Overview of the ALS Upgrade

David Robin
Project Director, Advanced Light Source Upgrade
High Brightness Synchrotron Light Source Workshop, BNL
April 27, 2017

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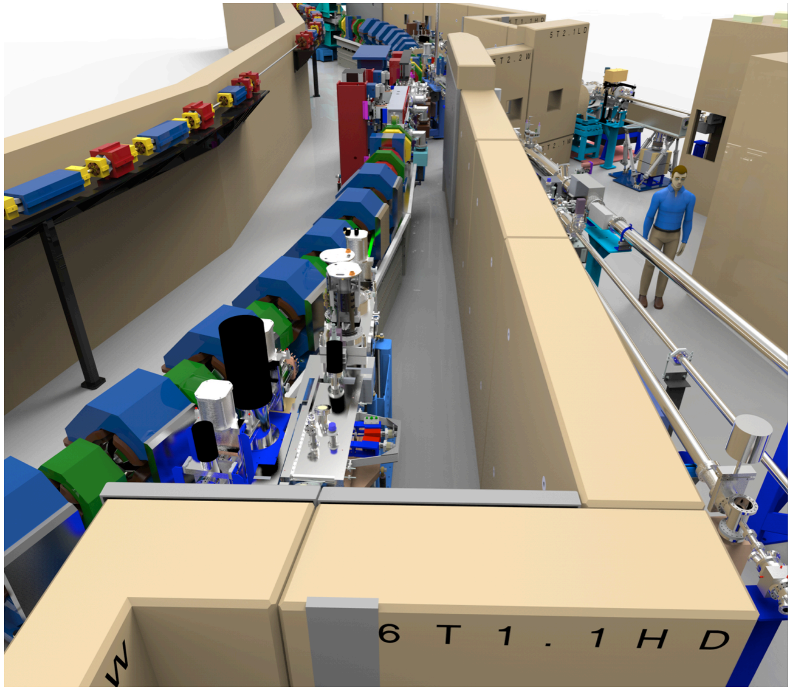
U.S. DEPARTMENT OF ENERGY | Office of Science

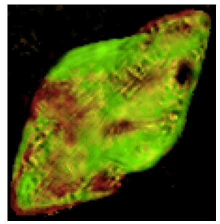
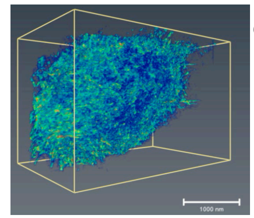
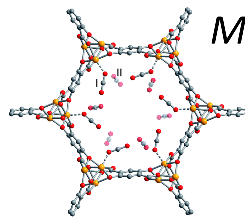
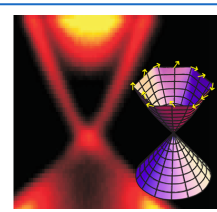
ALS-U
ADVANCED LIGHT SOURCE

Outline

- **Motivation**
- **Overview of ALS-U**
- **Status**



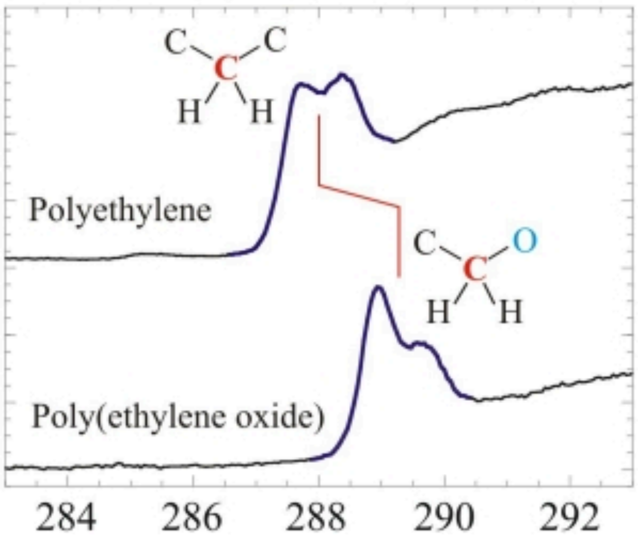
Challenges at the frontier of matter and energy require better understanding of the functionality of complex, heterogeneous materials

Transformative Opportunity	Example Application	Potential Societal Benefits
Understanding the Critical Roles of Heterogeneity	*battery*   *concrete* Charge motion	energy storage, environmentally friendly materials
Mastering Hierarchical Architectures	 *MOF* Controlling chemistry	chemical catalytic reactors, solar fuel production, water purification
Harnessing Coherence in Light and Matter	 Topological spin and quantum matter	ultralow-power computing, new classes of sensors, spin-based devices

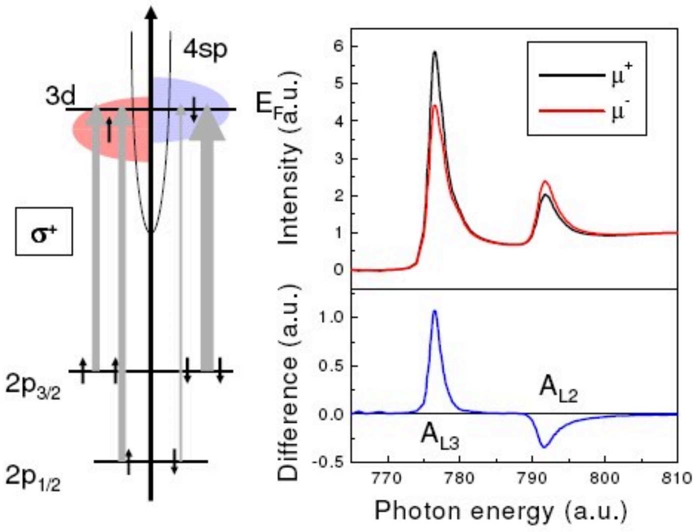
Requires new and improved probes

Soft x-ray light has the appropriate energy to interact strongly with the electrons that determine the *chemical, electronic, and magnetic properties of materials*

Probing Chemistry



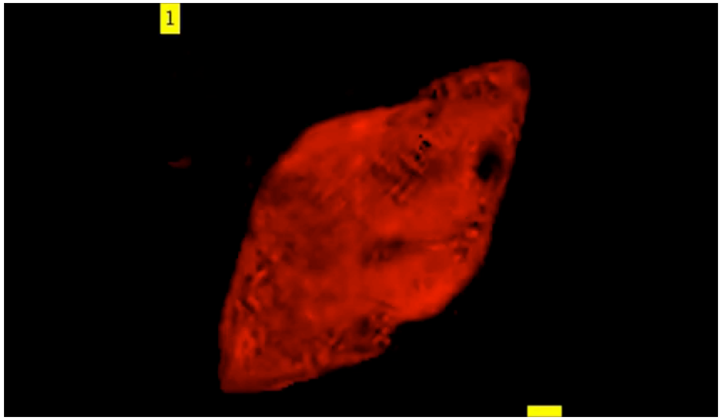
Probing Magnetism



*Bryan Bandli, Scanning Electron Microscopy Laboratory, University of Minnesota

High coherent flux **delivered** ***nearly continuously*** **is necessary to** ***resolve nanometer-scale features and interactions*** **and which allows** ***real-time observation*** **of chemical processes as they evolve and materials as they function.**

Charging and discharging in a grain of lithium Iron battery



"X-ray movies"

