Upgrade Paths for the ALS

David Robin

Outline

Possible Directions

- Brightness, Lifetime, Stability, Capacity, ...

Possible Upgrades

- Shorter Term
  - Modifications to the Storage Ring
  - Full Energy Injector
  - Replacing the older Insertion Devices
- Longer Term
  - Rebuilding the ring

Summary

Tradition of continuous upgrades

ALS was world's first soft x-ray third generation synchrotron light source

- First user operation in 1993
- Rapid growth in the user population
  - Supported more than 1500 users in FY02
- Nearly all of the nine available straight sections have been occupied with Insertion Devices (ID)s
  - 6 full length IDs (with 1 more planned)
  - 2 half length IDs (with 2 more planned)
- 3 Superconducting magnets (Superbends) have extended capacity of the ALS for harder x-rays

Performance Improvements

Have made many improvements to the ALS performance

Some examples:

- Increased lifetime by a factor of 2
  - 3rd harmonic cavities and reduced lattice errors
- Smaller emittances
  - Operate with 2% coupling
  - Have reached 0.1% coupling
- More stable beams (orbit, beamsize)
  - Transverse and longitudinal coupled bunch feedback systems
  - Insertion device compensation
- Larger single bunch currents
  - Transverse feedback systems
- Reduced parasitic bunch contamination

Possible Directions

Need to continue to upgrade the capabilities of the ALS keeping it at the forefront of synchrotron radiation sources

- Ensure that the ALS compares well with the newer 3rd generation light sources (SLS, SOLEIL, SPEAR3, …)

Possible directions to develop the ALS

- Increased Brightness
- Improved "Effective" Lifetime
- Improved Stability
- New Insertion Devices

- Longer wavelengths (M. Martin and J. Byrd)
- Shorter Pulses (B. Schoenlein, S. Leone and J. Corlett)

Increased Brightness and Flux
Survey of different operational regimes

Vacuum Ultra-Violet (VUV), 10 to 100 eV: valence electrons, shallow core levels

- ALS undulators fully optimized
- Polarization control necessary
  - Plan for a large period elliptically polarizing undulator

Soft X-ray (SXR), 100 - 2000 eV: core level electrons

- access to the K edges up to Si (Z=14) (eg. C, N, O K edges)
- access to the L edges up to Y (Z=39) (eg. 1st row transition metals)
- access to the M edges up to Ir (Z=78) (eg. rare earths)

Photon in photon out experiments (photon hungry)

- Inelastic scattering for the study of correlated systems (Mn/Cu L edges)
- Coherent scattering from magnetic materials (transition metals/rare earths)
- Nanometer scale diffractive imaging of materials

Substantial improvement possible in the few 100 eV - 2 keV current energy range possible

Increased Brightness and Flux (cont)
Survey of different operational regimes

Medium energy x-ray range, 2 - 10 keV

- access to K edges up to Zn (Z=30) (eg. P, S. Cl + 1st row transition metals)
- access to L edges up to W (Z=74) (eg. all 2nd row elements + actinides)

Not currently accessible using present ALS undulators but could be accessed using short period undulators

- Would allow expansion of current programs and access to new scientific areas

Hard x-ray range, > 10 keV

- heavy element spectroscopy
- x-ray diffraction

Accessed currently using a multipole wiggler and superconducting bend magnets

Brightness from an undulator

Brightness

$$B \prec \frac{\Phi_n}{\sigma_{Tx}\sigma_{Ty}\sigma_{Tx'}\sigma_{Tx'}},$$

Photon Beam Size

$$\sigma_{T_{x/y}} = \sqrt{\sigma_{x/y}{}^2 + \sigma_r{}^2}, \sigma'_{Tx/y} = \sqrt{\sigma'_{x/y}{}^2 + \sigma'_r{}^2}$$

$$\sigma_r \prec \sqrt{\lambda L}, \sigma_{r'} \prec \sqrt{\frac{\lambda}{L}}$$

Flux

$$\Phi_n \succ N_p \left(1 + \frac{K^2}{2}\right) \frac{F_n}{n_h} I_A$$

$$\lambda = \frac{\left(1 + \frac{K^2}{2}\right)}{2 n_h \gamma^2}, K = 0.934 \lambda_\mu B_0$$

Present Storage Ring Parameters

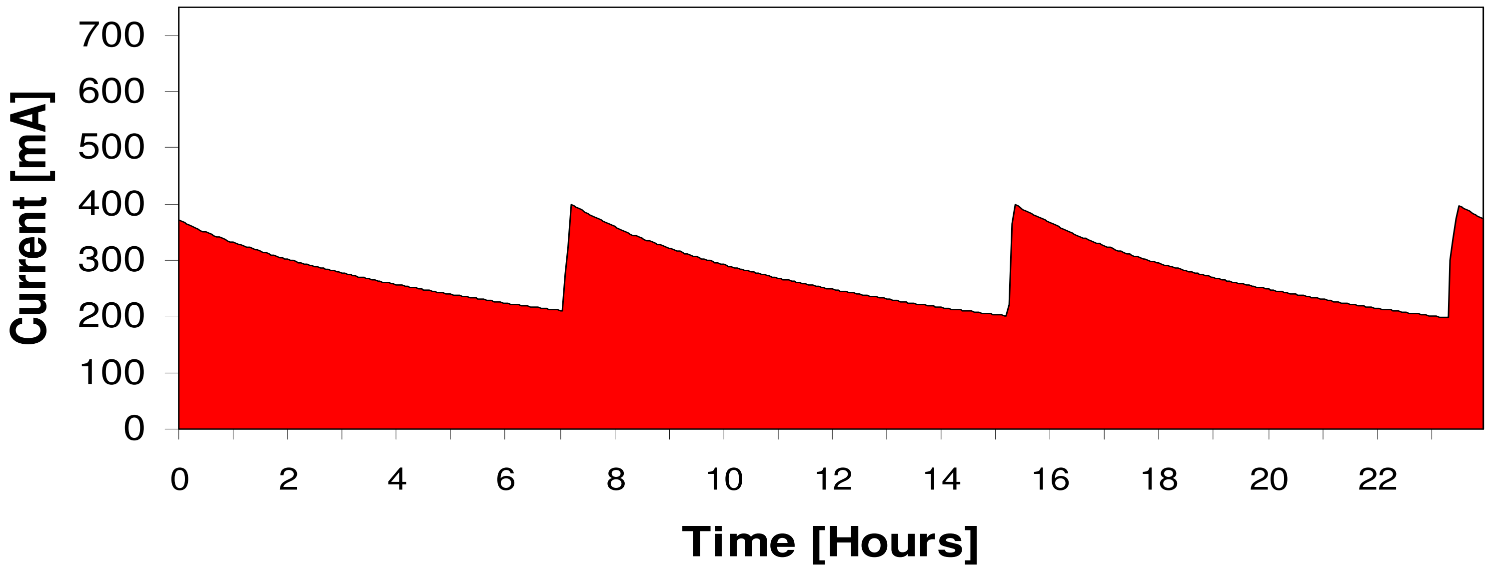
Parameter	Multibunch
Beam Energy	1.9 GeV
Beam lifetime	8 hrs at 400 mA
Beam current	400 – 200 mA (250 time averaged)
Horizontal emittance	6.75 nm-rad
Vertical emittance	0.15 nm-rad
Energy spread ($\Delta E/E$, rms)	0.1%
Bunch Length (FWHM)	70 ps
Vertical β-function in straights	3.6m
Minimum vertical gap in the straight	8.9mm

Present brightness limitation – beam lifetime

Brightness increases are possible by :

- **Increasing the time averaged beam current**
- **Reducing the beam size**
- **Reducing the insertion device gap**

These changes would result in unacceptably small beam lifetimes



Beam loss is caused by intrabeam scattering

- **Currently the fill the ring 3 times daily to 400mA and decays down to 200mA in 8 hours (with time averaged current of 250mA)**

Continuous Top-off Injection

The lifetime limitation can be mitigated through continually filling the ring → top-off injection

- Top-off mode is routinely used at the Advanced Photon Source (APS) and the Swiss Light Source (SLS)

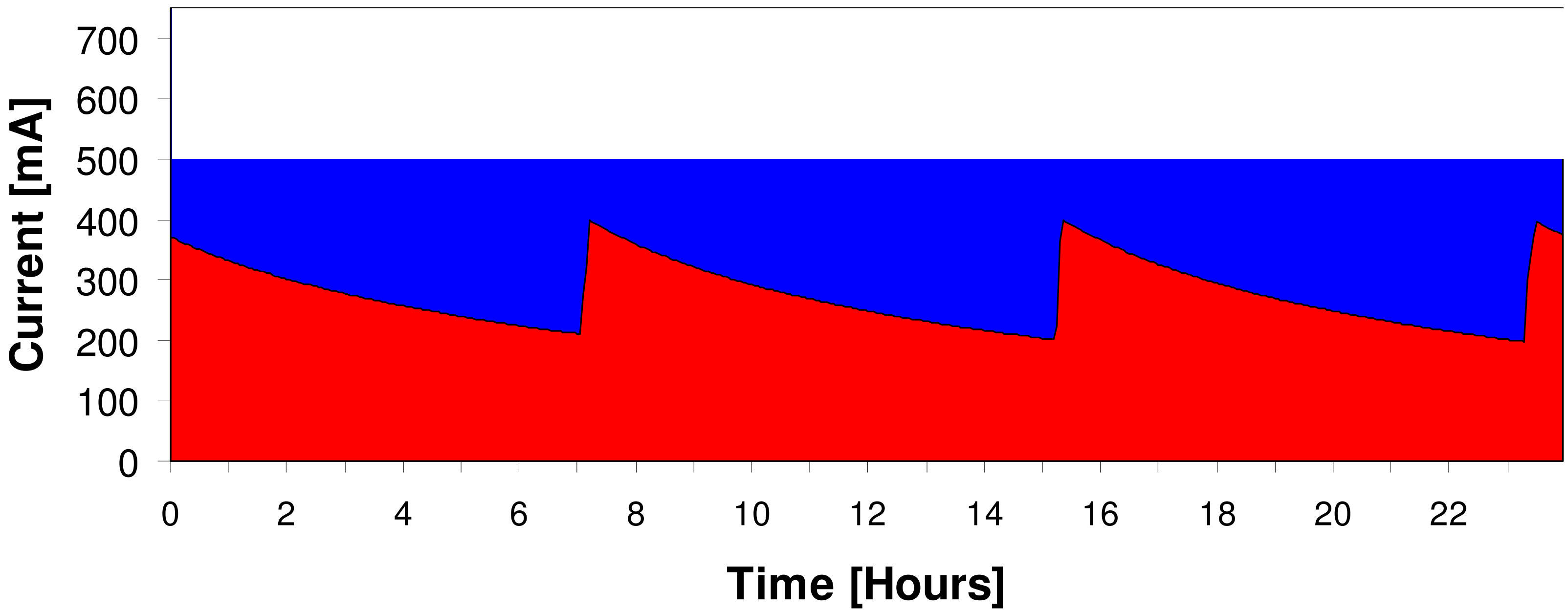
Requires a full energy injector

- Upgrade the injector from 1.5 GeV to 1.9 GeV
  - Can be done with modest cost and in a typical annual shutdown (1.5 – 2 months)

