies*
  - Improved imaging
    - *E.g., phase-contrast imaging*
  - Significantly longer straight sections, e.g.,
    - *Fast polarization switching*
    - *More canted devices*
  - Improved beam stability to match emittance reductions.

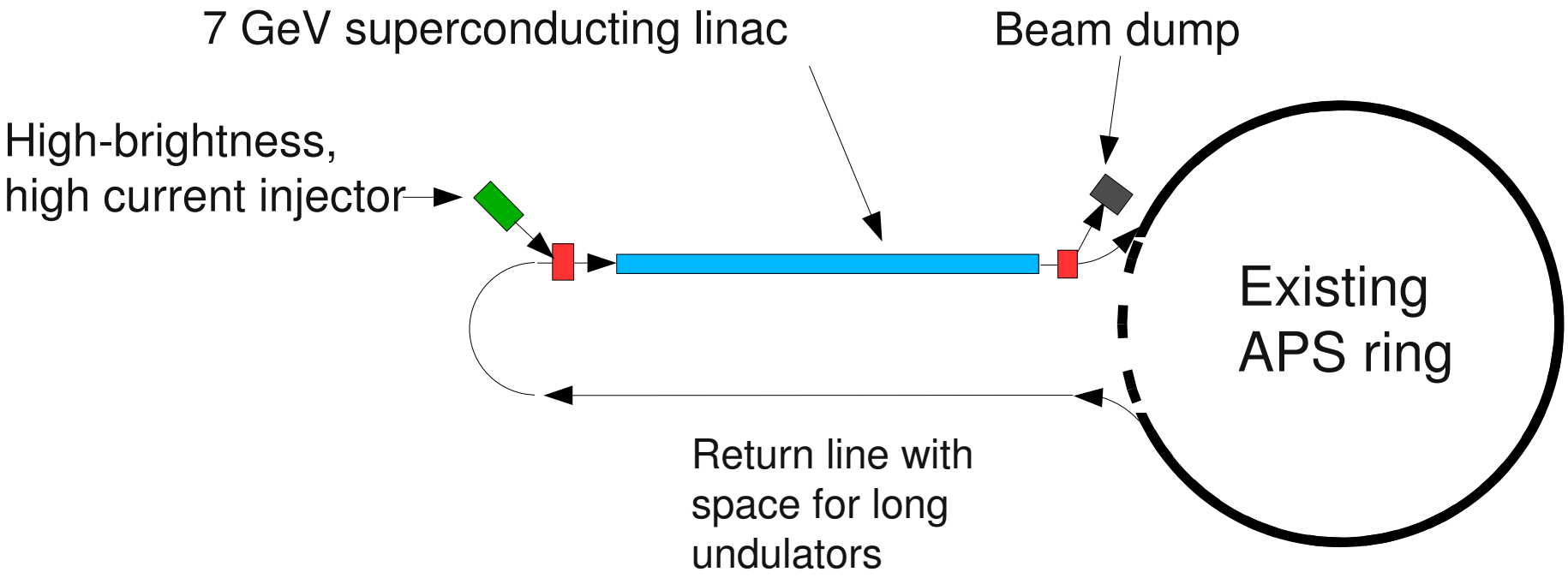
Basic Concepts for an Upgrade

- Storage ring upgrade:
  - Replace the existing storage ring
  - Upgrade the injector as needed
- Linac-based upgrade:
  - Add a 7 GeV Energy Recovery Linac[1] (“ERL”) injector
  - Existing ring is unchanged and serves as one recirculation arc.

[1]M. Tigner, *Nuovo Cimento* **37**, 1965.

Energy Recovery Linac Concept for APS

Linac provides continuous beam to the ring. Beam is never stored.



Lots of details (physics and civil eng.) ignored here!

ERL vs. Storage Ring in a Nutshell

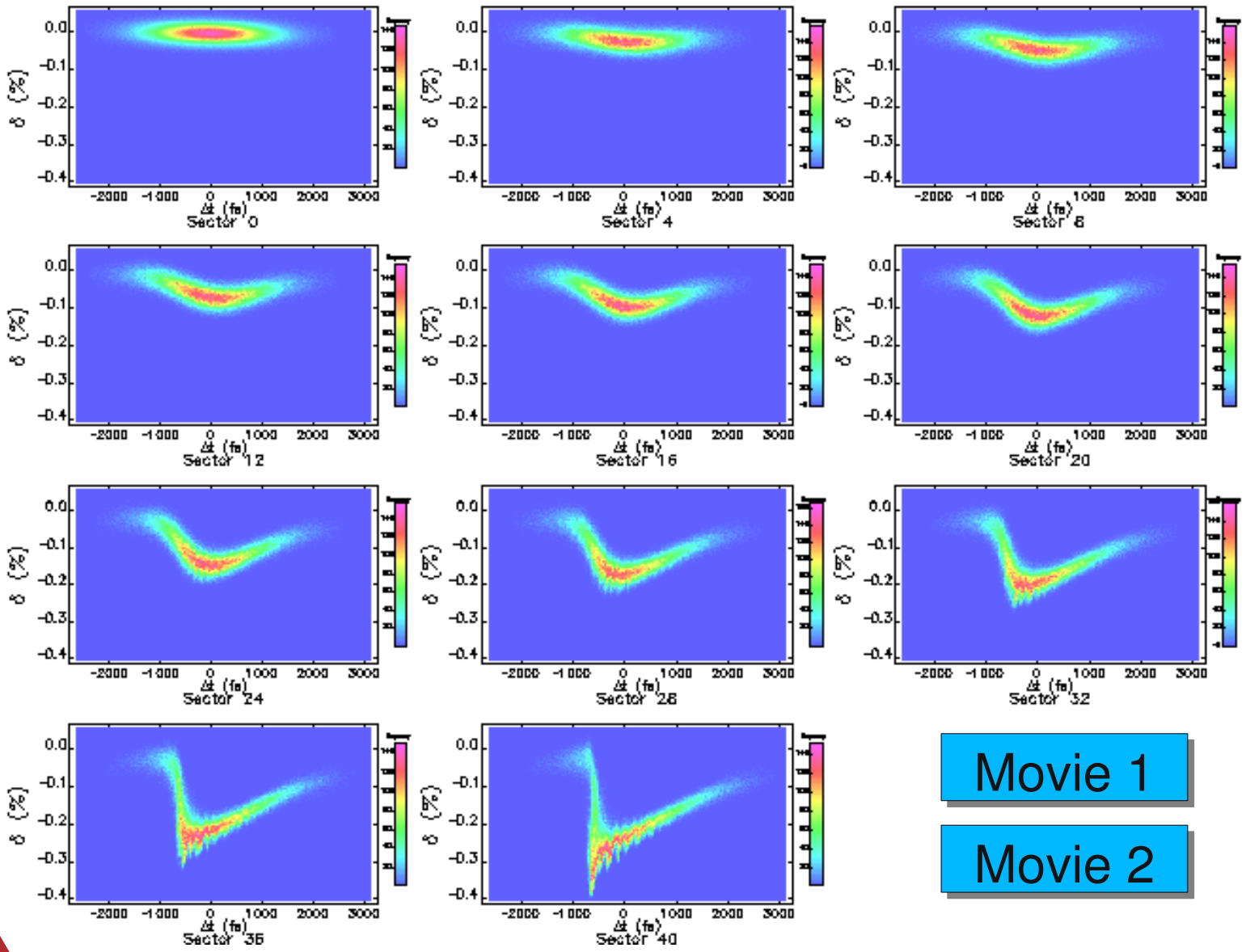
- Storage rings have difficulty providing
  - Short electron bunches (e.g., <10 ps)
  - Ultra low emittance (e.g., < 2nm)
  - Sector-by-sector beam customization
- All are easier for linacs, but serious challenges emerge
  - High average current
    - *Cathode lifetime*
    - *High beam power (100mA*7GeV = 700 MW)*
  - Production and preservation of ultralow emittances
  - High cost, including conventional construction.