Lim, Science 2016

Soft x-rays

Nearly continuous

High coherent flux

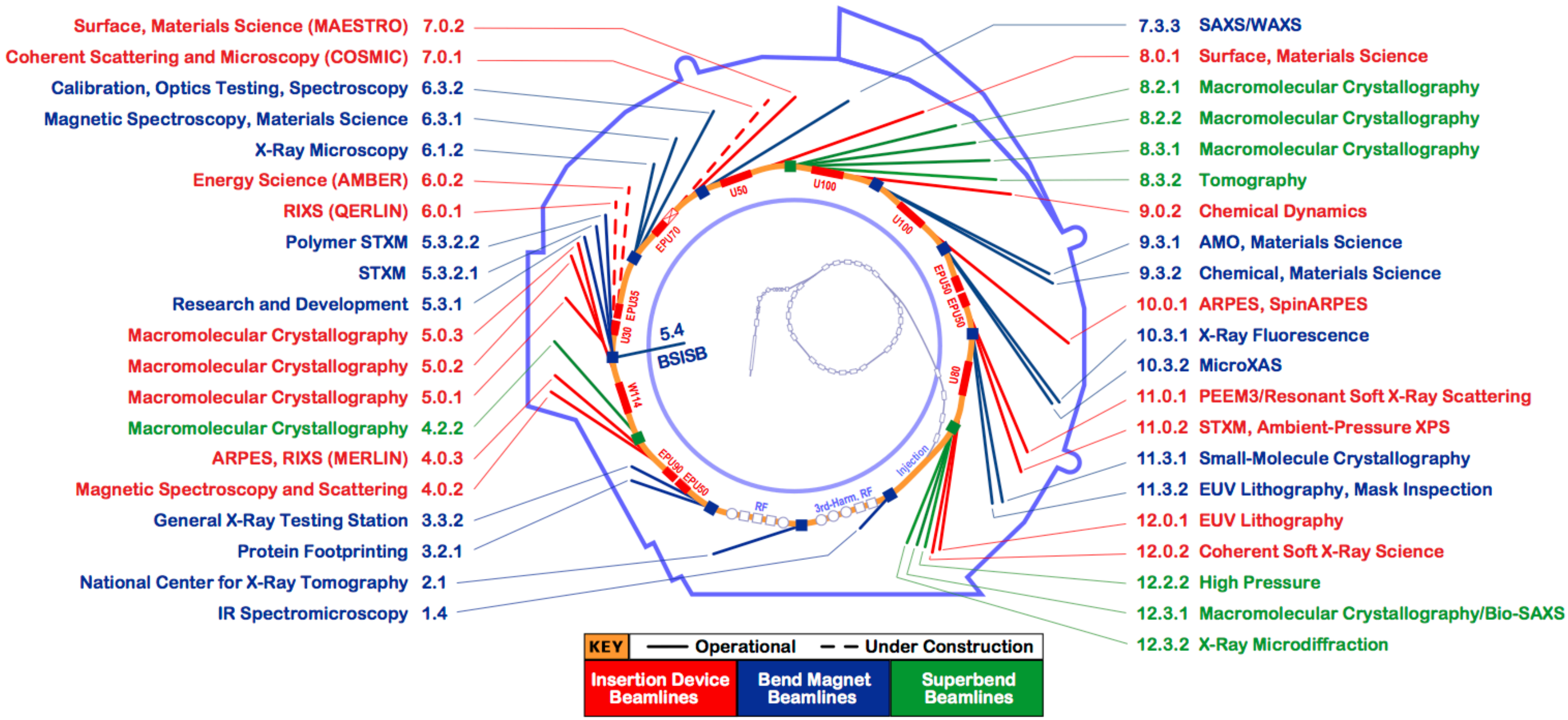
Exists today

Missing today

*Bryan Bandli, Scanning Electron Microscopy Laboratory, University of Minnesota

ALS has been in operation since 1993

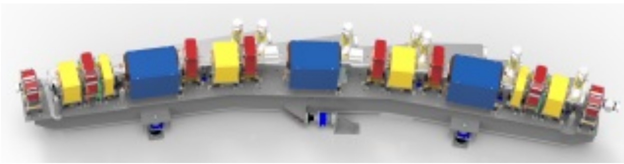
40+ beamlines serving about 2500 users/year

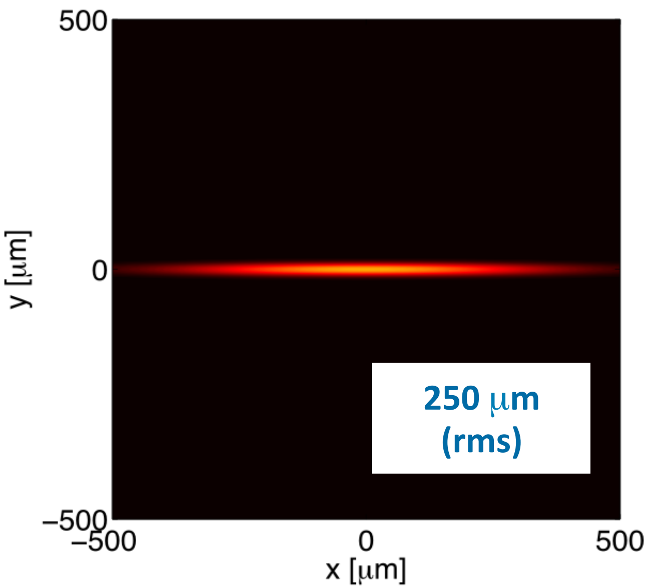


- Highest-brightness undulators for SXRs
- Bend-magnet sources for broadband IR and x-rays
- Superbend magnets for HXRs

Advanced Light Source Upgrade (ALS-U)

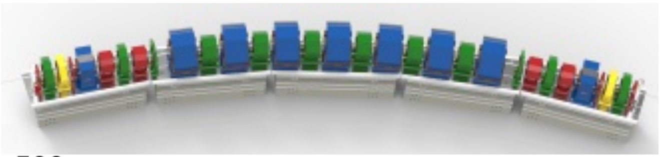
Advanced Light Source (Triple Bend Achromat)

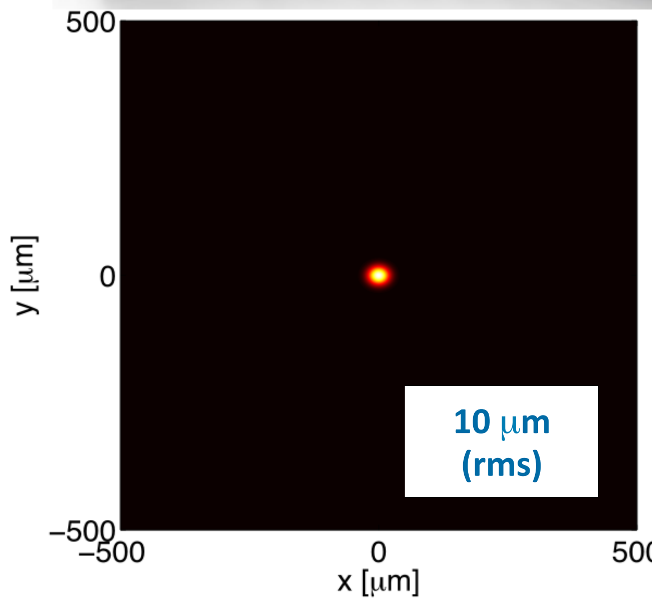




Study mostly *simply organized*, *homogenous*, and *static* materials

Advanced Light Source Upgrade (Multi-Bend Achromat)





Study more *complex* materials under *dynamic* conditions

Large increase in coherent fraction and flux

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ALS-U

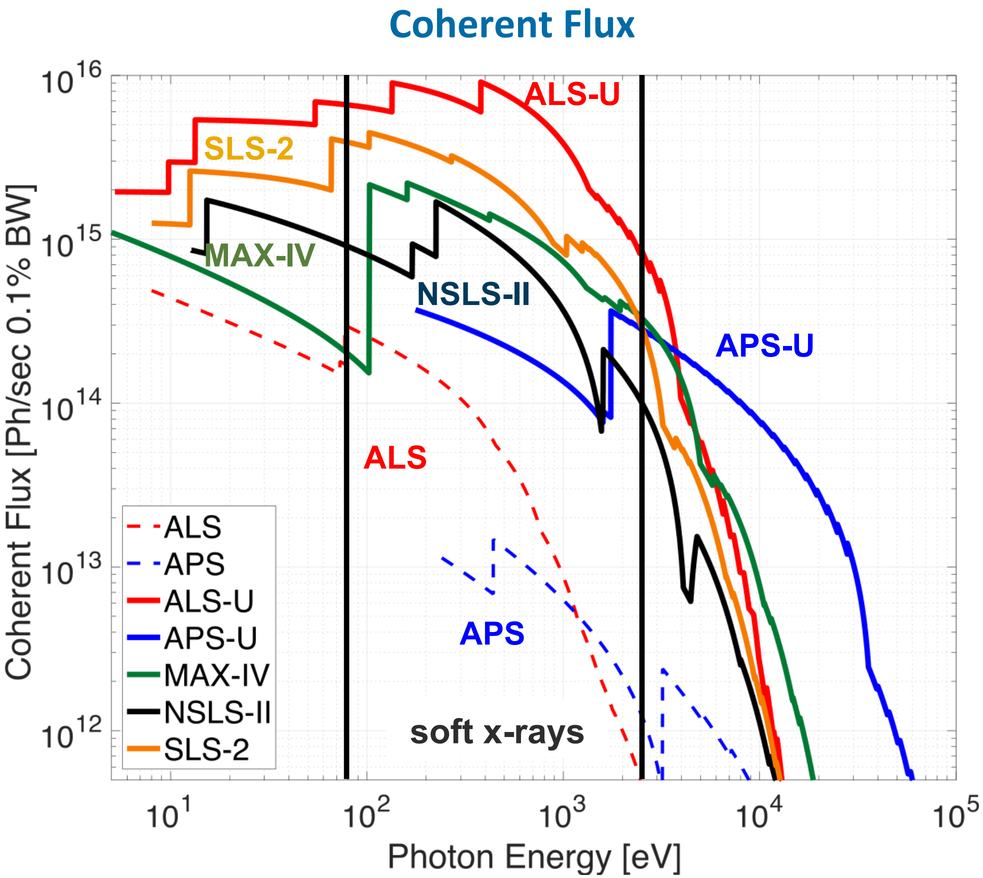
ALS-U: Designed to be the world's highest coherent flux soft x-ray synchrotron light source

Reasons

1. **Optimal beam energy (2 GeV)**
   - Highest flux
   - Minimizes beamline heating

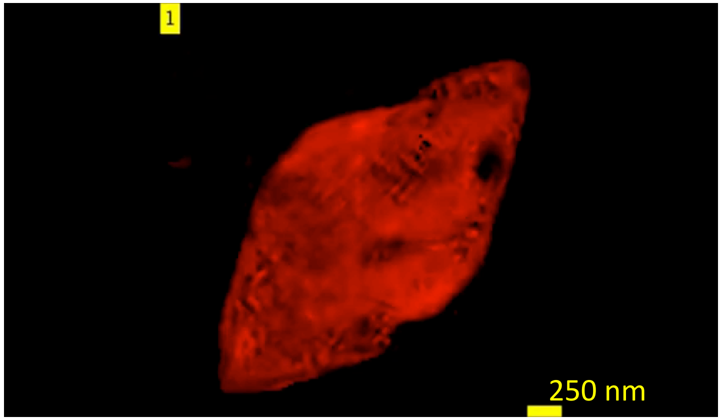
2. **Beams that are nearly fully coherent in transverse direction**
   - MBA technology with swap-out injection allows <70 pm-rad emittance round beams

3. **Optimal insertion devices**
   - Swap-out injection permits small, round (4-6 mm diameter) vacuum apertures



ALS-U will near the fundamental limit of what is possible with any currently envisioned storage ring technology