Added benefit

- Operating at constant current improves thermal stability

Continuous Top-off Injection



Increase in time averaged current by a factor of 2

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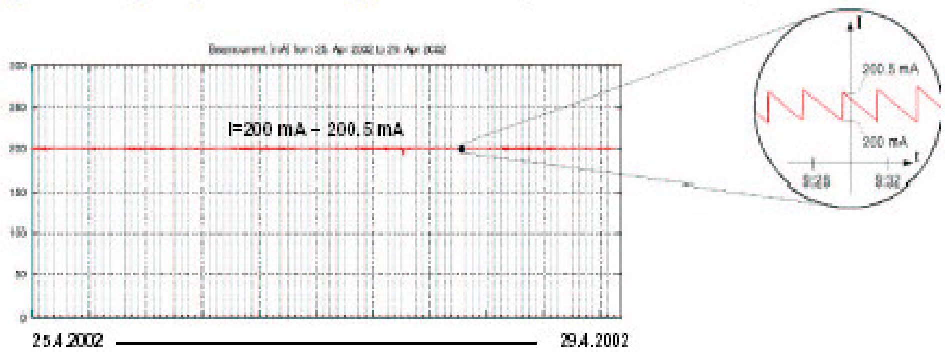
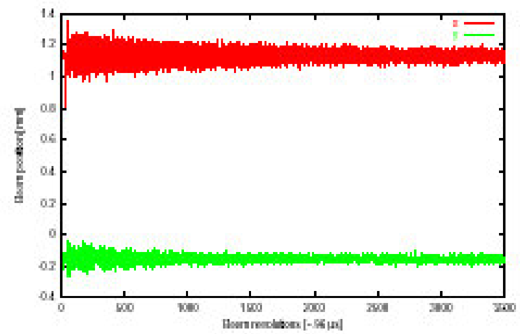
SR - Top-Up

Typical Top-Up Run in April 2002: (→**TUPRI012**)





- Beam Current Constant: $\Delta I/I < 3{\cdot}10^{-3}$
- Kicker Bump Closed: $x_{rms} \approx 100\ \mu\text{m}$, $y_{rms} < 50\ \mu\text{m}$
- Injection (every $\approx$ 2 min) with Closed Gaps: Losses @ **ID**s OK
- Injection with Shutters Open: Radiation in Experimental Areas OK
- Injection Efficiency: $\approx$ 80 % (large $\xi_y \approx +4$)
- Linac and Booster Alwarys Running → Gun and Kicker Triggers On/Off
- Users Like Top-Up (-: Mostly Top-Up Runs Scheduled :-)

Lifetime / Topoff

Operating in a top-off mode would allow

- Operation with effectively constant current
  - Average current increases by 100%
- Better stability
  - Beamline optics
  - Diagnostics
  - Vacuum chamber heating
  - RF system
- Possibility of operating with smaller bunch lengths
  - Operate the 3rd harmonic cavities in bunch shortening mode
    - Benefit for the femtosecond slicing program

Full energy injector

Currently the ALS has a 1.5 GeV booster synchrotron injector

- Inject in to storage ring at 1.5 GeV and ramp the ring energy to 1.9 GeV

Top-off requires an upgrade of the injector to 1.9 GeV

- Preliminary look at what needs to be upgraded
- Rough cost for upgrade is about 4 M$
  - High impact for modest cost

Increasing the brightness

Top-off opens the door to large increases in brightness

Larger beam currents

- **Increase the time averaged current by a factor of 3 from 250mA → 750mA**
  - **Top-off injection**
  - **Upgrade the RF system**
    - **Replace the cavities with HOM damped cavities and add a second RF power source**
    - **Can be done in a typical annual shutdown with reasonable costs**

Smaller beamsizes

- **Reduce the vertical beamsize by a factor of 5**
  - **Reducing the emittance by a factor of 15 from 0.15nmrad → 0.01 nmrad.**
  - **Reduce the vertical beta-function by 1.5 from 3.6m to 2.25m**

Smaller gap insertion devices

- **Reduce the magnetic gap by a factor of 3 from 14mm → 5mm**
  - **Use narrow gap permanent magnet or superconducting insertion devices.**

ALS STORAGE RING RF SYSTEM UPGRADE

Kenneth Baptiste, John Byrd, Slawomir Kwiatkowski

Increasing of the brightness of the ALS light can be achieved by increasing the value of the beam current (in actual proposal from 0.4A to 1A), which will require increasing the capabilities and modernizing the existing ALS Storage Ring RF system (SRRF).

At the present time ALS Storage Ring RF (SRRF) is equipped with two re-entrant 500MHz cavities powered by single 340kW klystron. The cell power of each cavity is set to Pcav=45kW (Vcav=670kV).

Table1 presents the comparison of three options for the future upgrade of the SRRF.

•Option #1: Requires one additional 300kW high power RF source (klystron with dc power supply and the low level rf chain) allowing each existing RF cavity to be driven by an independent RF source. The new RF system layout would be equipped with a system of waveguide switches, circulators and a Magic-Tee, which will allow the operation of the Storage Ring at a lower beam current in the case of the failure of the one RF amplifier systems. The main risk associated with this option is the added stress on the longitudinal and transverse active dampening systems caused by the interraction of the higher circulating beam current with the narrow band impedances of the poorly damped HOM modes on the existing ALS RF cavities.

•Option#2: This option replaces the 2 existing normal conducting RF cavities with a single “CORNEL” type superconducting RF cavity. The main advantages of this option are: higher achievable cavity voltage (~2.5MV per single cavity), very good HOM spectrum and the lower total RF power requirements. Negative aspects are: higher cost and the longitudinal dimensions of the cavity (3.2m).

•Option#3: This option is similar to #1 except that we will replace the 2 existing normal conducting RF cavities with two new HOM free normal conducting cavities in addition to adding a second RF source. This new HOM free 500MHz cavity has been designed to replace existing RF cavities at several third generation light sources in Europe. A prototype was manufactured last year and final high power tests are under way at the DELTA facility.

ALS RF UPGRADE OPTION:	Required RF POWER[kW]	Number of cavities	Required ALS shutdown period for installation	Risk factor	ESTIMATED COST [M$]
#1	540	2	~6 weeks	Significant	2.4
#2	380	1	12 weeks min.	Small	5.7
#3	540	2	~8 weeks	None	3.2

Cost estimate for ALS SRRF upgrade

Option #	1	2	3
RF Cavity & Support Structure	0	1500k$	2*250k$
Cavity tuners	0	500k$	2*50k
Klystron (TH2161B)	300k	0	300k
600kW Klystron Power Supply	500k	0	500k
300kW circulator, load	300k	0	300k
Waveguides, waveguide switches	150k	0	150k
Low Level RF System	100k	0	100k
Misc. electrical and mechanical hardware	50k	50k	50k
Installation	200k	200k	200k
Engineering	400k	500k	500k
450W 4K Kryostat	0	2000k	0
Contingency (20%)	400k	950k	520k
TOTAL	2400k	5700k	3220k

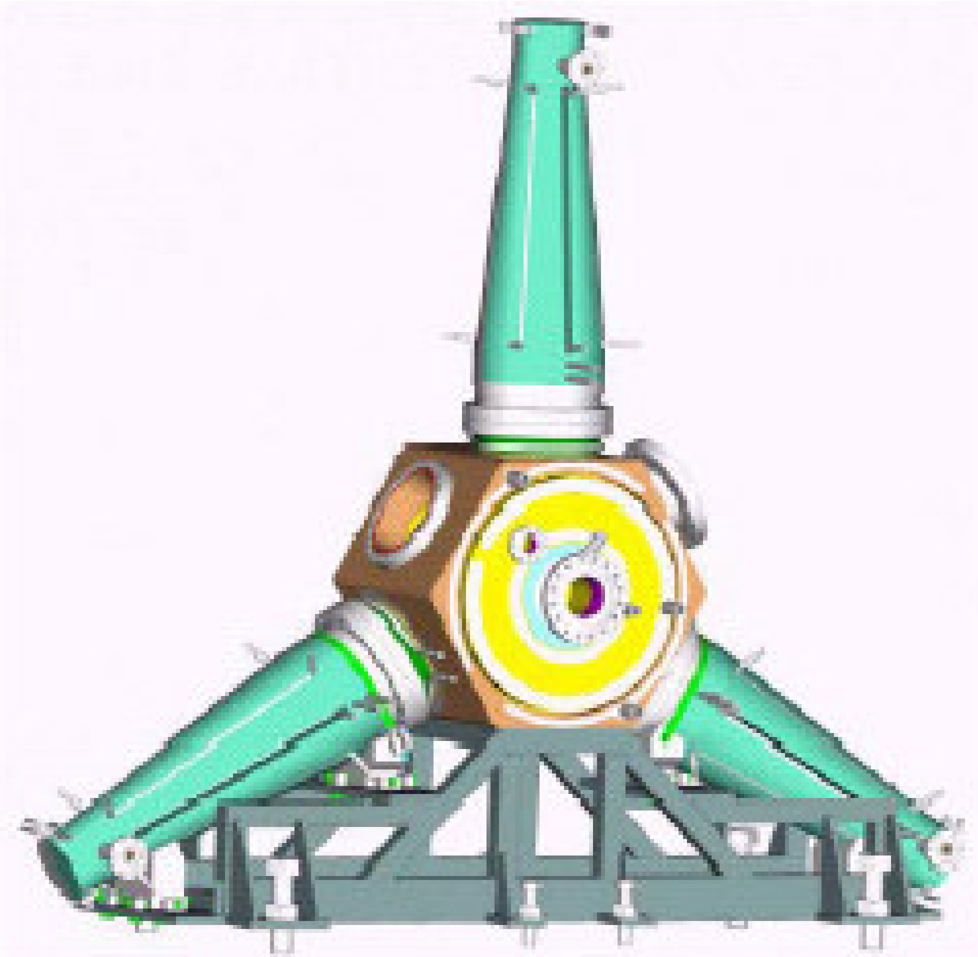
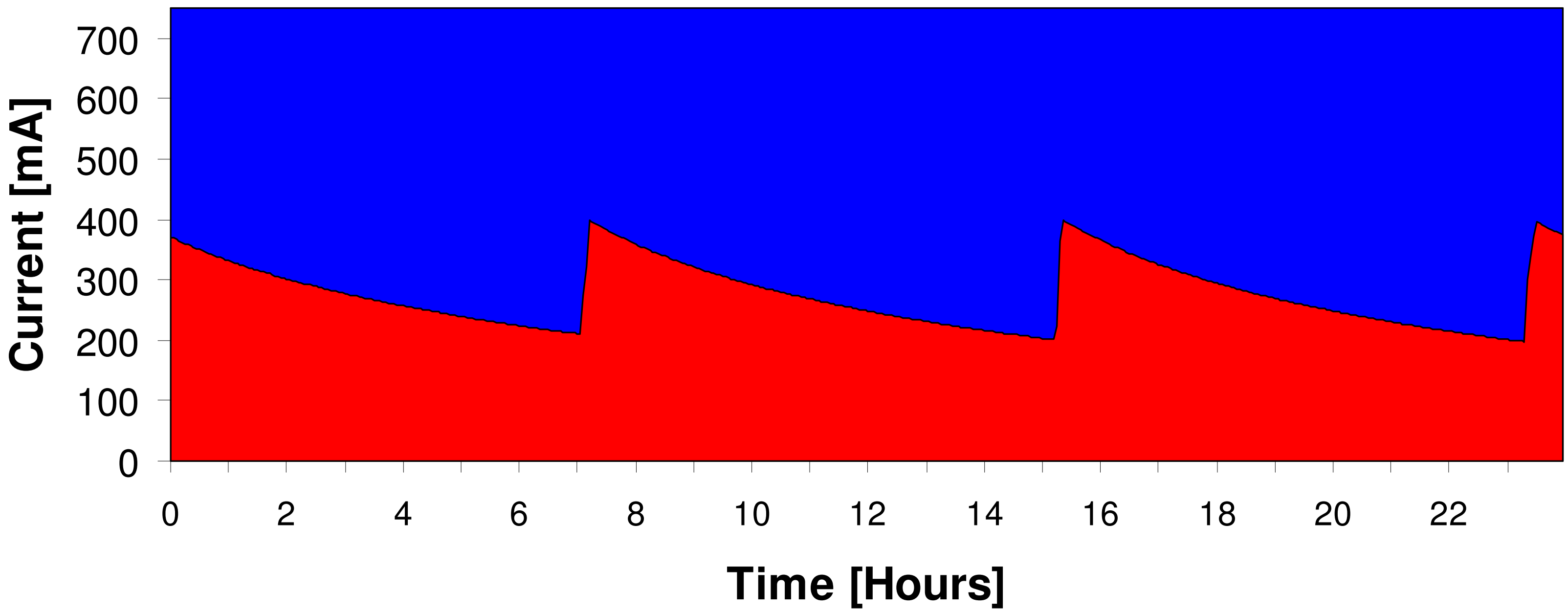


