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Successful Completion of the ALS Brightness Upgrade

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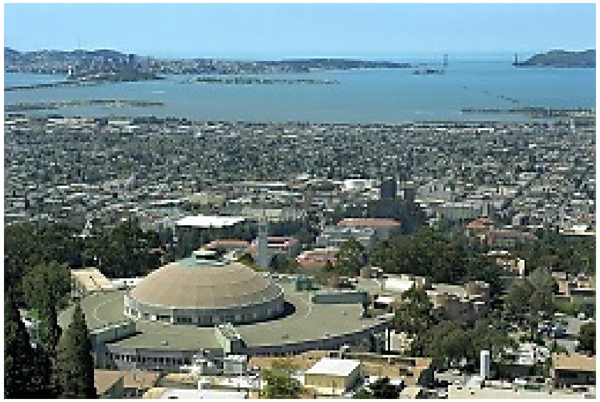
Outline

- Introduction - ALS Upgrades
- Brightness Upgrade
  - Lattice Choice
  - Magnet Design
  - Installation/Commissioning
- Future directions
- Summary

Examples of 3rd Generation Rings (Current/Future)



ALS (1993) 1.9 GeV

ε_x= 2.0/2.5 nm, ε_y= 25 pm, I=500 mA

SLS (2002) 2.4 GeV

ε_x= 3.9 nm, ε_y=10 pm, I=300 mA

Diamond (2007) 3 GeV

ε_x= 3.0 nm, ε_y= 10 pm, I=300 mA

NSLS-II (2014) 3 GeV

ε_x= 1.1 (0.5) nm, ε_y= 8 pm, I=300(500) mA

APS (1995) 7 GeV

ε_x= 2.5/3 nm, ε_y=25 pm, I=100 mA

Soleil (2006) 2.75 GeV

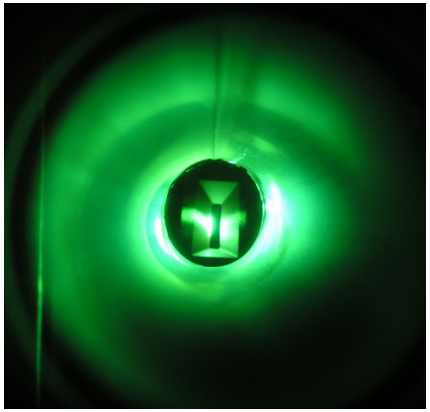
ε_x= 3.7/5.6 nm, ε_y=35 pm, I=450(500) mA

MAX-4 (2016) 3 GeV

ε_x= 0.2-0.3 nm, ε_y= 8 pm, I=500 mA

ALS Accelerator Upgrade Timeline

1993 | 1995 | 1997 | 1999 | 2001 | 2003 | 2005 | 2007 | 2009 | 2011 | 2013



First Light to users

Nb3Sn Undulators

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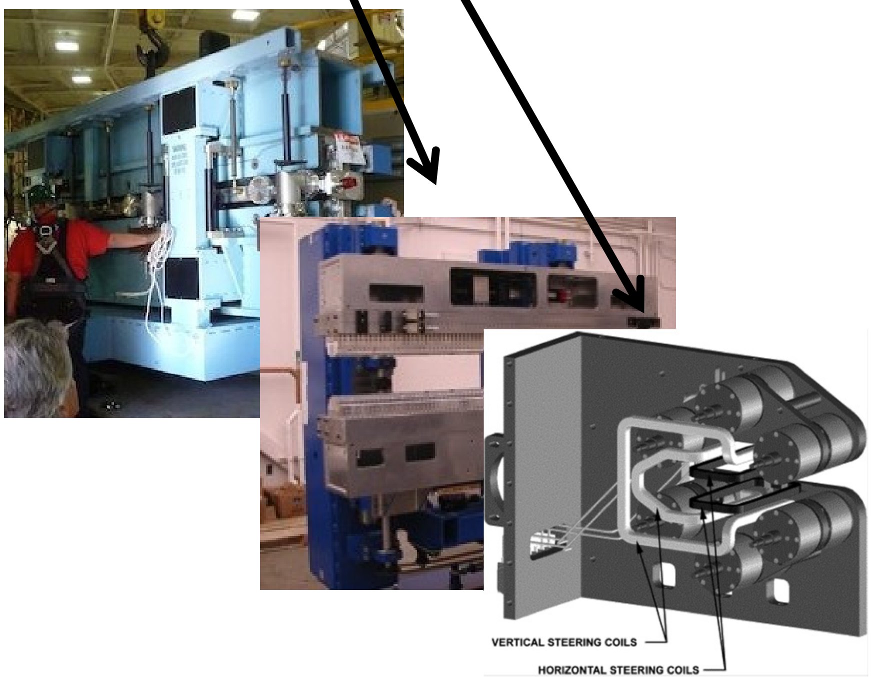

Continuous ID improvements:
Planar, EPU, IVU, Canting/Chicaned

ALS Accelerator Upgrade Timeline

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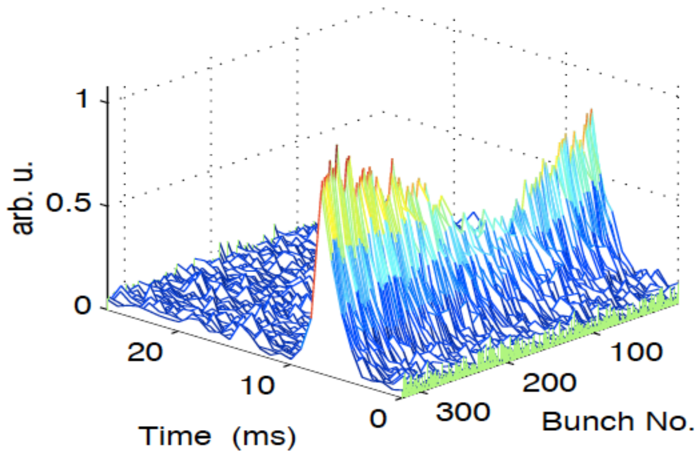

Broadband Multibunch Feedbacks

U.S. DEPARTMENT OF ENERGY
Office of Science

ALS Accelerator Upgrade Timeline

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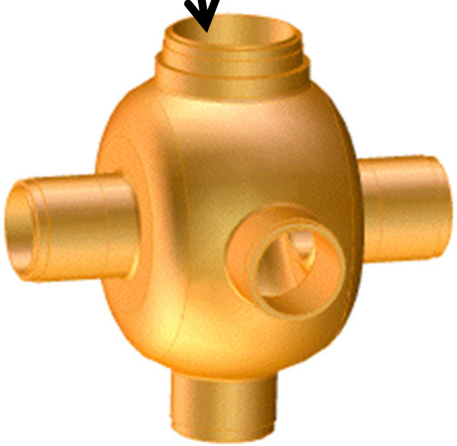
Expanded spectral range
1.5 – 1.9 GeV

First Light to users

Superbends (hard xray)



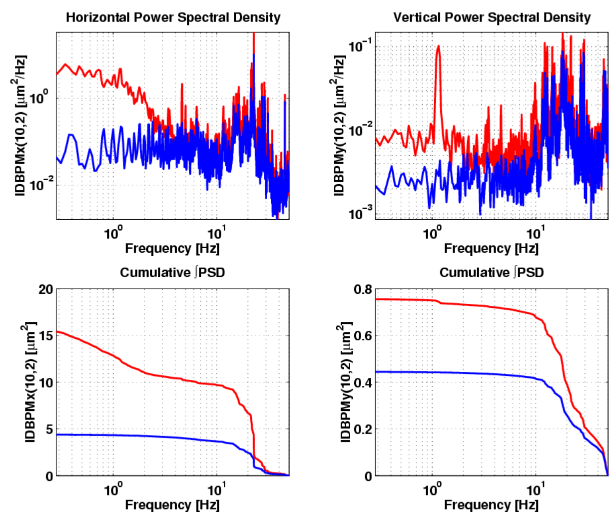
Harmonic Cavities
Lifetime

ALS Accelerator Upgrade Timeline

1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013

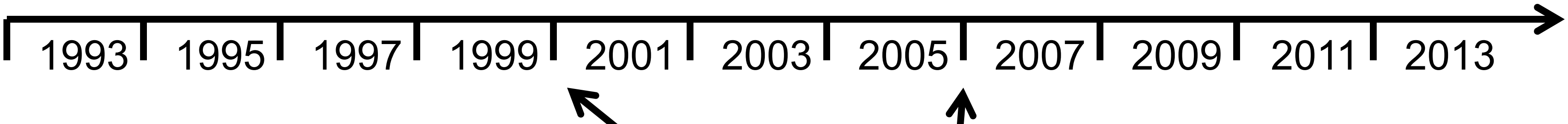
Improved Coupling Control
Brightness, Stability

