Overview of SR Upgrade Options

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Outline

- Strength of storage ring option
- Summary of APS present performance
- Upgrade constraints
- Lattice design concepts
- Damping wiggler option
- Ultimate SR studies literature search
- Brightness curves
- Conclusion

Demonstrated Strength of Storage Rings

- High brightness (e.g., APS, ESRF, SPRing-8)
- High current and flux (e.g., 1 A is not out of the question)
- Stable and reliable
- Well known technology
- Safety issues well understood and controlled
- Relatively inexpensive

Present Performance of APS

- Stored current, emittances, brightness
- Orbit stability
- Bunch patterns
- Topup: Lifetime, current stability
- Multiple users in straight sections: three canted undulator sectors
- Customized two sectors with reduced horizontal beam size

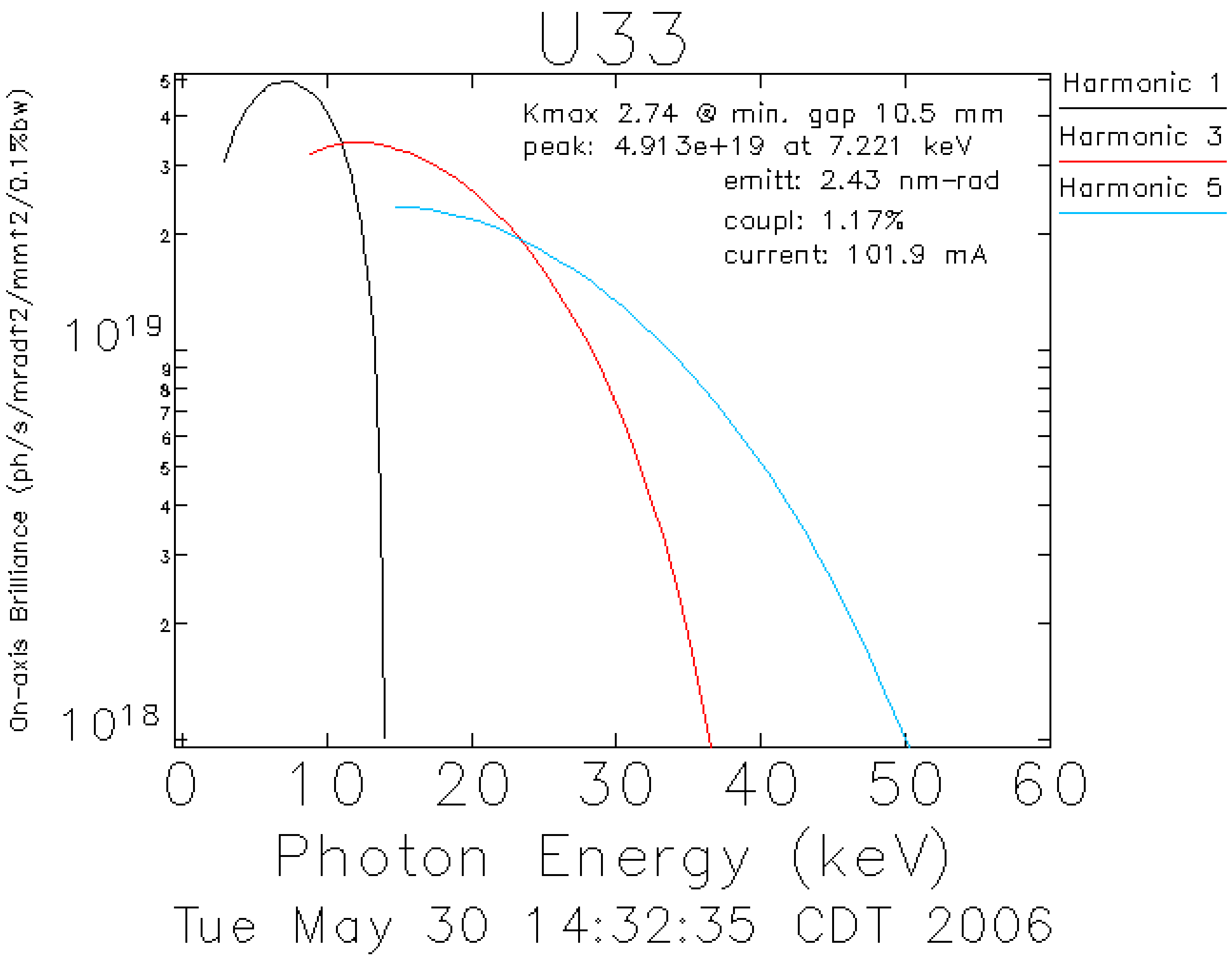
Performance Parameter Table

Energy	7 GeV
Horizontal Emittance	2.5 nm-rad
Effective Horizontal Emittance	3.1 nm-rad
Vertical Emittance	0.025 nm-rad
Momentum Spread	9.6×10^{-4}
Total Current	100 mA
Single bunch current	16 mA
Available straight sections for IDs	34
Space for IDs	5 m
1-mrad canted undulator sectors	3