Fig.1 High power HOM damped cavity (product of collaboration between BESSY,Daresbury Lab, DELTA,MAX-Lab and NTHU)

Top-off + RF upgrade



Increase in time averaged current by a factor of 3

Increasing the brightness

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Larger beam currents

- **Increase the time averaged current by a factor of 3 from 250mA → 750mA**
  - **Top-off injection**
  - **Upgrade the RF system**
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Smaller beamsizes

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Smaller gap insertion devices

- **Reduce the magnetic gap by a factor of 3 from 14mm → 5mm**
  - **Use narrow gap permanent magnet or superconducting insertion devices.**

Present vs Upgrade brightness

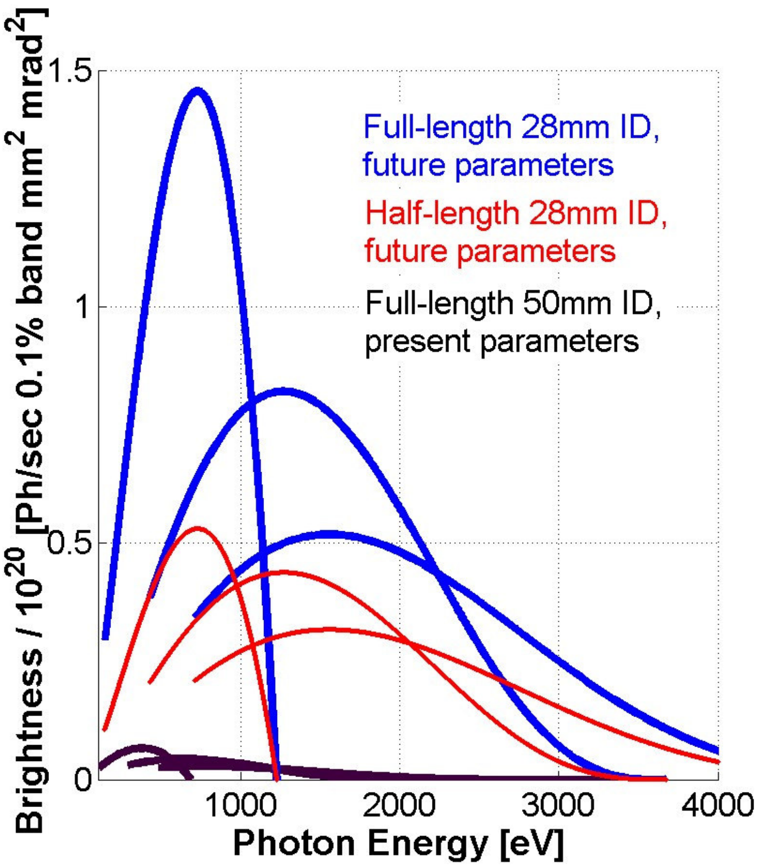
Example

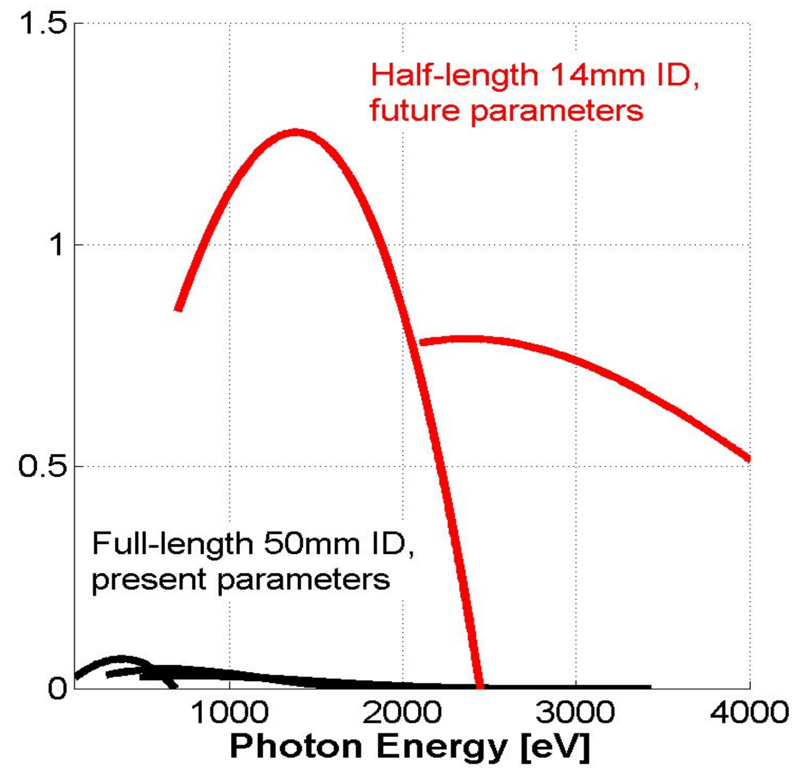
Comparison of the

- **Present work horse with present ring parameters**
  - **Existing 4.45m (full length), 50mm period device**
- **Future devices with upgraded ring parameters**
  - **4.45m (full length), 28mm period**
  - **1.9m (full length), 28 mm period**
  - **1.5m (half length), 1.4 mm period**

Photon Energy	Present Brightness	Future Brightness	Improvement
500 eV	$5.7*10^{18}$	$1.2*10^{20}$ (w/long 28 mm) $4.5*10^{19}$ (w/short 28 mm)	**20** **8**
1000 eV	$3.5*10^{18}$	$1.1*10^{20}$ (w/short 14 mm)	**32**
2000 eV	$6.1*10^{17}$	$8.6*10^{19}$ (w/short 14 mm)	**140**
4000 eV	Not accessible w/ undulators	$8.1*10^{19}$ (w/short 14 mm)	**-**

Brightness Now and After Upgrade





- In-vacuum insertion devices
- Superconducting device

Summary of "short term" brightness upgrades

- Brightness gains are achievable
  - A factor of 1 to 2 orders of magnitude in the soft x-ray regime with normal conducting ID and superconducting ID
- Increase in energy range
  - From 2000 to 4500 eV for normal conducting ID
  - From 2000 to 8000 eV for superconducting ID
- Increase in hard x-ray bend and superbend brightness
  - Factor of 8

With these improvements the ALS to compares well with the newer 3rd generation light sources (such as SLS, SOLEIL, …)

Note :

Stability requirements become tighter as one reduces the vertical beamsize

- Need to continue to improve the stability of the beam

Beam lifetime becomes shorter

- Lifetime is limited by intrabeam scattering
- Almost all changes increase the density of the bunch

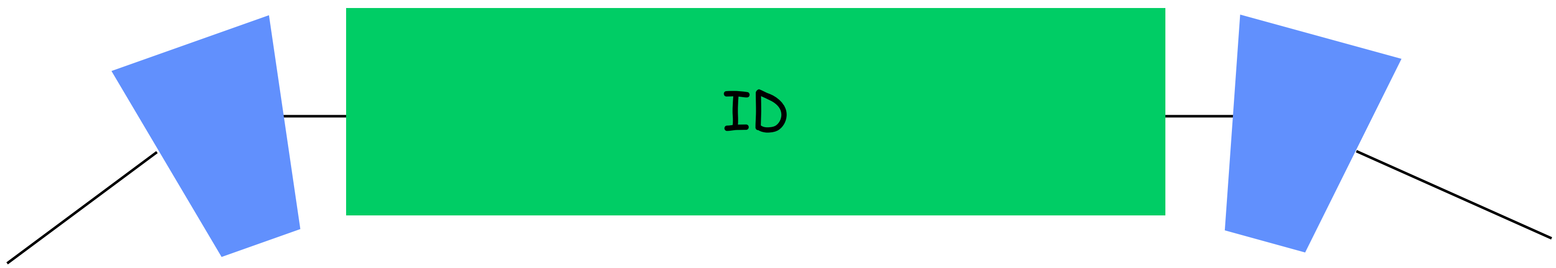
Other improvements

Increasing the insertion device capacity

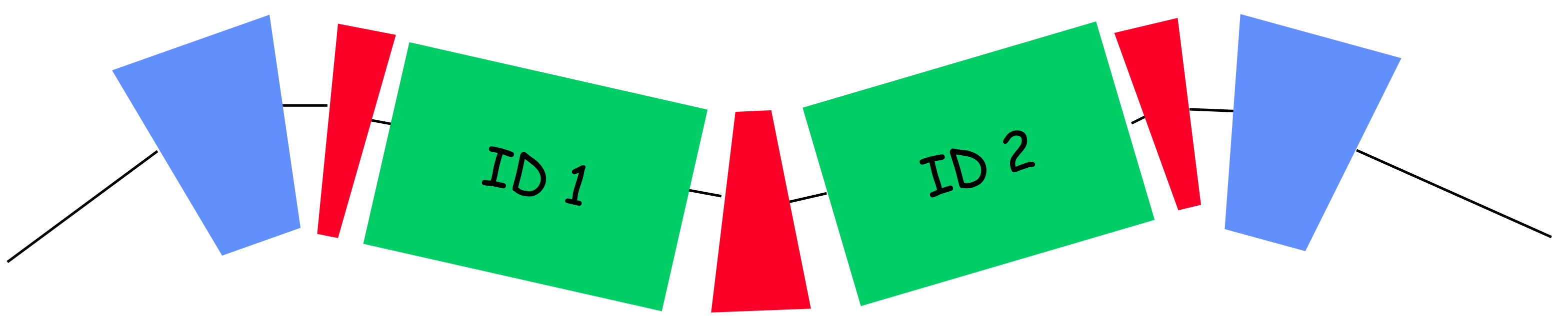
- Soon all of the 9 available straights will be occupied with insertion devices
- Insertion device beamtime is overbooked
- ALS must increase its capacity to satisfy user demand
- Most of the insertion devices are full length (4.5 meter) planer undulators
- Solution is to convert many of the ALS straights to chicaned straights with two half length insertion devices
  - Up to 5 new insertion devices
  - Already have chicaned two of the 9 straight sections
  - New insertion devices would have more capabilities than the older devices (polarization control, larger energy range, …)

