20-Year BES Facilities Roadmap Workshop

February 22-24, 2002

Doubletree Hotel and Executive Meeting Center
1750 Rockville Pike
Rockville, MD 20852

- **Saturday and Sunday Facility Presentations**
- **Sunday Night and Monday Report Writing**

Subcommittee Members

- Geri Richmond, U of Oregon (Co-Chair)
- Sunil Sinha, UCSD (Co-Chair)
- Nora Berrah, Western Michigan U. (BESAC)
- Joe Bisognano, Synchrotron Radiation Center, Wisc.
- Collin Broholm, Johns Hopkins (BESAC)
- Phil Bucksbaum, U. of Michigan (BESAC)
- Jack Crow, National Magnetic Lab, Florida
- Pascal Elleaume, European Synchrotron Rad. Fac., France
- Eric Isaacs, Bell Labs/Lucent (BESAC)
- Gabrielle Long, NIST (BESAC)
- Gerhard Materlik, Diamond Light Source Ltd.
- Les Price, ORO
- Kathy Taylor, Retired GM (BESAC)

Technical Representatives

- ANL-- Robert Kustom
- BNL-- Jim Murphy
- LBNL-- Howard Padmore
- ORNL-- Norbert Holtkamp
- PNNL-- Ray Doug
- SLAC-- Max Cornacchia
- TJNAF-- Swapan Chattophadhyay

Saturday and Sunday Presentations

- Linac Coherent Light Source
- SNS Power Upgrade
- Transmission Electron Aberration Microscope
- SNS Long Wavelength Target Station
- High Flux Isotope Reactor Target Station II
- Linac-based Ultrafast X-ray Source
- National Synchrotron Light Source Upgrade
- Linac Coherent Light Source Upgrade
- Green-Field Free Electron Laser
- Advanced Photon Source Upgrade
- Keeping the Advanced Light Source at the Cutting Edge
- *Complex Interfacial Catalysis Facility*
- *Energy Recovering Free Electron Laser Sci. User Facility*
- *The Ames Plant Metabolomics Resource Facility*
- *Accelerator Based Continuous Neutron Source*

ADVANCED PHOTON SOURCE
ACCELERATOR SYSTEMS DIVISION
Seminar Announcement

SPEAKER:	Kwang-Je Kim Associate Division Director
TITLE:	**Greenfield FEL**
DATE:	Thursday, March 27, 2003
TIME:	1:30 p.m.
LOCATION:	A1100

A fourth-generation light source based on high-gain free electron lasers (FELs) is becoming a reality! The Linear Coherent Light Source (LCLS) project at SLAC is funded for engineering design and is scheduled to turn on in 2009. The TESLA FEL at DESY has also received a positive recommendation for construction to be complete by 2012. These facilities will produce intense, coherent x-ray beams with unprecedented brightness and time resolution. This talk is about a "Greenfield FEL," a high-gain FEL facility genuinely optimized for user operation taking into account lessons learned from the first FEL facilities--what will be its requirements and what do we need to do to build it. This talk was given at the BESAC Subcommittee Meeting on the BES 20-year road map, February 22-24, 2003.

Advanced Photon Source Upgrade Path

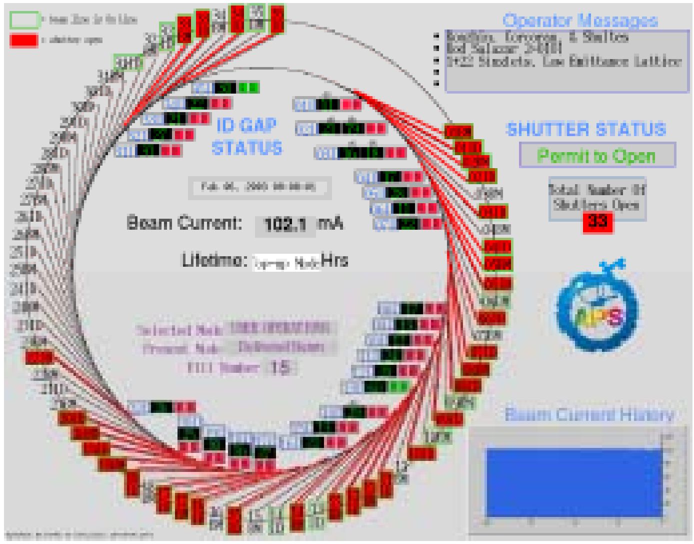
Defining the State-of-the-Art

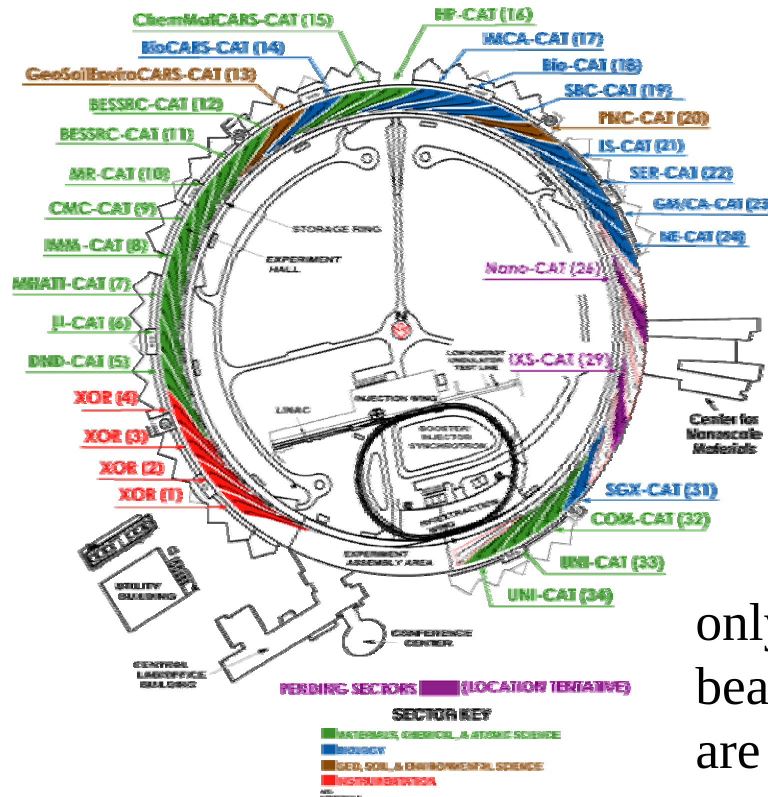
Presented to BESAC Subcommittee on 20-year Facilities Roadmap