ERL Ultrafast Mode

- Cornell ERL group[1] lists the following parameters for "ultra-fast" operating mode:
  - 0.35 nm emittance in both planes (at 7 GeV)
  - 1 mA average current
    - *1 nC per bunch at 1 MHz*
  - Very short bunch length: 50 fs rms
  - Energy spread of 0.3% rms
- Can these values be delivered to APS users?

[1] G. Hoffstaetter, FLS-2006.

Impact of Coherent Synchrotron Radiation



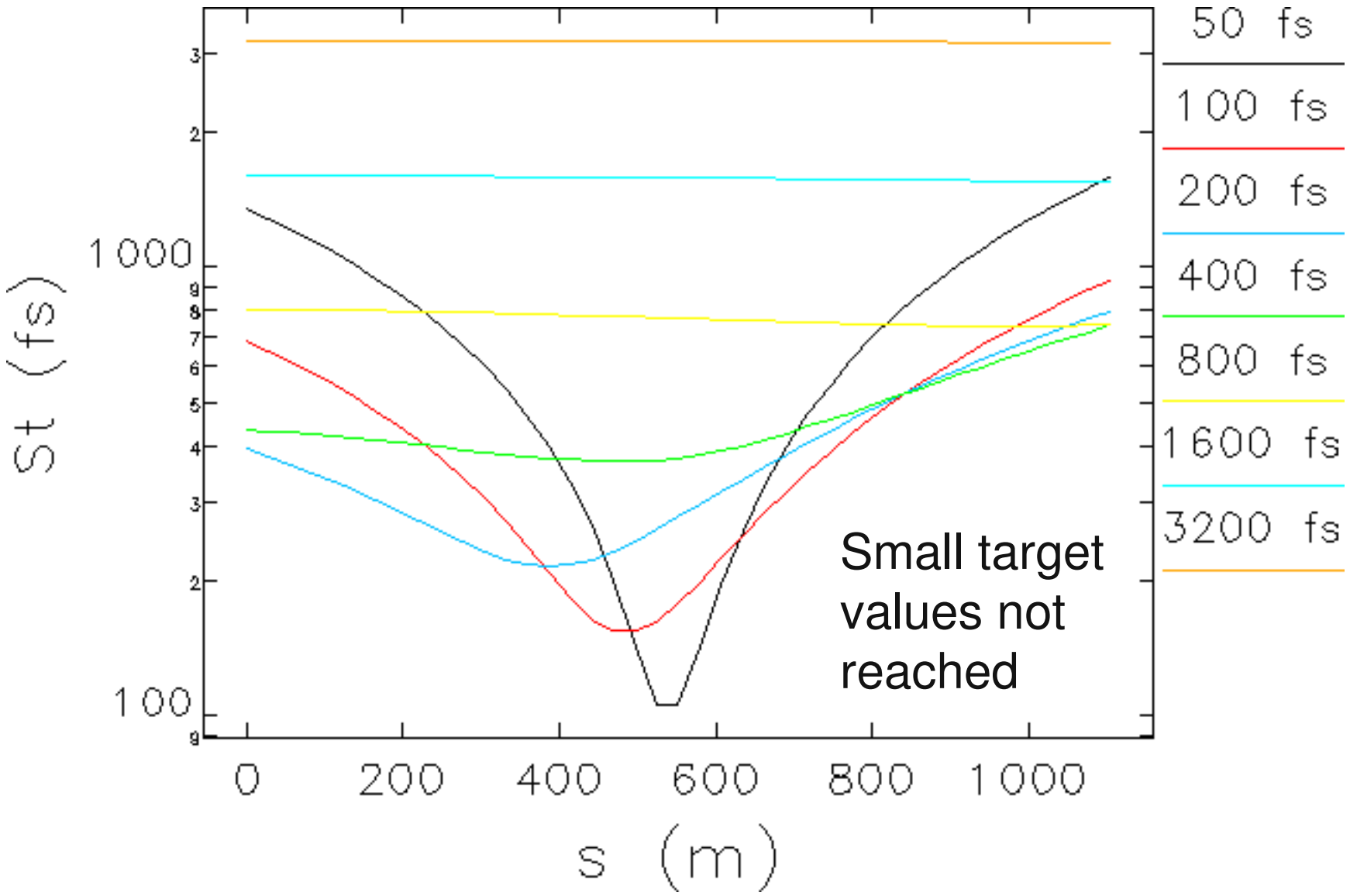
Longitudinal phase space at 4 sector intervals.