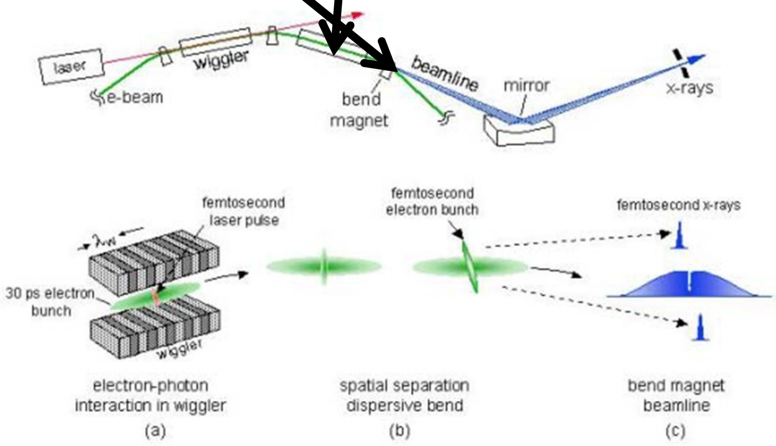
Reduced vertical
Beta function



Fast Orbit Feedback
Submicron orbit stability

ALS Accelerator Upgrade Timeline





Fs-slicing
Bend magnet/Undulator

ALS Accelerator Upgrade Timeline

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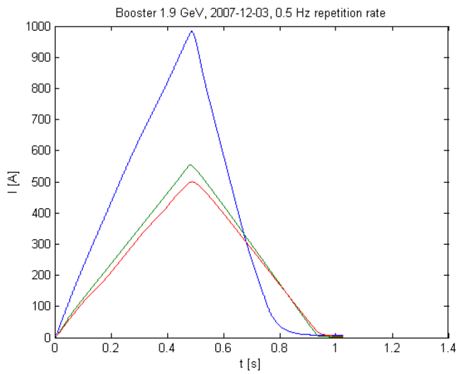

Full Energy Injection
500 mA

ALS Accelerator Upgrade Timeline

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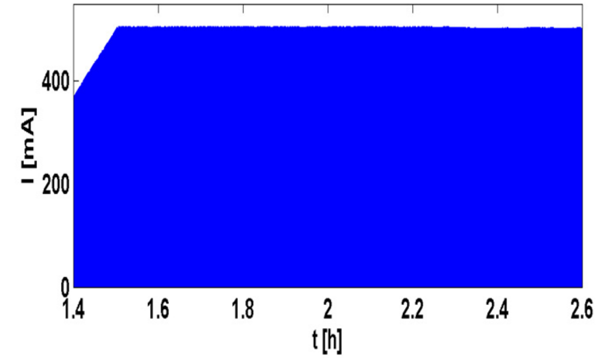
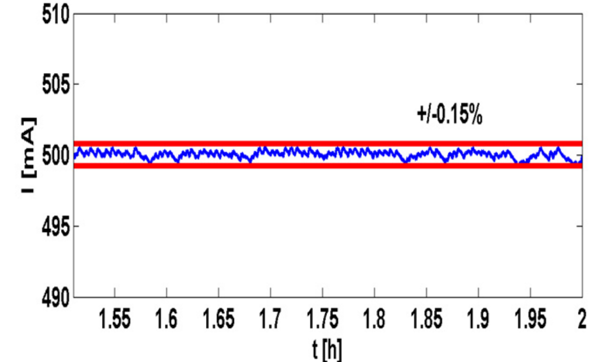