Cartoon of the Chicane straight

Long straight - one 4.5 meter ID



Chicaned straight - two 2 meter IDs



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Longer Term Upgrades

Can one imagine more radical changes – Rebuilding the ring

- Smaller horizontal emittances or larger number of straight sections by redesigning the magnetic lattice
  - Theoretical emittance lattice?
- Larger beam energies

We are studying the feasibility and benefits of these longer term upgrades

Summary

There are clearly ways that the ALS can upgrade to improve its performance

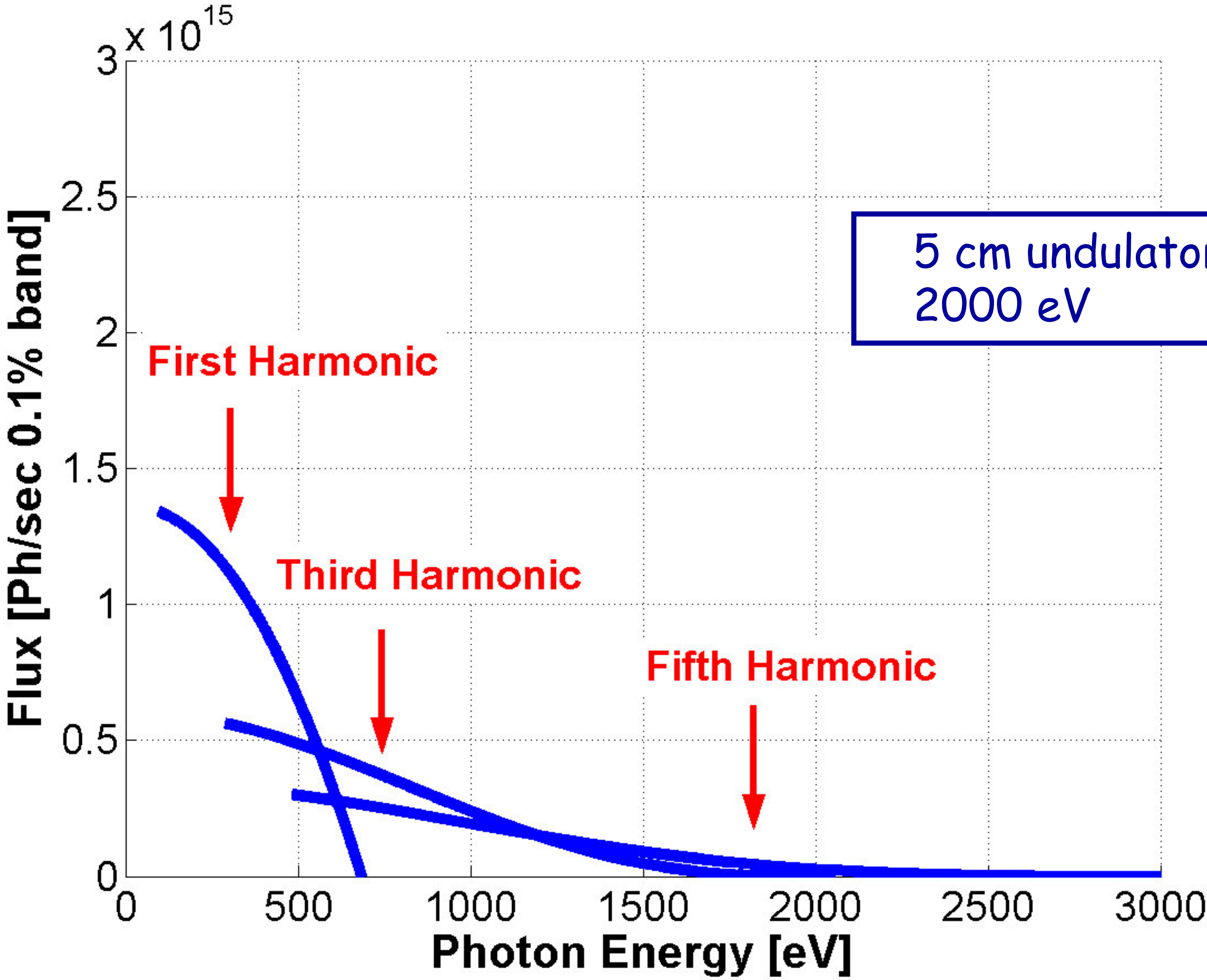
- Improve the brightness by 1 to 2 orders of magnitude in the soft x-ray regime
- Able to extend undulator operation up to much higher photon energies
- Replace the existing IDs to increase the capacity and capabilities of the facility
- Beginning to consider more radical changes to the facility

Preparation for Top off and higher current

Many items need to be studies and they can be done in parallel.

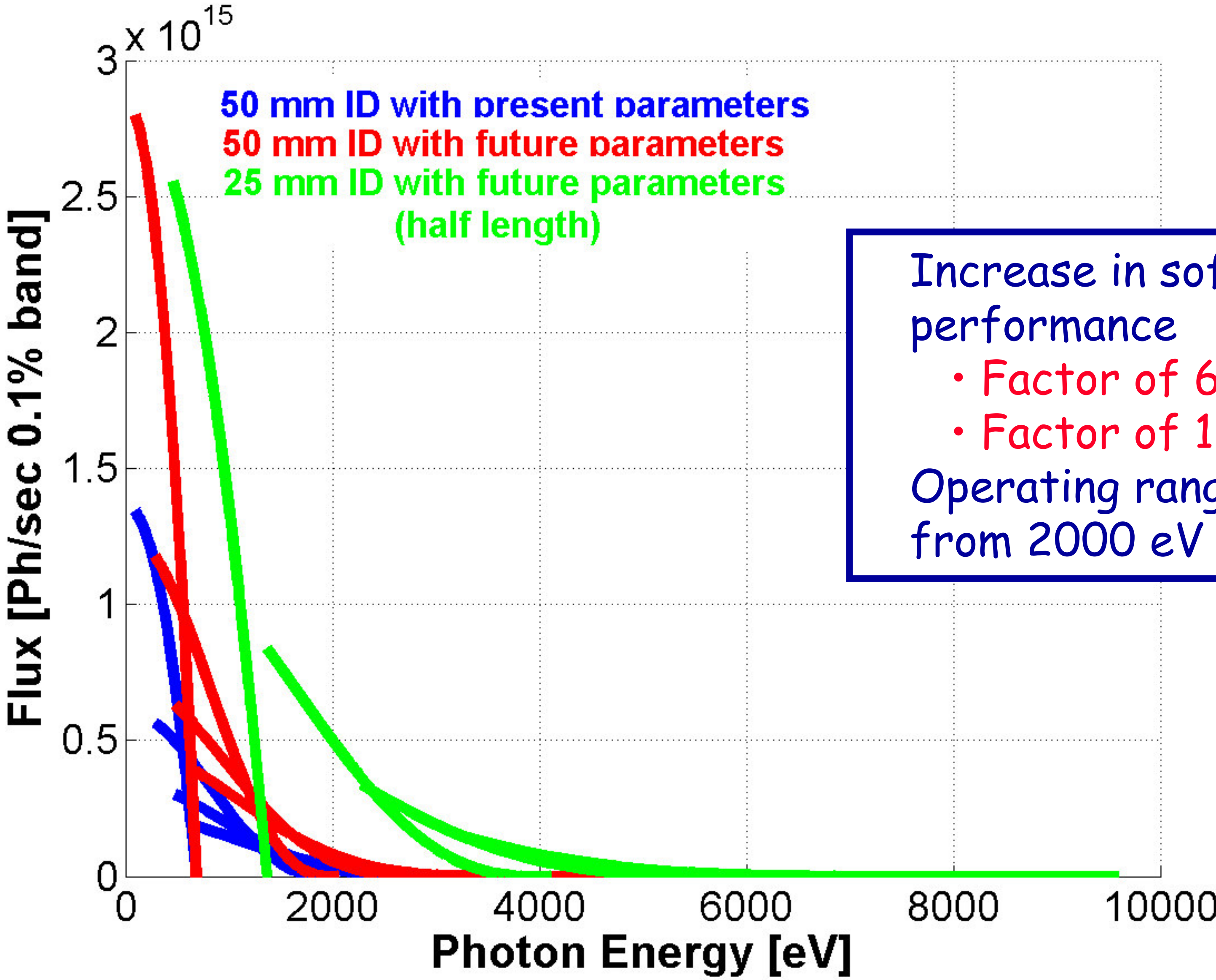
- Complete study of the injector upgrade
- Complete the study of radiation issues
- Study the effect of the injection bumps