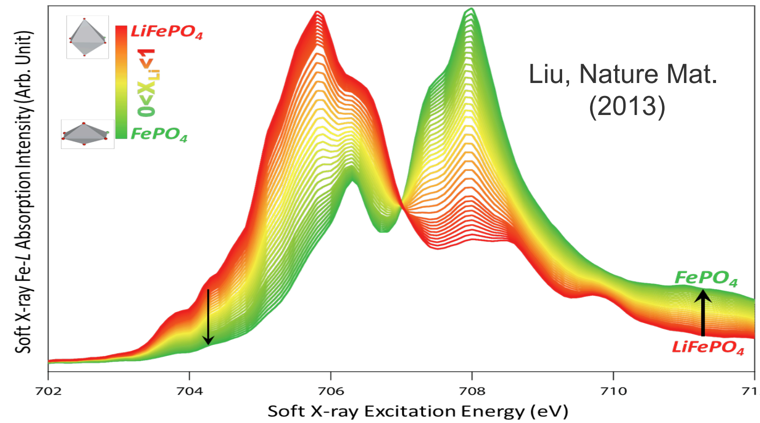
Map spatiotemporal chemical kinetics in heterogeneous media at ~kHz frame rate



“X-ray movies”

Lim, Science 2016

(2D movie; ~15 nm resolution;
2 energies; 30 sec/frame)



	30 nm	10 nm	3 nm
ALS	180 s	4 hours	23 days
ALS-U	1.8 s	144 s	5 hours

X-ray exposure time required to image this particle in 3D with full spectral coverage

ALS-U will revolutionize our ability to observe in real time the impact of interfaces and defects on nanoscale material and chemical kinetics

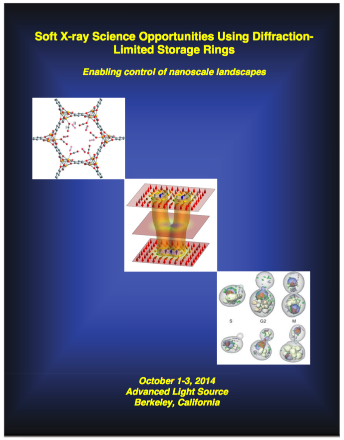
ALS-U Timeline and Status

Jul 2013

BESAC Subcommittee on Future X-ray Light Sources:
“The Office of Basic Energy Sciences should ensure that U.S. **storage ring** x-ray sources reclaim their world leadership position.”

Oct, 2014

Workshop on Soft X-ray Science Opportunities using Diffraction-Limited Storage Rings, LBNL – result presented at Feb 2015 BESAC Meeting



Since FY14

Received funding from LBNL for R&D as well as pre-project development. In FY16 received funding from BES for Research and Development for the Advanced Light Source Upgrade

Jun 2016

BESAC Prioritization Panel grades ALS-U as “Absolutely Central” to contribute to world leading science and as “Ready to Initiate Construction”

Sep 2016

ALS-U receives approval of Mission Need (CD-0) from DOE/BES with a cost range of \$260M to \$420M

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ALS-U

ALS-U core team

Steve Kevan
Science Lead

David Robin
Project Director

Ken Chow
Project Manager

Christoph Steier
Accelerator Systems Lead

Ken Goldberg
Beamline and Optical Systems Lead

Jim Haslam
Installation and Removal Lead

Scope of the ALS-U project

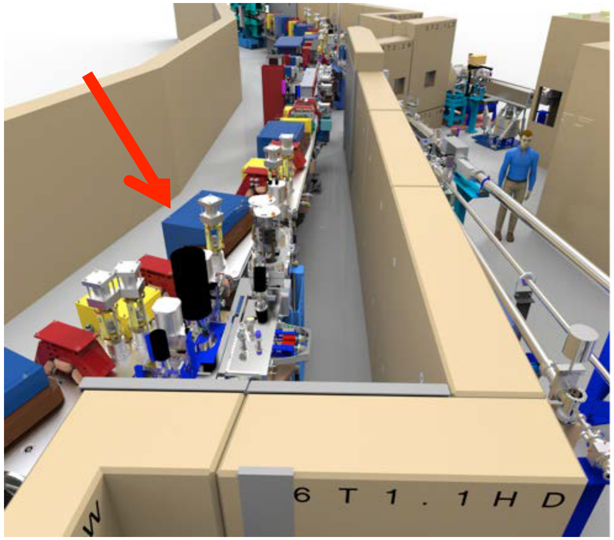
1. **Replacement** of the existing triple-bend achromat storage ring with a new, high-performance storage ring based on a multi-bend achromat.

2. **Addition** of a low-emittance, full-energy accumulator ring in the existing storage-ring tunnel to enable on-axis, swap-out injection using fast magnets.

3. **Addition** of new undulator beamlines that are optimized for novel science made possible by the beam's high soft x-ray coherent flux.

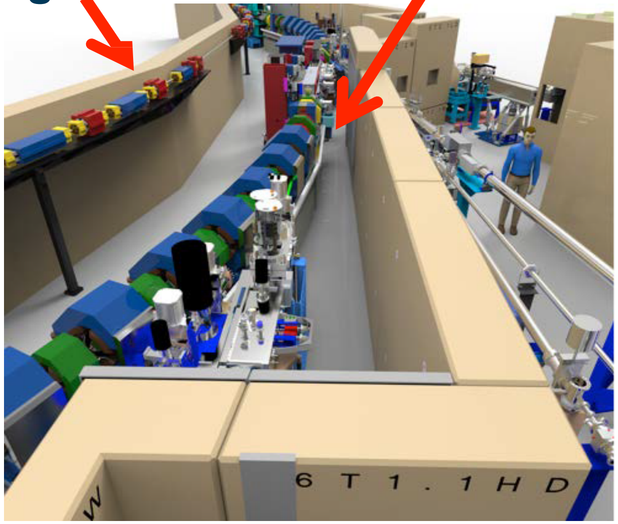
4. **Upgrade** of the optics on existing beamlines and realignment or relocation of beamlines where necessary.

Existing Ring



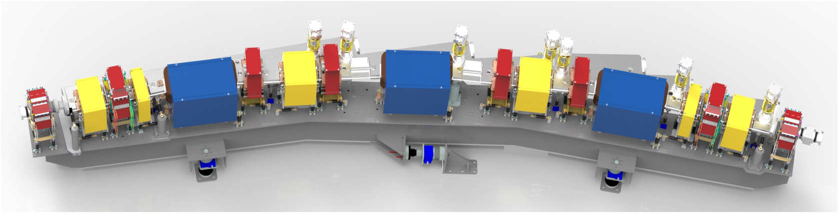
New accumulator ring

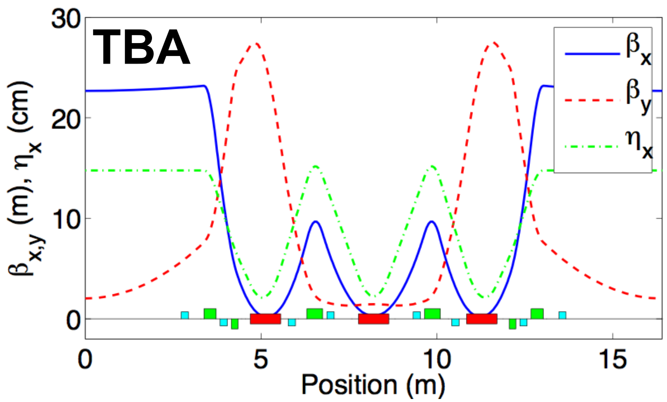
New ALS-U MBA ring



Baseline ALS-U lattice uses compact 9BA

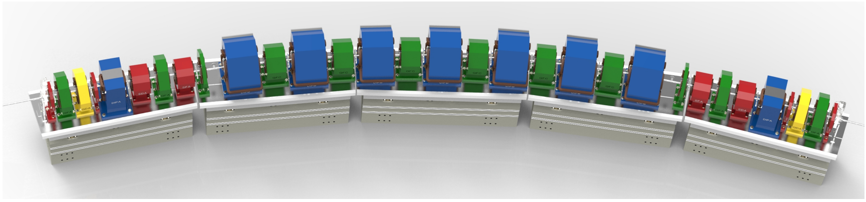
ALS today
triple-bend achromat (TBA)

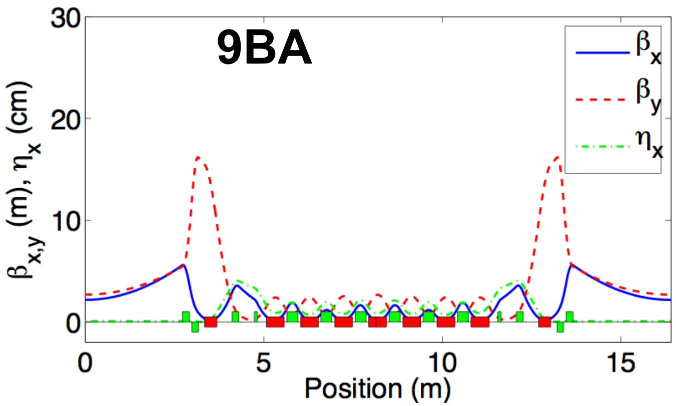




$\varepsilon_x = 2000$ pm @ 1.9 GeV

ALS-U
multi-bend achromat (9BA)