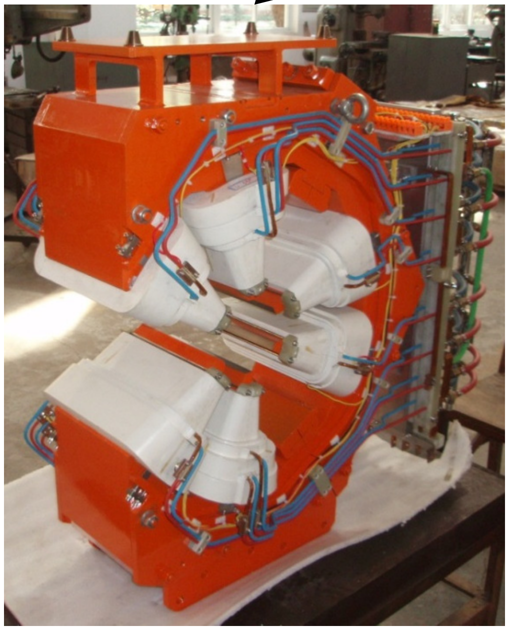


Continuous Top-Off

Reduced vert. emittance

ALS Accelerator Upgrade Timeline

1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013

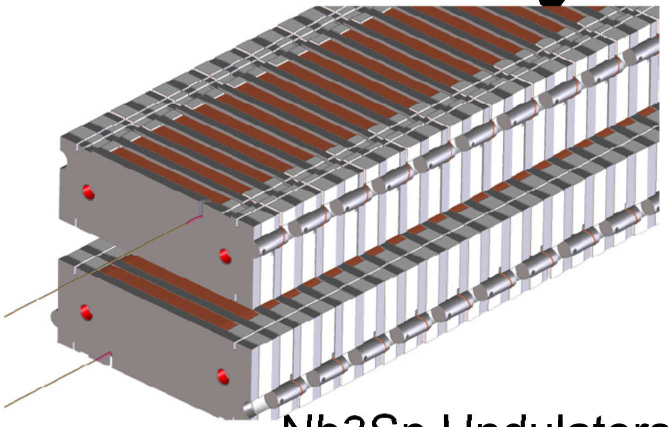


Brightness Upgrade
2.0 nm horiz. emittance

ALS Accelerator Upgrade Timeline

Future

1993 | 1995 | 1997 | 1999 | 2001 | 2003 | 2005 | 2007 | 2009 | 2011 | 2013



Nb3Sn Undulators

ALS Accelerator Upgrade Timeline

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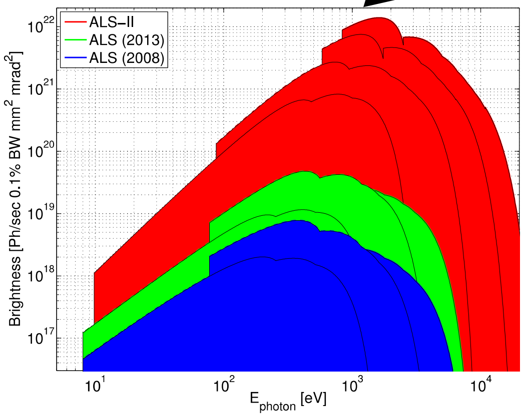
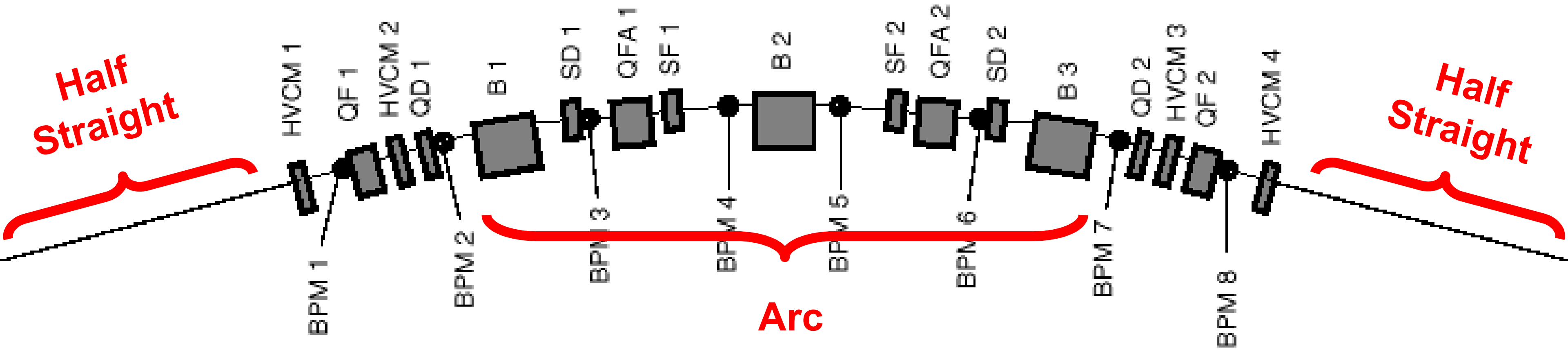
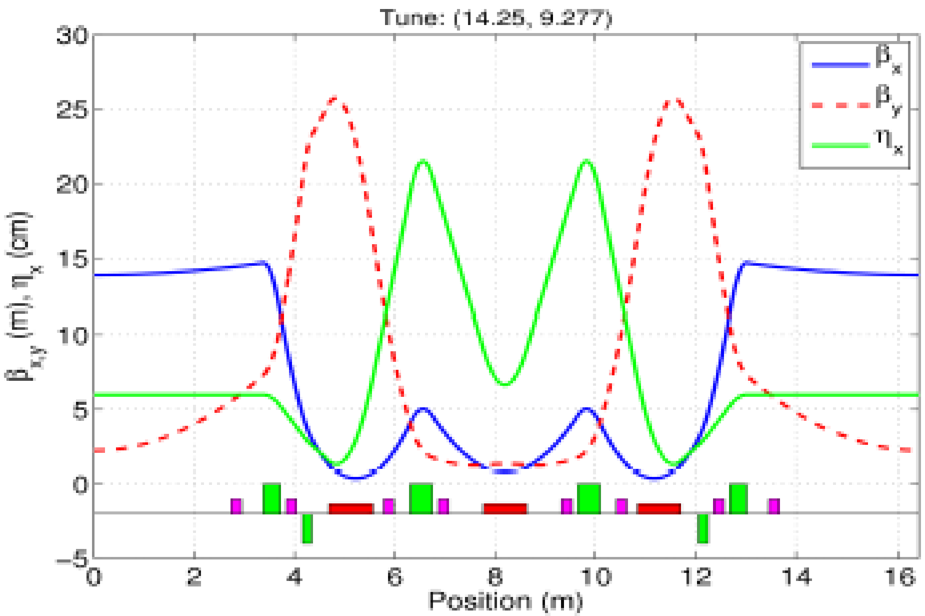


Diffraction Limited Upgrade

ALS Lattice / Upgrade

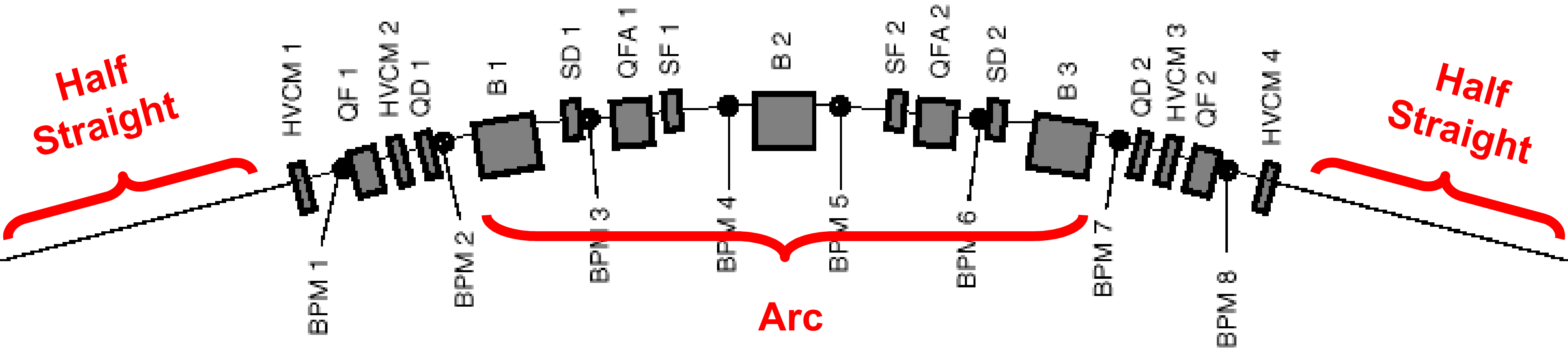


- The ALS is typical example of a low emittance lattice:
- Triple bend achromat that minimizes the dispersion at the location where synchrotron radiation is emitted (i.e. in dipoles)



$$\text{Emittance} \propto \int_{Bend} \frac{\gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2}{\rho^3} ds$$

ALS Lattice / Upgrade



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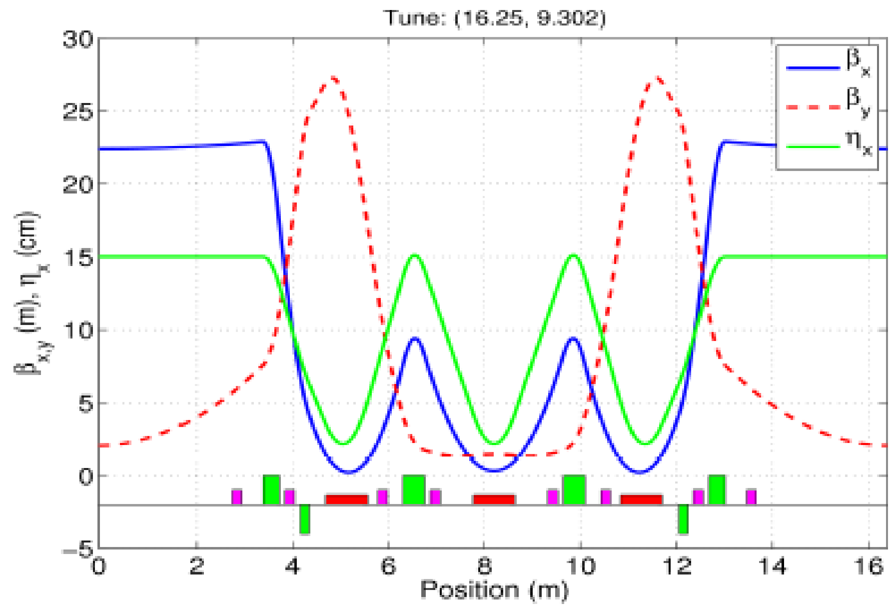
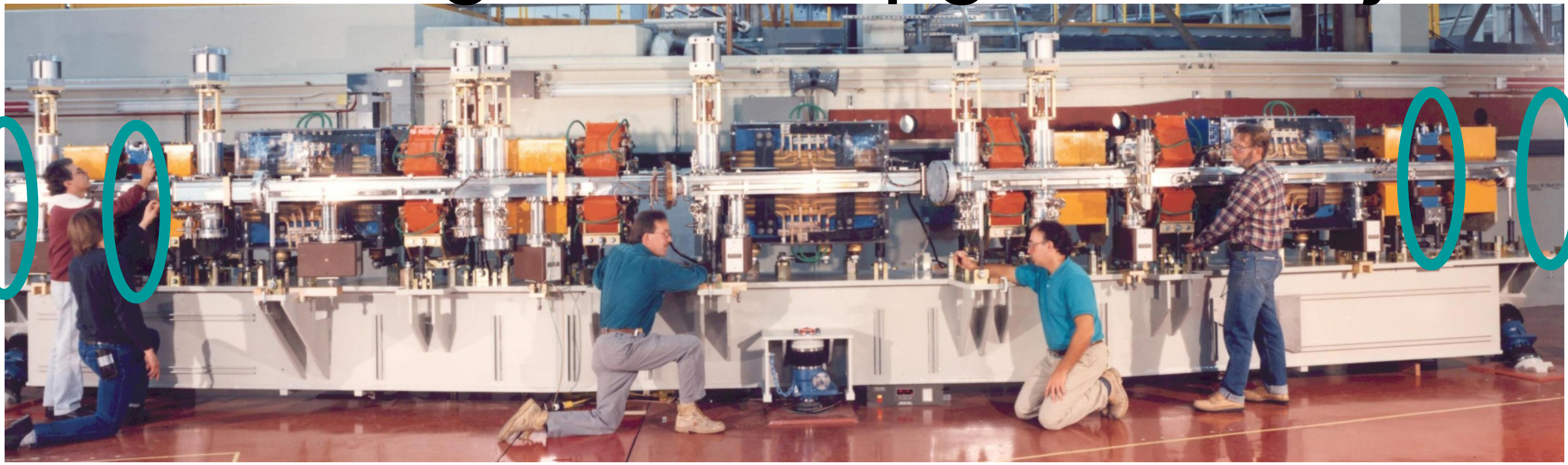