Present Flux
Example: 50 mm undulator, 4.45 m long



5 cm undulator is used up to 2000 eV

Flux comparison
Full length 50mm and half length 25mm undulator

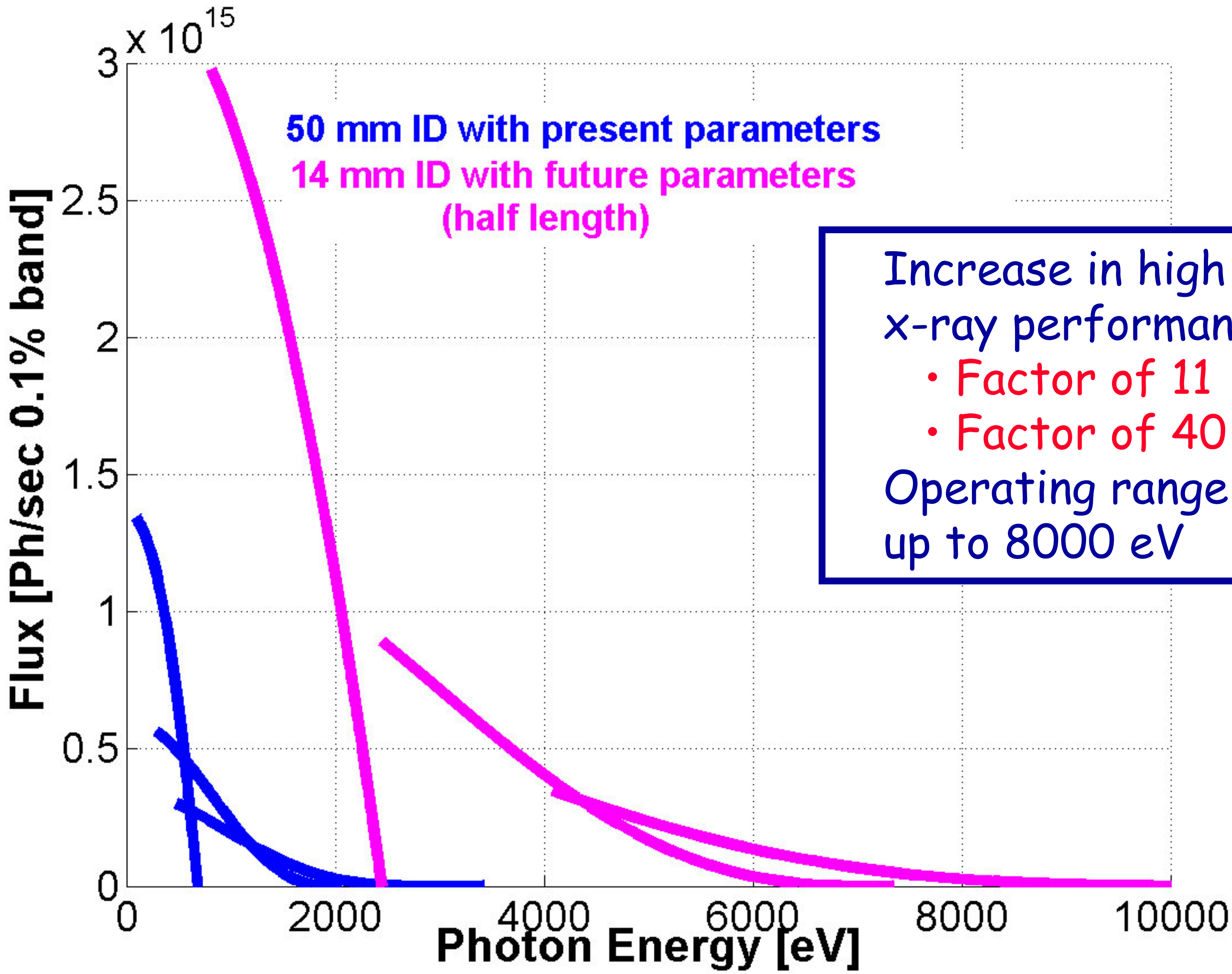


Increase in soft x-ray performance

- Factor of 6 at 1000 eV
- Factor of 12 at 2000 eV

Operating range increased from 2000 eV to 4500 eV

Flux comparison
Example: 50 mm and 14 mm s.c. undulator

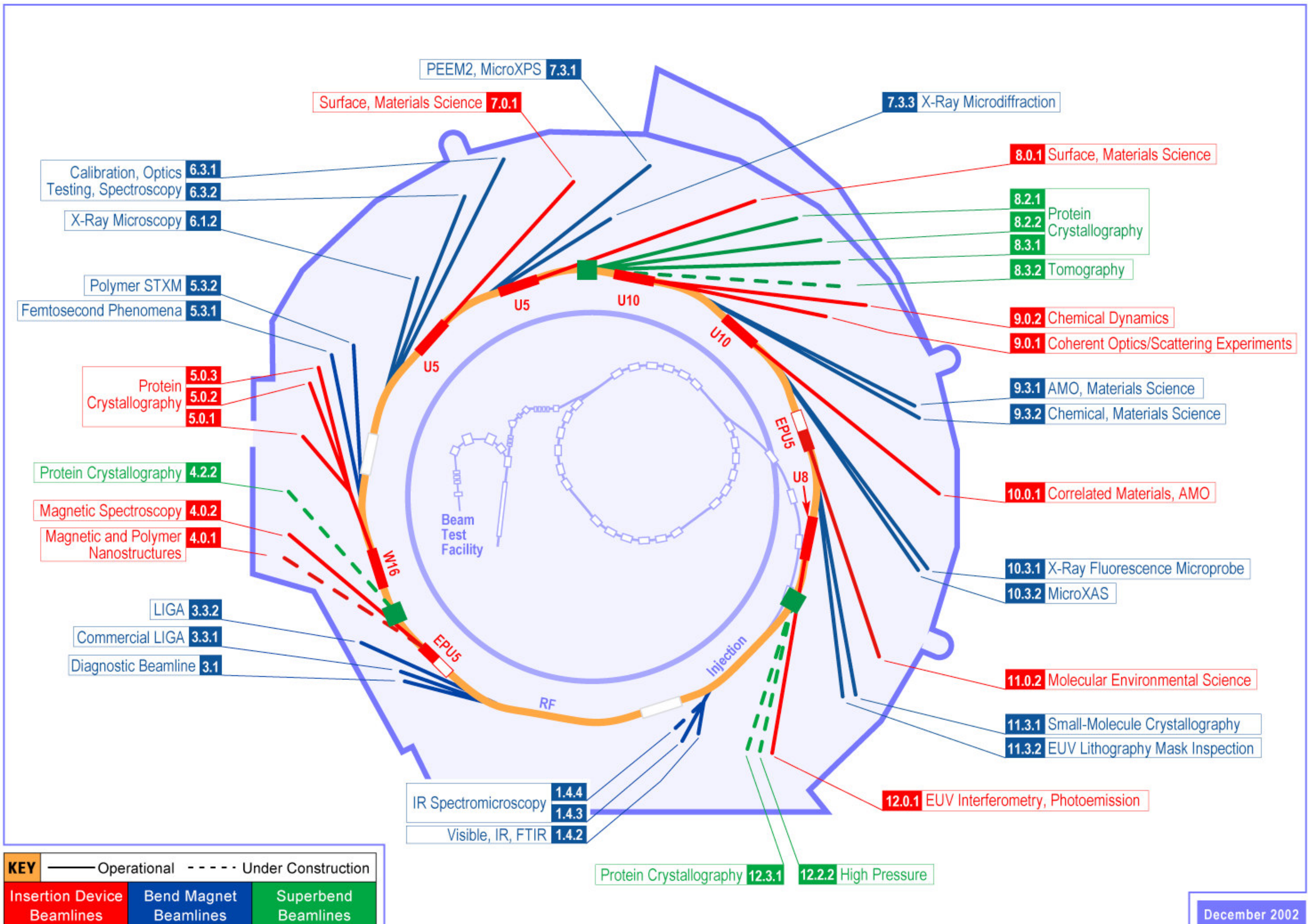


Increase in high end of soft x-ray performance

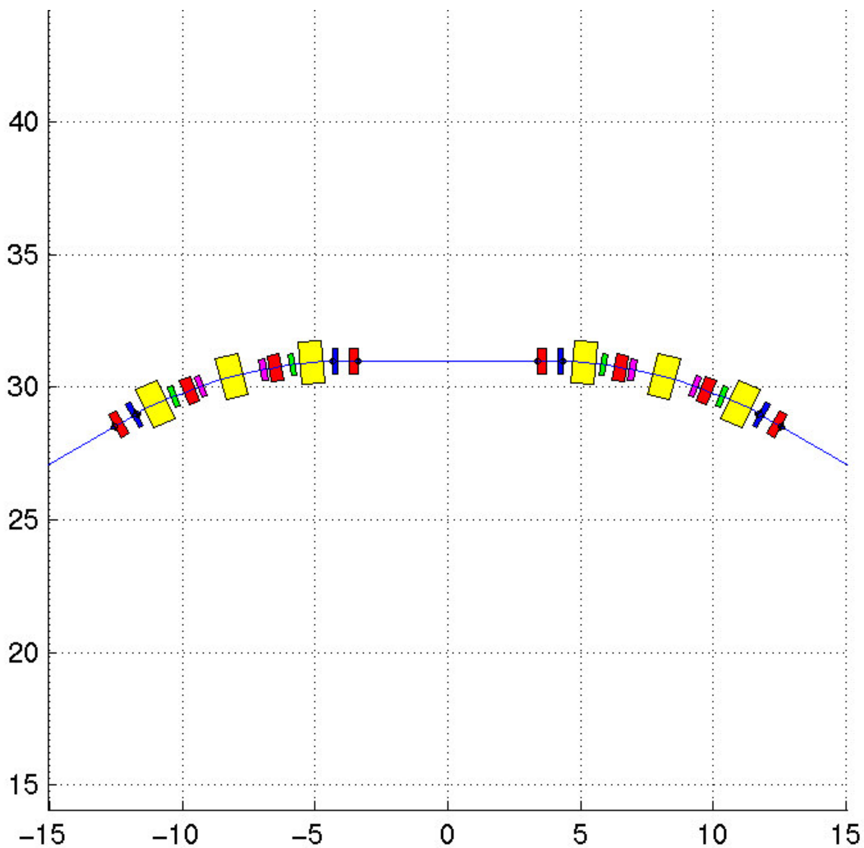
- Factor of 11 at 1000 eV
- Factor of 40 at 2000 eV

