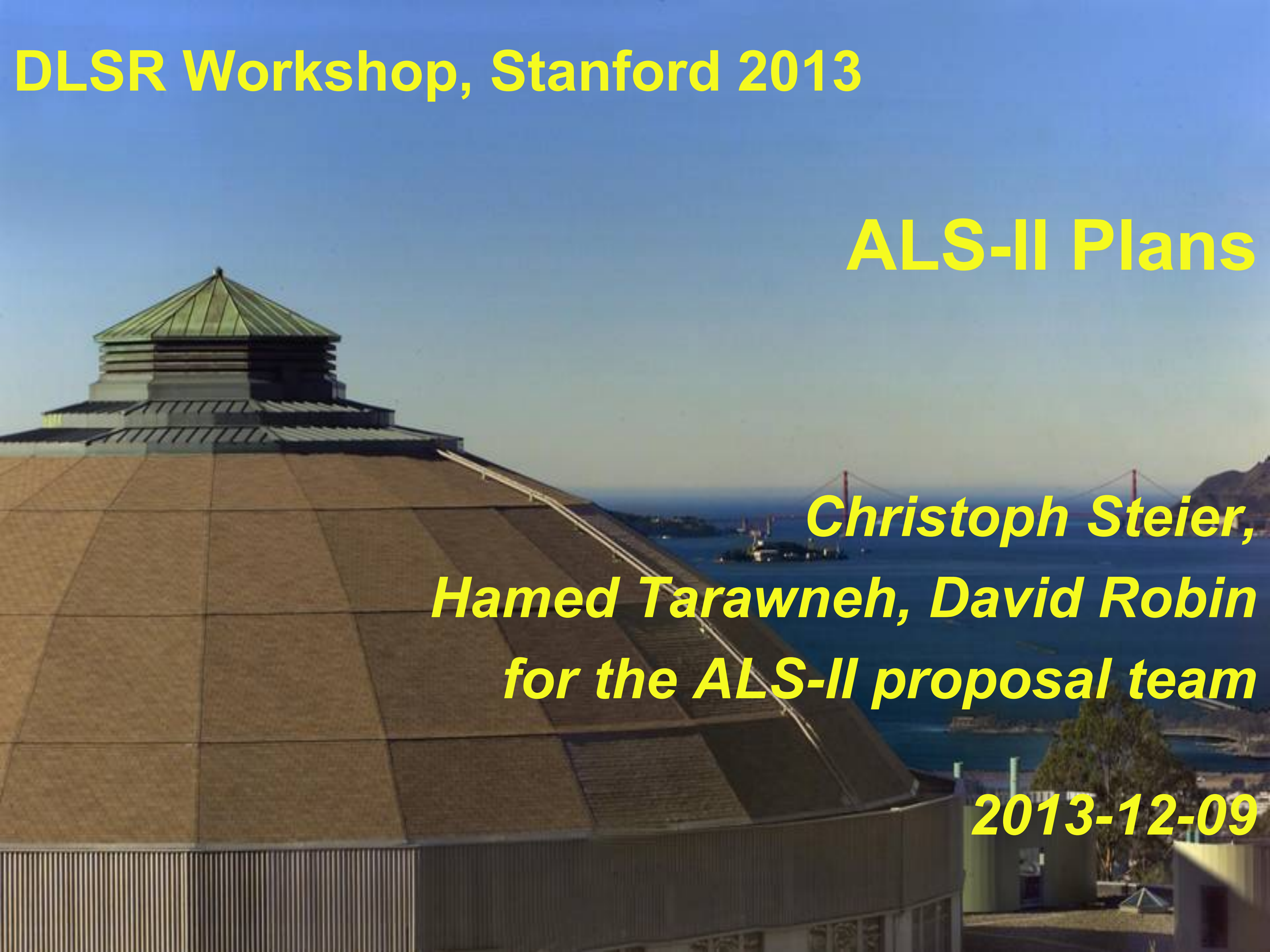


DLSR Workshop, Stanford 2013

ALS-II Plans

Christoph Steier,
Hamed Tarawneh, David Robin
for the ALS-II proposal team

2013-12-09

Outline

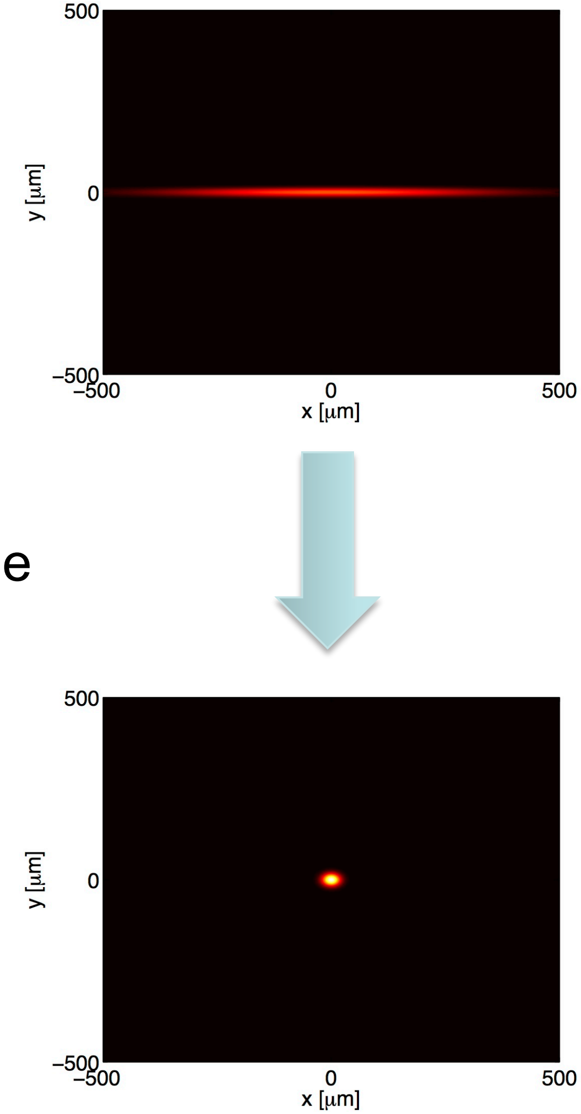
- Diffraction Limited Storage Rings
  - International Context
- ALS-II Proposal
  - Goals
  - Hardware Layout
  - Performance Projections
  - Examples of Accelerator Physics Challenges
- Proposal Development
- Summary

Recent Advances Enable Ultra-Bright Rings

- Storage ring light sources have not reached their practical limits of brightness and coherence.
- Dramatic improvements are on the horizon due to transformational advances in accelerator design.

- What’s Changed:
  - Tightly-packed multi-bend achromat lattices via new magnet and vacuum technology.
  - Success of top-up, better understanding of storage ring scaling, advances in simulation, optimization, and alignment.

- High confidence that diffraction-limited rings are feasible.
- International community is now upgrading existing facilities and building new facilities with diffraction limited capability that will enable new science.



International Context : Activity towards brighter storage rings

Under construction

BNL**: NSLS-II** (2014): 3 GeV, 1100 pm (500pm) x 8 pm, 300(500) mA (**New**)

Sweden: **MAX-4** (2016): 3 GeV, 230 pm x 8 pm, 500 mA (**New**)

Brazil**: SIRIUS** (2016/17): 3 GeV, 280 pm x 8 pm, 500 mA (**New**)

Advanced design stage

Japan**: SPRING-8-II (**2019): 6 GeV, 67 pm (**Upgrade**)

ESRF
Upgrade Programme
2009-2018

France: **ESRF-II** (2019): 6 GeV, 160 pm x 3 pm, 200 mA (**Upgrade**)

APS-II and ALS-II proposal

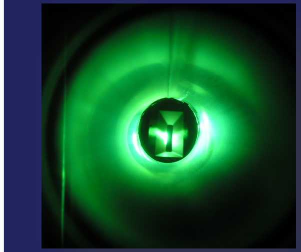
APS-II: 6 GeV, 60 pm x 2 pm, 200 mA (**Upgrade**)

ALS-II: 2 GeV, 52pm x 52pm, 500 mA (**Upgrade proposal**)

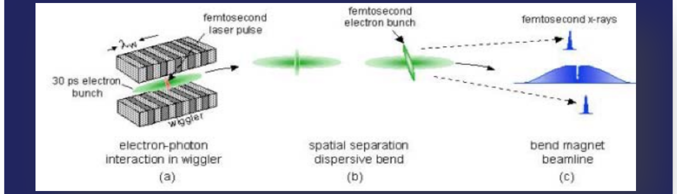
In addition China (BAPS), Switzerland (SLS) and others are developing plans for DLSR