Targeting 1 ps rms bunch length

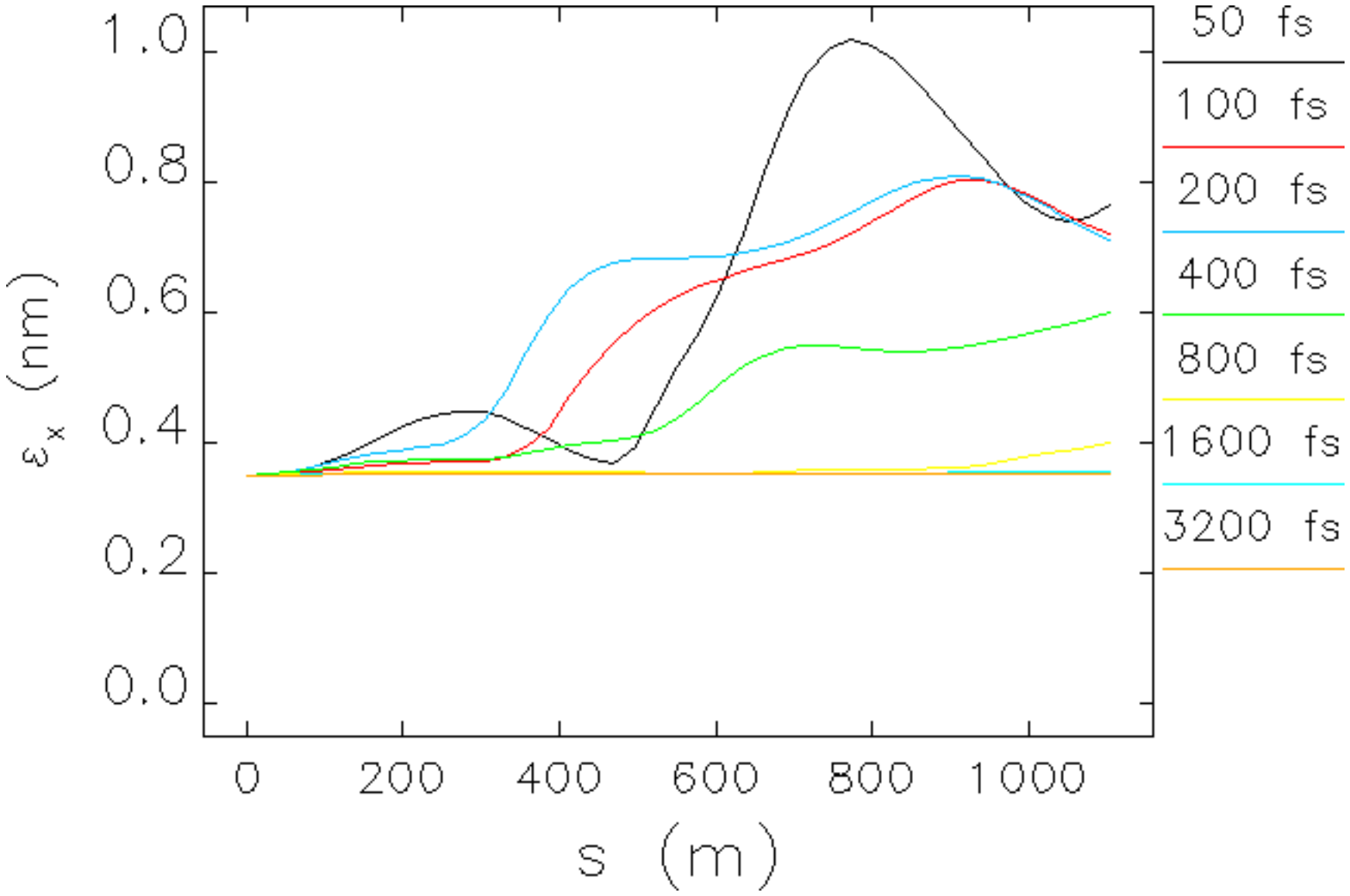
Movie 1

Movie 2

Evolution of Rms Bunch Duration



Horizontal Emittance Evolution



Discussion of ERL Ultrafast Mode

- For ~1ps, seems ok, but
  - Assumed smooth, gaussian input bunches
  - Corrupted longitudinal phase space will impact energy recovery
  - Pulse-to-pulse jitter not included
- Average current is 1 mA, so flux down 100-fold
- Brightness is down even more
  - Vertical emittance ~14-fold bigger (0.025 nm now)
  - Horizontal emittance ~6-fold smaller
  - Average brightness down ~200-fold
- Charge per bunch down 60-fold, so peak brightness basically unchanged.

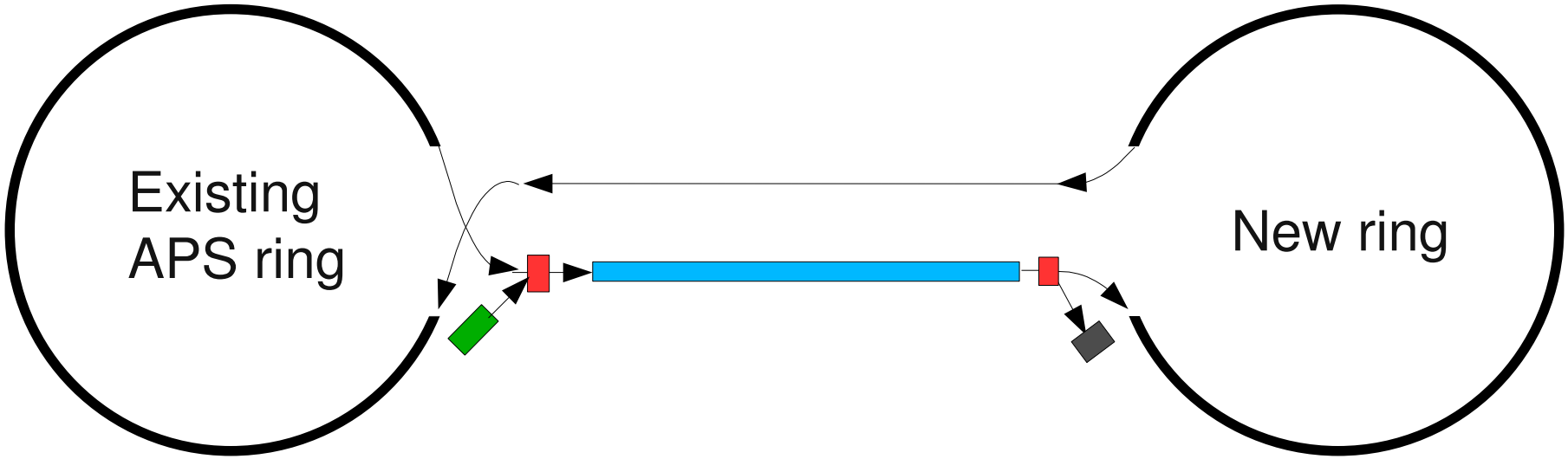
Other ERL Modes[1]