Operating range increased up to 8000 eV

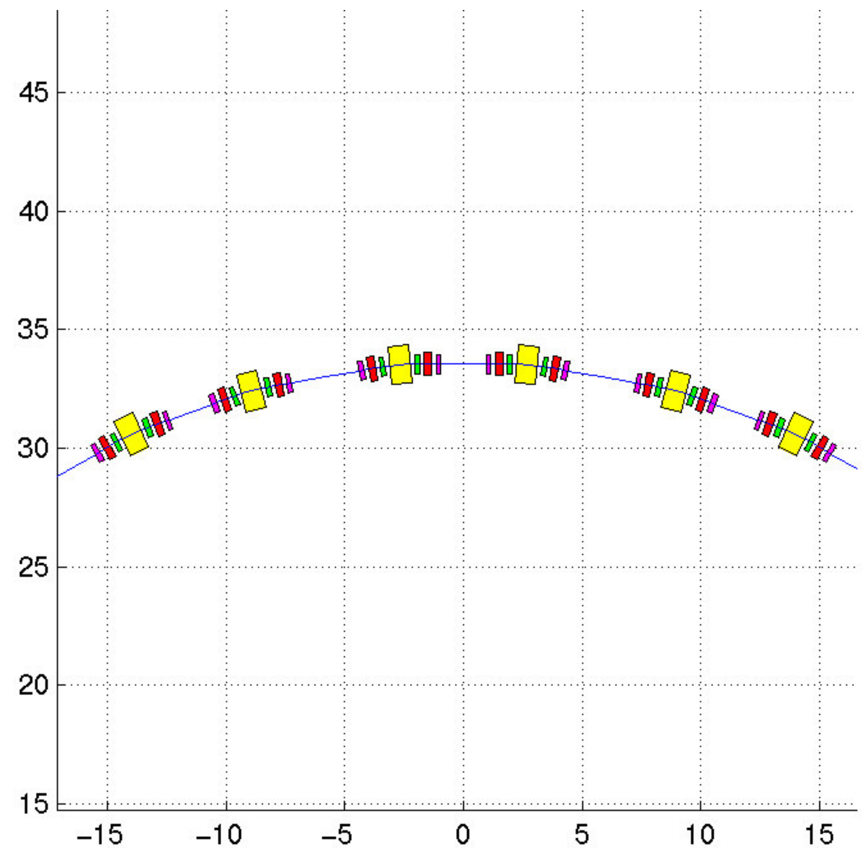
Beamlines at the ALS 2002



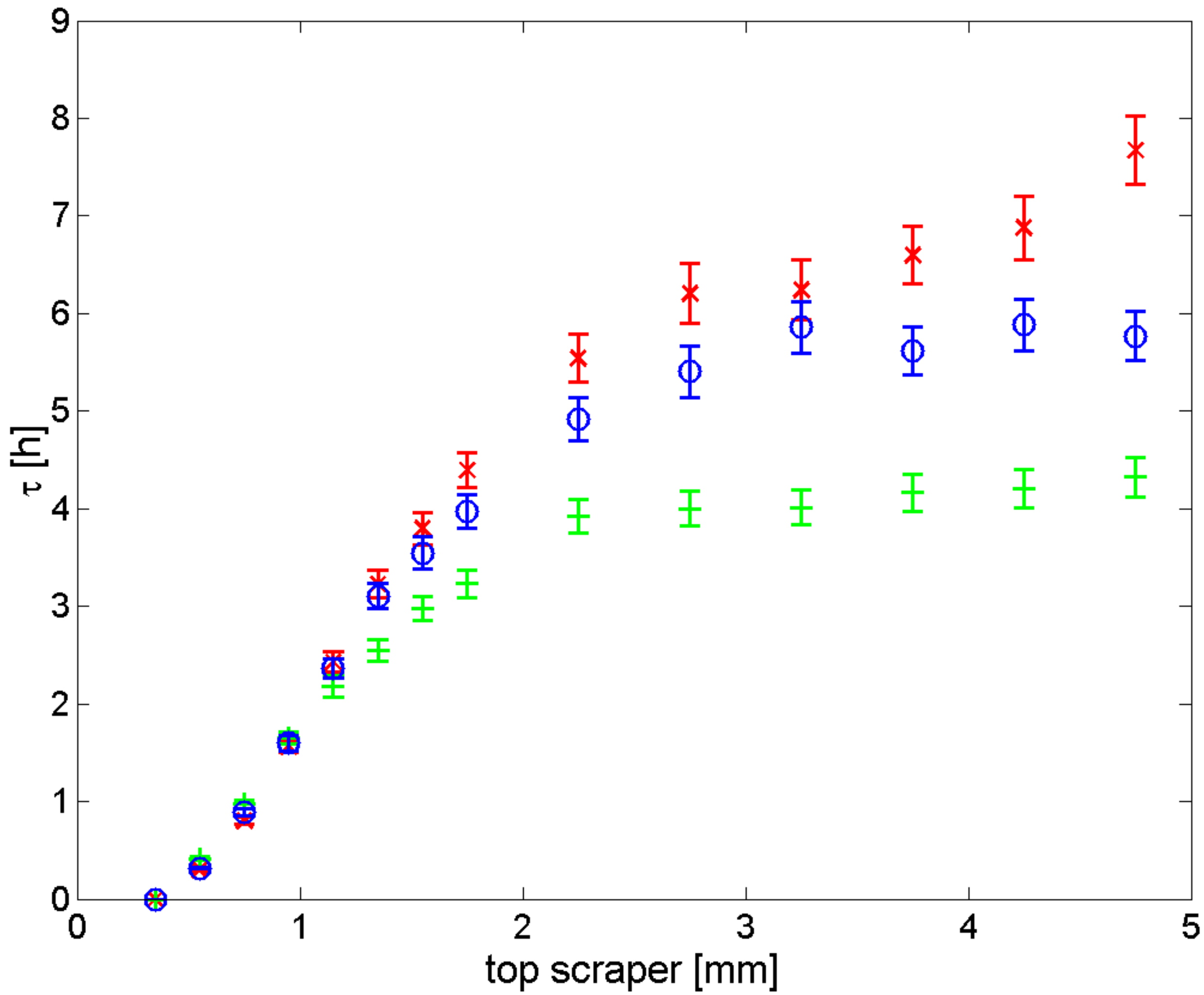
ALS triple bend achromat lattice



Theoretical minimum emittance lattice



Scraper scan



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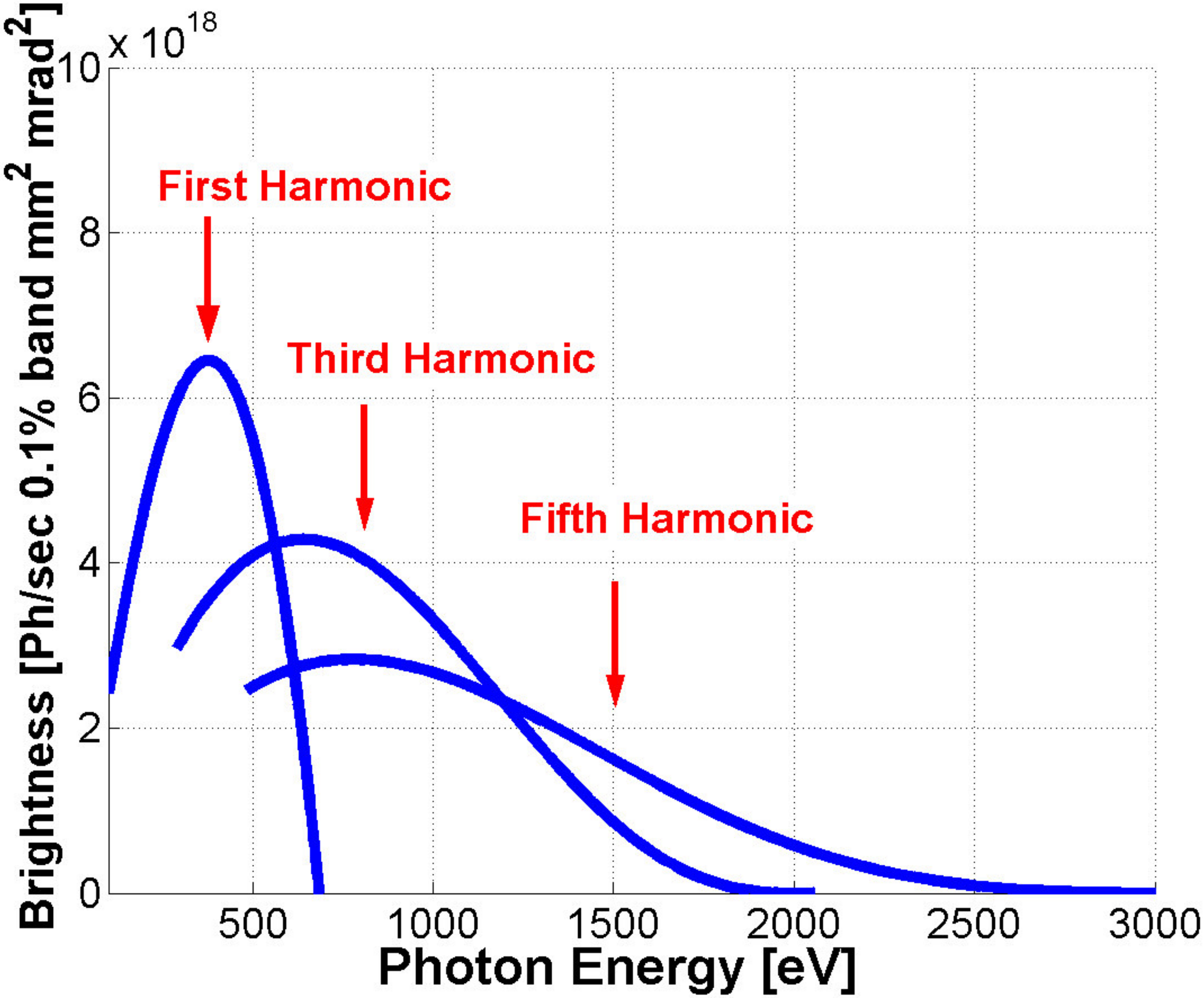

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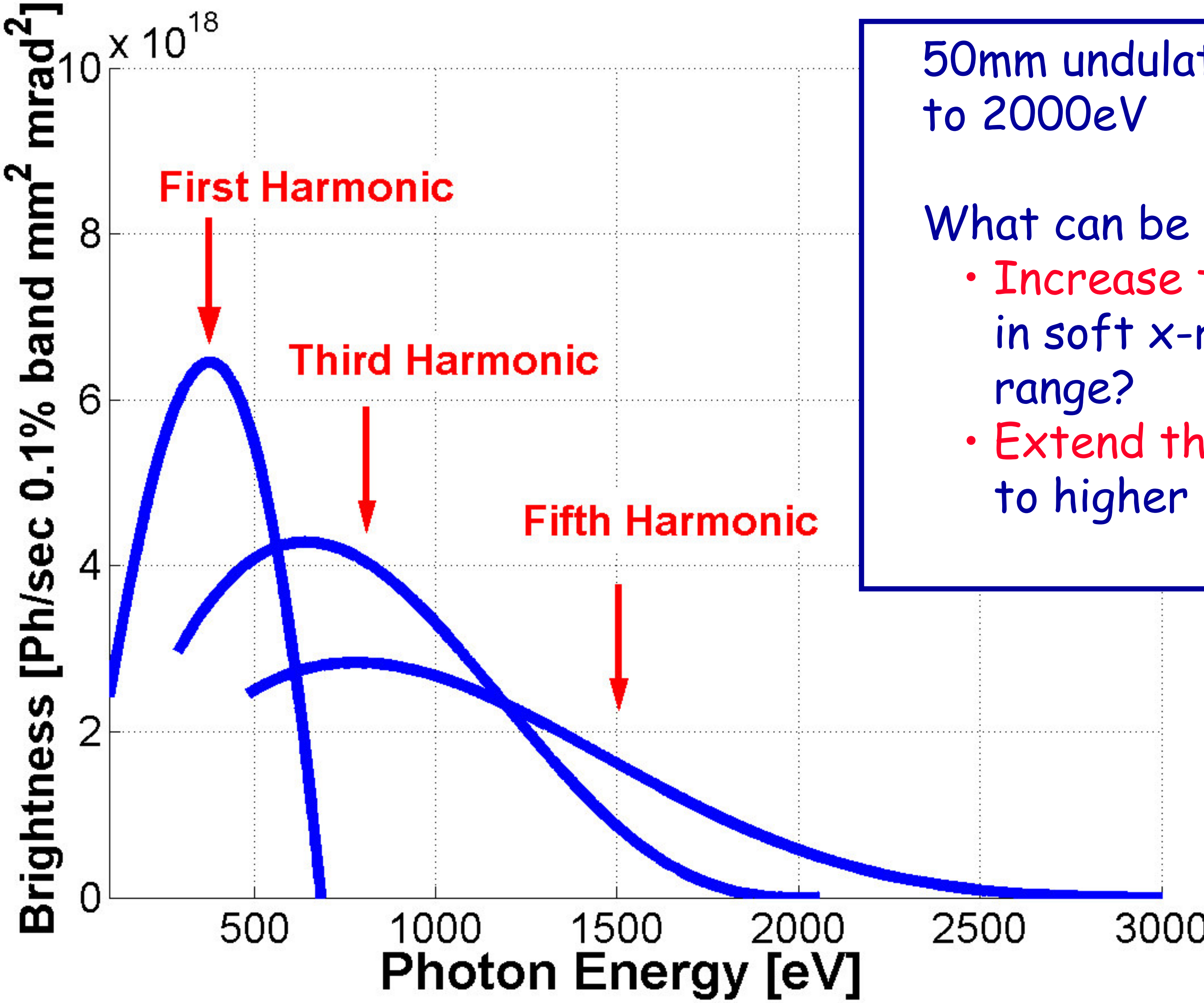


50mm undulator is used up to 2000eV

What can be done to
- Increase the brightness in soft x-ray energy range?
- Extend the photon range to higher energies?