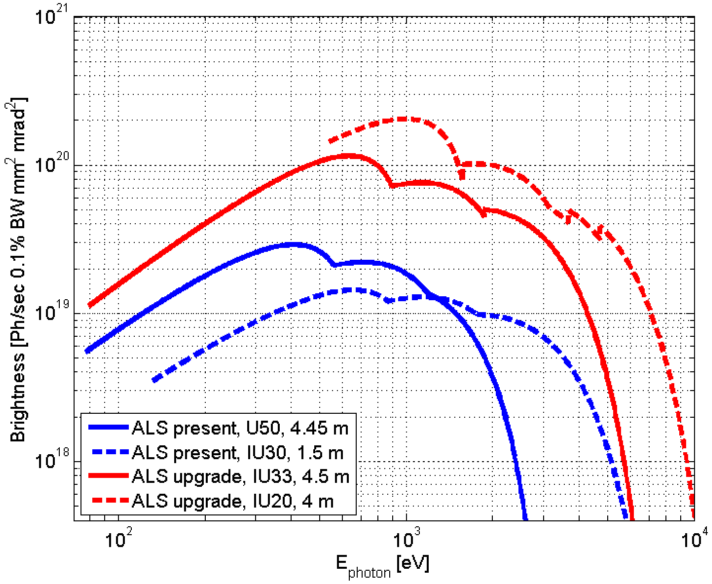
ALS Brightness Upgrade Project



Install 48 New (combined function) Sextupoles

- Horizontal emittance is reduced to 1/3 from 6.3 nm rad to 2.0 nm rad
  - Brightness inversely proportional
- Completed in spring 2013

Of existing light sources, only PETRA-III has a lower emittance



C. Steier, et al., NIM A, DOI: 10.1016/j.nima.2010.11.077.

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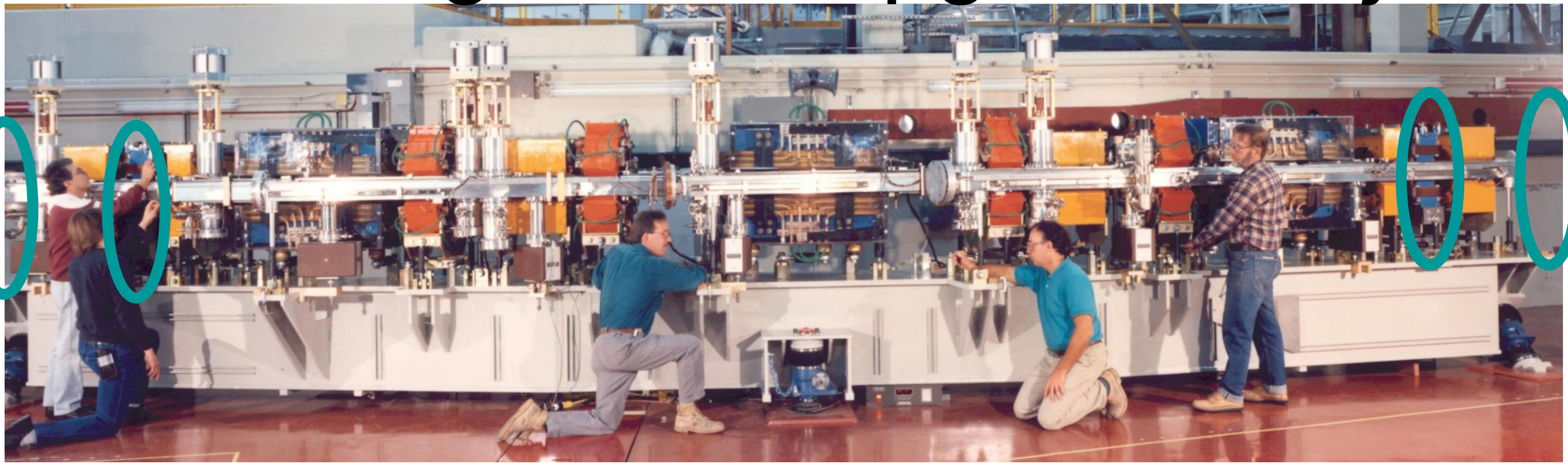

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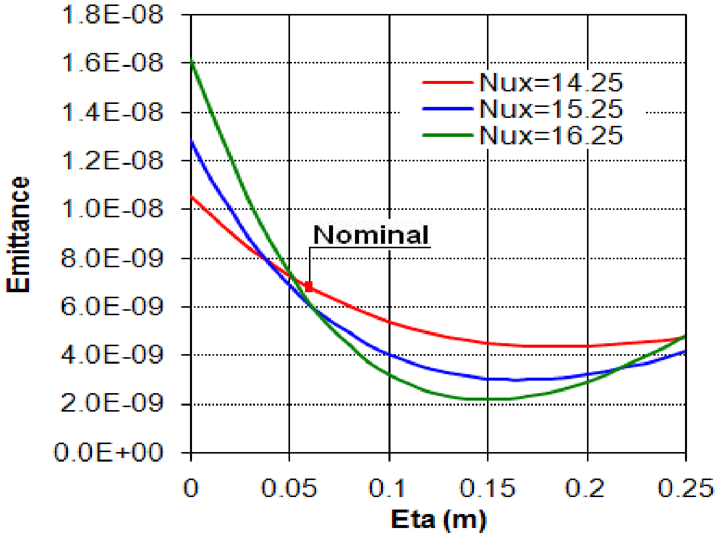


H. Nishimura, et al.– Proceedings of the 2007 PAC Conf

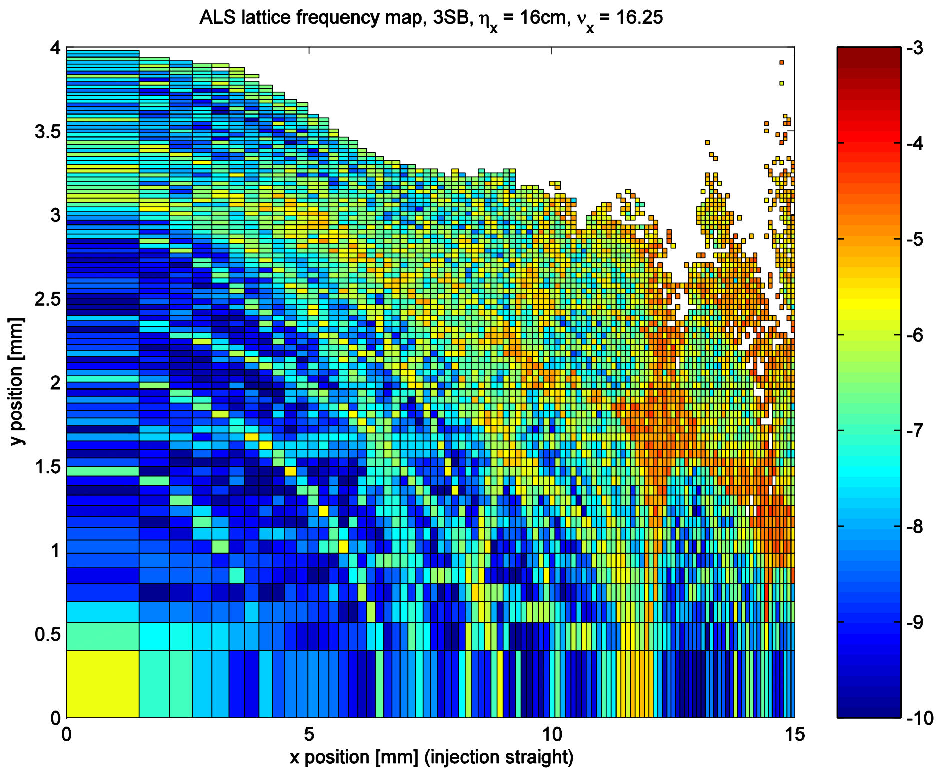
C. Steier, et al., NIM A, DOI: 10.1016/j.nima.2010.11.077.