February 23, 2003

By J. Murray Gibson

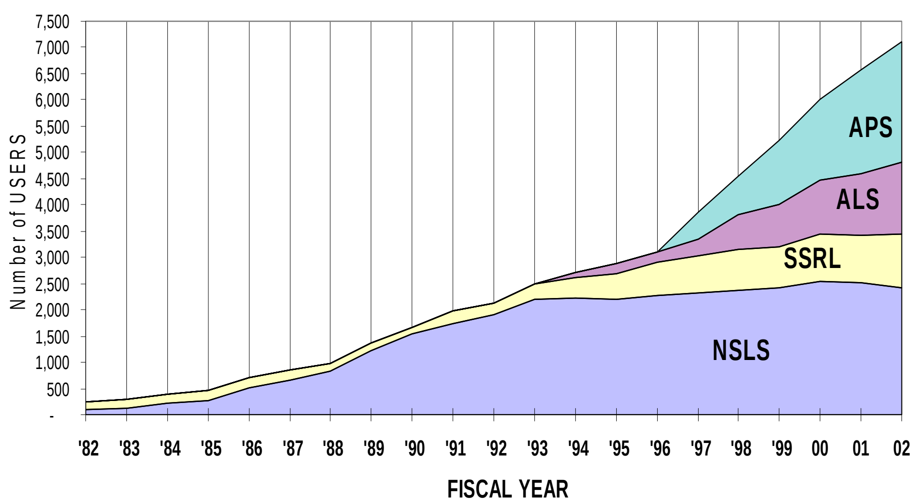
APS Today





only 4 ID beamports are not yet committed

38 functioning beamports (25ID, 13BM)
68 total available



APS user community to reach ~10,000 in a decade

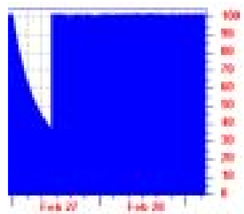
State-of-the-Art 3rd Generation Science in 20 Years?

- *Individual* nanoscale objects can be observed in *real-time*
- Electronic, dynamic and magnetic properties of a *single nanostructure* can be measured
- *A few atoms* can be chemically identified
- A full dataset for protein structure analysis can be collected in *less than a second*
- X-ray imaging of objects with *nm resolution* is routine

History of Innovation

- Top-up operation

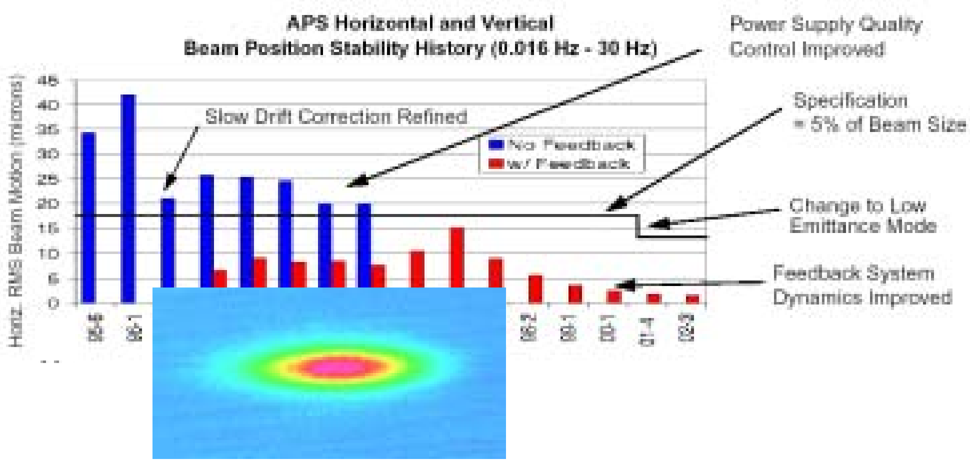
mA



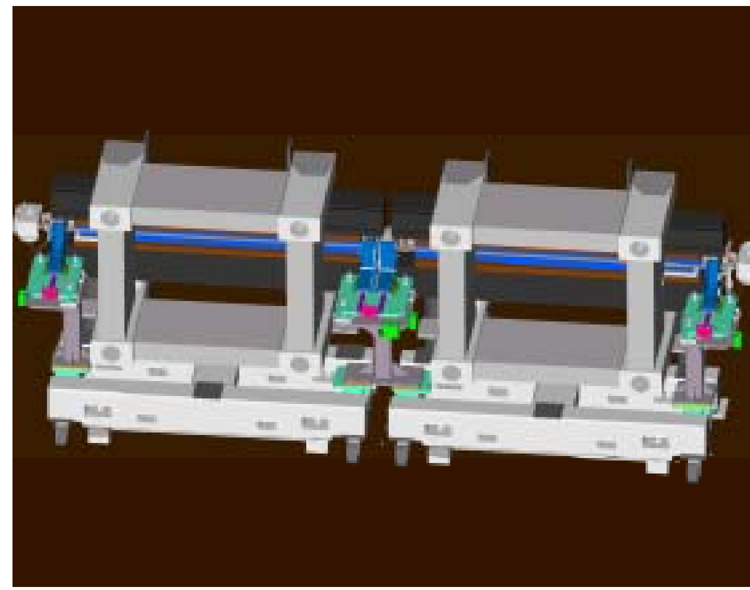
  –*Low emittance*

  –*Stable optics*

- Improved beam stability



Canted
Undulators



- driven by bio users

Guiding principles for next 20 years

- The mission of the Advanced Photon Source is to deliver world-class science and technology by operating an outstanding synchrotron radiation research facility accessible to a broad spectrum of researchers
- Need for 3rd Generation Sources will not go away in 20 years, and our user base will grow to ~10,000
  - 4th generation is revolutionary, but does not supercede 3rd generation
- Our users and staff should be connected with the next generation capabilities
  - short pulses (fs), higher coherence.
- APS capabilities must increase continually
  - over 1000 times improvement in “useable” brilliance possible within 20 years
- Maintain strong partnerships (such as CATs), and open access for general users

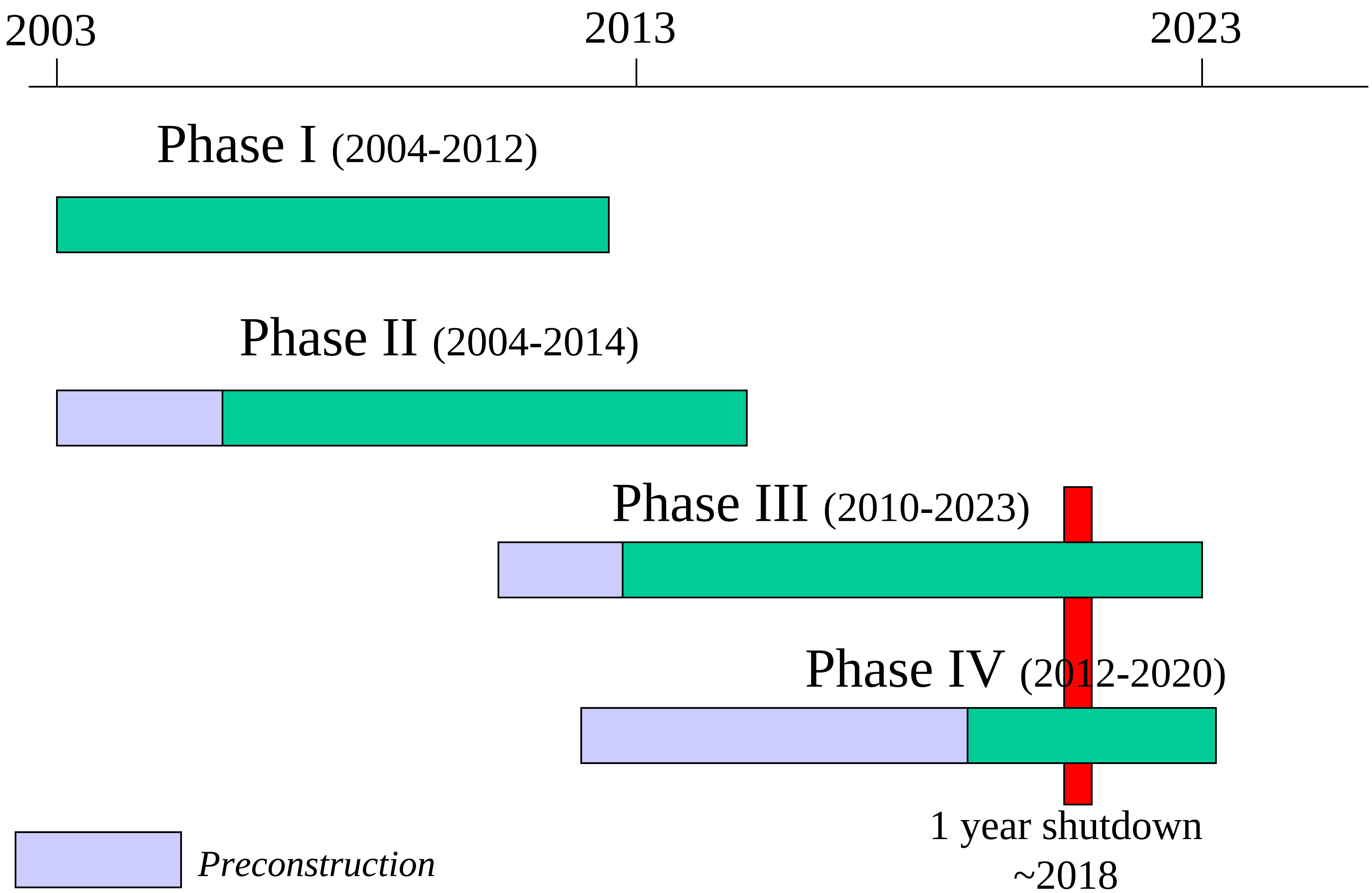
Defining the state-of-the-art in 3rd generation x-ray sources and science