- High-flux:
  - 30 pm emittance with 0.02% rms energy spread and 2 ps rms bunch length
  - 100 mA with 1.3 GHz bunch rate
  - Flux is high only high relative to other ERL modes
    - *Cornell assumes 25 m undulators as well*
  - Advantage may come from ability to microfocus
- High-coherence:
  - Same as high-flux, but
    - *8 pm emittance*
    - *25 mA at 1.3 GHz rate*
- CSR is a likely a minor issue for these modes.

[1]G. Hoffstaetter, FLS-2006.

Energy Recovery Linac Concept for APS

- Existing APS ring doesn't preserve beam properties as well as we might wish
- A more ambitious facility might include a second ring that does better
- New ring could be a later upgrade



Storage Ring Alternative

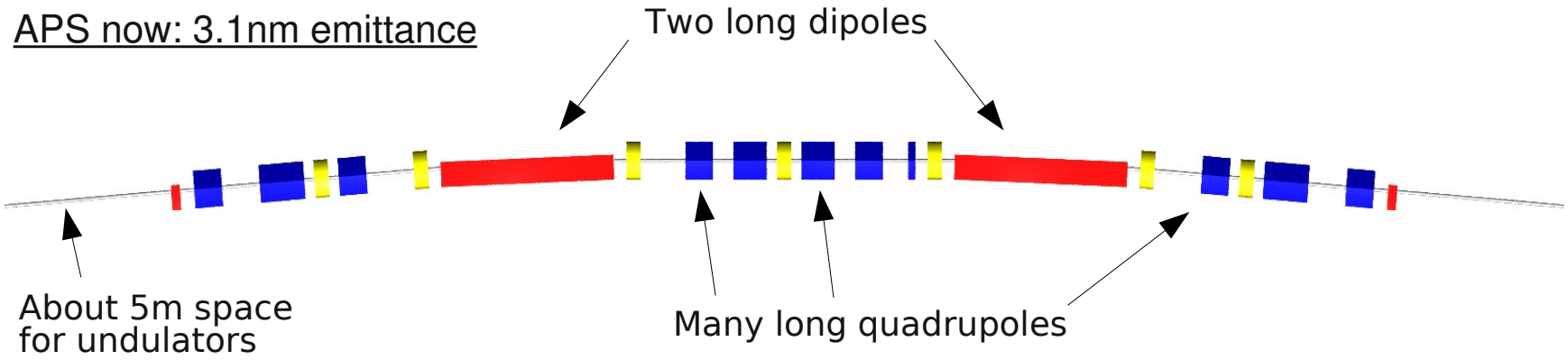
- Could upgrade the APS storage ring to provide
  - Longer straight sections
  - Lower emittance
  - Higher current
  - Short x-ray pulses
  - Novel insertion devices
  - Customized source properties
- Do nothing to preclude ERL upgrade in the future.

Long Straight Sections Very Important

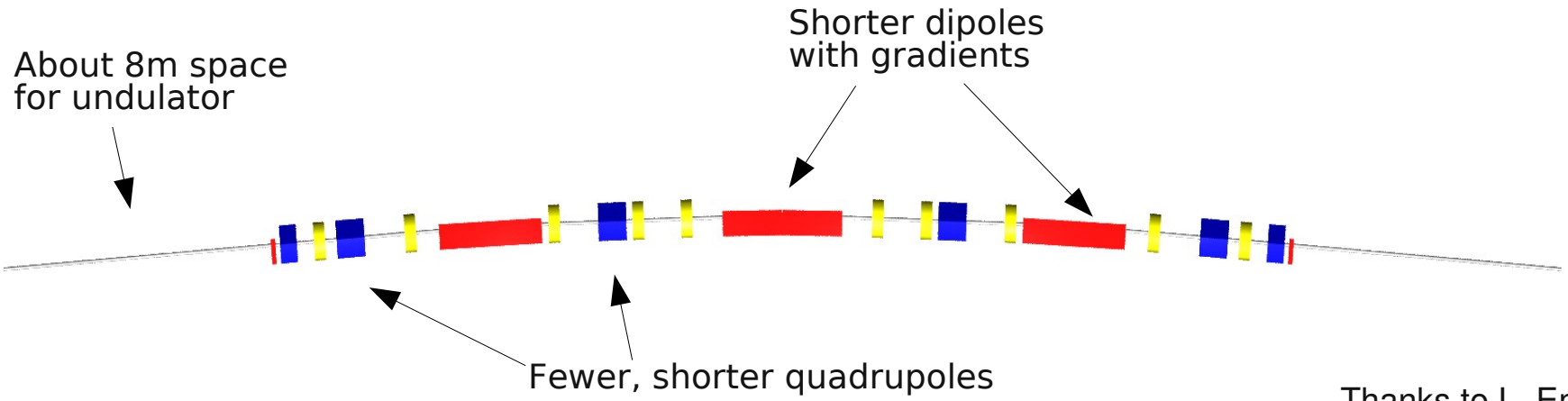
- APS straight sections now allow 4.8 m for insertion devices
- Longer straight sections interesting for many reasons
  - Flux-starved experiments
  - Long devices for reduced x-ray bandwidth
  - Getting more from expensive end station equipment by having several IDs
  - Canted devices to increase number of simultaneous experimental stations
  - Provides more space for cryostats for superconducting crab cavities.