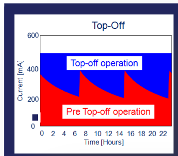
Pioneering accelerator upgrades allow for a brighter, more capable ALS

first light

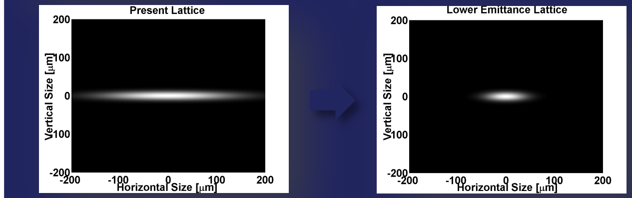


production of short femtosecond X-ray pulses





top-off at 500 mA brightness upgrade

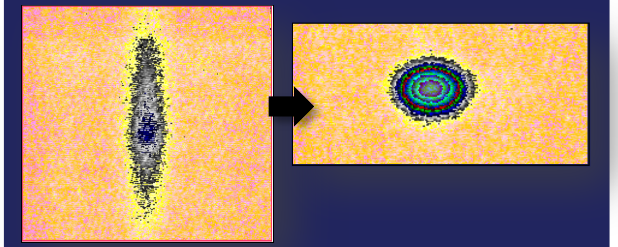


1993

2003

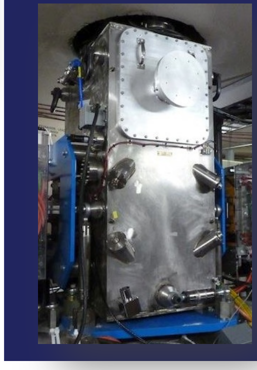
2013

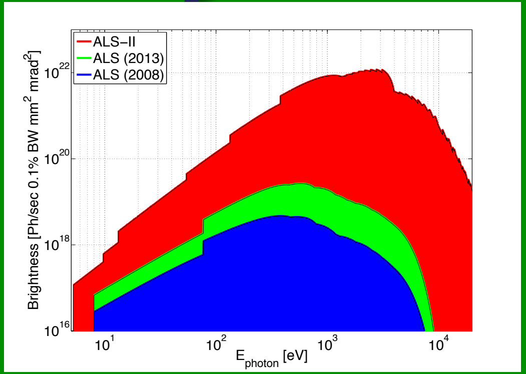
2023



multibunch systems allow stable beams, much higher brightness

superbend → hard X-ray



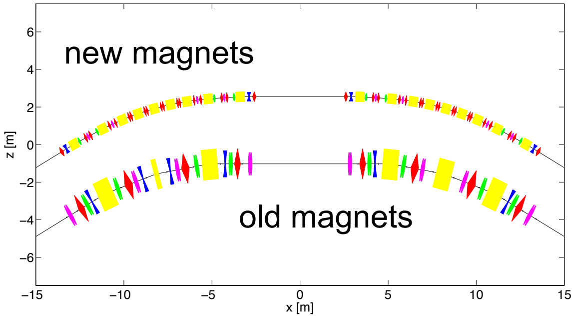


what will the upgrade to 100x brightness look like?

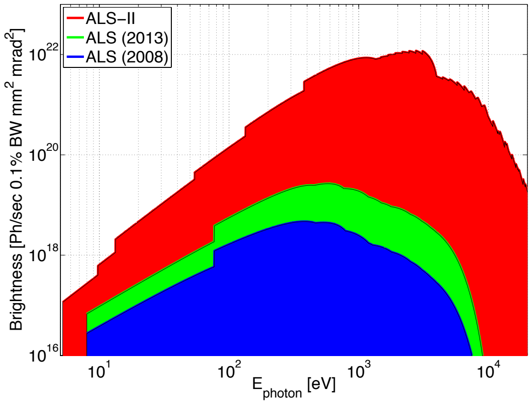
ALS-II Goals (tentative)

1. Reduce the horizontal emittance from 2000 pm to about 50 pm and optimize the beta functions
2. Maintain the existing ID straight sections in their current state
3. Maintain the existing bending magnet beamlines
4. Preserve the almost constant multibunch current at 500 mA
5. Further improve excellent Beam Stability (Electron+Photon)
6. Preserve single bunch capability
7. Upgrade injection system for on-axis swap-out injection
8. Reuse existing hardware when effective for cost+performance
9. Operate with costs comparable to present ALS
10. Limit the downtime for installation and commissioning to about one year.

Science at a (soft x-ray) Diffraction Limited SR

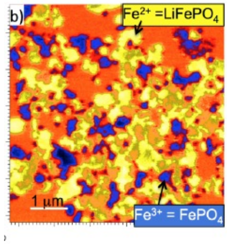


Upgrade of ALS to diffraction limit



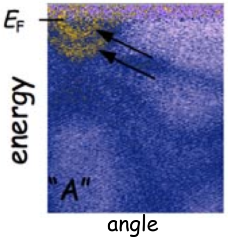
100x increase in brightness

Diffraction Limit upgrade on a 200m circumference ring enables nanoscale microscopes with chemical, magnetic, and electronic resolution



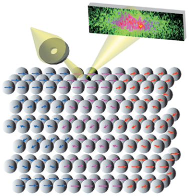
Chemical Maps

From 20 nm to 2 nm; from 2D to 3D
Resolve nano-interfaces in a cathode
Observe the flux in a catalytic network



Electronic Maps

nanoARPES of complex phases
at 25 nm resolution

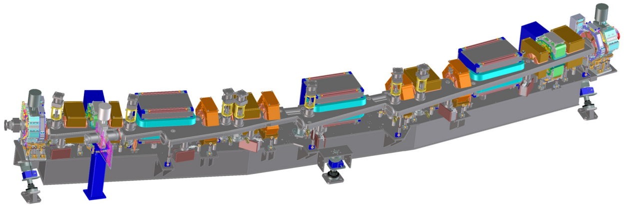


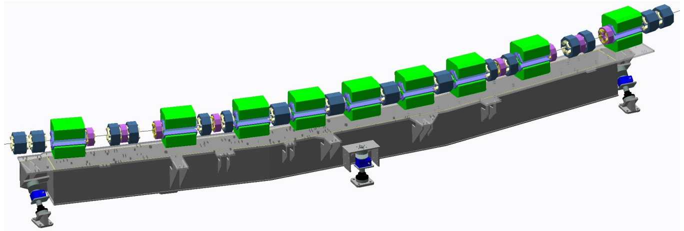
Magnetic Maps

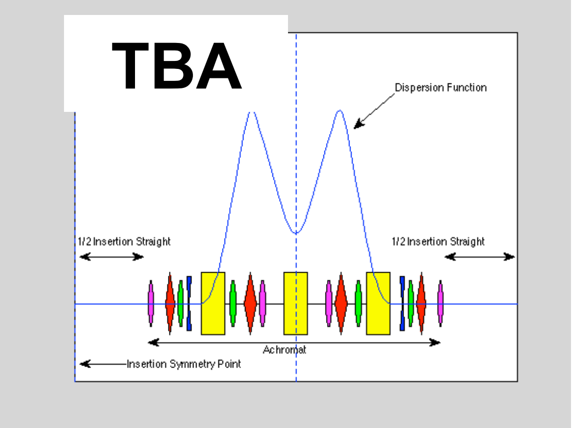
Thermally-driven domain fluctuations
imprinted in speckle at nm resolution

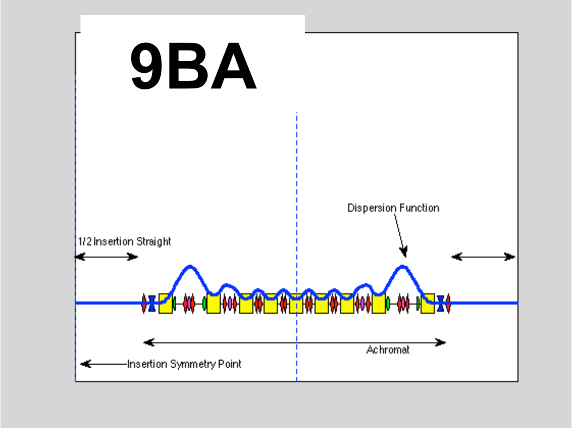
Multi-bend achromats pave way to the diffraction limit

Lattice design of ALS evolved from a triple-bend achromats (TBA) to a multi-bend (9BA) achromat for ALS-II. Result is a large reduction in emittance, $\varepsilon_x = \sigma_x \sigma'_x$









MBA: Strong Focusing and Low Dispersion

First used for MAX-IV.