APS phases of innovation in the next 20 years

- Phase I – Maximizing Beamline Operations
- Phase II – Maximizing Source Capabilities
- Phase III – Next Generation Facility
- Phase IV – Super Storage Ring

  – Phases II, III and IV each represent at least an order of magnitude increased useable brilliance

APS Upgrades Timeline



Phase I – Maximizing Beamline Operations (2004-2012)

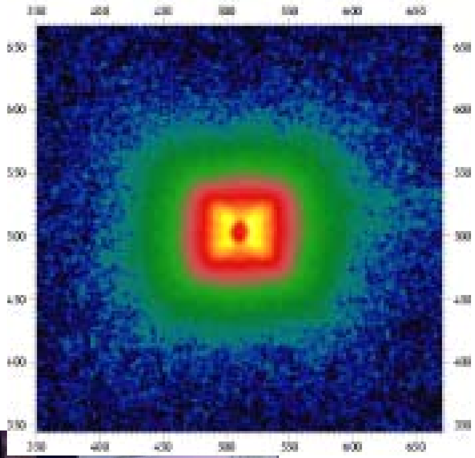
- 10 beamlines to be constructed in the next 8 years (5 years per beamline)
  - more than 1 beamline possible per beamport
- 10 beamlines to be upgraded
  - most likely BES sectors (~26 beamports)
- Construction
  - APS and partner user responsibility
- Operation
  - APS responsibility

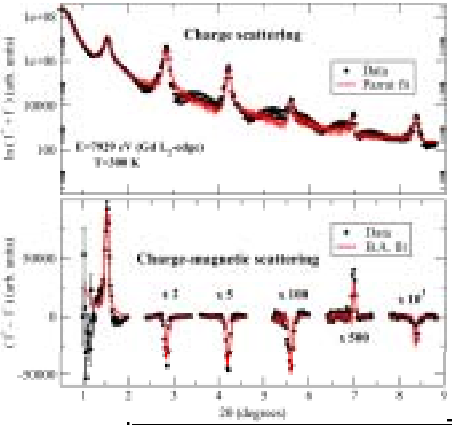
The Importance of the Science

- New capabilities will be optimized (in parallel with optimized sources during Phase II)
- All beamlines will be well operated and accessible
- Quantity and quality of output will increase
- Science Advisory Committee oversees choices

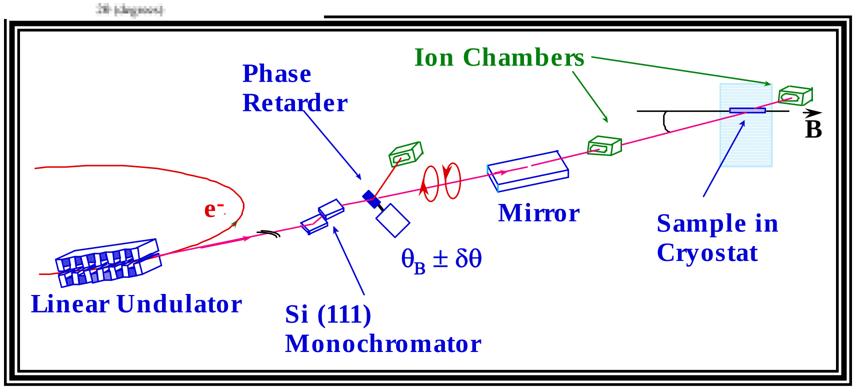
Two kinds of beamlines:

a "turnkey" beamline to efficiently collect - SAXS

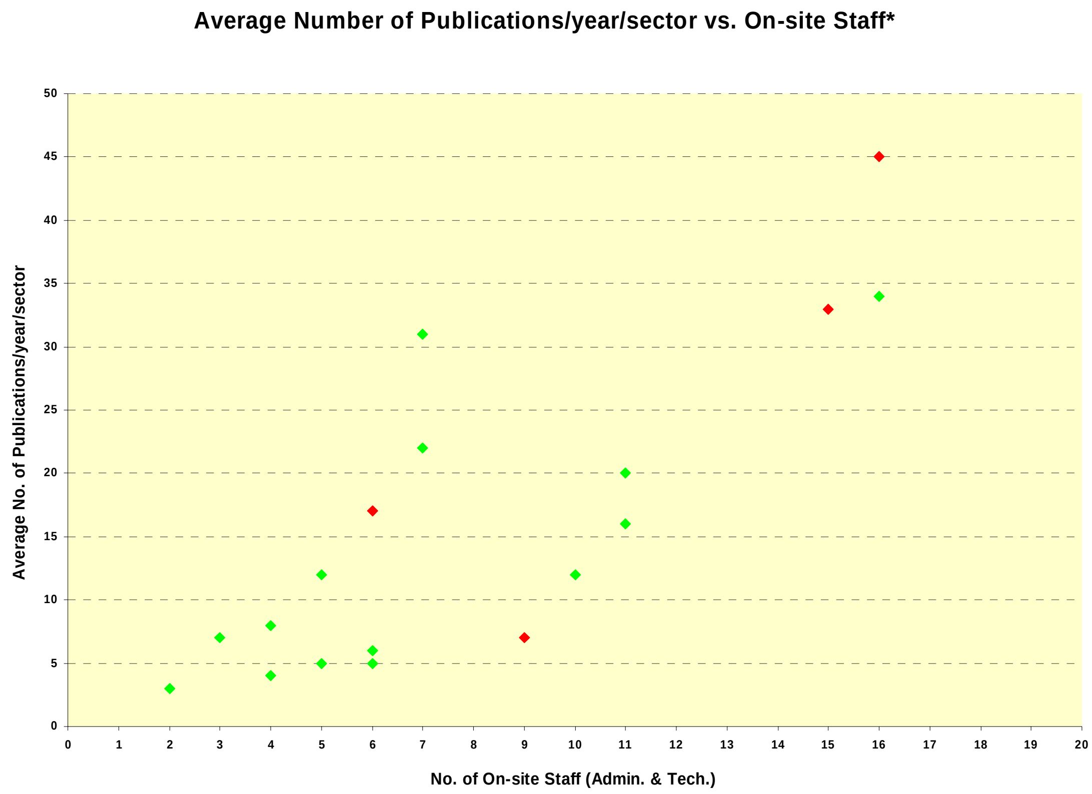




a dedicated beamline to "do experiments" - magnetic scattering



Beamline operation support leverages science

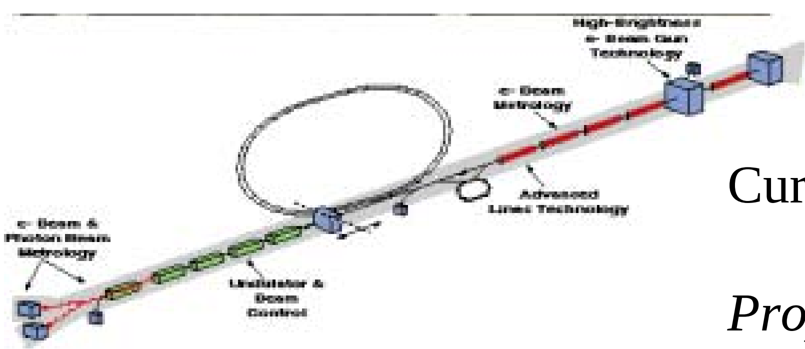


Readiness for Phase I

- Beginning now but limited by resources
- Capital resources and manpower for operations
  - our current staff level permits insertion device development and some beamline design assistance ~1/3 beamlines
  - operational staff support must grow by ~100 people (+20% current operating budget)
- Continuing incremental improvements in detectors, optics will occur during Phase I
- VUV-FEL facility is a special beamline -

APS “LEUTL” FEL beamline

- Allows accelerator physics activities such as gun development for 4th generation
  - – demonstrated SASE at ~100nm
  - – operates independently in non-top-up mode
- VUV-FEL user facility for ~$10M



Currently serving a single user:

UV single-photon ionization

Proposed facility offers better capabilities, more users and complete independence from SR

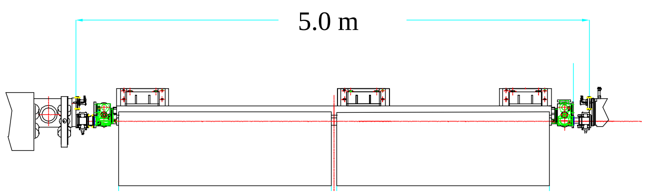
Phase I – Cost, Schedule, Scope and Management

- Estimated cost \$160M over 8 years
  - average 2-3 new beamlines per year, up-front weighting on new beamlines
- Funds for new instruments should be ½ inside, ½ outside facility (for partnering)
  - With research funds outside
- Operational funds should be inside facility (~\$20M extra in today's dollars)
- SAC role, external peer review also on partner proposals

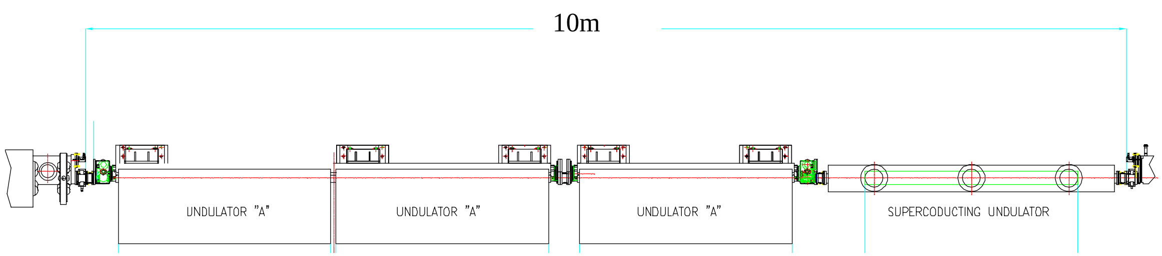
Phase II – Maximizing Source Capabilities (2004-2014)

- Innovative undulators, front ends and related components
- Higher brilliance, optimized for application
- Improve front ends and high-heat load optics for higher current operation
  - APS operates at 100mA, would reach 300mA at end of Phase II
- Increasing brilliance by more than an order of magnitude
- Continuing accelerator improvement
  - even greater improvement beam stability