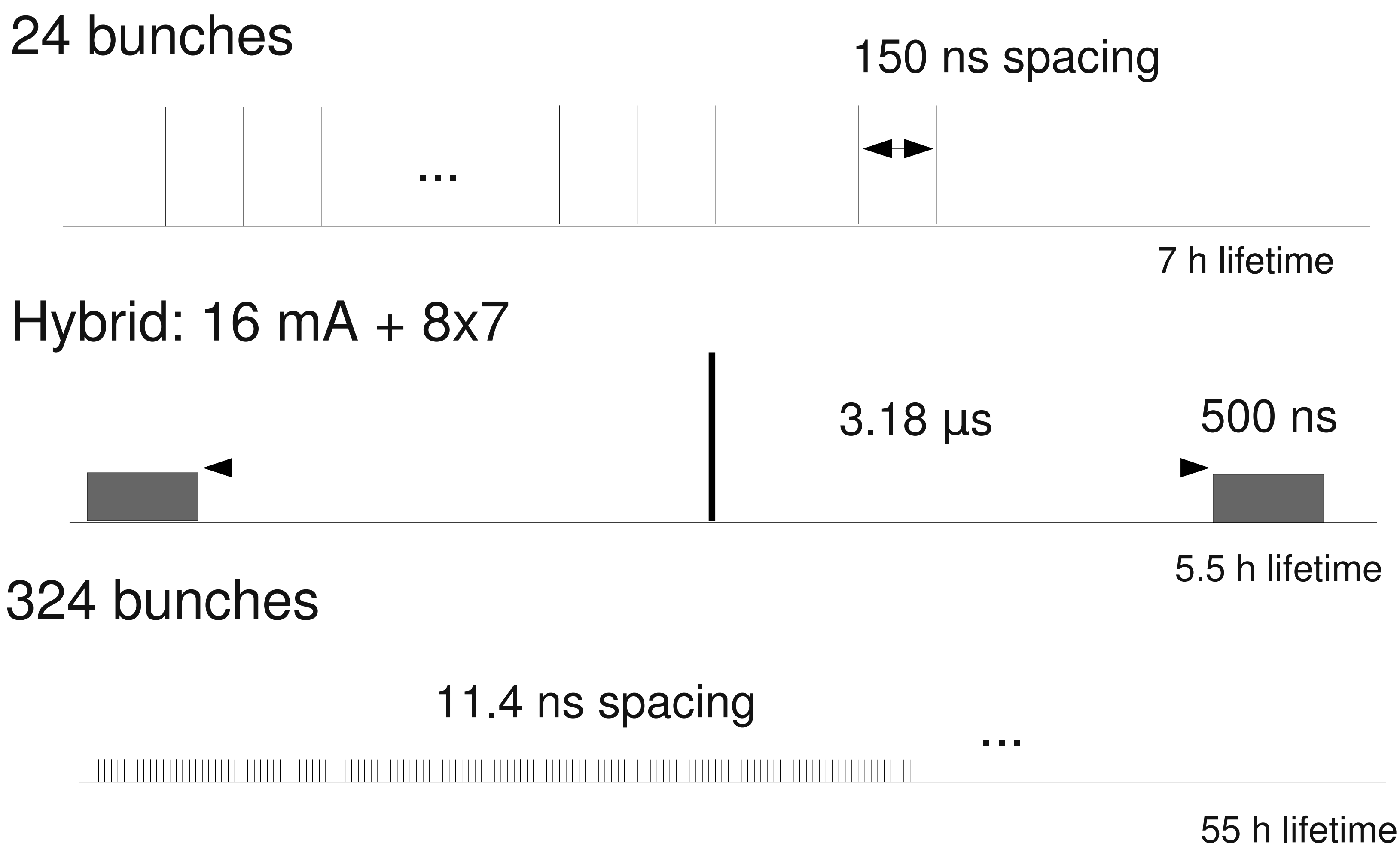
To be improved

Orbit Stability, H/V 100Hz BW	4.4/1.9 µm
RMS beam size H/V	275/8.5 µm

Brightness


U33
Kmax 2.74 @ min. gap 10.5 mm
peak: 4.913e+19 at 7.221 keV
emitt: 2.43 nm-rad
coupl: 1.17%
current: 101.9 mA
Harmonic 1
Harmonic 3
Harmonic 5
On-axis Brilliance (ph/s/mrad†2/mm†2/0.1%bw)
10^19
10^18
0 10 20 30 40 50 60
Photon Energy (keV)
Tue May 30 14:32:35 CDT 2006

Bunch Patterns (T=3.68 μsec)



Upgrade Constraints and Parameters

- Energy 7 GeV
- Retain user sectors, i.e. no additional sectors for rf cavities
  - Retain straight section centers and ID beam ports and alignment. Allow BM ports to move a bit if necessary.
  - Keep “same” rf frequency, circumference, cell length
- Straight section length can be increased up to some limit
- Keep bunch patterns; use 200 mA instead of 100 mA

Upgrade Constraints and Parameters

- Lattice Nonlinearities
  - Dynamic aperture (with errors) must be large enough for 100% injection of a booster bunch
    - *APS presently has a hor. dynamic aperture of 10 mm (β_x=20 m)*[1]
      - Model matches measurement
      - Inject 100% with an injection oscillation of 6 mm (stored beam oscillates with 2.0 mm of opposite phase)
  - Momentum aperture large enough for lifetime
- Not too low momentum compaction factor (α_c), which controls single bunch instabilities (present APS value 2.8×10^{-4})

[1]V. Sajaev and L. Emery, "Dynamic Aperture Study and Lifetime Improvement at the APS," PAC 2005, p. 3632

Lattice design concepts

- Reduce emittance through increased number of dipoles per sector

$$\epsilon_x \sim \theta^3 \sim N_d^{-3}$$

  - Optimize dynamic aperture with families of sextupoles
  - Stop increasing N_d when dynamic aperture gets too small
  - N_d=3 or N_d=4 is probably the only practical change for a 27-m cell, based on reduction of dispersion function and increasing sextupole magnet strengths. N_d=9 is used in a 60-m cell in a recent Spring-8 proposal[1].
- Check dynamic aperture with errors and with errors plus correction

[1]K. Tsumaki and N. Kumagai, "Very low emittance light source storage ring," NIM A 565 (2006), p. 394