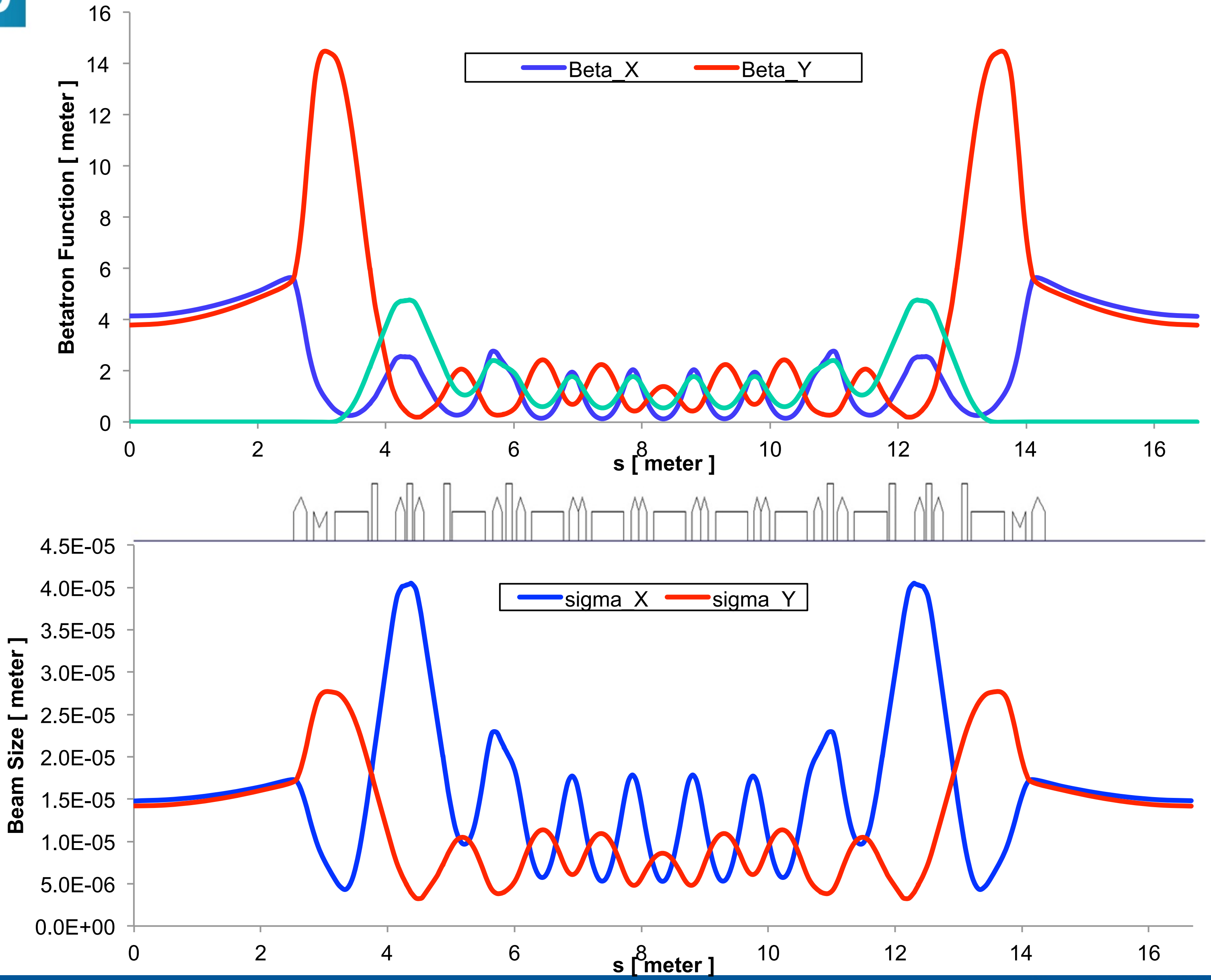
$$\varepsilon_x = \boxed{2000\text{ pm}} \;@\; 1.9 GeV$$

$$\varepsilon_x = \boxed{52\text{ pm}} \;@\; 2.0 GeV$$

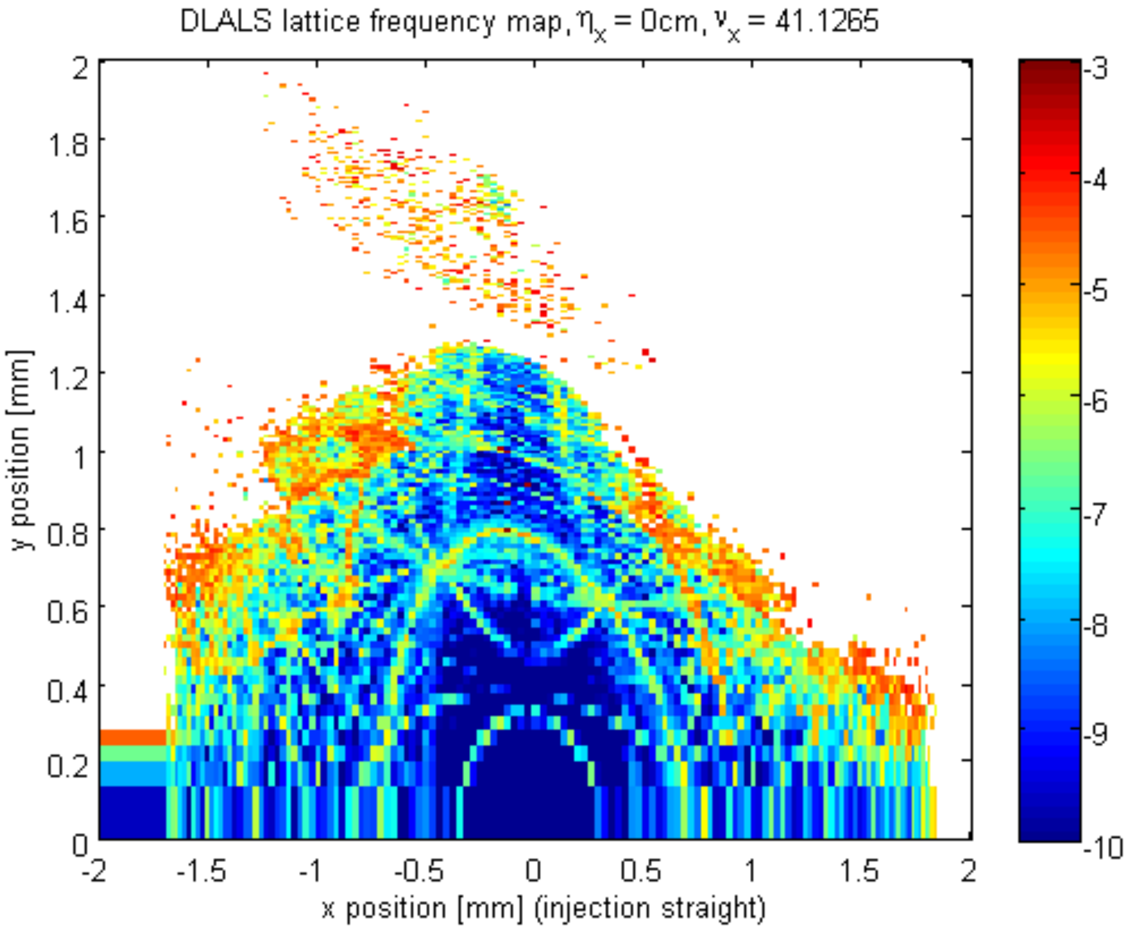
$$\varepsilon_x = C_L \frac{E^2}{\boxed{N_D^3}}, \qquad \varepsilon_x \propto \frac{E^2}{C^3}$$