Science Example -Extended straight section and inelastic x-ray spectroscopy

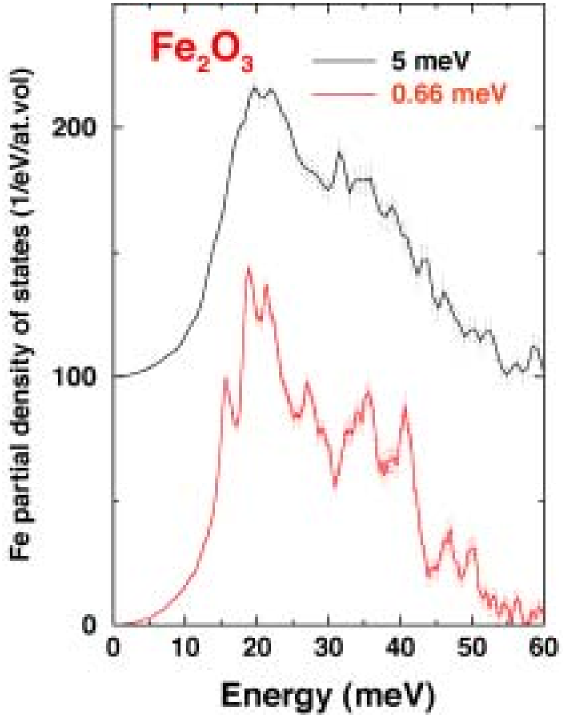


CURRENT STRAIGHT SECTION

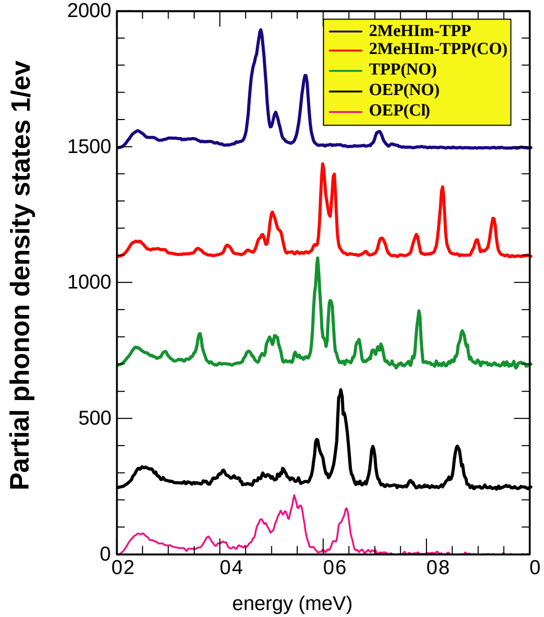


PROPOSED EXTENDED STRAIGHT SECTION

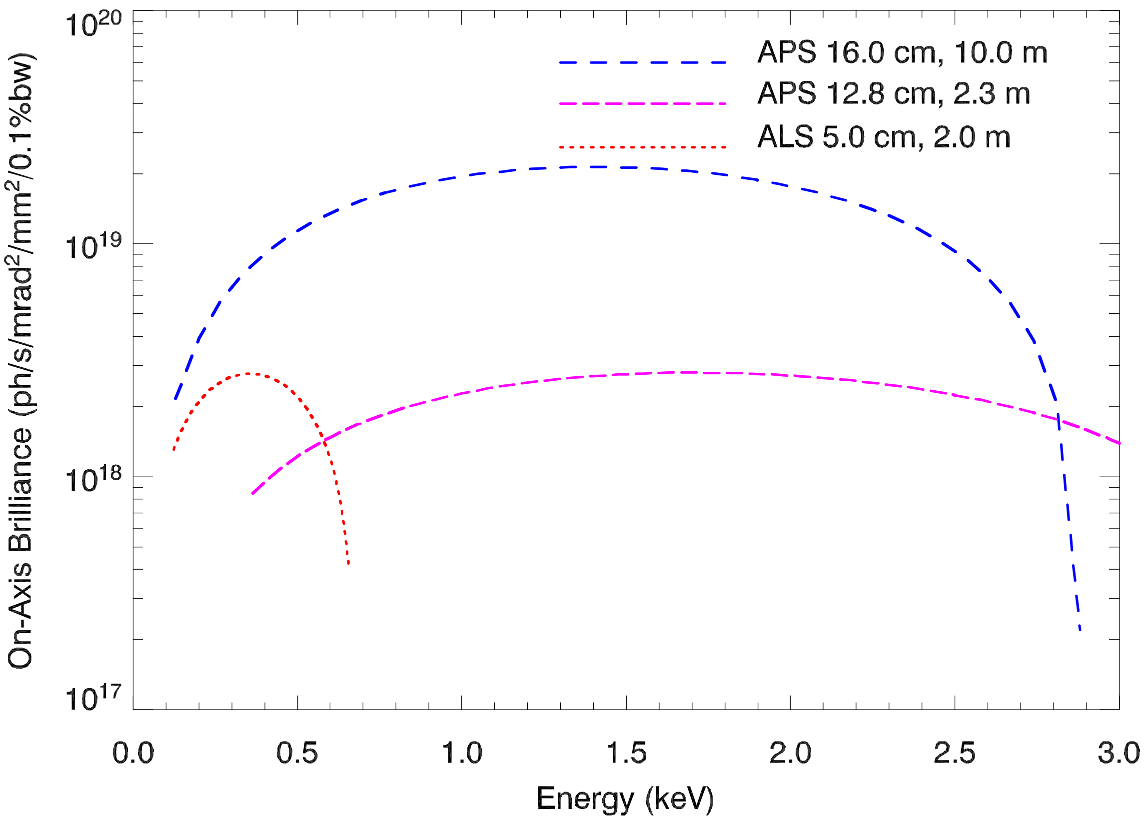
LONG STRAIGHT SECTION WITH THREE UNDULATORS "A" AND ONE SUPERCONDUCTING UNDULATOR



- The heme doming coordinate in myoglobin is directly involved in the oxygen-binding reaction
- Doming modes are expected in the range of 6-8 meV
- With a high enough resolution it becomes possible to study the influence of addition of ligands to the functional behavior of proteins



Science example - magnetic studies with soft x-rays
Brilliance Tuning Curves for Elliptically Polarized Devices



Advantages of high energy rings:

- Low emittance
- High beam stability
- Large energy tunability

⇒ **Superior performance**

APS (7 GeV, 100 mA):10 m long straight section, λ =16.0 cm, N = 62

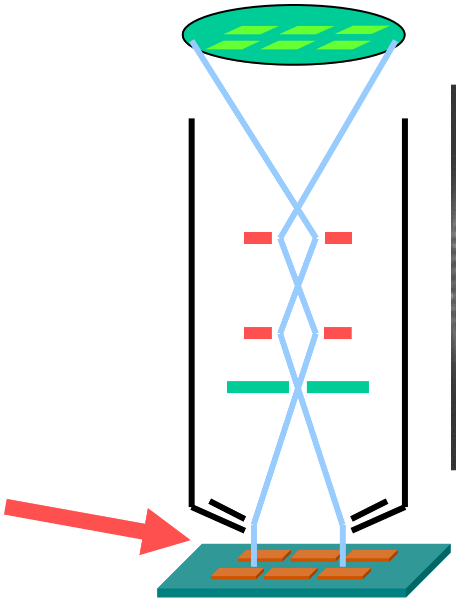
APS (7 GeV, 100 mA):5 m long straight section, λ =12.8 cm, N = 18 (current device)

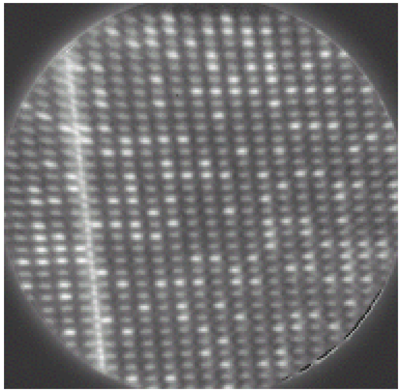
ALS (1.9 GeV, 400 mA): 2 m long straight section, λ = 5.0 cm, N = 37

Polarization-dependent spectroscopy

Helicity dependent X-ray emission provides information concerning spin polarized density of bulk occupied states

Photoemission Microscopy

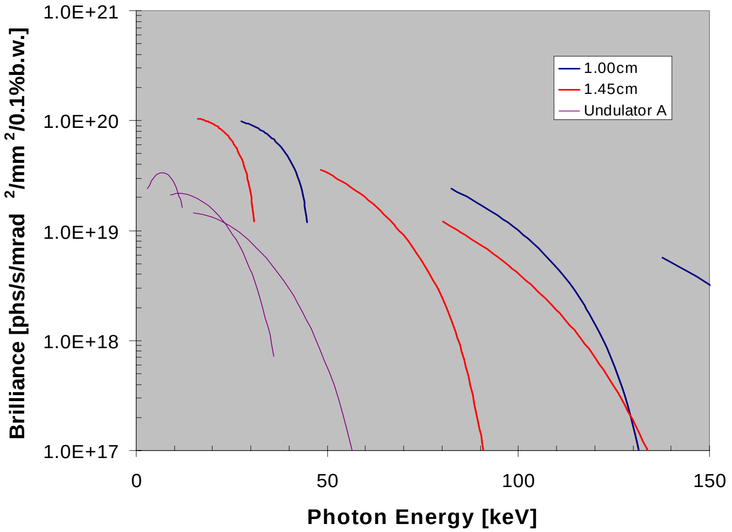




Spatial resolution target of 2 nm

- Magnetic contrast:
  - Domain imaging
  - Ground states in nanoscale systems
  - Interactions in particle arrays
  - Finite size effects
- Chemical contrast
  - Self-assembled systems
  - Segregation
  - Local electronic structure
  - Buried layers (~5 nm)
- Soft x-ray advantages:
  - High magnetic contrast
  - Access to TM, RE, semiconductors