Short term upgrade
Present and Potential Future Parameters

Several parameters can be adjusted to increase the brightness

Larger beam currents
- Can operate at 500 mA

Smaller emittances
- Have reduced the vertical emittance to 0.01 nm rad

Smaller beta functions
- Have reduced the vertical beta function from 3.6 m to 2.3 m

Smaller vertical gap vacuum chambers
- Smallest vacuum chamber height for the ALS is 8.9 mm
- Have reduced the gap (with scrapers) to 5 mm

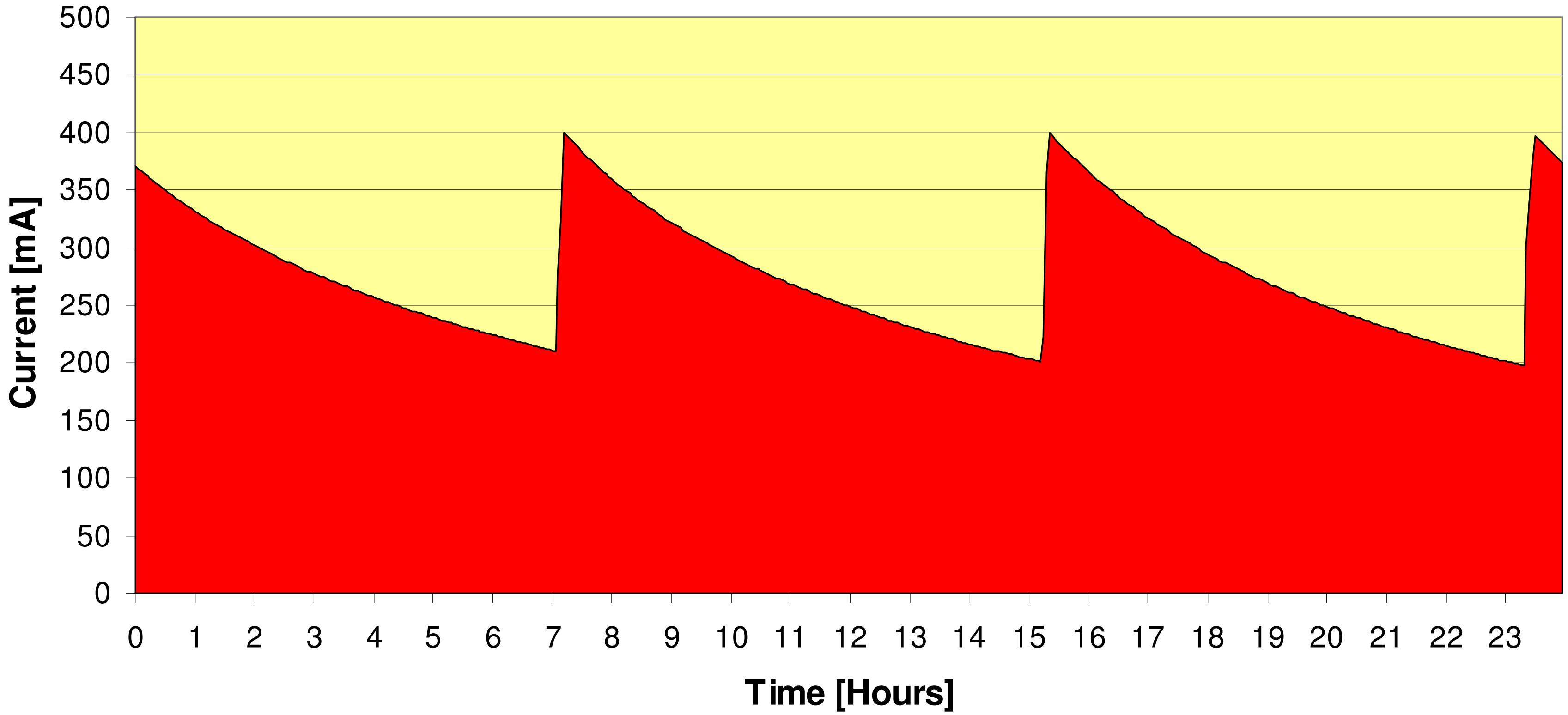
Smaller gap insertion devices
- Magnetic gap of the 50 mm period undulators are 13.9 mm
- Could reduce the magnetic gap (to nearly 5 mm with an in vacuum insertion device)
    - Use smaller period undulators
        - Recent developments allow use of in vacuum IDs (5-6mm) – ESRF, SPRING 8, SLS, NSLS

Summary of improvement factors

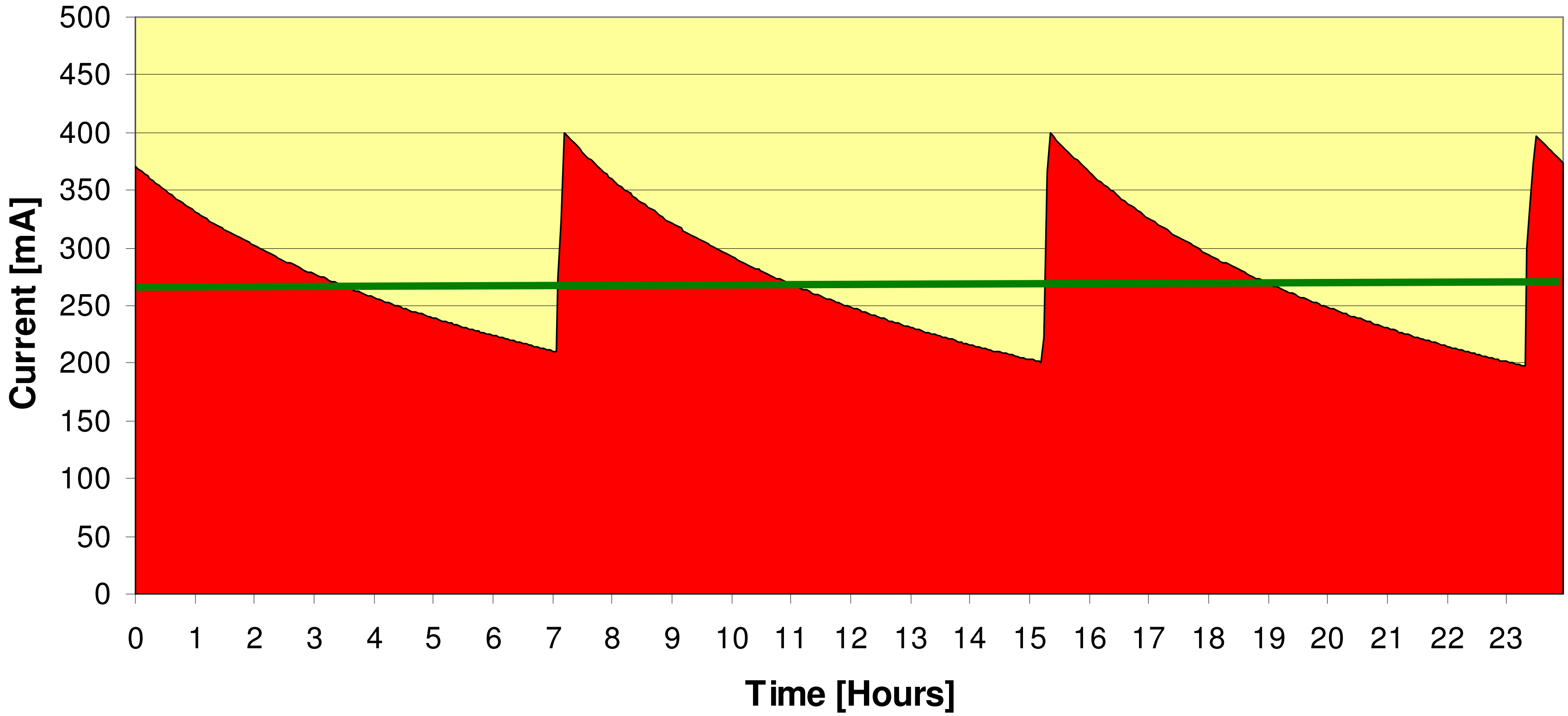
Parameter	Present	Future	Improvement factor
Vertical emittance [nm-rad]	0.15	0.01	15
Time averaged beam current [mA]	260	500*	2
Vertical β-function in straights[m]	3.6	2.3	1.5
Vertical magnetic gap [mm]	14	5	3

* If we go to continuous top-off injection

Beam current (one day history)



Time averaged current



260 mA time averaged current

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Brightness comparison
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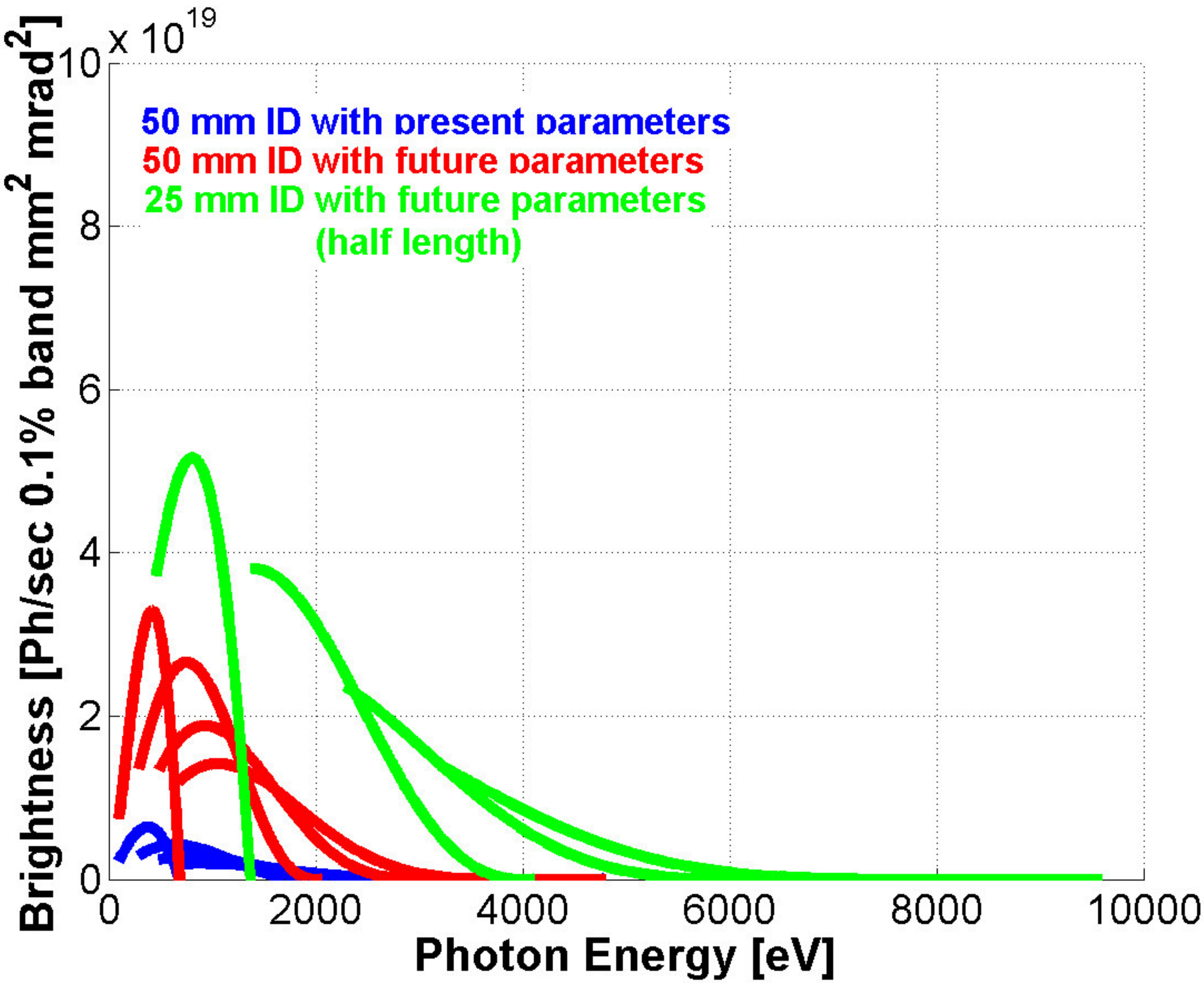