$$\varepsilon_x = C_L \frac{E^2}{N_D^3}$$

$\varepsilon_x < 70$ pm @ 2.0 GeV

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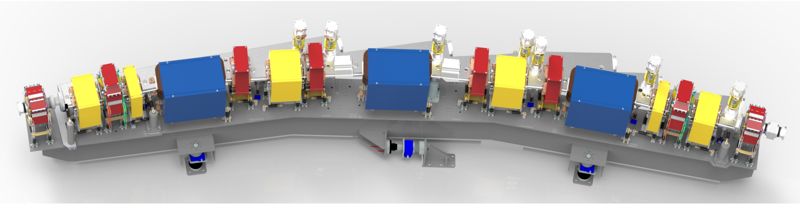
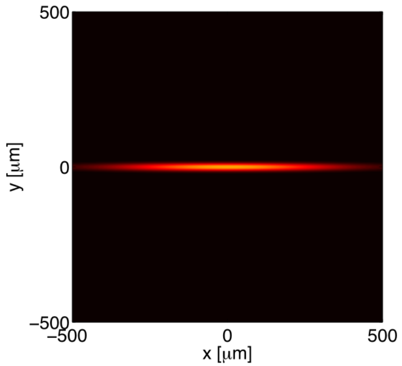
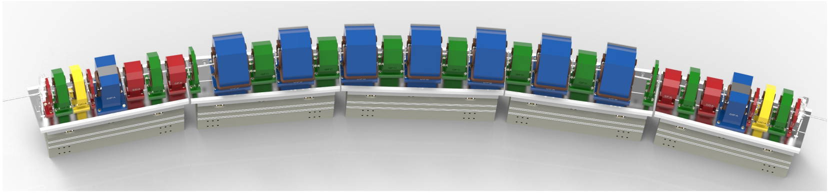
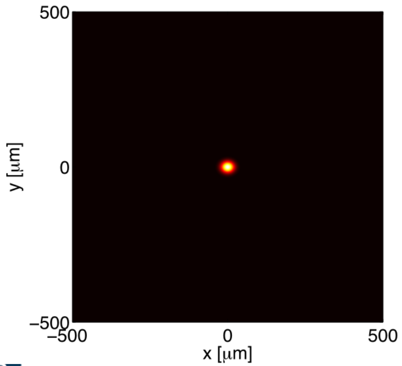
ALS-U

ALS and ALS-U in numbers









Parameter	Units	ALS	ALS-U
Electron energy	GeV	1.9	2.0
Horiz. emittance	pm	2000	<70
Vert. emittance	pm	30	<70
Beamsize @ ID center (σ_x/σ_y)	mm	251 / 9	<10 / <10
Beamsize @ bend (σ_x/σ_y)	mm	40 / 7	<5 / <7
bunch length (FWHM)	ps	60-70 (harmonic cavity)	120-200 (harmonic cavity)
RF frequency	MHz	500	500
Circumference	m	196.8	~196.5

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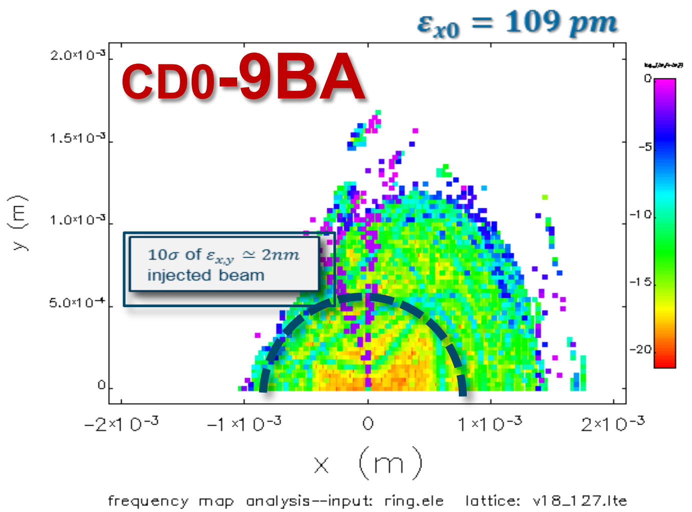
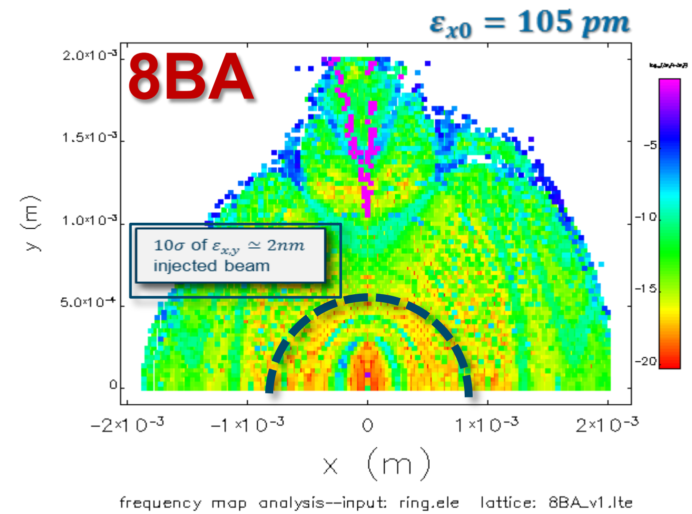
ALS-U

Exploring the 8BA option

(On-momentum) dynamic aperture:

There are 8BA lattice solutions with better (on-momentum) Dynamic Aperture and equal/better emittance than 9BA





Errore-free lattices

- **Unfortunately, "momentum aperture" tends to be worse than in the 9BA**
  - Momentum aperture largely determines the life time of stored beam (consequences in radiation-output stability, demand on injection system)
- **Optimization work still ongoing**
  - Working closely with magnet experts (C. Swenson, J-Y Jung) to sort out feasibility of magnet specs
- **Evaluating trade-offs between on/off momentum dynamic aperture and target emittance**

Led by M. Venturini

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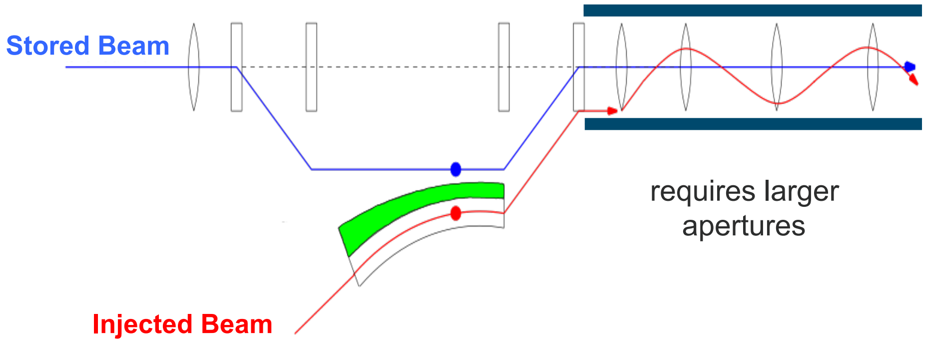
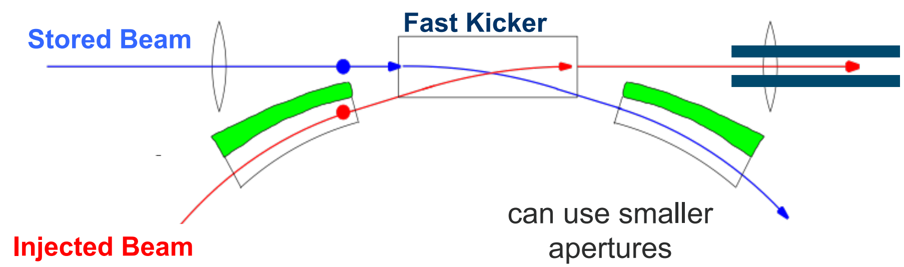
Swap-out and recovery with a full-energy accumulator

Traditional off-axis injection



On-axis swap-out injection

(initially proposed by M. Borland)



Swap-out enables:

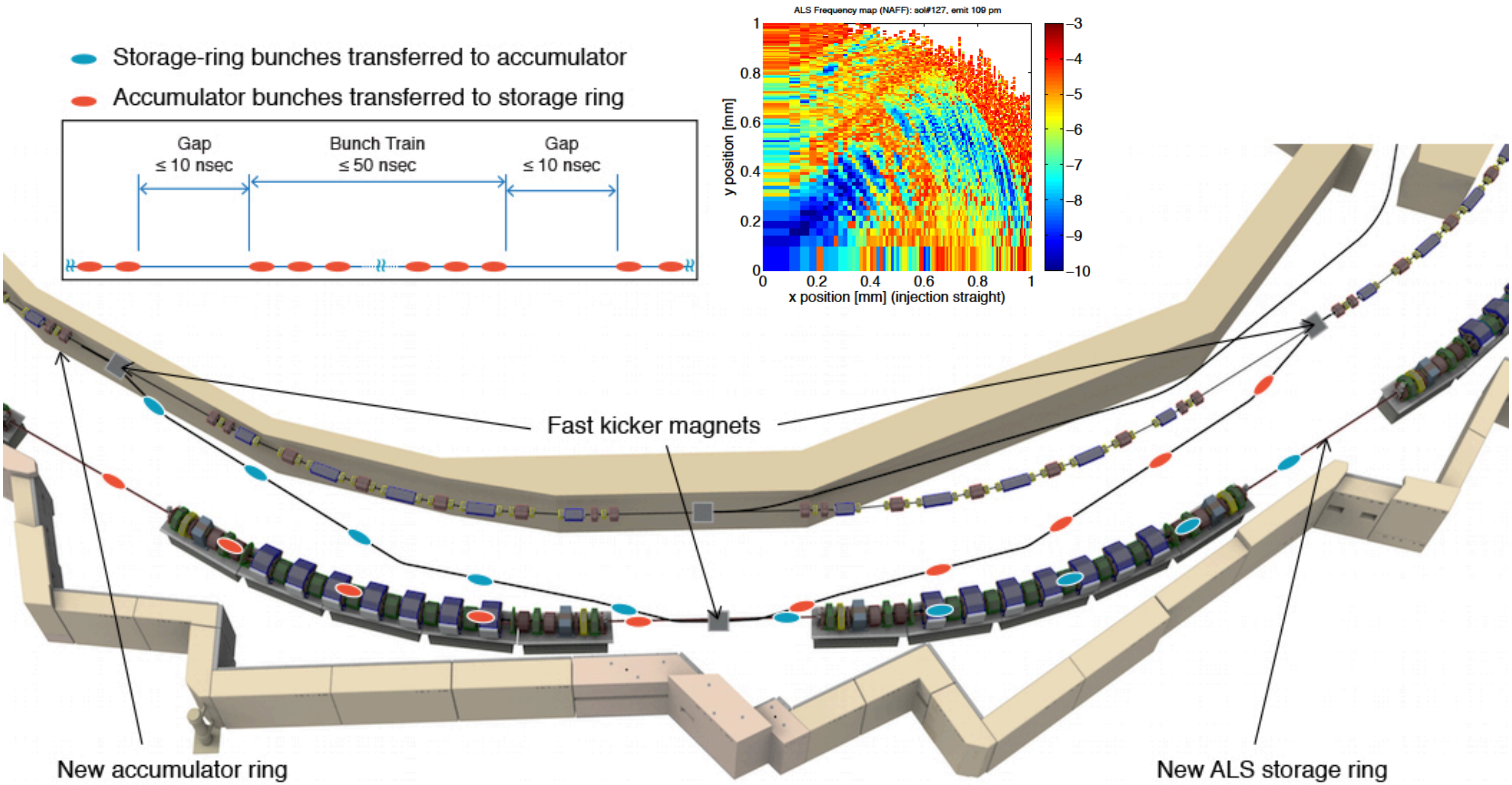
- Stronger-focusing MBA lattices with smaller dynamic apertures
- Round beams - more useful shape and reduced emittance growth
- Vacuum chambers with small round apertures → Improved undulator performance