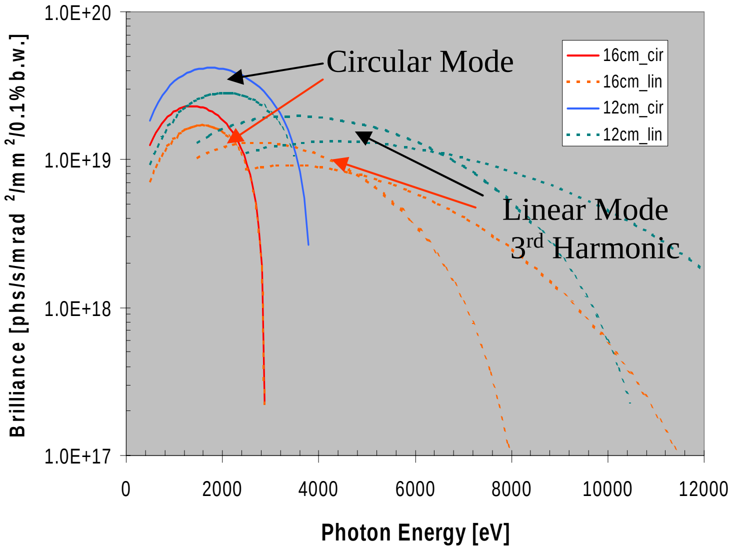
Readiness for Phase II - *Current R&D*



Superconducting Small Period Undulator

1.45 cm period
L=2.4 m, N=165
Gap=7 mm
Maximum K = 1.4

1.00 cm period
L=2.4 m, N=240
Gap = 3 mm
Maximum K = 1.17



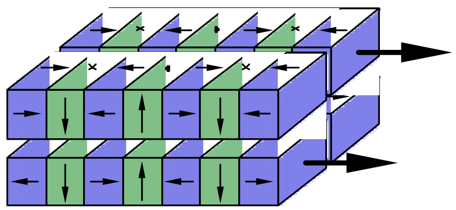
Variable Polarization Undulator

Electro-magnetic Device

λ=16 cm, L=10 m, N=62

APPLE type PM Device

λ=12 cm, L=10 m, N=82



Assumed APS storage ring parameters: 3.5 nm-rad, 1% coupling, 100 mA

Phase II – Cost, Schedule, Scope and Management

- $100M over 10 years, ramping up from $5M per year in the first year, to $20M in the last year
- APS will remain at the state-of-the-art in insertion device design
  – Connection with LCLS and other 4th generation sources

Phase III – Next Generation User Facility (2010-2023)

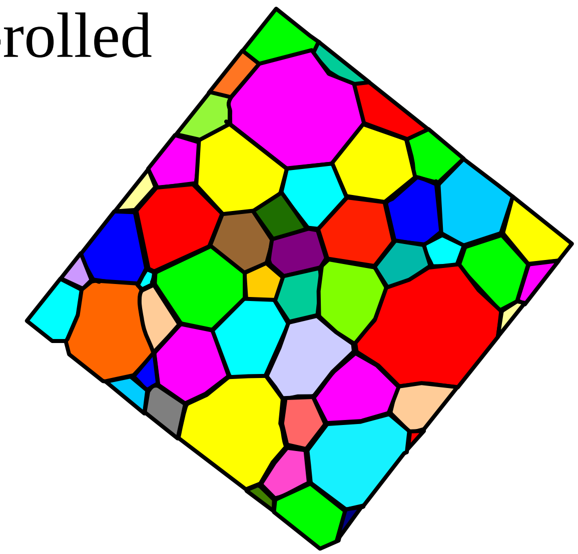
- By 10 years from now user community will approach 10,000
- APS will be primary 3rd generation hard x-ray source, with great capabilities and easy accessibility
- Need to develop beamlines and automation to reach next level

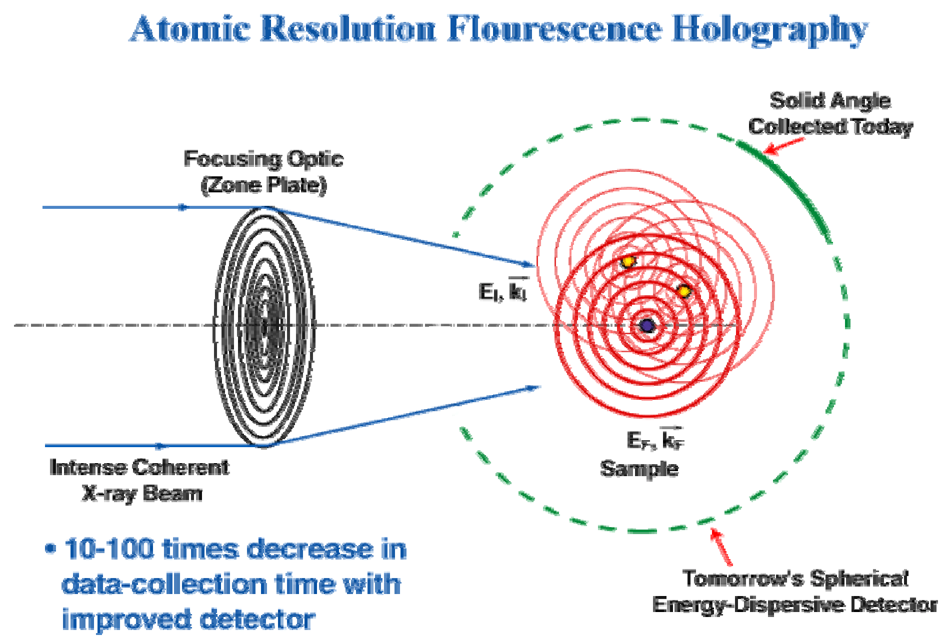
The Importance of the Science

- Current performance is limited by beamlines – optics, detectors
  - One or two orders of magnitude improvement available in many cases
- Automation offers both remote access, better user support and new experimental capabilities