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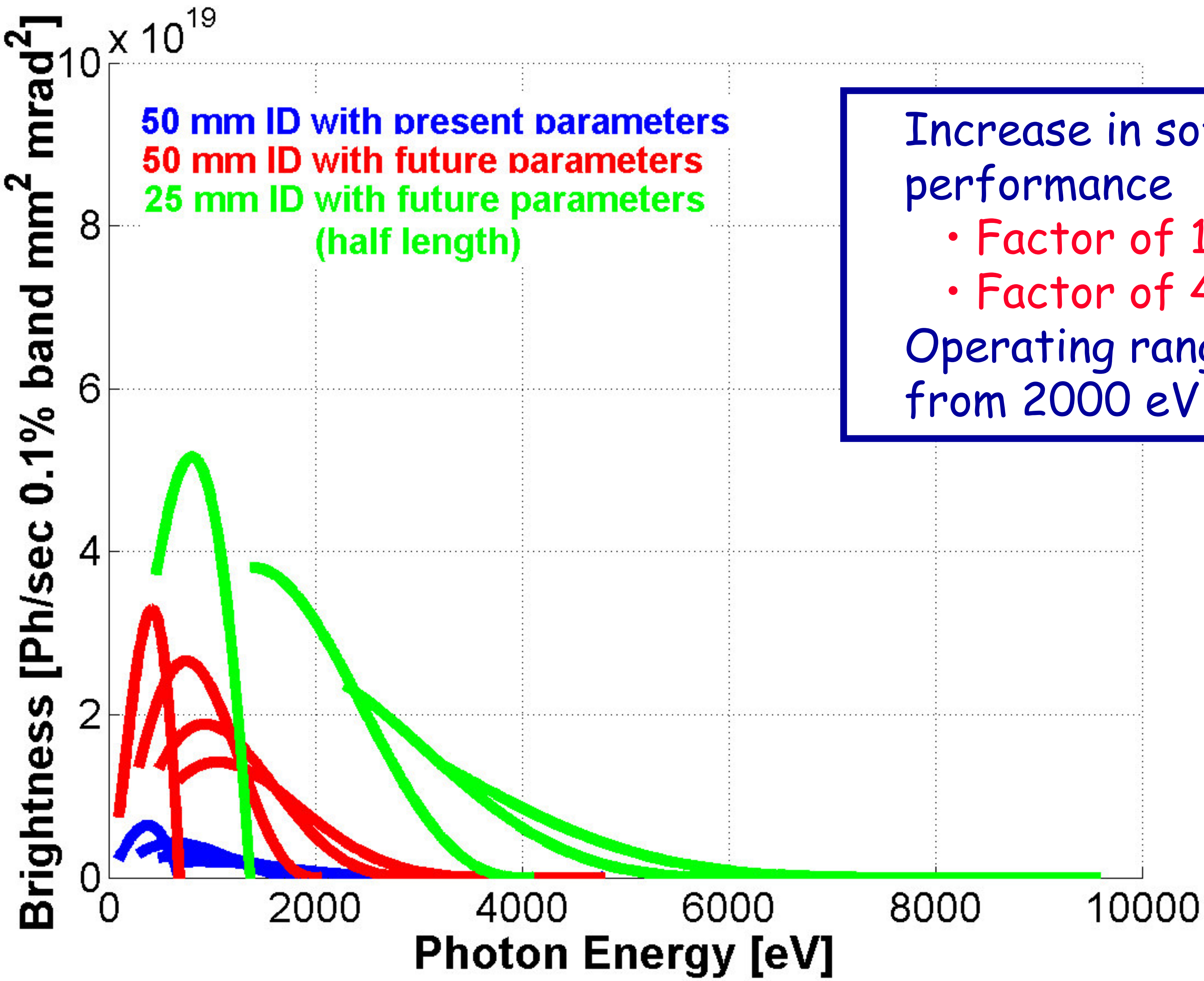


Increase in soft x-ray performance
- Factor of 10 at 1000 eV
- Factor of 40 at 2000 eV

Operating range increased from 2000 eV to 4500 eV

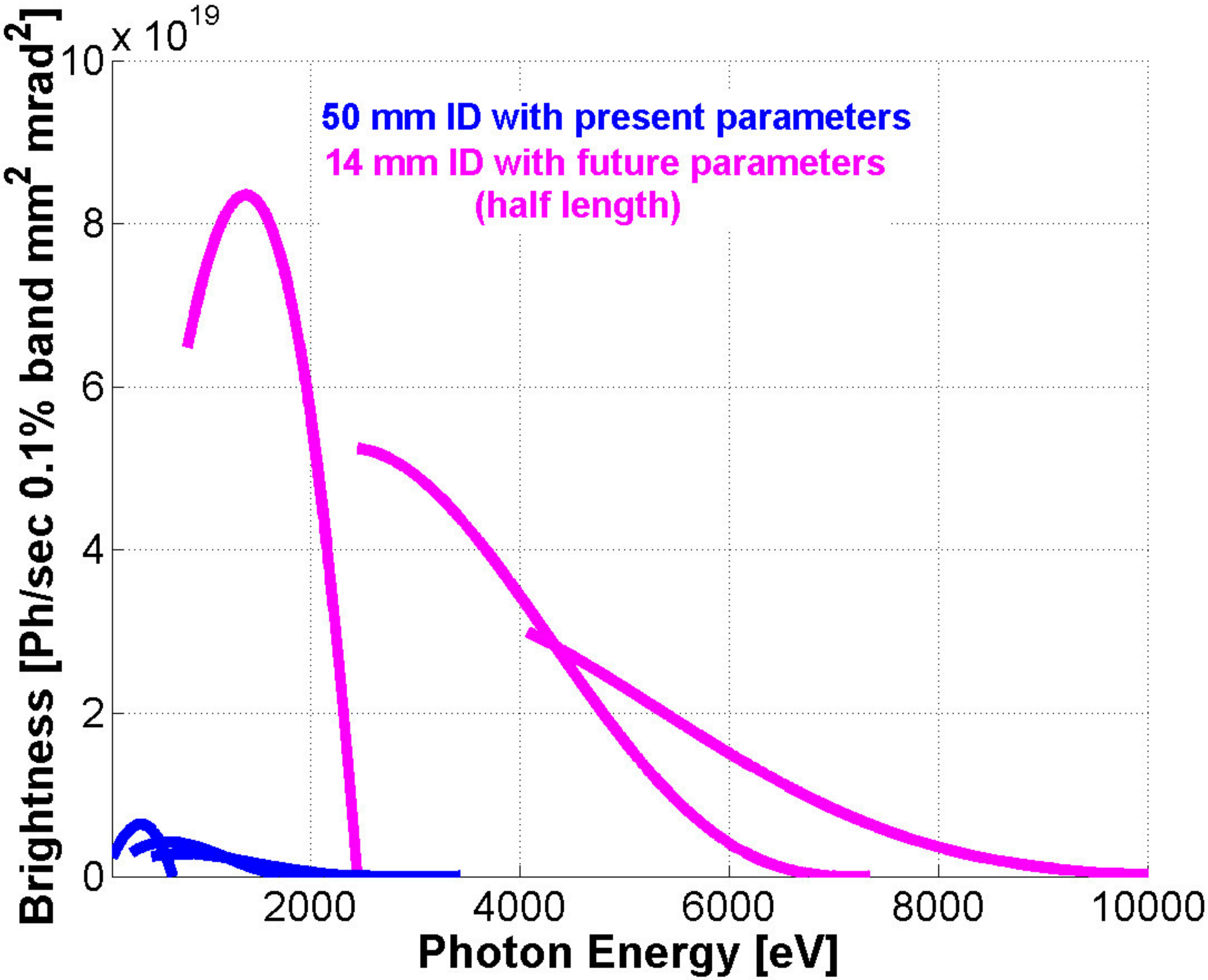
New Insertion Devices

Superconducting undulators (s.c.)

Superconducting undulators have the promise to outperform permanent magnet devices

- ACCEL is building a 1.5Tesla device, 14mm period, with 5mm gap
- New materials have the promise of even larger fields
  - Expertise of LBNL supercon group

Brightness comparison
Example: 50mm and 14mm s.c. undulator



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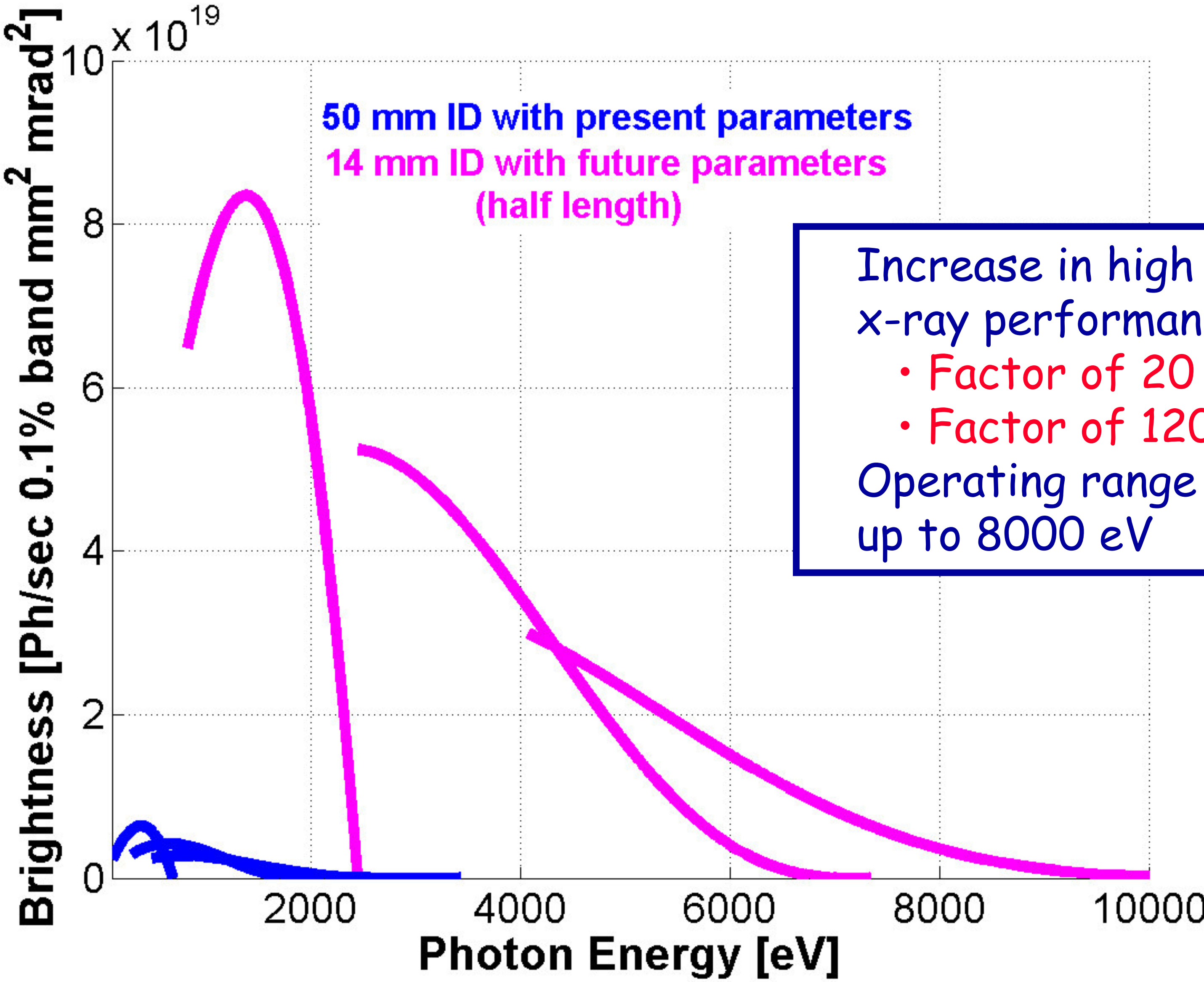

Increase in high end of soft x-ray performance

- Factor of 20 at 1000 eV
- Factor of 120 at 2000 eV

Operating range increased up to 8000 eV