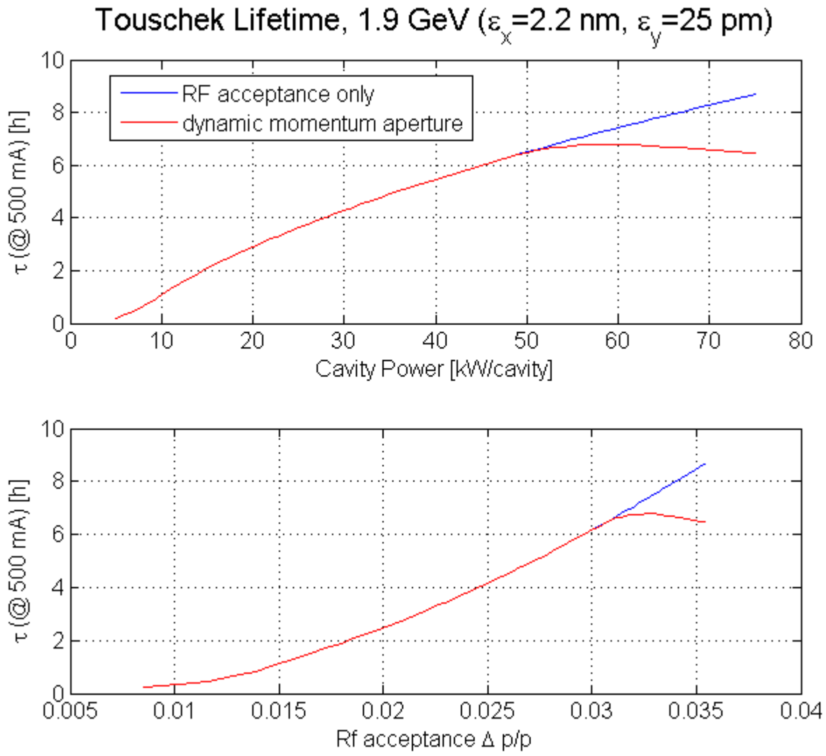
Why do we add sextupoles?

- Reducing the equilibrium emittance is achieved changing settings of existing quadrupoles
- Problem is nonlinear dynamics:
  - Sextupoles are too weak to correct chromaticity
  - Strengthening them would dramatically reduce dynamic aperture (lifetime, injection efficiency)
- Need additional degrees of freedom
  - ‘Harmonic’ Sextupoles
  - ALS lattice already full – needed to replace existing corrector magnets with multi-magnets
- Possibility for low alpha operation
  - THz, short bunches

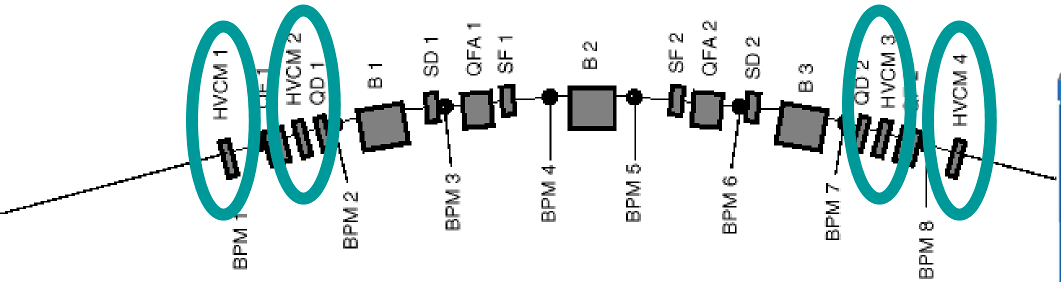
Baseline Lattice: Dynamic Aperture

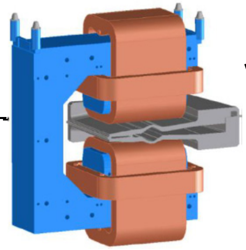
- Dynamic aperture is fairly large (larger than current lattice)
- Dynamic Momentum Aperture larger
- Touschek Lifetime longer than present lattice
  - Despite higher density



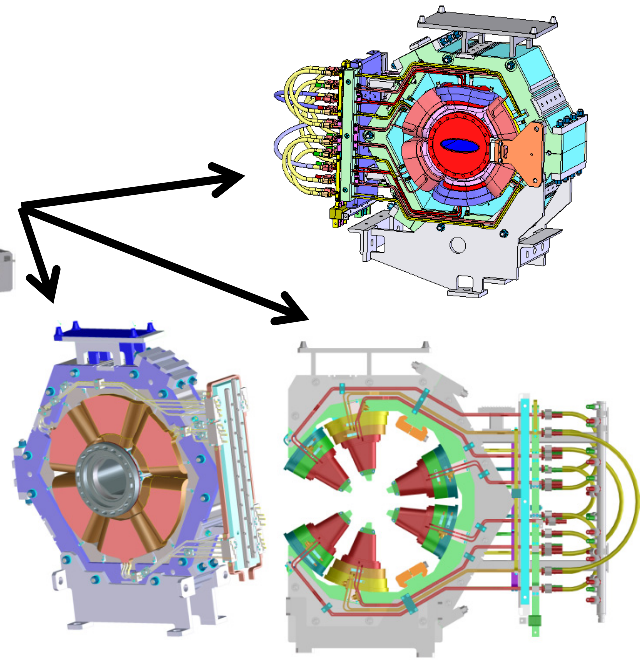


Project History





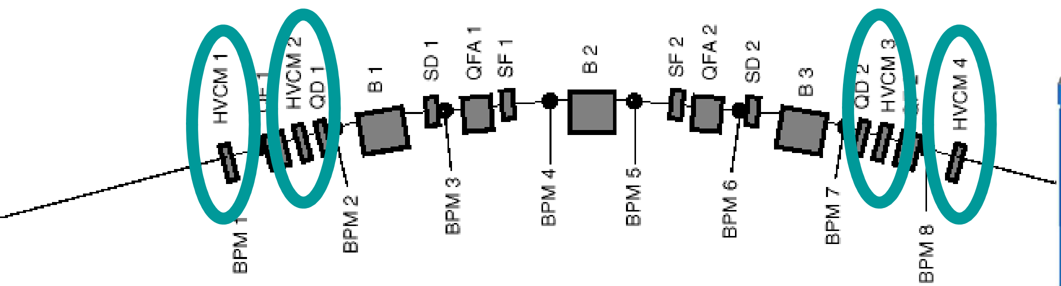
Old Correctors

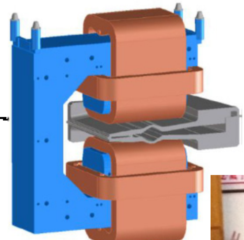


Sextupole / Corrector Multimagnets

- Received funding (summer 09)
- Comprehensive project review (12/09)
- Awarded magnet contract (9/10)
- Detailed magnet design review (3/11)
- Prototypes of 3 magnet types complete (12/11)
- First set of 13 production magnets shipped (4/12)
- All magnets received (8/12)
- Pre-Installed 13 of 48 sextupoles (1/13)
- Remaining magnets and power supplies installed (3/13)
- User operation in high brightness mode (2.0 nm emittance) – since (4/13)