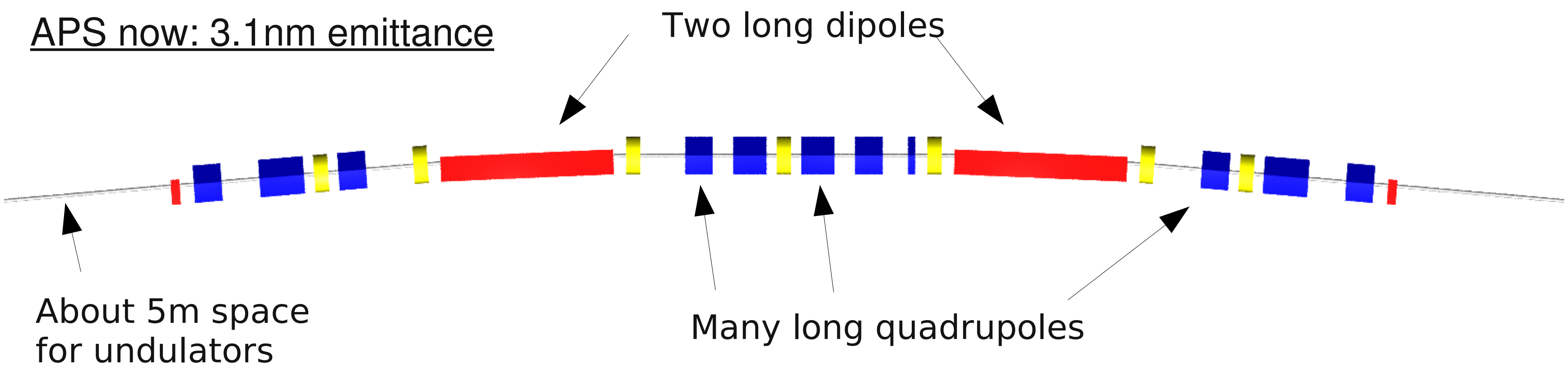
Lattice design concepts (cont'd)

- Decide whether dispersion should be present in ID section
- Add gradient to dipole to reduce the number of quadrupole magnets
- Longer straight sections
  - Limited because of β functions (physical acceptance, source size)
  - Triplet in middle of straight section, e.g. for β_y = 1m and L_{ID}=2 m. [2] (not used here)
- Add straight section in middle of arc for extra ID
- Check that reduced-horizontal-beam size matching works in all respects

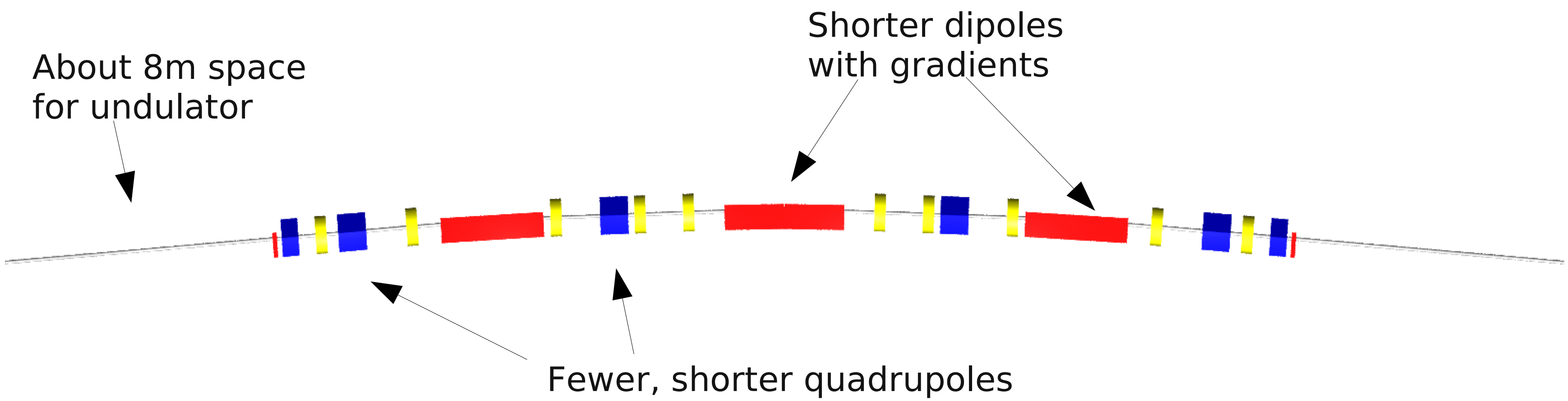
[2] A. Ropert, “Towards the ultimate Storage-ring based light source,” EPAC 2000, p.83