Triple-Bend Design (APS1nm)

APS now: 3.1nm emittance



Possible upgrade: 1nm emittance



Thanks to L. Emery
for help with figures.

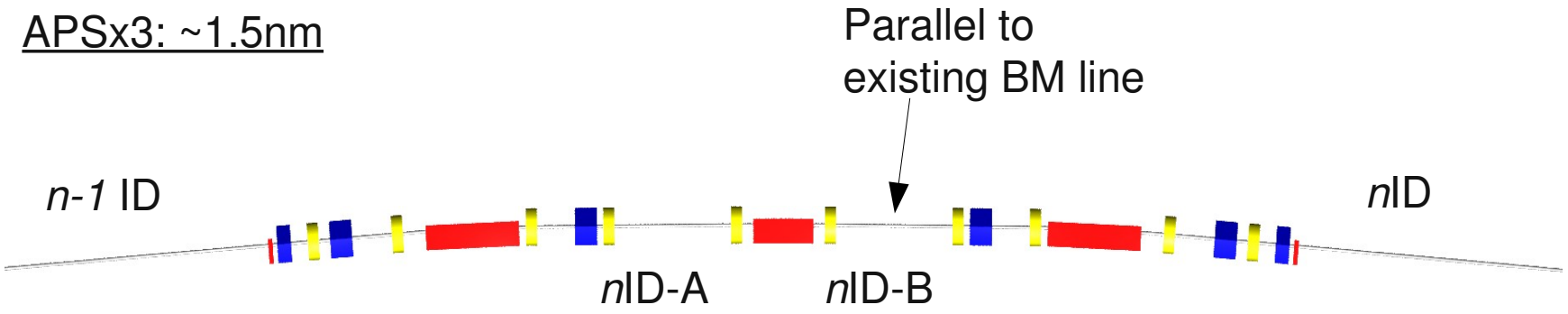
Beam Size and Divergence (Typical)

Case	*# of Sectors*	*x rms (microns)*	*x' rms (microrad)*	*y rms (microns)*	*y' rms (microrad)*
Today	40	275	11.4	8.5	3
Normal (long)	32	~120	~10	~7	~1
Small size	4	>35	<22	~7	~1
Small divergence	4	<245	>5	~6	~1

- Small size/divergence sectors assumed to be symmetrically arranged
- Still cause significant difficulties for nonlinear dynamics

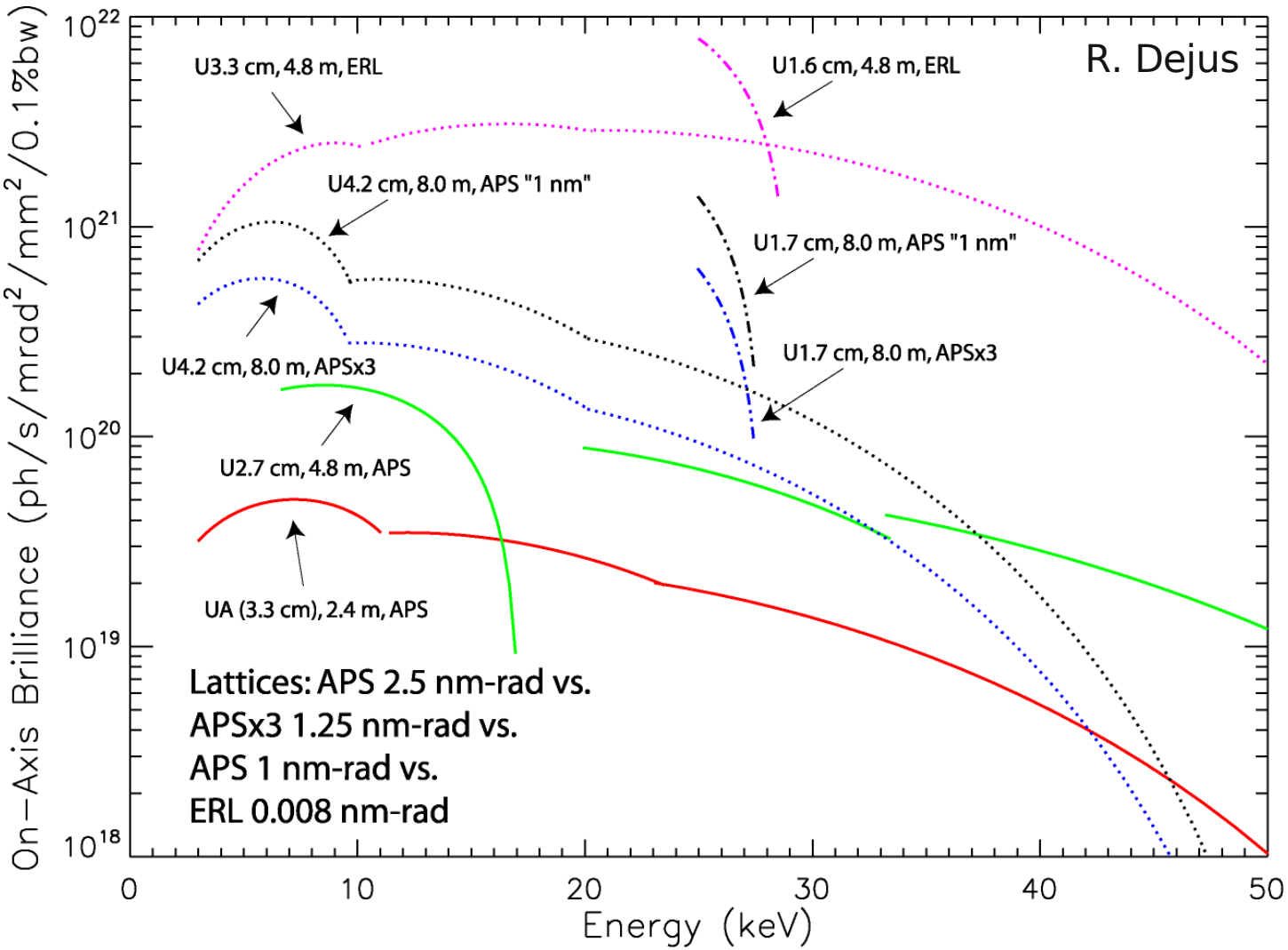
Another Option: APSx3

- This is an evolution of the 1nm lattice
- Offers three times as many ID beamlines
- Could provide a three-pole wiggler for beamlines that still want bending-magnet-like source
- Downside:
  - Emittance doesn't improve much
  - Source size/divergence customization is harder.