C_L = lattice constant
N_D = # dipoles
C = Circumference

Betatron Functions & Beam Sizes of Candidate Lattice

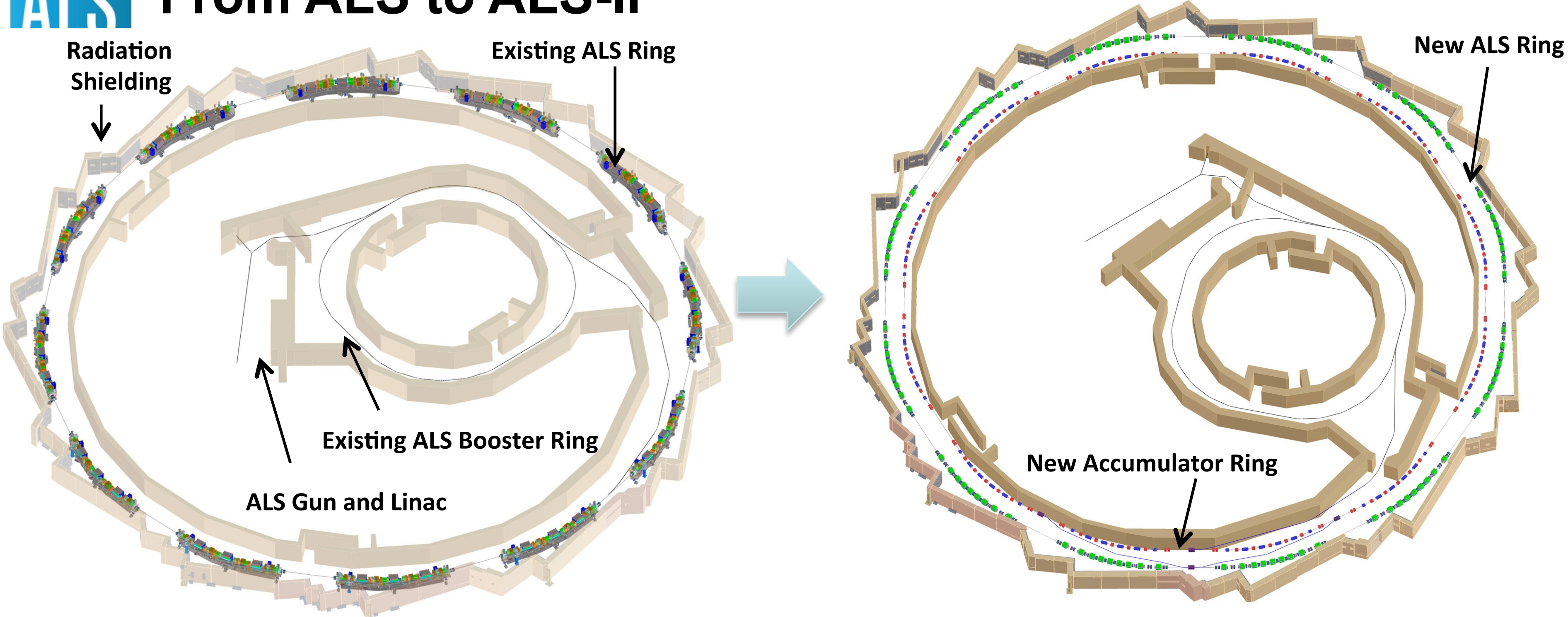


Nonlinear Dynamics



- Using genetic algorithms for lattice optimization
- Nonlinear dynamics with initial optimization looks very promising
- Dynamic aperture appears sufficient (>100 $\sigma_{x,y}$) for on-axis injection of small emittance beam and sufficient Touschek lifetime.

From ALS to ALS-II

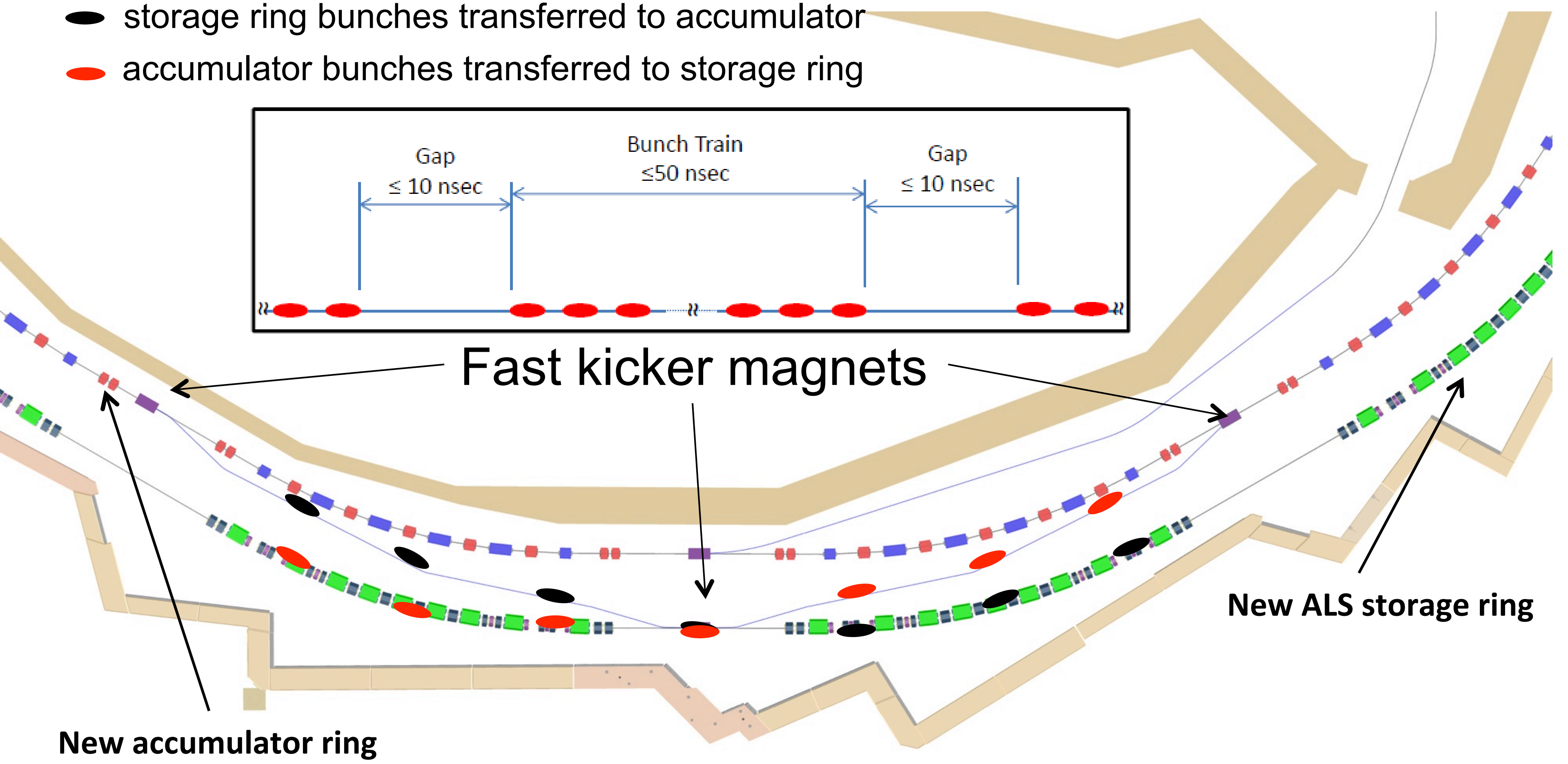


- New high performance storage ring based on multi bend achromat (9 bends per arc) in same building and tunnel
    - Same circumference, straight section length, location and symmetry
- Injector upgrades:
    - Full energy accumulator ring in shared storage ring or booster tunnel
- Optics, Undulator, conventional facilities, detector upgrades, …
    - Scope + timing to be decided