Triple-Bend Ring Design (APS1nm)

APS now: 3.1nm emittance

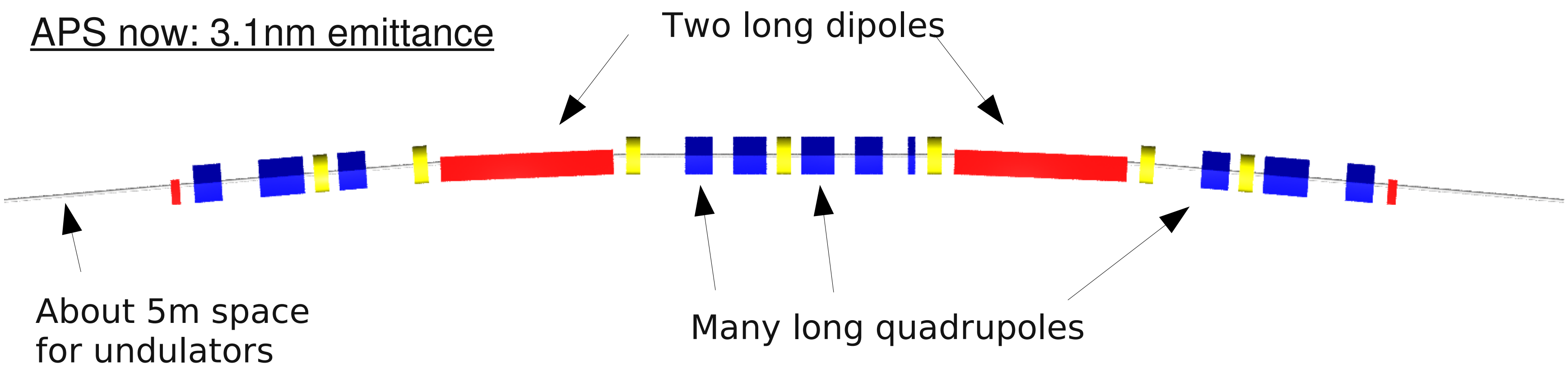


“APS 1nm”: 1nm emittance

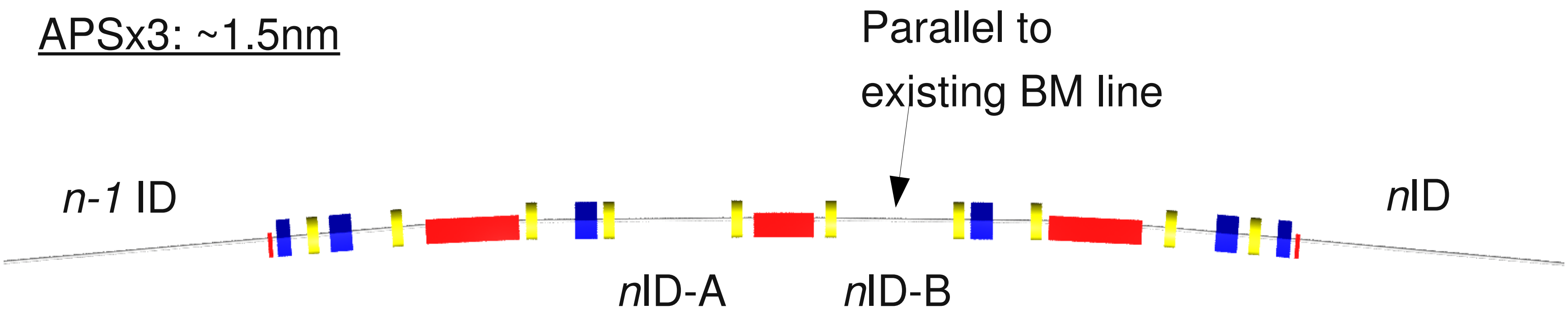


Another Option: APSx3

APS now: 3.1nm emittance



APSx3: ~1.5nm



2.1m magnet-to-magnet
in new straight sections.