Project History





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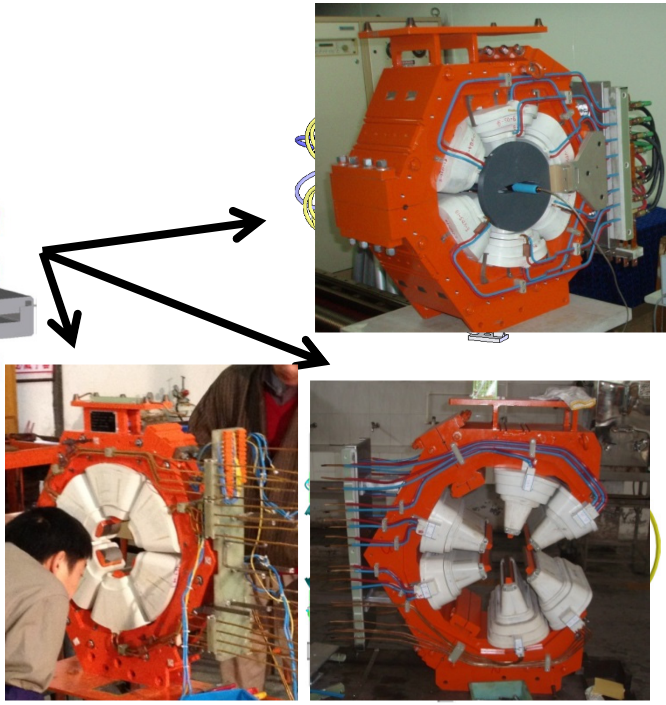

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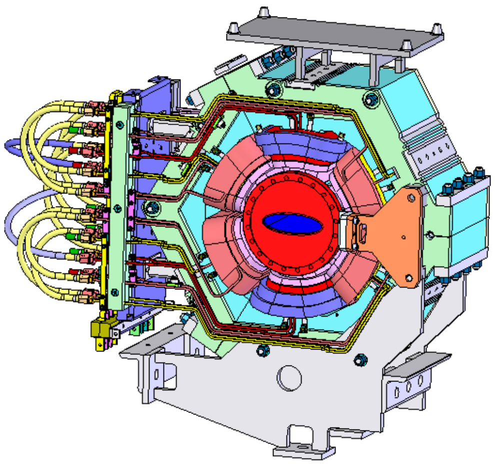
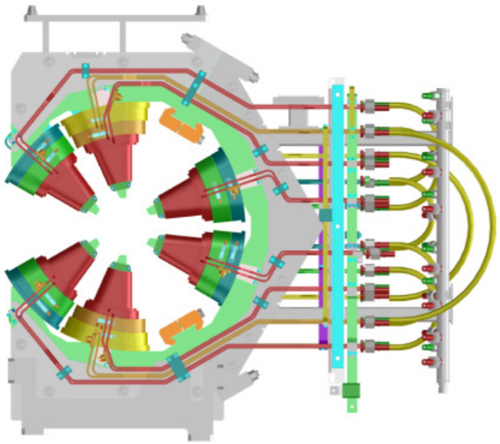
Magnet Design



- Very tight space constraints (magnets, vacuum chamber, beamlines)
- New magnets are sextupole+ correctors+skew quads
  - Small hysteresis, fast time response for fast orbit feedback



- Pole tip radius bigger than existing magnets (vacuum chamber clearance)
  - Bad: Relatively high pole tip fields
  - Good: Smaller multipoles where it counts for beam
- Installed at high beta function

Accelerator Physics Work

Top-off calculations with new magnets

- Re-analysis necessary, new field profiles
- No hardware changes necessary
- Wider ranges on topoff interlocks

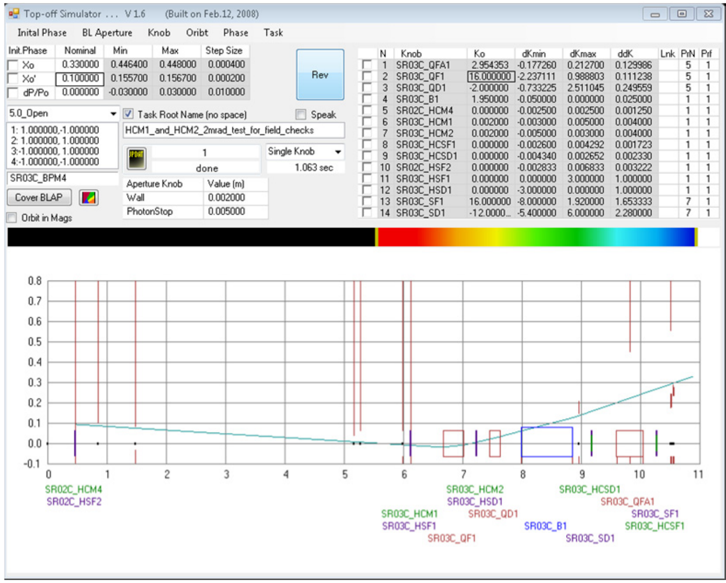
New fs-slicing bump for new lattice

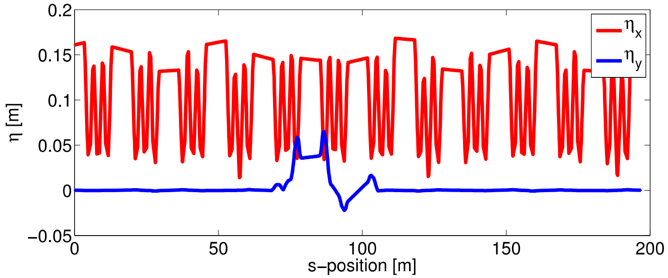
- Using MOGA optimization techniques
- Making use of new skew quadrupoles
- Also evaluating to switch to horizontal slicing
- Shorter pulses

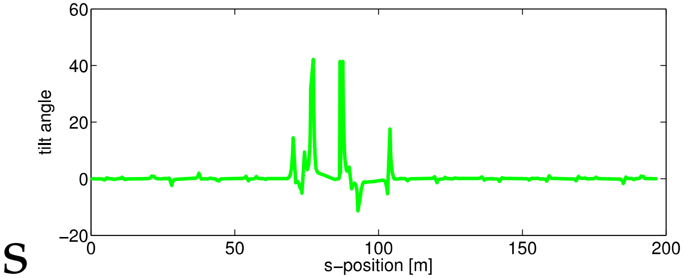
Supporting analysis of magnet test results – Reducing Commissioning Risk

- Hysteresis
- Bandwidth
- Multipole content

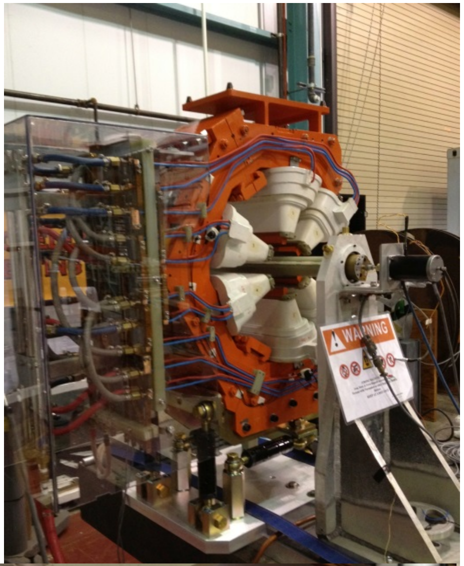
Continuing work to explore low β_x lattices







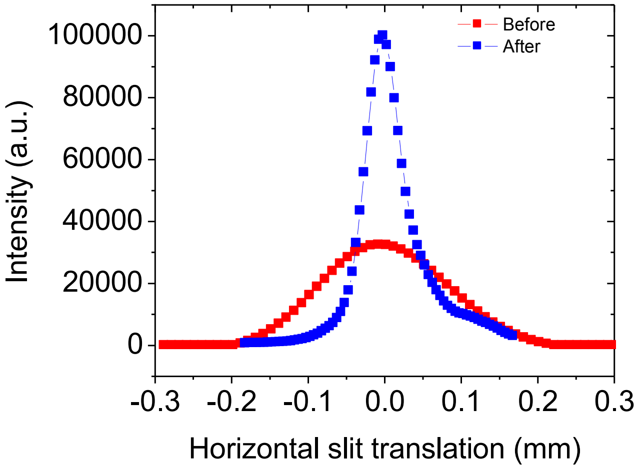
ALS Fiducialization, Test, (Pre-)Installation