Swapping beam accumulator and storage ring bunch trains

● storage ring bunches transferred to accumulator

🔴 accumulator bunches transferred to storage ring



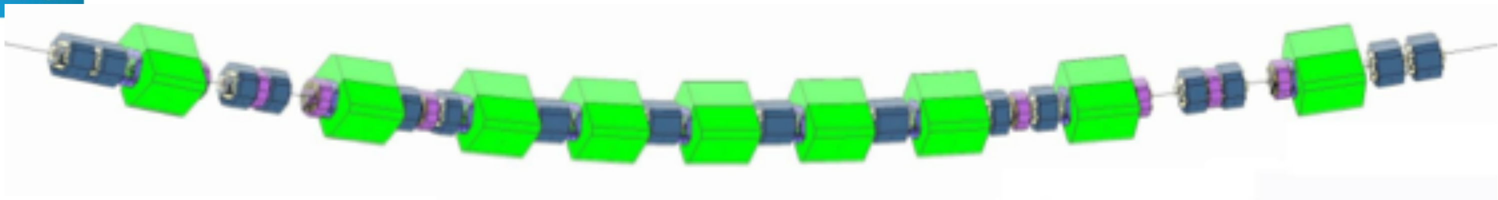
Fast kicker magnets

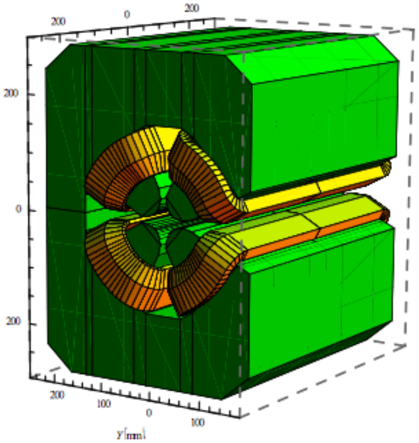
New ALS storage ring

New accumulator ring

Swap-out injection was first proposed by M. Borland for possible APS upgrades

Example Magnets: One sector (1/12 of the ring)

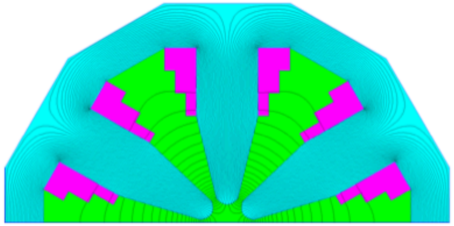




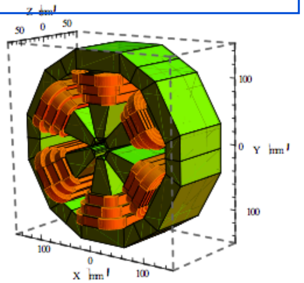
High gradient quadrupoles and sextupoles

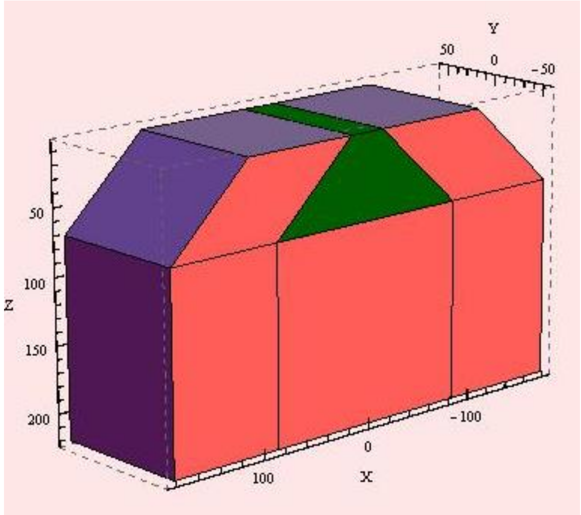
100 T/m

Superbend insertions



$3000\ \mathrm{T/m^2}$





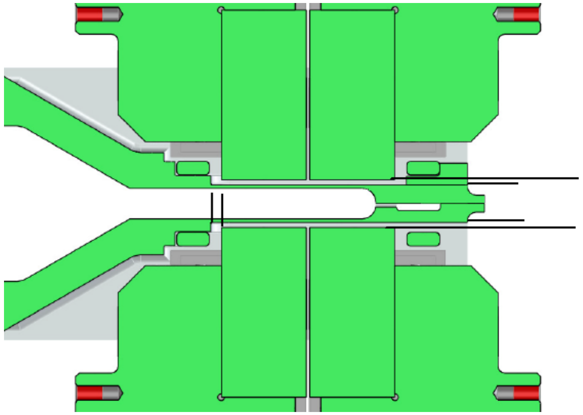
Gradient dipoles

0.78 T & 50 T/m

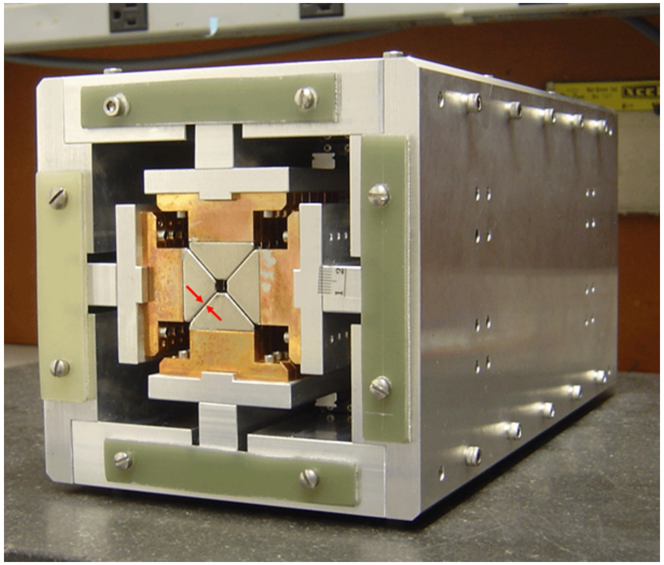
- Magnet spacing moderate (>10 cm), 12 mm pole radius
- All magnet strengths feasible with conventional magnets

Advantage of smaller apertures

- Smaller apertures in DLSR arcs enable strong gradients to minimize emittance
- However, DLSRs also allow smaller apertures in straights
  - Smaller gaps allow higher performance (shorter period, i.e. more flux) undulators
  - Round beam allows to go from flat undulator geometries (which were fine for linear polarization) to round ones
  - Potentially large advantage for polarization control undulators (could be both permanent magnet or s/c)
  - Will evaluate substantially cheaper undulators