Only ALS-U and APS-U plan to include swap-out

Swap-out with full energy accumulator enables:

- Bunch train swap-out and recovery of the stored beam current
  - Lower demand on the injector
  - Very small (~nm) injected emittance
  - More flexibility in fill patterns

Swapping accumulator and storage ring beams



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

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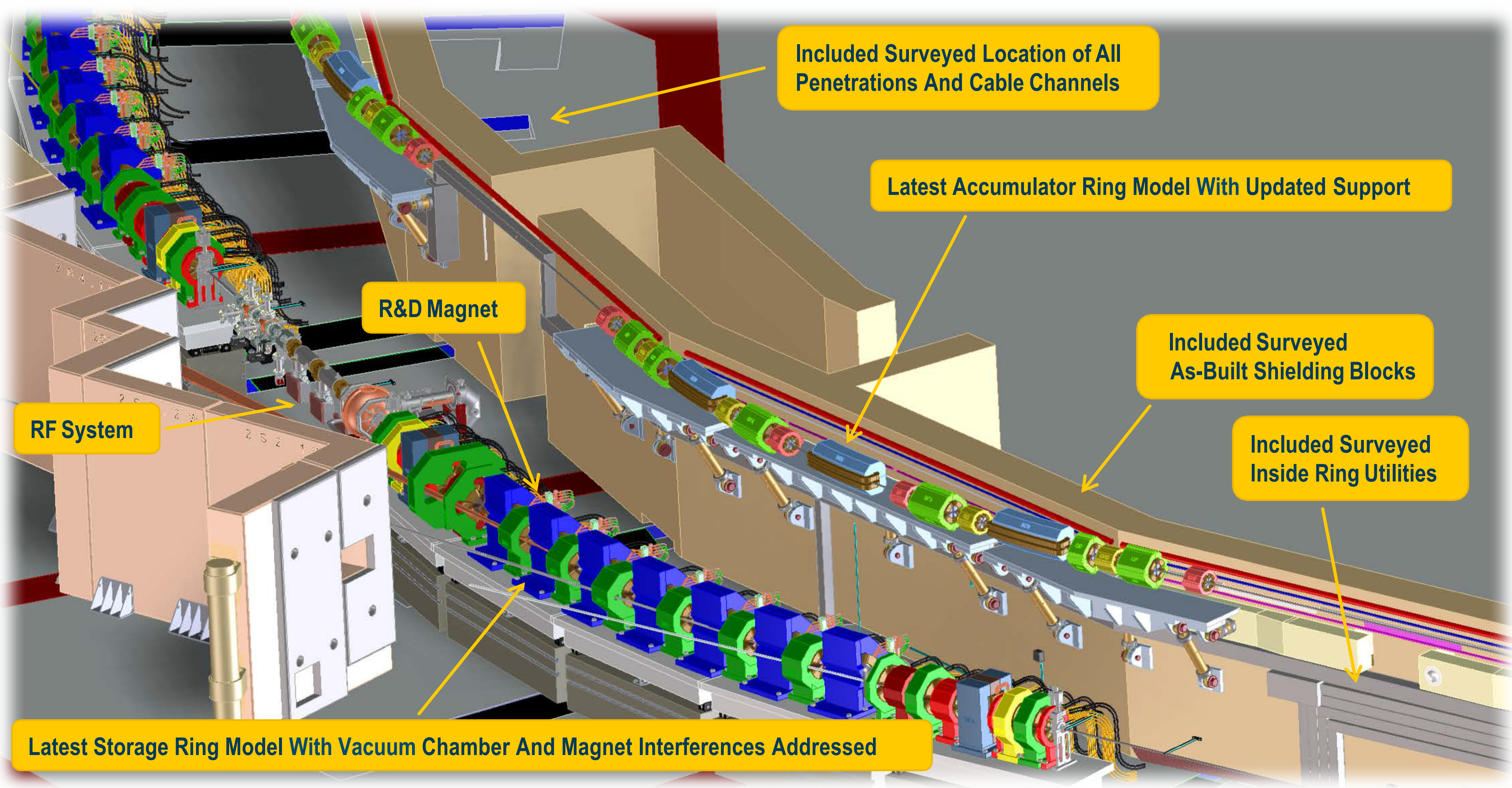
Conceptual layout of the storage ring and accumulator



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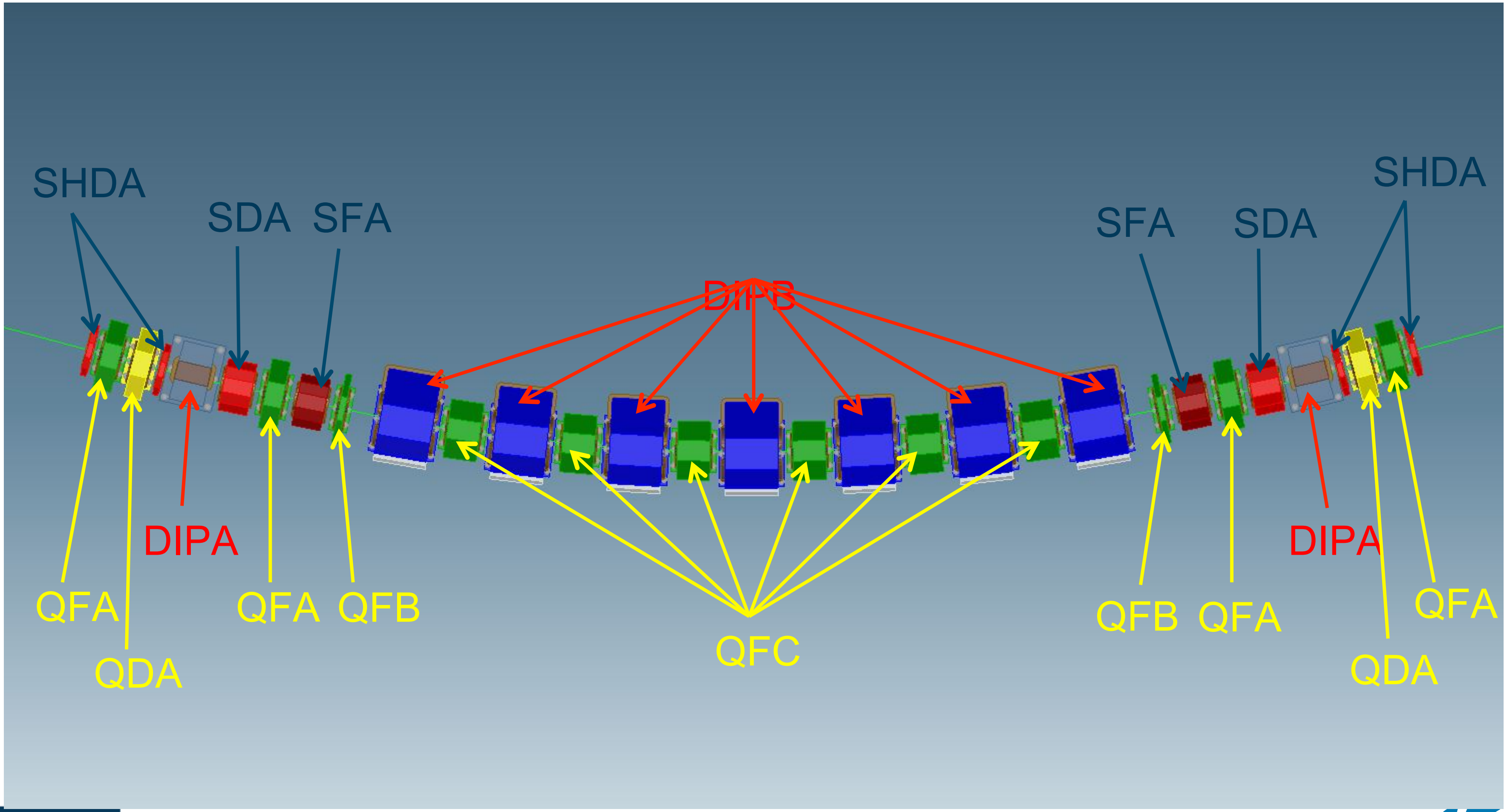
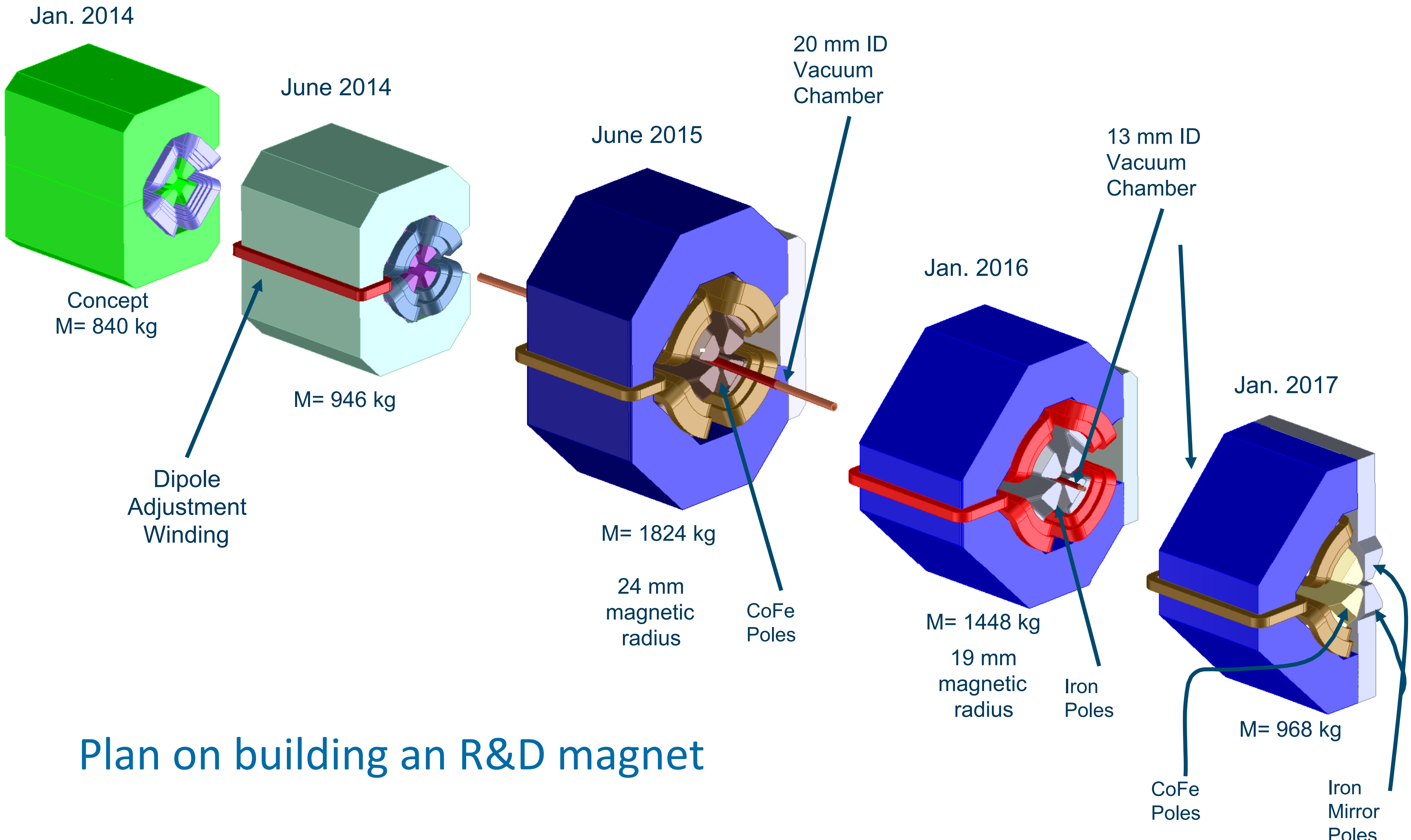
Sector Magnets for 9 Bend Lattice