Detectors and Optics Limit Performance

Hot-rolled Al

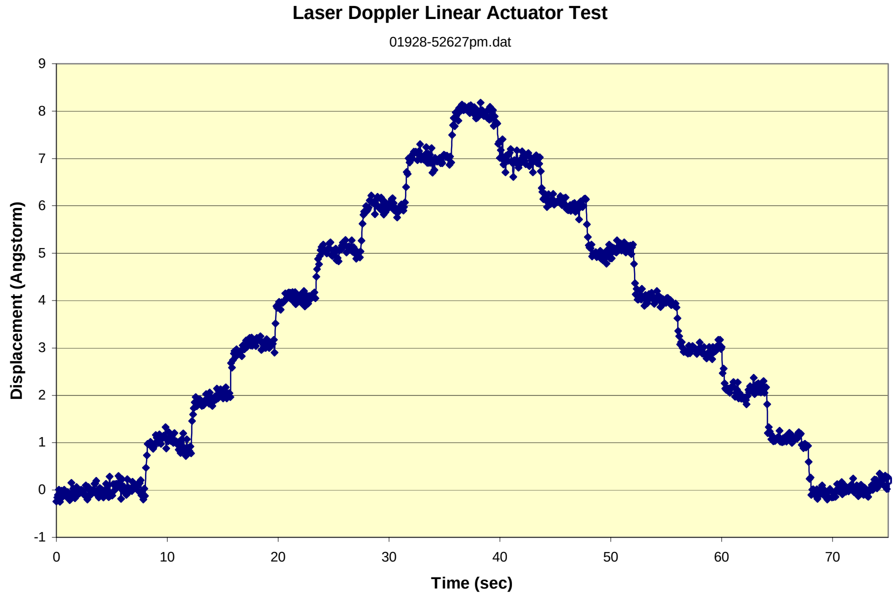


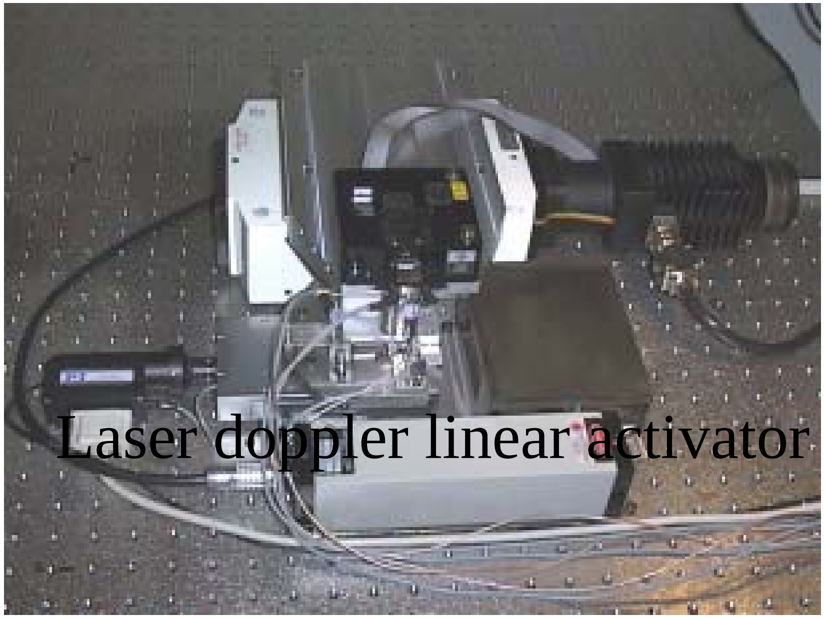


Map grain orientation and stress in real samples 10^4 μm^3 at 1 μm resolution takes 54 hours to collect data
CCD read-out time = 52 hours

Automation

- Not just remote access and user support
- Precision and control exceeds human capabilities



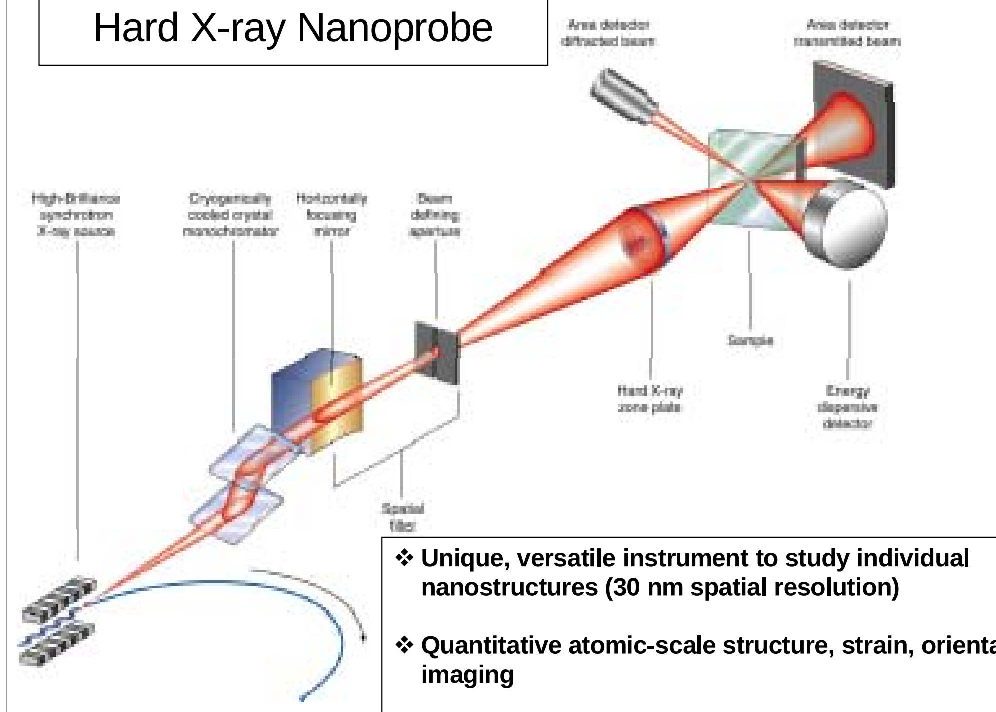


Laser doppler linear activator

Automation leads to new science

- Nanoprobe
  - Scan real and reciprocal space in nanovolumes
- Adaptive optics with feedback
- Multi-parameter "smart" scans

Hard X-ray Nanoprobe



- ❖ Unique, versatile instrument to study individual nanostructures (30 nm spatial resolution)
- ❖ Quantitative atomic-scale structure, strain, orientation imaging
- ❖ Sensitive trace element and chemical state analysis
- ❖ Ability to penetrate overlayers, environments, fields

Readiness for Phase III

- This builds on Phase I and II for a complete reinstrumentation of all beamlines. Incremental developments will be going through Phases I and II. Education and outreach will be facilitated by an Institute for X-Ray Science and Technology, including a theory component.

Phase III – Cost, Schedule, Scope and Management

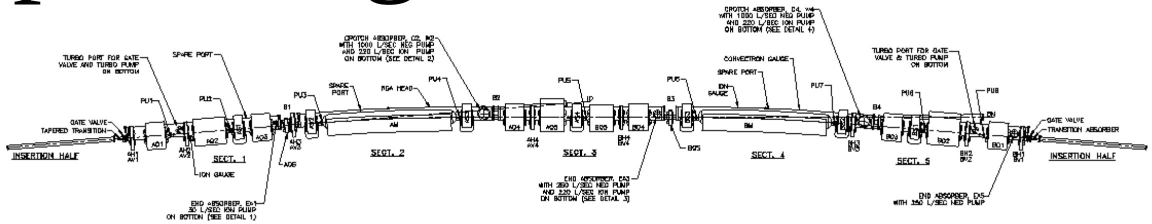
- Estimated cost for enhancements of beamlines is $400M
- Funding should include partner users in construction, proposals and SAC oversight
- Center for X-Ray Science and Technology involved, with partner members
- Most construction activities organized by APS, operation remains APS responsibility
- Additional $45M conventional facilities upgrades will be needed in 20-year period

Phase IV – Super Storage Ring (2012-2020)