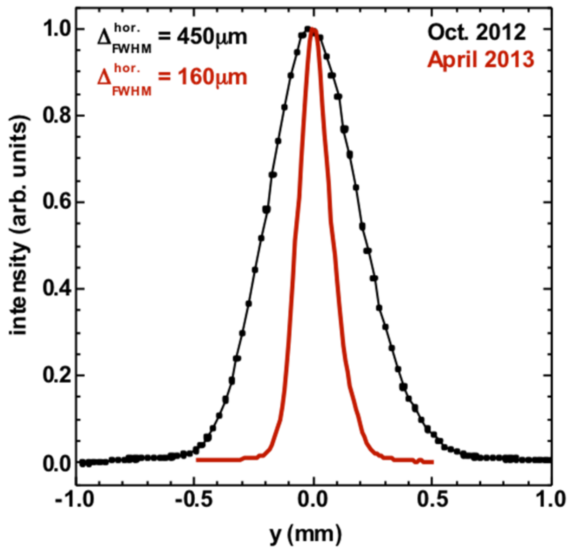
- To minimize risk of full installation and commissioning, many tasks were carried out before installation shutdown:
  - After shipment all magnets were tested at LBNL
    - Electrical, water, mechanical, protection
  - Repeated magnetic measurements for ¼ of magnets
    - excellent agreement
  - All magnets were mechanically re-fiducialized
    - Mechanical rather than magnetic fiducialization used for alignment
  - Developed + tested lifting/rigging and tools for installation

- Started (pre-)installation of new sextupoles in October 2012 – during normal maintenance periods
  - 13 of 48 magnets installed before shutdown – corrector coils in routine use in (slow+fast) orbit feedback

Commissioning Results

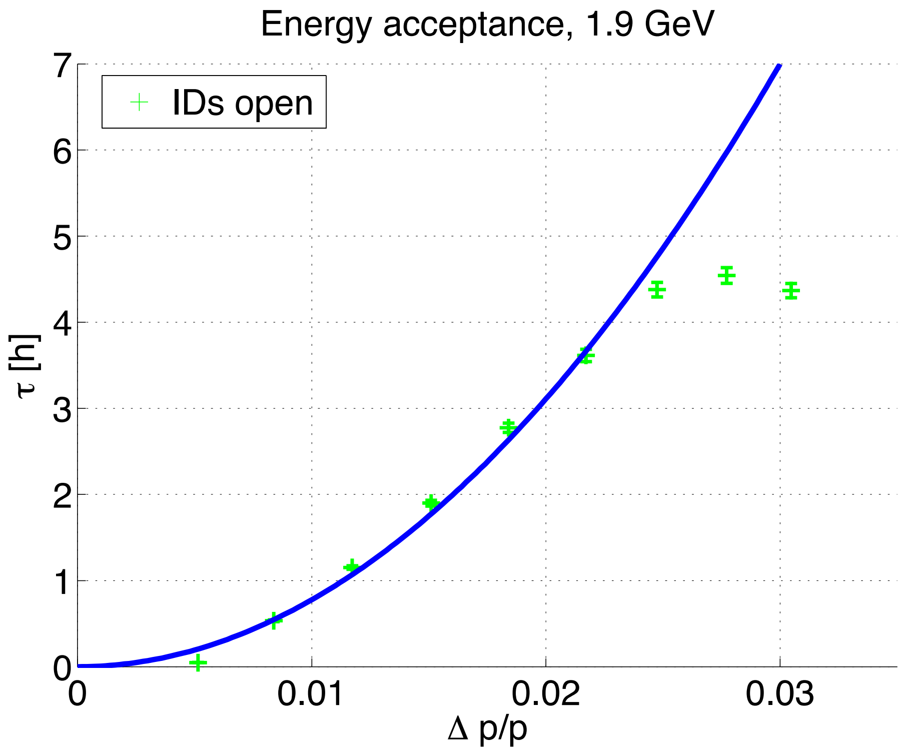


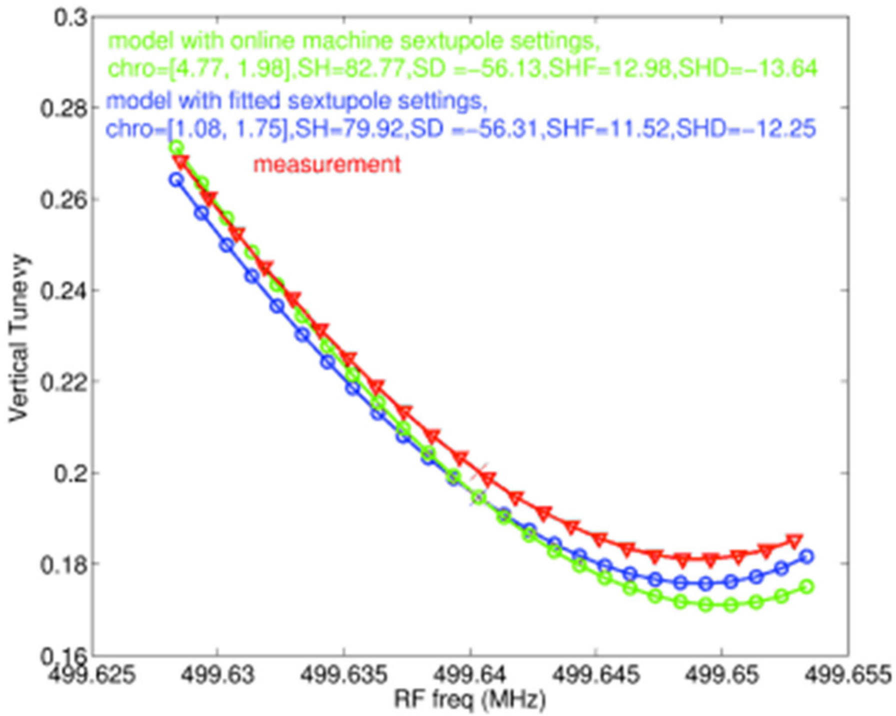
Measured horizontal photon beam profiles showing the reduction in size and increase in brightness. Above: BL 12.3.2, Below: BL 6.3.1



- Installation completed on time (Mar/Apr 2013)
- Quick Commissioning Progress (days!)
  - Benefit of pre-installation and commissioning: orbit feedbacks, detuned upgrade lattice
- Managed to deliver low emittance beam during BLC shifts – and continue into user operations
  - 3 months ahead of schedule
- Beamlines able to resolve brightness increase
- Reliable operation (no faults due to new lattice or hardware so far)