Gradient in Dipoles

- Adds complexity to compact designs but is feasible
- Existing ring with gradients:

	Gradient (1/m2)
Aus. LS	"modest"
ALBA	-0.58
ALS	-0.81
CLS	-0.39
Elettra	-0.43
MAX II	-1.62
NSLS X-ray	-0.05
SPEAR III	-0.33
SRRC	-0.37

- Ring with no gradient dipoles: APS, BESSY II, CAMD, DLS, ESRF, MAX I, PAL, Shanghai, Soleil, Spring8

Damping wiggler option

- Wiggler magnets in zero-dispersion straight sections can increase damping term D through emission of much more synchrotron radiation than regular bends

$$\epsilon_x = C\gamma^2 \frac{\langle H/\rho^3 \rangle}{D}$$

- PETRA III and ILC damping ring get low emittance using lots of wigglers

	PETRA III[1]	ILC DR[2]
Energy (GeV)	6	5
Circumference (km)	2.4	6.6
Total wigglers (m)	80	196
Emittance (nm-rad)	1	0.5
Emittance w/o wigglers (nm-rad)	4	5

[1]K. Balewski et al, "PETRA III: A New High Brightness Synchrotron Radiation Source at DESY," EPAC 2004
M. Tischer et al, "Damping Wigglers for the PETRA III Light Source," PAC 2005
[2]A. Xiao, L. Emery, private communication

Damping wiggler option

- Factor of two in existing light sources difficult[3]
  - not enough room for wigglers
  - need more rf sectors, no room for that either!

[3] M. Borland, L. Emery, OAG-TN-2006-033

Ultimate SR Studies

- ESRF[1], Spring8[2], APS XPS[3] design studies with various combinations of free parameters and constraints
  - Number of straight sections x 2, or new number
  - Circumference x 2, or new number
  - Straight section length
- Common specification: much lower emittance for coherent x-rays
- Limitations are magnet strength, nonlinearities, lifetime for reasonable bunch charge, and possibly single bunch charge limit (never reported)
  - Usually one show-stopper among the above

[1] A. Ropert, “Towards the ultimate Storage-ring based light source,” EPAC 2000, p.83

[2] K. Tsumaki and N. Kumagai, “Very low emittance light source storage ring,” NIM A 565 (2006), p. 394