Evolution of 3.33° Central Arc Magnets

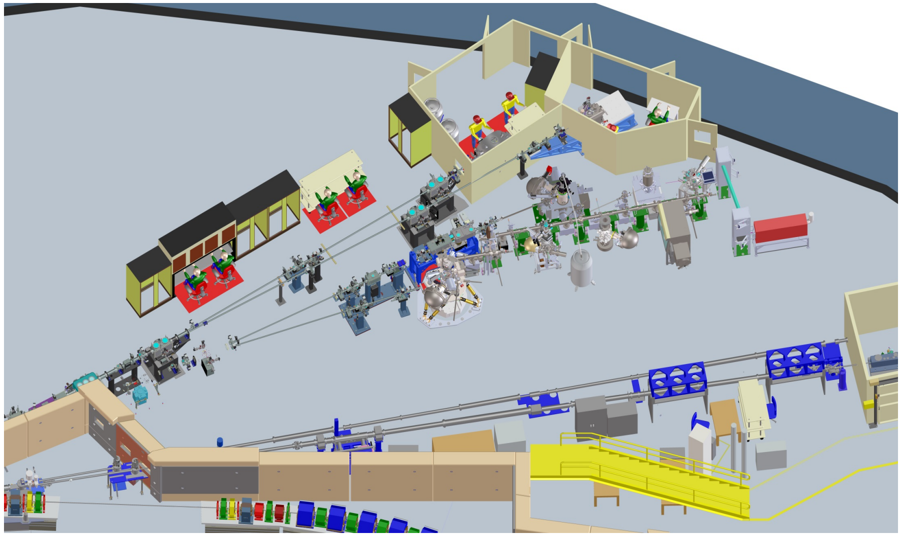


Plan on building an R&D magnet

Led by C. Swenson

Scope 3 and 4. Current Plans has an upgrade of the relevant experimental systems, providing specialized beamlines to take advantage of new ALS-U capabilities and to keep existing beamlines operating with high efficiency

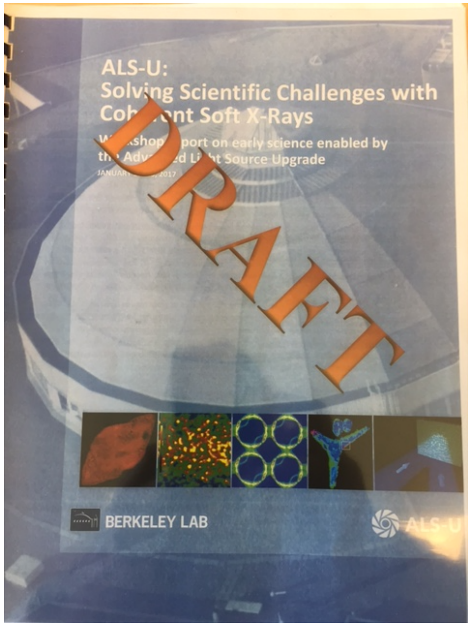
- **Addition of new beamlines optimized for the science case with high coherent soft x-ray flux**



- **Beamline optics upgrades for all existing ID or bend-magnet beamlines where required to take advantage of the higher coherence**

- **Realignment of bend-magnet beamlines due to small changes in source-point locations**

January Science Workshop: Solving Scientific Challenges with Coherent Soft x-rays – January 18-20, 2017



- **Workshop Focused on the Unique Science Enabled by ALS-U**
- **Workshop report ("early science document") has been drafted**

Technical challenges and mitigation strategies have been identified and separated into two categories

Category 1. Risks that are typical of MBA designs and are similar for all new and upgrade projects that employ MBAs, such as:

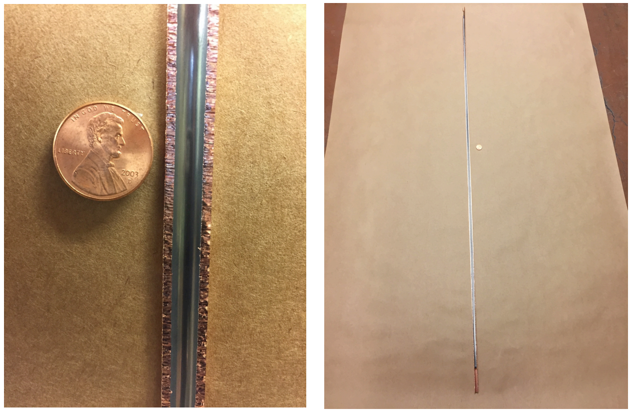
- Small (~20 mm) aperture NEG-coated vacuum chambers
- Tightly packed MBA lattice

Category 2. Those that are specific to ALS-U related to optimizing a machine for soft x-rays with the resulting lower electron beam energy, such as:

- Swap-out injection
- Emittance increase due to intrabeam scattering
- Very small (4 to 6 mm) aperture NEG-coated vacuum chambers

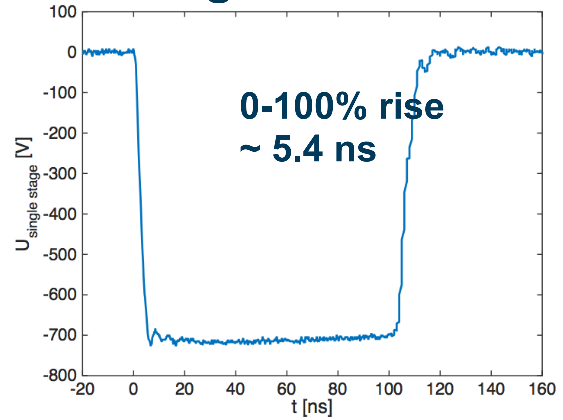
Substantial R&D progress to date on mitigating technical challenges specific to ALS-U

Very small NEG coated vacuum chambers



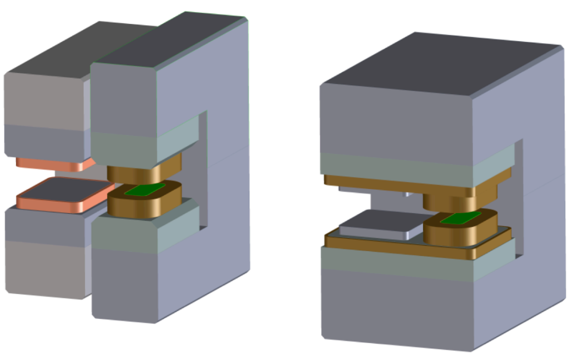
Coated 6 mm chamber (world record)