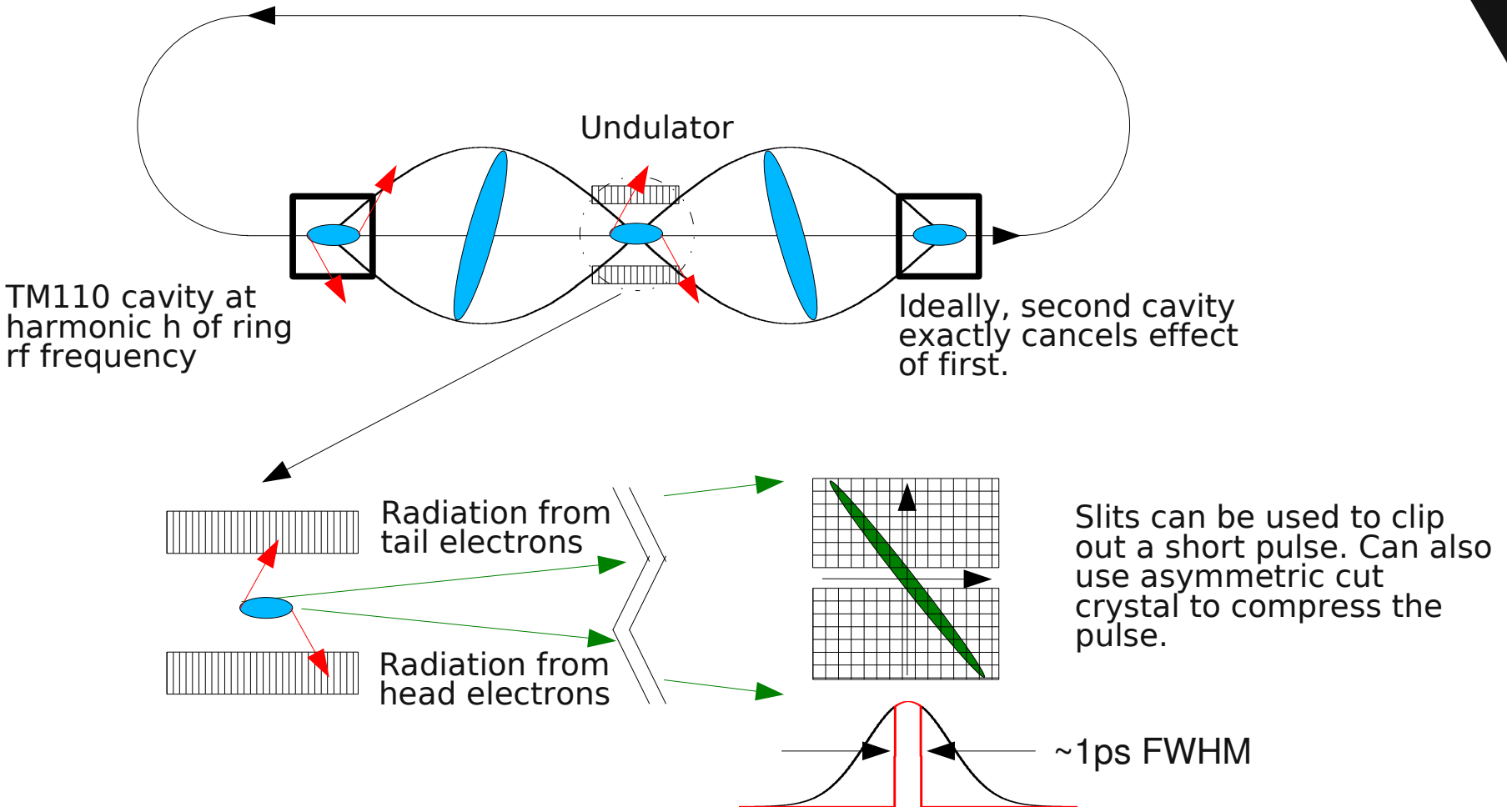
Thanks to L. Emery for help with figures.

Spectral Brightness Predictions



- 100 mA (APS), 200 mA (APSx3, APS 1 nm-rad), 25 mA (ERL)