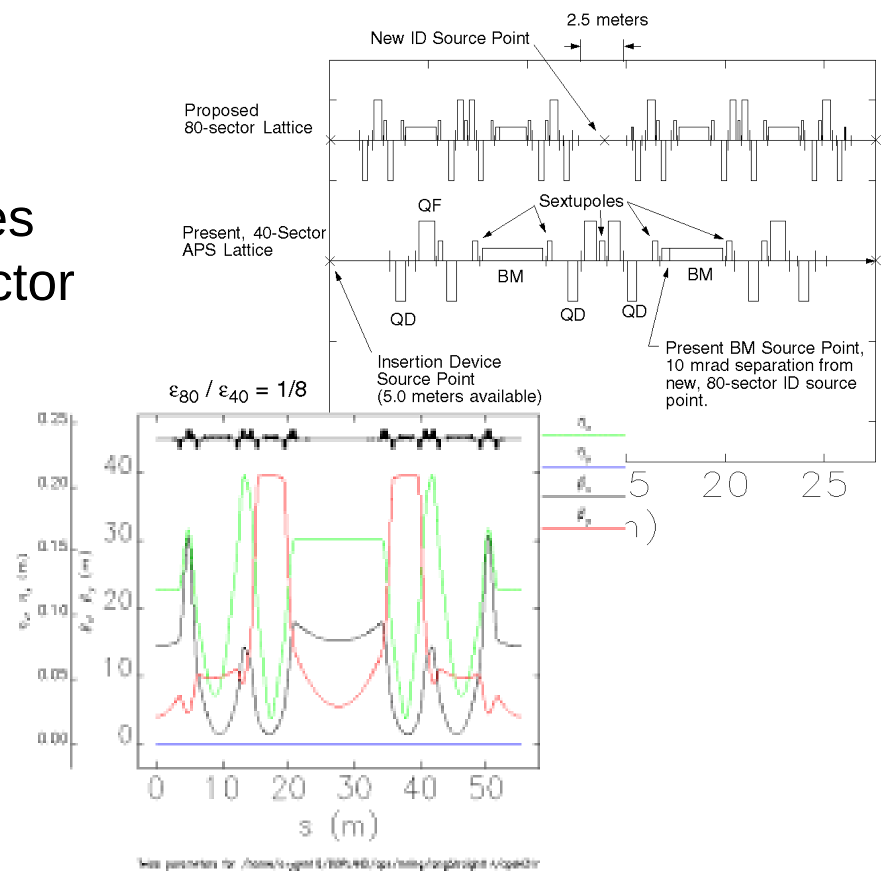
- To upgrade user capabilities and maximize value of embedded infrastructure and community
- Reduce emittance by at least a factor of 10
  - Less than 0.3 nm-rad effective emittance
  - Very short lifetime
    - Requires refined top-up and new injector
- Beam stabilization at 10nm level
- Requires new storage ring and injector
  - New injector offers 4th generation capabilities

Preconcept stage– not yet designed

Super Ring - 80 Sector Lattice



- **Flexible lattice, uses existing enclosures**
- **use existing BM ports**
- either
  - two short insertion devices (3 - 4 meters) / double sector
- or
  - one long insertion device (up to 12 meters)
  - plus one hard bending magnet source



Nano-scale Beam Stabilization

Necessary in conjunction with reduced beam emittance

- Support nanoprobe experiments
- Aggressive attack on
  - noise sources, microhertz to Megahertz
  - improved instrumentation and feedback capability

New Injector Complex

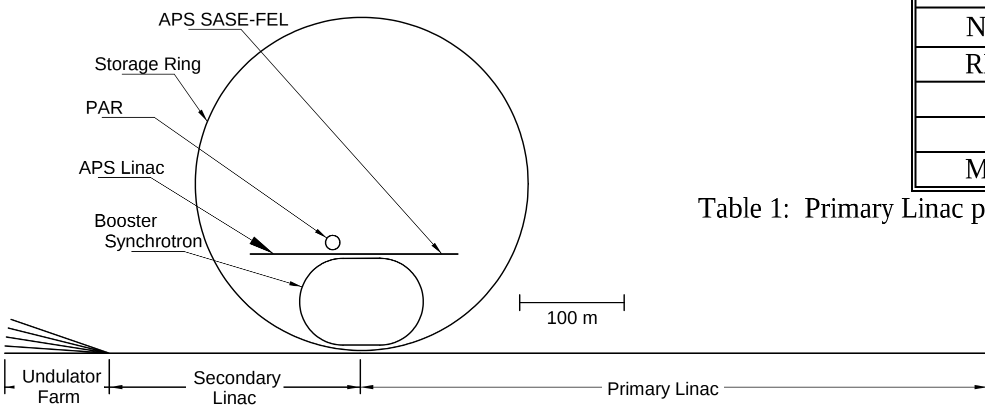
- Several possibilities for injection
  - New booster
  - LINAC source
  - Need high rep rate and emittance x10 smaller than present booster

LINAC Augmented Light Source

- Fast injection, low emittance
- Offers 4th gen.
  - plus new use of existing injectors (UV, IR)

PARAMETER	VALUE	UNITS
General		
Total length	600	m
Cryomodules	34	
Energy gain per module	240	MeV
Total beam energy	8.16	GeV
Average gradient	13.6	MV/m
RF system		
Operational frequency	1.3	GHz
Average beam power	800	kW
Beam		
Charge per bunch	1	nC
Bunches per macropulse	1	
Normalized RMS emittance	14	μm
RMS bunch length		
At injector	10	ps
At exit of linac	< 1	ps
Macropulse repetition rate	100	Hz

Table 1: Primary Linac parameters



The Importance of the Science

- Offers a factor of more than 10 improved brilliance to embedded beamline and user base
- Stability will enable higher performance for nano-beams etc.
- New LINAC injector will offer 4^{th} gen. capabilities, e.g. time resolved
  - Secondary LINAC and endstations
  - Existing injector liberated for other uses
- Possible for special operating mode giving fs pulses into storage ring experiments

Readiness for Phase IV

- In approximately 15 years, this would provide a major upgrade in capabilities
  - Unlikely that any other APS scale storage ring will be built in the foreseeable future
- Actual accelerator choices would be mandated by developments in ERL/FEL along the way
  - Could be connected to green-field FEL
  - Leverage leadership for insertion devices

Phase IV – Cost, Schedule, Scope and Management

- Estimated cost of Super Storage Ring
  - $350M
- Estimated cost of LINAC construction
  - $250M
- Alternate injector approach to replace booster much less expensive, but does not offer 4th gen. or UV/IR capabilities

How the phases are linked to the impact

- Multiple increases of more than 10x each phase in performance
  - almost 10,000 times increase in useable brilliance in 20 years
- APS will define the state-of-the-art and have a major scientific impact
- Total investment proposed is ~$1.3B over 20 years, comparable with depreciation cost of APS (operating budget in that period >$2B)

Conclusion

- Phased upgrade plan maintains APS as premier 3rd generation x-ray storage ring
  - 3rd generation sources will not be obsolete!
- Embedded capabilities and user community in 15 years leads to desire for continually improved and augmented capabilities
  - Connect with 4th-generation capabilities
- Requires increased operating budgets for operational support responsibilities (only ~20% in today's dollars)

Defining the state-of-the-art in 3rd generation x-ray sources and science