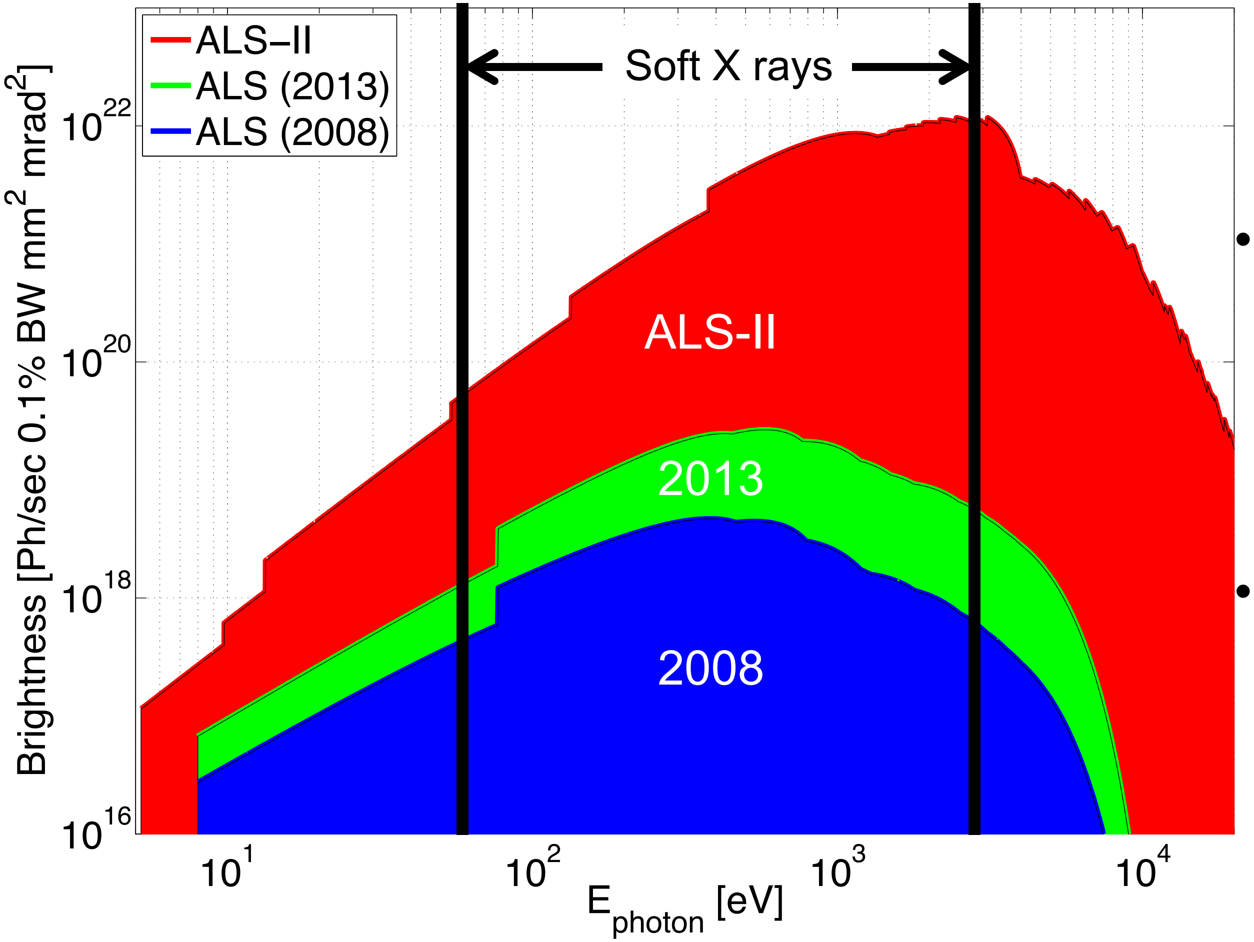


ALS: MAESTRO EPU



A. Temnikh – Delta Undulator

Brightness increase: From ALS to ALS-II

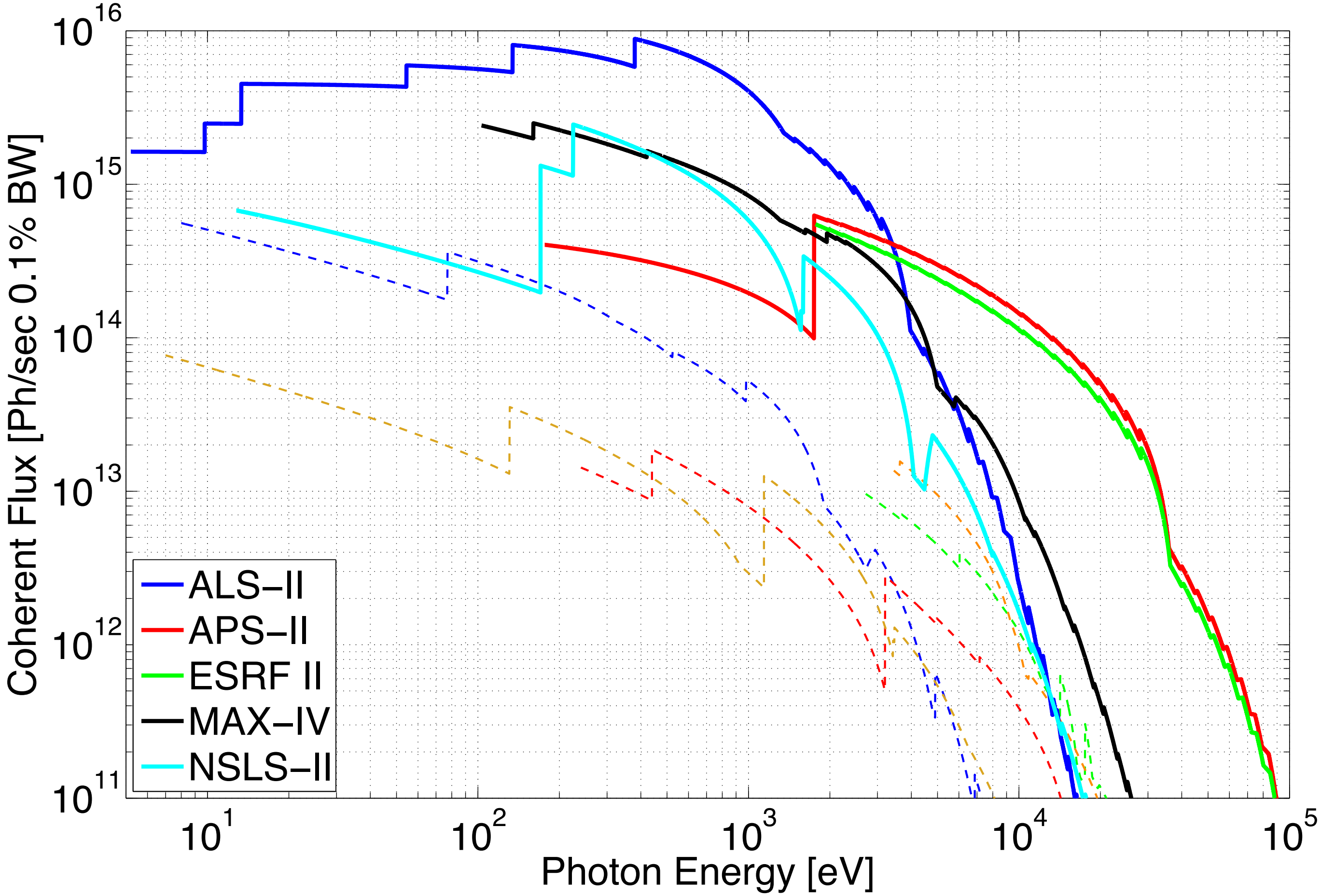


- Recent ALS upgrades led to top-off, high-current operation, and brighter beams
- Additional brightness improvement covers the x-ray spectrum with **100x** improvement in SXR and even greater gain in HXR
- Reaching diffraction limit for soft x-rays in small ring, leveraging infrastructure
  - More cost effective and faster to implement than new ring

ALS and ALS-2 in numbers

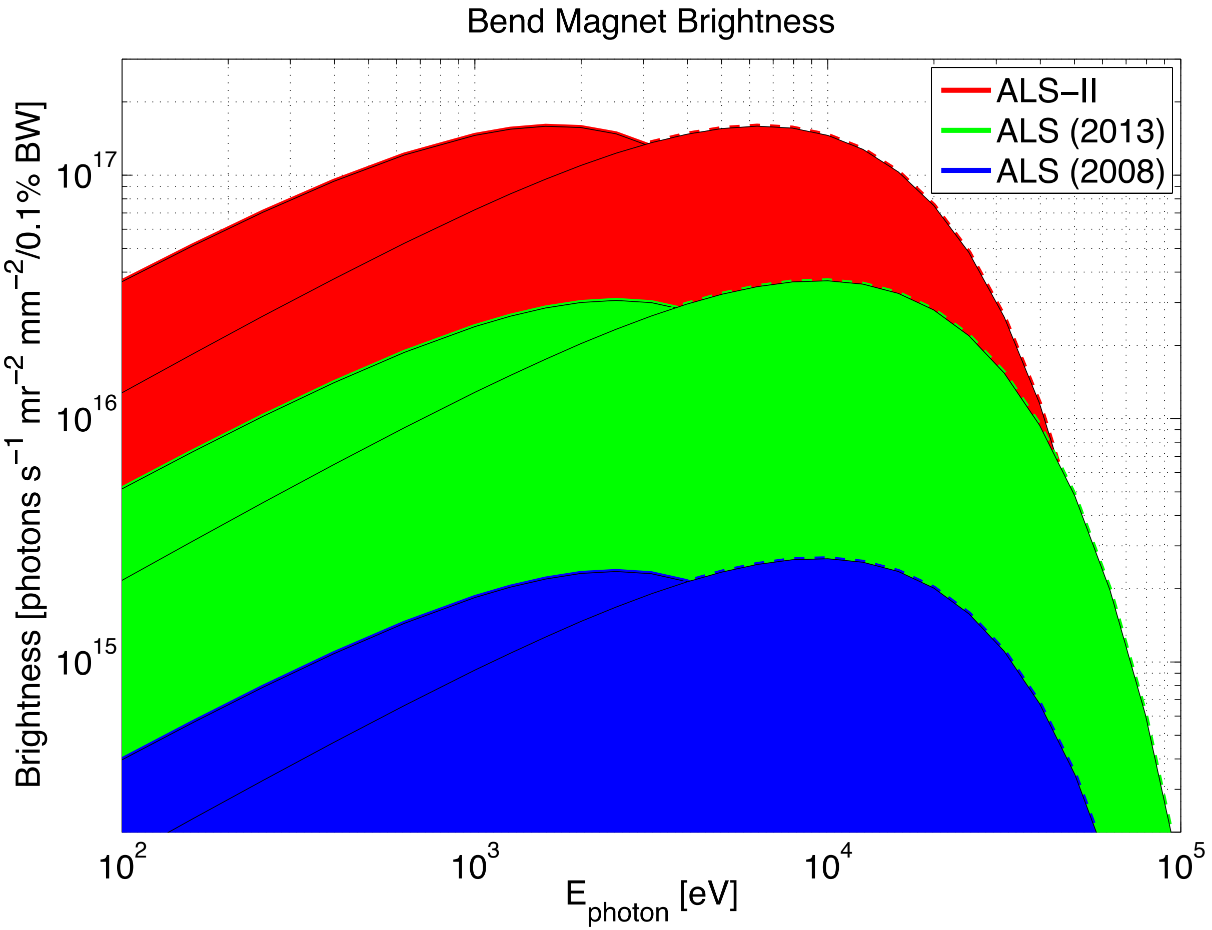
Parameter	Units	Current ALS	ALS-2
Electron Energy	GeV	1.9	1.9-2.2 (2.0 baseline)
Horiz. Emittance	pm rad	2000	~50
Vert. Emittance	pm rad	30	~50
Beamsize @ ID center (σ_x/σ_y)	μm	251 / 9	<15 / <15
Beamsize @ Bend (σ_x/σ_y)	μm	40 / 7	<5 / <7
Energy Spread	ΔE/E	9.7×10^{-4}	$<8.5\times10^{-4}$
Typical Bunch Length (FWHM)	ps	60-70 (harmonic cavity)	150-200 (s/c harmonic cavity)
Circumference	m	196.8	~196.2
Bend Magnet Angle	degree	10	3.33