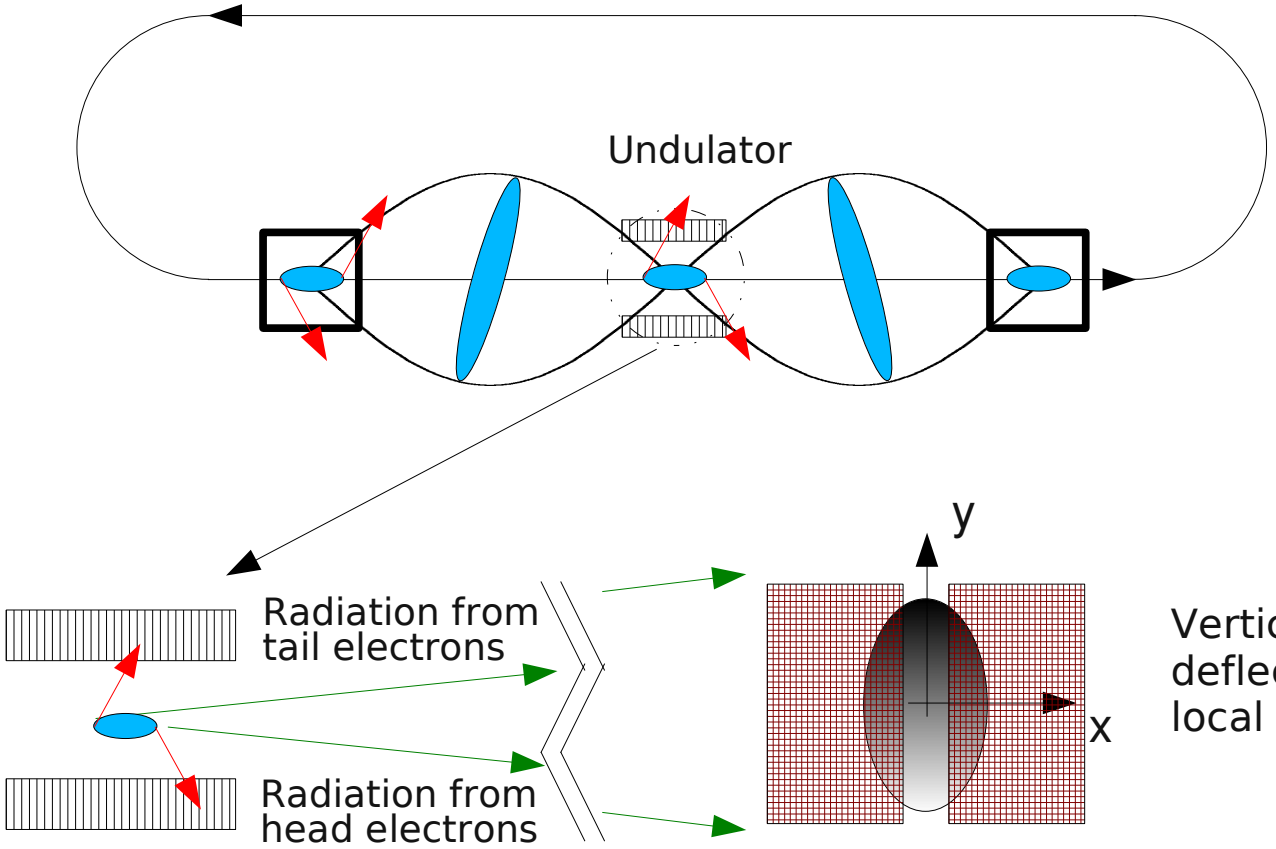
Zholents' Transverse Rf Chirp Concept



~1ps FWHM possible for existing APS
(K. Harkay *et al.*, PAC 05, p. 668.)

Large Area Coherent Imaging

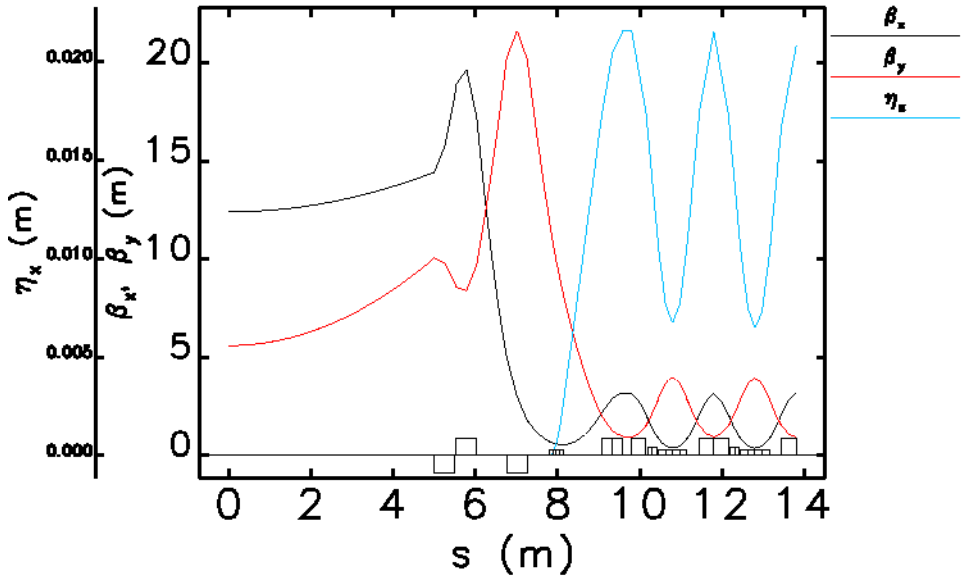
This is another concept[1] for using a crabbed beam.



Vertical *time-dependent* deflection doesn't change local coherence properties.