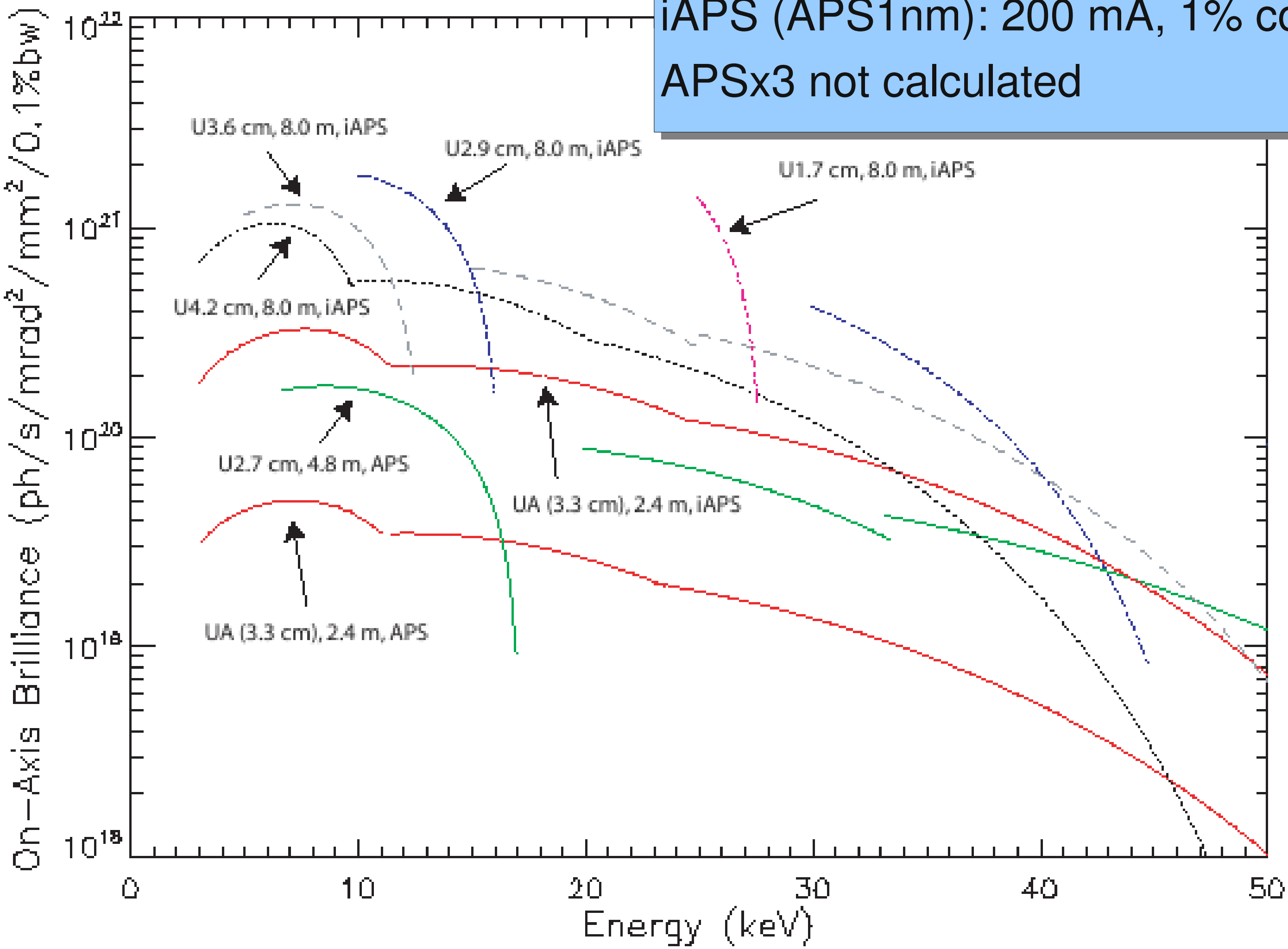
[3] M. Borland, “A 0.2 nm lattice for APS upgrade with long straights,” OAG-TN-2006-022

Ultimate SR (cont'd)

	ESRF	Spring-8	APS XPS
Design type	4-bend achromat	10-bend achromat	4-bend achromat
Energy (GeV)	7	6	7
Circumference (m)	2000	1999	1104
Sectors	50	32	40
Sectors for IDs	40		34
Space for IDs (m)	7	5 est.	8
Emittance (nm-rad)	0.3	0.034	0.2
Momentum spread (%)	0.13	0.09	0.16
Ideal DA (mm)		5 (β_x=25 m)	0.75 (β_x=12 m)
Momentum aperture (%)		1.5 est.	1.5
Momentum compaction	3-6x10^{-5} est.	8x10^{-6}	3.7x10^{-5}

Brightness curve

APS: present APS, 100 mA, 1% coupling
iAPS (APS1nm): 200 mA, 1% coupling
APSx3 not calculated



Conclusions

- Two lattice options with reduced emittance and more space for IDs
  - Emittance is reduced by factor 2-3 relative to present 3 nm-rad
  - Space for IDs increase 60% or more
- Upgrades proposed lie between present APS and “ultimate” ring designs
- Uses conventional technology that is pushed to a “realistic” limit.
- Following talks cover the details of the two ring options