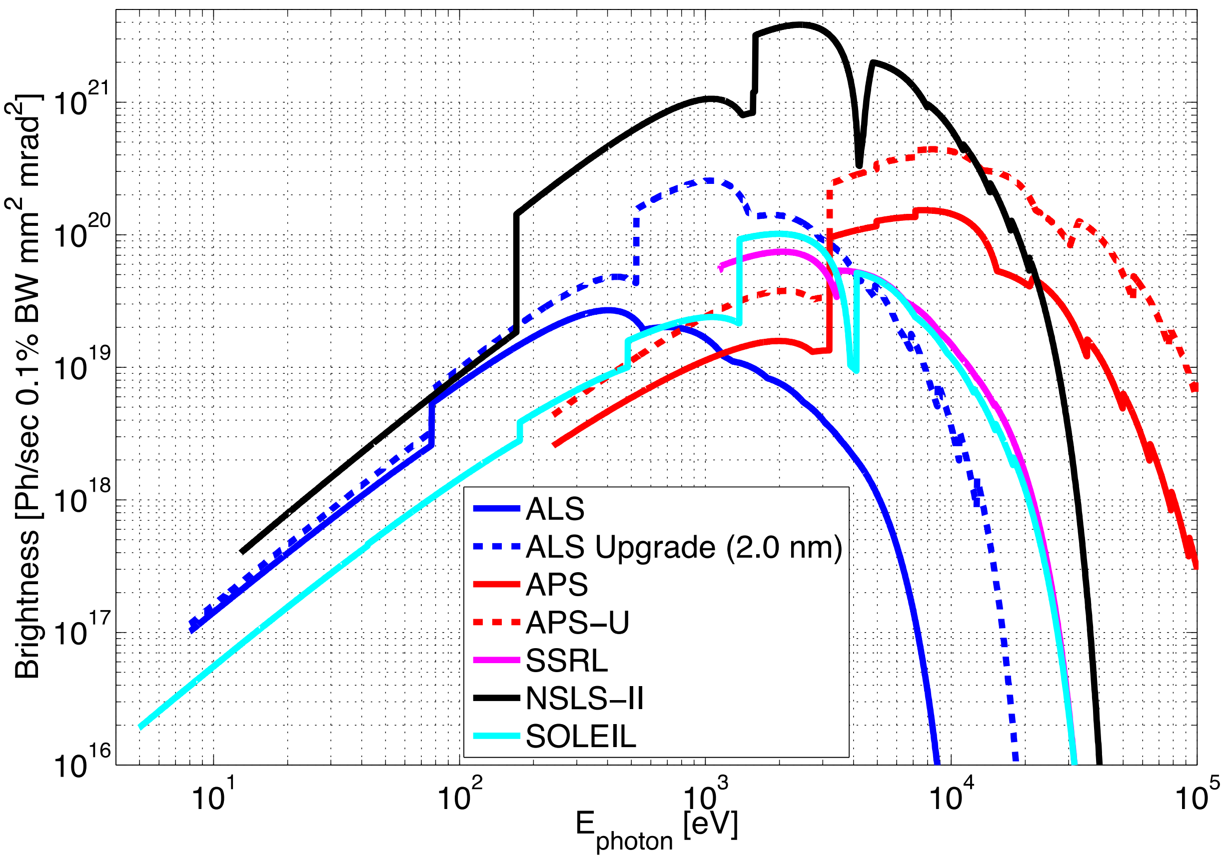
Beam Dynamics Measurements





- Nonlinear beam dynamics measurements show good agreement with predictions
- Confirmed larger dynamic and momentum aperture than high emittance lattice without harmonic sextupoles

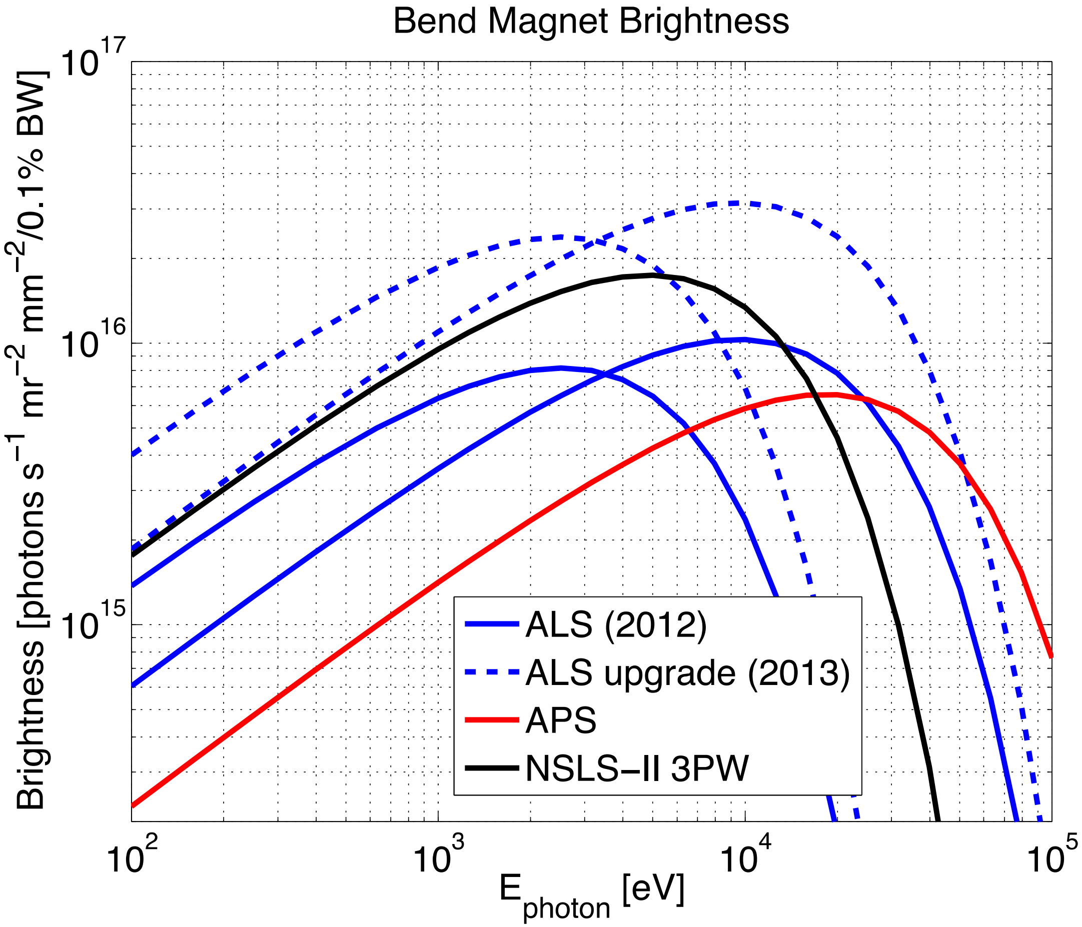
Brightness Comparison



Triple Bend Achromat provides very bright bend and Superbend source points from center bend magnets – ALS (2 nm) above NSLS-II 3PW

- Comparison to existing and future light sources (and upgrades)
- Below 1 keV (soft x-ray) ALS is competitive now
- Future: NSLS-II and Max-4 will outperform ALS above 100 eV

Brightness Comparison



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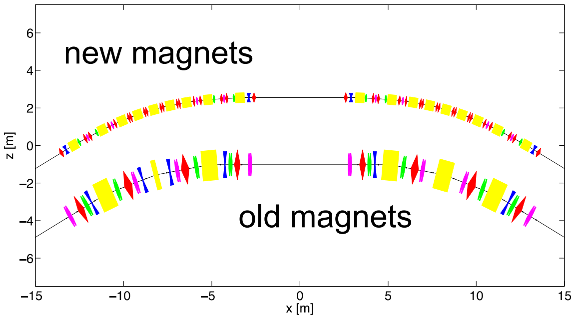
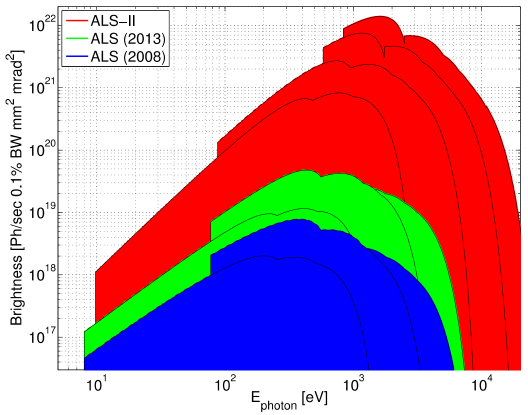
Looking beyond completed Brightness Upgrade: Assuring world class capabilities for the future

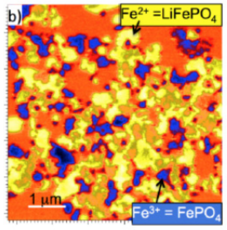


Potential upgrade of ALS ring to diffraction limit

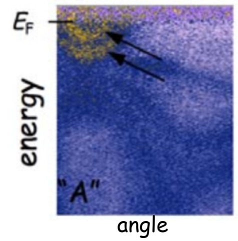


100x increase in brightness

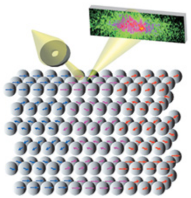
Diffraction Limit upgrade on a 200m circumference ring enables nanoscale microscopes with chemical, magnetic, and electronic resolution



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

Summary

- Biggest challenge (as well as opportunity) for 20 year old ALS – Continuous Renewal
  - Well balanced plan between machine/facilities upgrades and beamline/endstation renewal
- Major Machine Renewal example: Brightness upgrade reduced horizontal emittance from 6.3 to 2.0 nm
  - Completed on time and on budget without any teething period
- Photon beamlines can resolve brightness increase and realize (full) benefit
- Dramatic performance improvements beyond the current upgrade are possible (at moderate cost) using a multi bend achromat lattice and are now being actively studied.