Coherent Flux



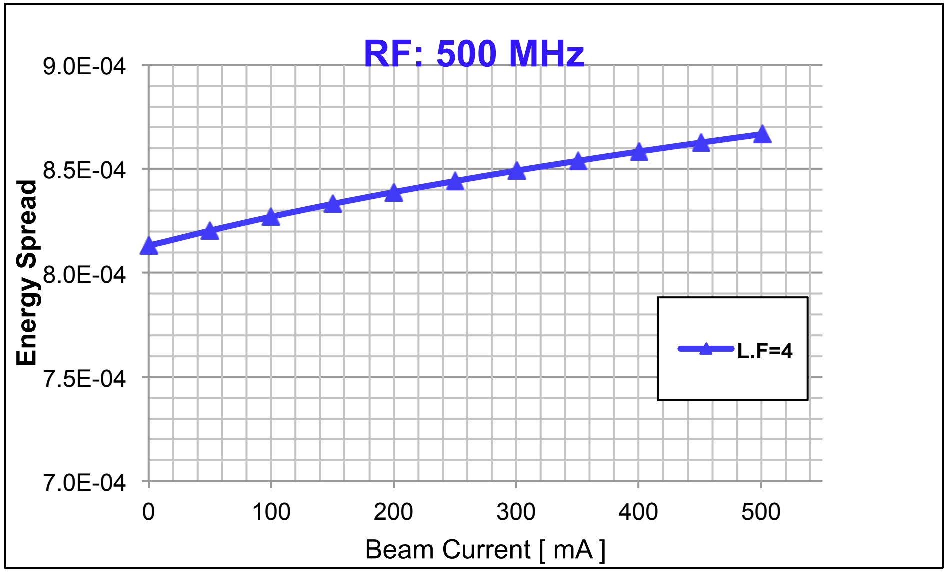
- ALS-2 could provide leading coherent flux in soft x-rays
- Highest coherent flux below 3 keV

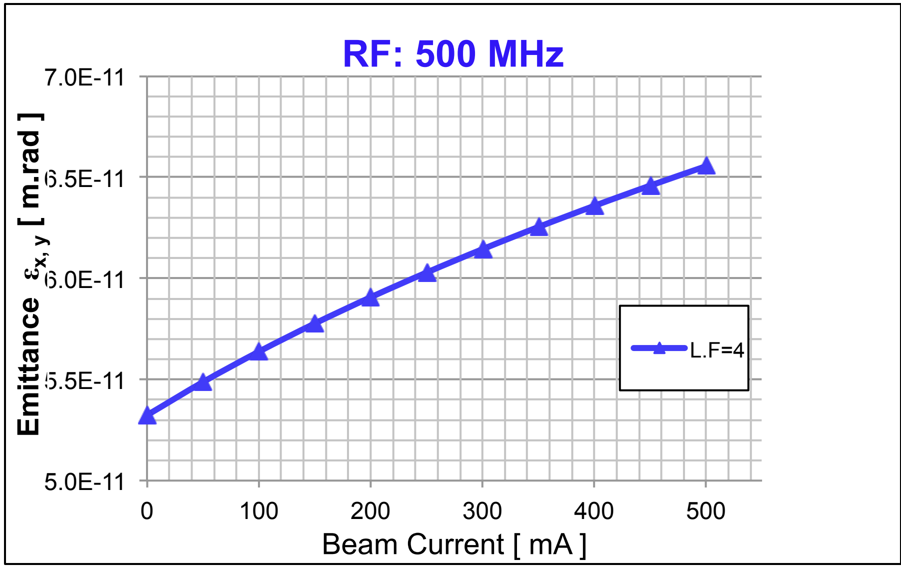
(Superbend-) Bend Brightness



- ALS bend brightness now higher than APS and NSLS-II bends/3PW
- ALS-2 would increase bend brightness by another factor of 5
- 3 T magnet on ALS-2 better than Superbends on ALS up to 40 keV

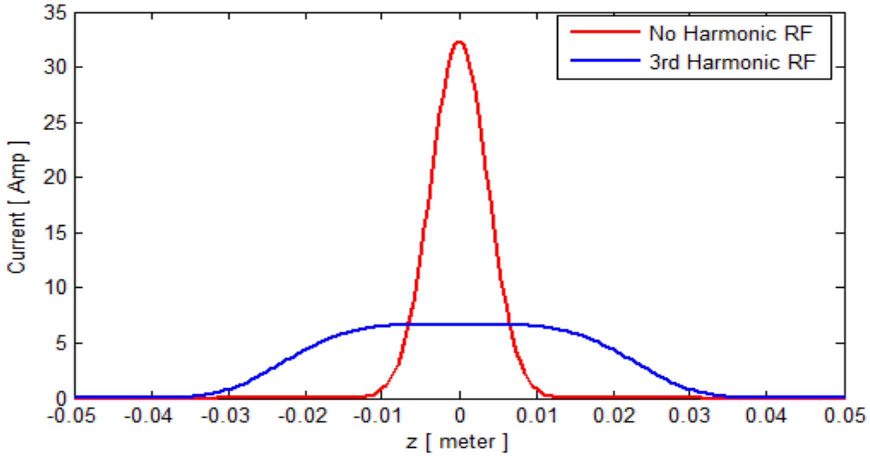
Intra Beam Scattering

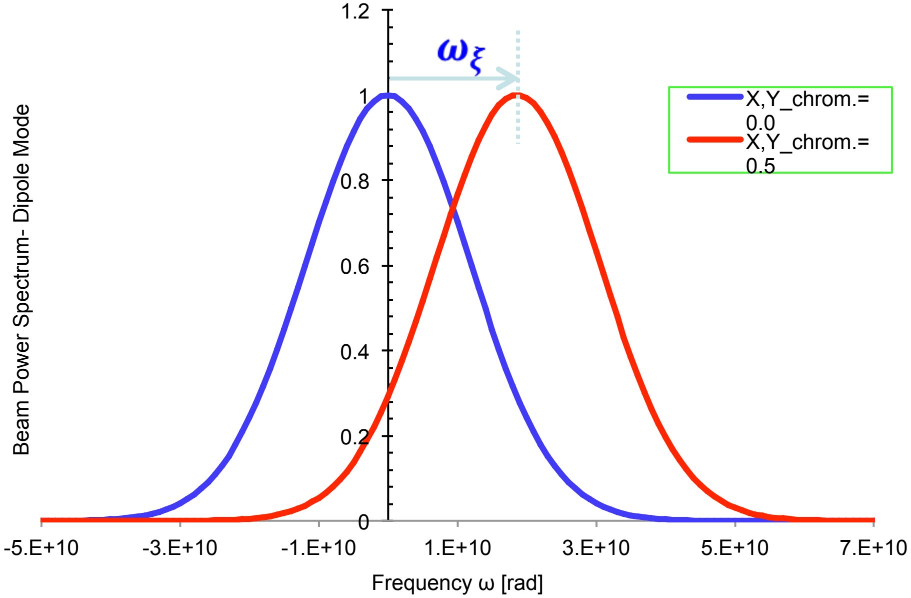




- Bunch Lengthening essential to keep IBS in check
  - Additional energy loss of IDs helps (not included above)
- Lengthening factors appear realistic with s/c third harmonic RF
- Requires small gap(s) in bunch train