[1]E. Gluskin

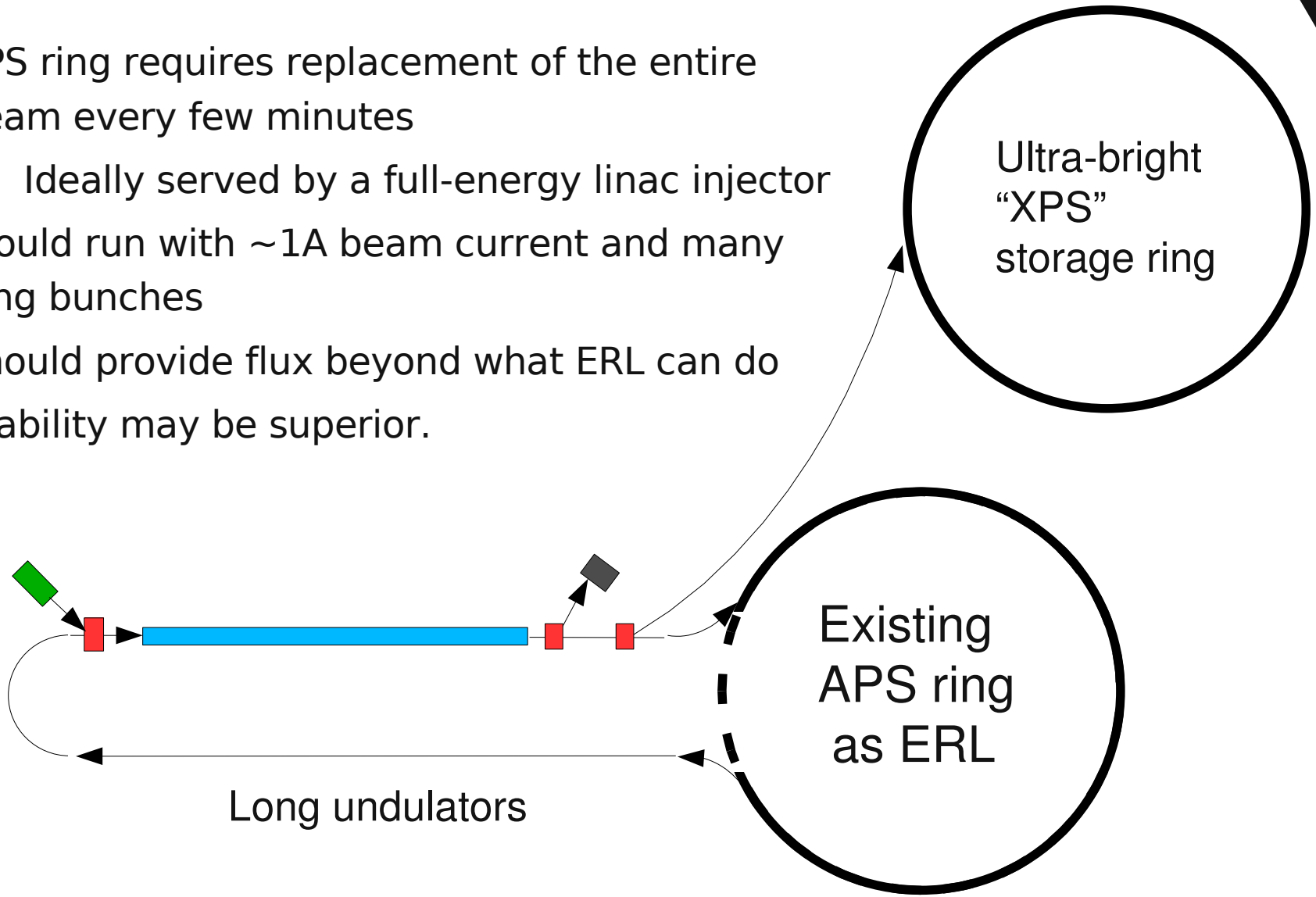
“XPS11” Six-bend Lattice



- 0.1 nm emittance x and y
- 8 m for undulators in each straight
- Poor injection aperture and short lifetime
  - On-axis injection only
  - Dedicated 7 GeV linac injector needed
- Magnets may not be feasible.

A Hybrid Possibility

- XPS ring requires replacement of the entire beam every few minutes
  - Ideally served by a full-energy linac injector
- Would run with ~1A beam current and many long bunches
- Should provide flux beyond what ERL can do
- Stability may be superior.



Summary: Ring Upgrade

- Pros
  - Well-known technology, should deliver as promised
  - Long straight sections, possibly 3x number of IDs
  - Smaller horizontal beamsize (~120 microns)
  - Improved brightness (10~100x)
  - Support for ps pulses, large-area coherent imaging
- Cons
  - Lattice flexibility very difficult to achieve
  - Considerable dark time required for installation
  - Brightness improvement is disappointing relative to
    - *Detector/beamline improvements*
    - *ERL projections*
  - Ultra-bright rings require 7GeV linac injector.

Summary: ERL Upgrade

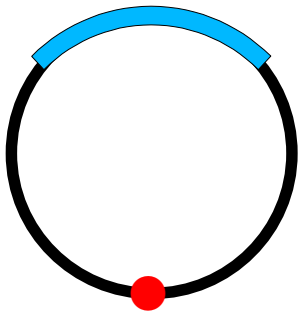
- Pros
  - 60~500-fold brightness increase in high-coherence mode
  - Short bunches (few ps to 100 fs rms) in ultrafast mode
  - Greater flexibility of source size/divergence
  - No long dark time for installation
  - Possibility for expansion to second ring.

Summary: ERL Upgrade

- Cons
  - Many unanswered issues about feasibility
    - *Can injector deliver as promised?*
    - *Can beam quality be preserved?*
    - *Can gun sustain 100 mA?*
  - Simulations so far show beam quality not well maintained with ultrashort mode
    - *Impacts users downstream of compression point*
    - *May interfere with energy recovery even for 1 ps case*
    - *X-ray flux similar to crab cavity system.*
  - Incompatible operating modes (flux, coherence, ultrashort).

Hybrid ERL Modes

- Can we mix ERL operating modes?
  - Probably not, because injector configuration, compression, etc. are charge dependent
- Can we mix Ultrafast ERL and stored beam?
  - Partial solution to ERL operating mode issues
  - Run ring with stored beam crowded on one side as in present hybrid mode
  - Run ERL at 271 kHz to match ring revolution frequency
    - *Need fast kickers (<3 us)*
    - *Need high rate kickers (271 kHz)*
    - *Need highly stable kickers due to small emittance*
  - “Only” 2 MW, maybe full ER not needed?
  - No physics reasons this won’t work.



Conclusion

- Storage ring upgrade and ERL promise different things
- ERL is more speculative, but would be revolutionary
- Ring is less speculative, but not revolutionary
  - Speculative XPS-style ring is revolutionary but requires injector that is nearly an ERL
  - Any ring replacement requires significant dark time
- ERL can be added to APS with little dark time
- After switching to ERL operation, could gradually modify the ring to incorporate desirable features, e.g.,
  - Long straights
  - More beamlines
- Many options for expansion once 7 GeV linac is built, e.g., XPS, more ERL rings, FEL.

Acknowledgements

- Participants in upgrade discussions and computations:

  M. Borland, J. Carwardine, Y. Chae, G. Decker, R. Dejus, L. Emery, R. Flood, R. Gerig, E. Gluskin, K. Harkay, M. Jaski, E. Moog, A. Nassiri, V. Sajaev, N. Sereno, H. Shang, R. Soliday, N. Vinokurov, Y. Wang, A. Xiao, C. Yao

- Others:

  G. Hoffstaetter (Cornell)