On-axis Injection – Fast pulsed magnets



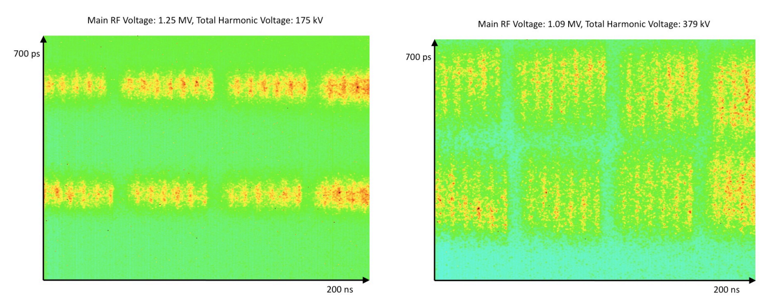
Single stage of inductive adder achieves 5 ns rise (7 ns needed)

Magnets – SR Production



Developing Superbend options

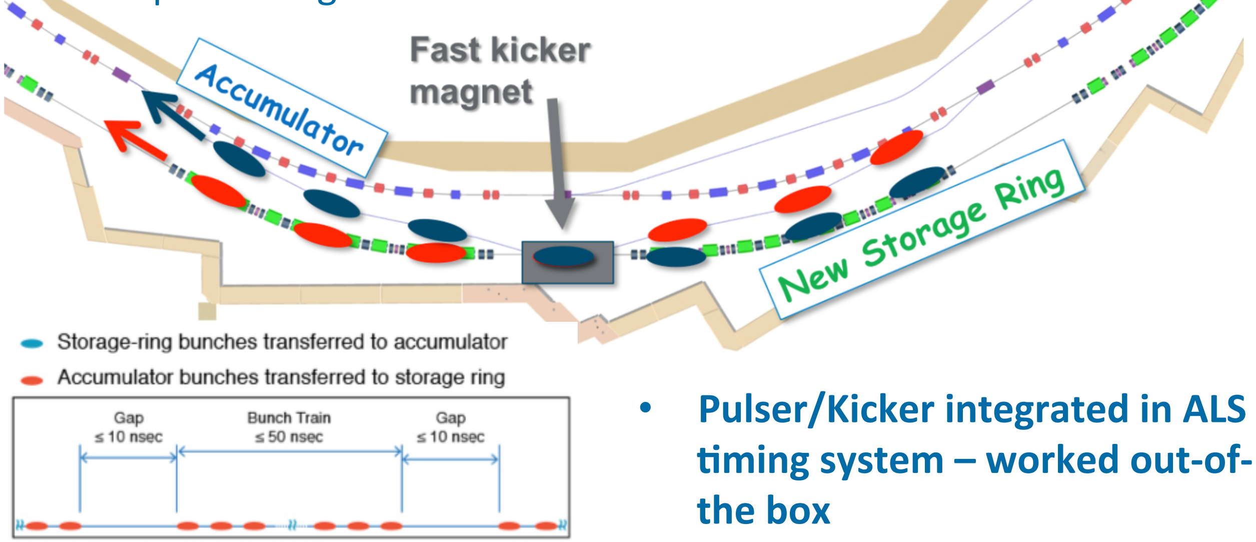
Harmonic Cavities - Transients

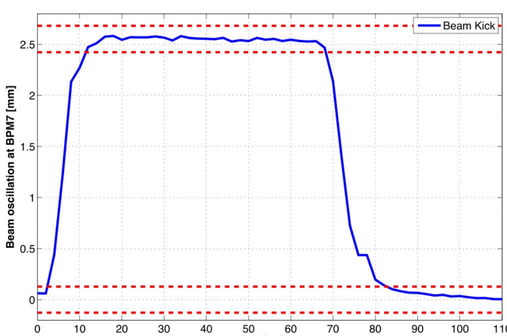


Achieved needed bunch lengthening with ALS-U bunch trains in ALS (3HC)

Successful On-Axis Kicker and Pulser for Swap-out and exchange of bunch trains

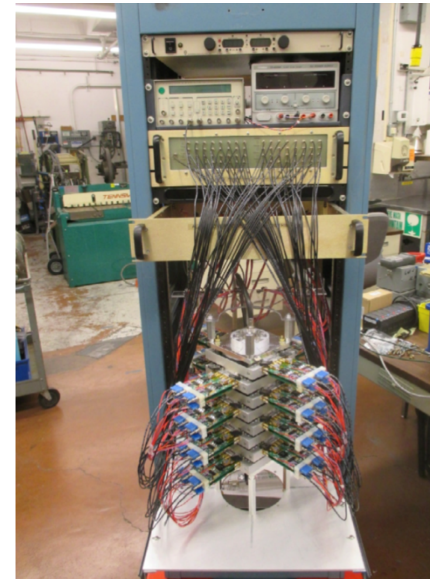
- Plan to operate storage ring with ~11 bunch trains of 25 bunches each
- Need to swap out and replace one train without perturbing the others





- **Pulser/Kicker integrated in ALS timing system – worked out-of-the box**
- **Beam test results are very good – consistent with expectation, fulfills almost all requirements**

Key technical challenge has been mitigated



Pulser (inductive adder)

Stripline kicker (in ALS)

Led by C. Steier, W. Waldron

Successful initial tests of automated commissioning and getting to stored beam

Motivation:

- Traditional **manual** machine commissioning is slow and will be more challenging for the smaller dynamic aperture MBAs.
- New BPMs and algorithms offer the opportunity to largely automate and shorten the time to commissioning

Experimental test setup:

- Developed trajectory response matrix and correction code
  - Configurable number of turns, correctors, and singular values.
- Test example with all correctors off – beam makes only one turn due to a single badly aligned sextupole

Result of test:

- **Correction sufficient after 3 injection shots to store beam!**
  - Residual closed orbit error about 1 mm peak

Led by C. Steier

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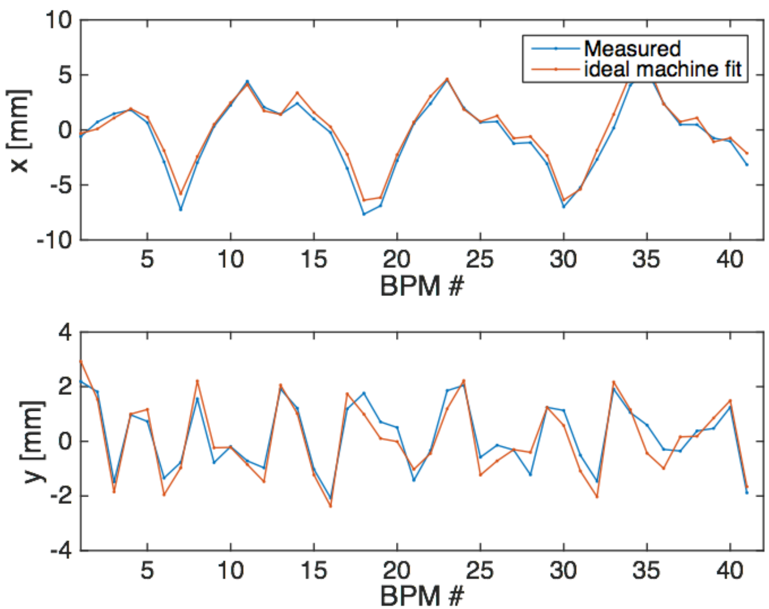
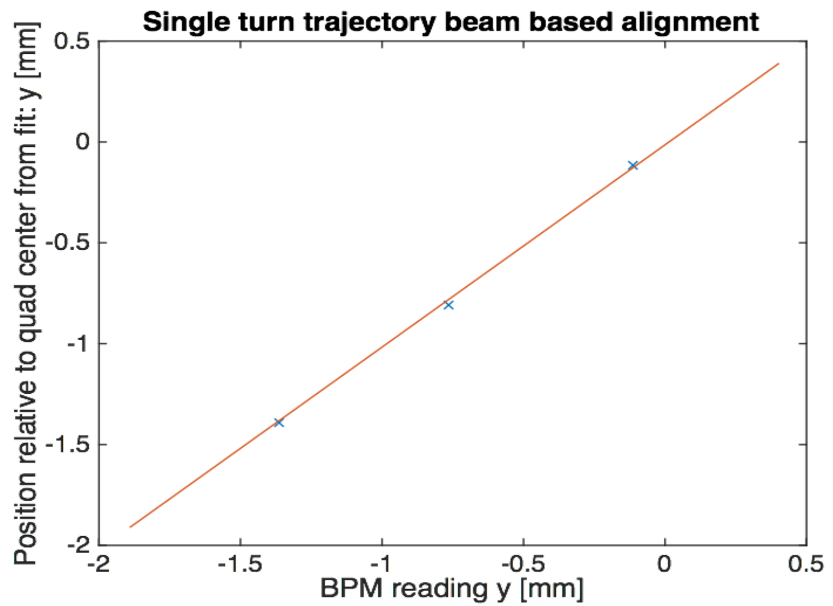
Beam based alignment using turn-by-turn BPMs

- Demonstrated trajectory correction and ability to do better than 100 micron accuracy beam-based alignment without requiring stored beam.



Intentionally offset first turn trajectory of injected beam in the ALS and trajectory fits using the ideal machine model.



Beam based alignment measurement using only first turn trajectory measurements. Result agrees within 50 microns with stored beam measurements.