Instabilities





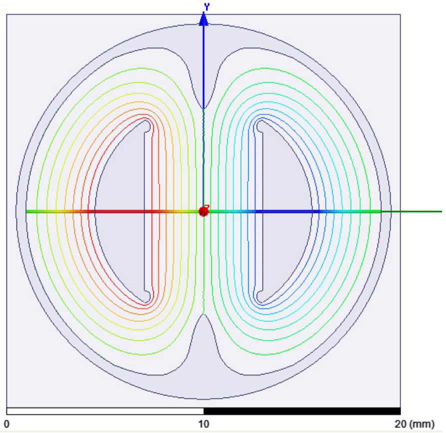
- In general, low momentum compaction factor (which comes with small emittance) lowers single bunch instability thresholds
- Bunch lengthening (3HC) successfully mitigates effects

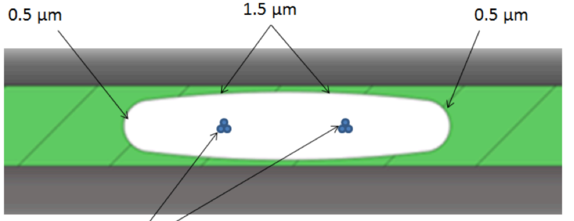
Proposal Development

- Significantly ramped up effort both on physics and engineering side to fully develop ALS-2 proposal
- Finished top-down cost estimate, bottoms-up estimate being finalized
- LDRD funding for R+D in FY14 to retire risks
- Potential project could be executed
  - In under 6 years total, with under 1 year dark time
- There are many design optimizations being explored
  - Beam energy, radiation sources (undulators, bends, IR, …), beamline arrangements, fill patterns, RF frequency, …
- Close collaboration with prospective users to shape the proposal

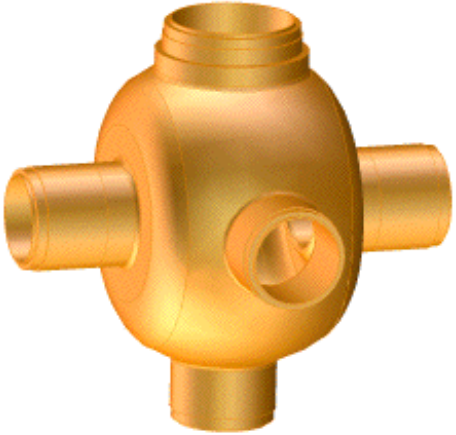
R+D Areas currently pursued

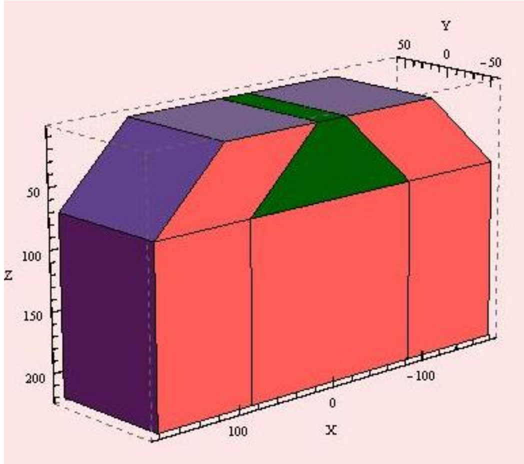
- Pulsed Magnets/ Injection
- Vacuum System, small gap NEG coated chambers
- RF system, harmonic RF, transients, fill pattern
- Magnets, Radiation Production
  - Will have talks (Christoph, Andre, John, Hamed) in breakout sessions





Ti-Zr-V Cathodes are formed by a wire triplets. Dia. Wire ~ 1 mm.





ALS-II will be optimal for soft x-ray science

Highest SXR flux

- A lower energy ring can have higher current, as well as more undulator periods for a given wavelength compared with higher energy rings

Highest SXR brightness

- Diffraction limited (i.e. high transverse coherence) to about 2 keV
- In SXR, will deliver higher brightness than higher energy rings
- Useful energy range extends from VUV to hard x-rays

Cost effective upgrade of a world leading facility

- Small diameter ring, with relatively low construction costs
- Easier beamline optics due to lower heat loading
- Utilizes and further enables an existing and extensive SXR infrastructure
- Maintains and expands existing strengths of ALS (excellent beam stability, high capacity, broad photon energy range, polarization control)

Summary

- Dramatic performance improvements beyond ALS are possible (at moderate cost) and are now being actively studied.

- It is feasible to reach diffraction limit (i.e. transverse coherence) up to about 2 keV with ALS sized ring, i.e. ALS is ideal place for soft x-ray DLSR

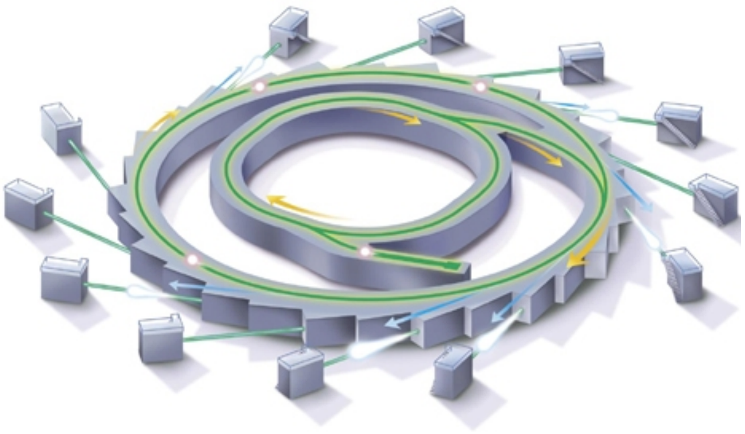
- Proposal development work is ramping up and close coordination with potential users has started

- Long term goal to keep LBNL as leading center for soft x-ray science with ALS-2

Backup Slides

Strengths of a Ring based Light Source

- **Stability:** High positional and photon energy stability. Turn-to-turn amplitude stability is at shot noise limit.
- **Tunability:** Easy and rapid photon energy tunability.
- **Access:** Serves ~ 50 instruments simultaneously at 100s of MHz x-ray pulse rep rate each.
- **Quasi-CW Operation:**
  - Long pulses at high repetition rates: close to unity duty cycle.
  - Minimally perturbative.
  - Space charge resolution limits in photoemission are minimized by long pulses.
  - Discrimination in photon counting detection eliminates fluorescent background.



Brightness / Coherent Fraction

$$\varepsilon_r = \text{diffraction limited emittance} = \sigma_\gamma \sigma'_\gamma = \frac{\lambda}{4\pi} = \begin{cases} \text{80 pm @ 1 keV} \\ \text{8 pm @ 10 keV} \end{cases}$$

- **Brightness is inversely proportional to convolution of electron beam sizes and divergences and diffraction emittance**

$$\text{Brightness} = \frac{\text{Spectral Flux}}{(2\pi)^2 \sigma_{Tx}\sigma_{Tx'}\sigma_{Ty}\sigma_{Ty'}} \qquad \sigma_{Tx} = \sqrt{\underset{\text{Electron}}{\sigma_x^2} + \underset{\text{Photon}}{\sigma_\gamma^2}}$$

- **Coherent fraction = ratio of diffraction-limited emittance to total emittance**

$$f_{coh} = \frac{F_{\text{coh,T}}(\lambda)}{F(\lambda)} = \frac{\sigma_\gamma \sigma'_\gamma}{\underbrace{\sigma_{\text{Tx}}\sigma_{\text{Tx}'}}} \frac{\sigma_\gamma \sigma'_\gamma}{\sigma_{\text{Ty}}\sigma_{\text{Ty}'}}$$

DLSRs produce photon beams with dramatically larger coherent fraction due to reduced horizontal emittance

Design choices/Challenges of ALS-II

- Design Choices:
  - Enabled by decade of progress in nonlinear dynamics, instabilities, magnet+vacuum technology:
    - Smaller magnet and vacuum apertures
    - Advanced Lattice
    - New Injection Method
- Challenges:
  - Physics: Stability, Lifetime, Injection – integrated design optimization
  - Engineering: Magnets, vacuum systems, insertion devices
- All challenges appear manageable.
  - Refine design in connection with science case development