Led by C. Steier

ALS-U Optics: Issues and R&D

ALS → ALS-U **horizontal source** ~25× smaller: **power density** is higher

Optics Quality: A much higher quality manufacturing needed to preserve wavefront
- 1 manufacturer worldwide working at the tolerances necessary
    - *mainly an issue of qualification of optical metrology*

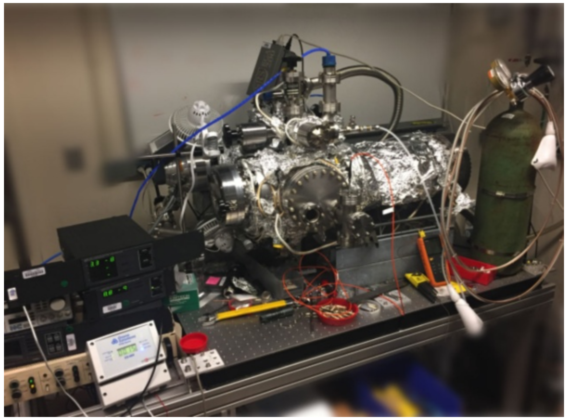
Vibration: A lower level of (horizontal) vibration is required for stable beams
- Water-induced vibration is the main issue
- Developed sophisticated fluid dynamics modeling capability
- Comparing theory to bench-test models of cooled mirrors

Mirror Cooling: ALS-U requires much better cooling to preserve mirror shapes
- Optimized, water-cooled Si optics will work at present ALS undulator power levels (FEA)
- LN2-cooled optics can meet the slope error tolerance for the most powerful undulators.
    - Introduces issues of stress-induced shape change and contamination

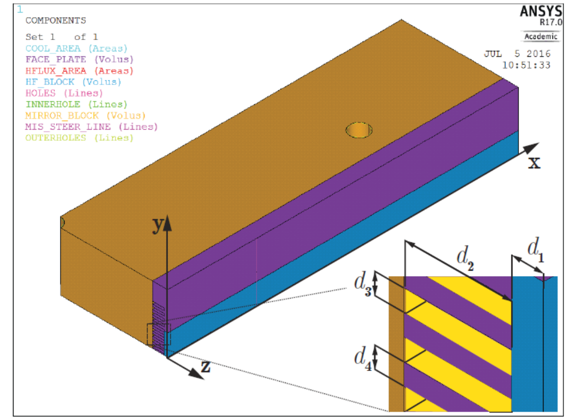
Carbon Contamination: Much lower levels of carbon are needed
- Carbon is a phase shifter and beam attenuator: effect is like a physical surface bump
    - Potentially very damaging to the preservation of wavefront quality
- Avoidance requires much better UHV conditions, and in situ plasma cleaning

Led by K. Goldberg

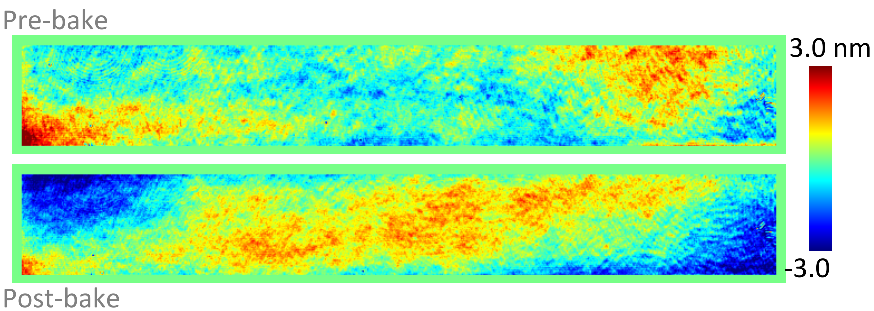
Optics Challenges: ability to preserve coherent wavefront



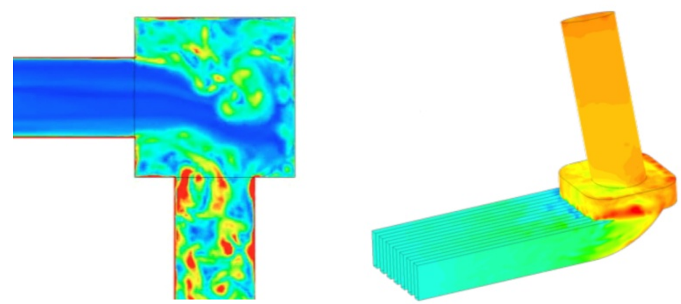
Understanding how to remove/prevent carbon



Understanding the dynamic response of mirrors to changing power density, e.g. ID polarization changing



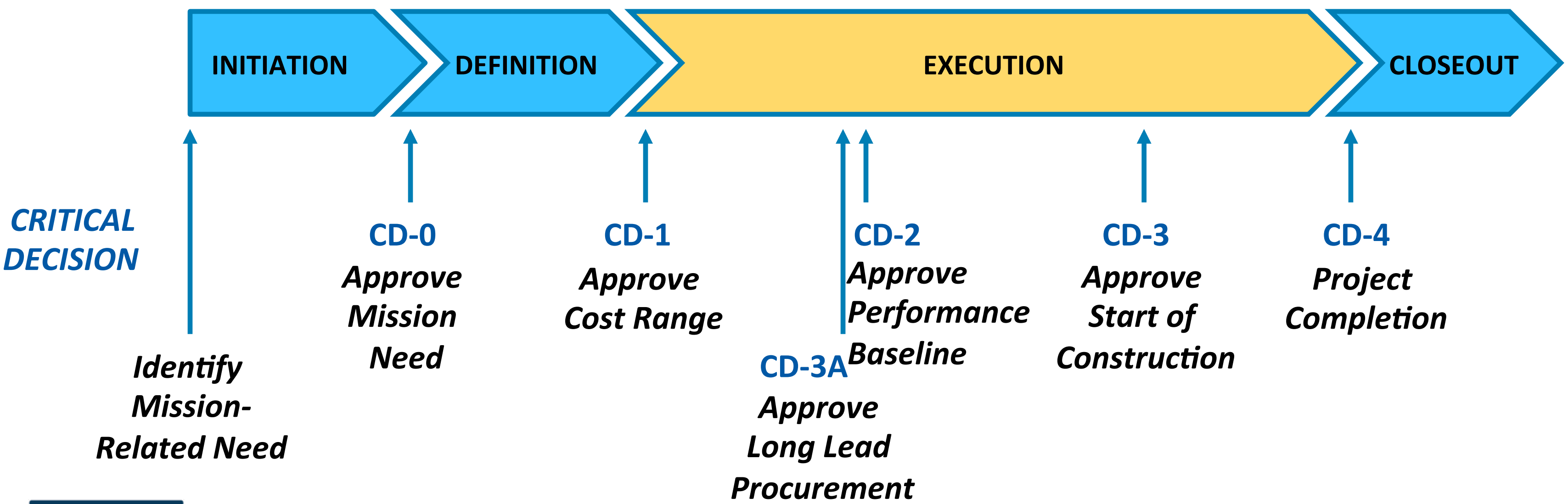
Si mirror shape changes induced by mirror baking



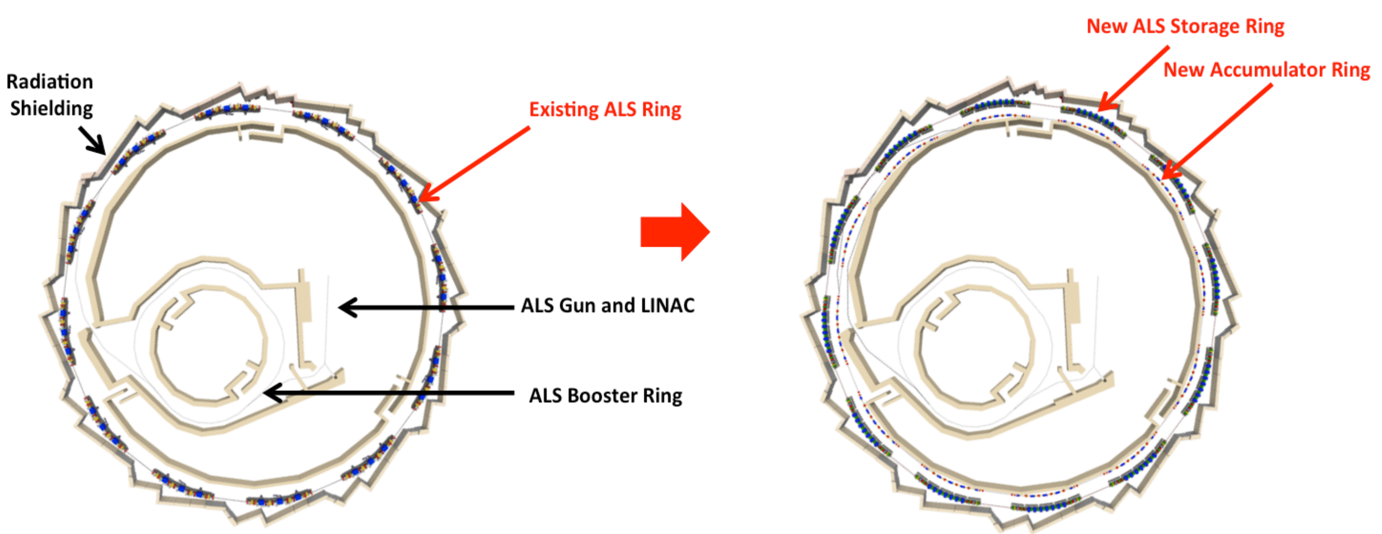
Water- and cryo-cooled-mirror fluid dynamics simulations

Focus areas for this year

- Continue key R&D
- Develop conceptual design
- Enhancing user engagement
- Set up the project



Very excited that ALS-U has begun



ALS-U will meet a key BES/DOE need by providing world-leading soft x-ray beams with high coherent flux to enable cutting-edge science.

- Laboratory Director has named ALS-U the top priority project for Berkeley Laboratory
- Technical issues and risks are identified, and R&D is underway to mitigate significant technical risks and uncertainties.

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Thank you
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