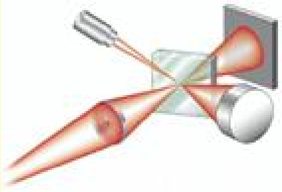
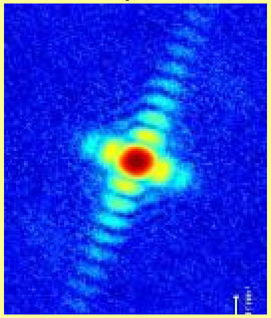
National Synchrotron Light Source II

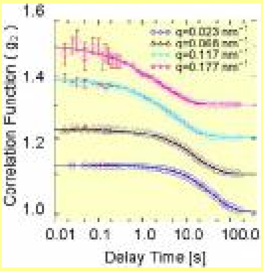
New Capabilities



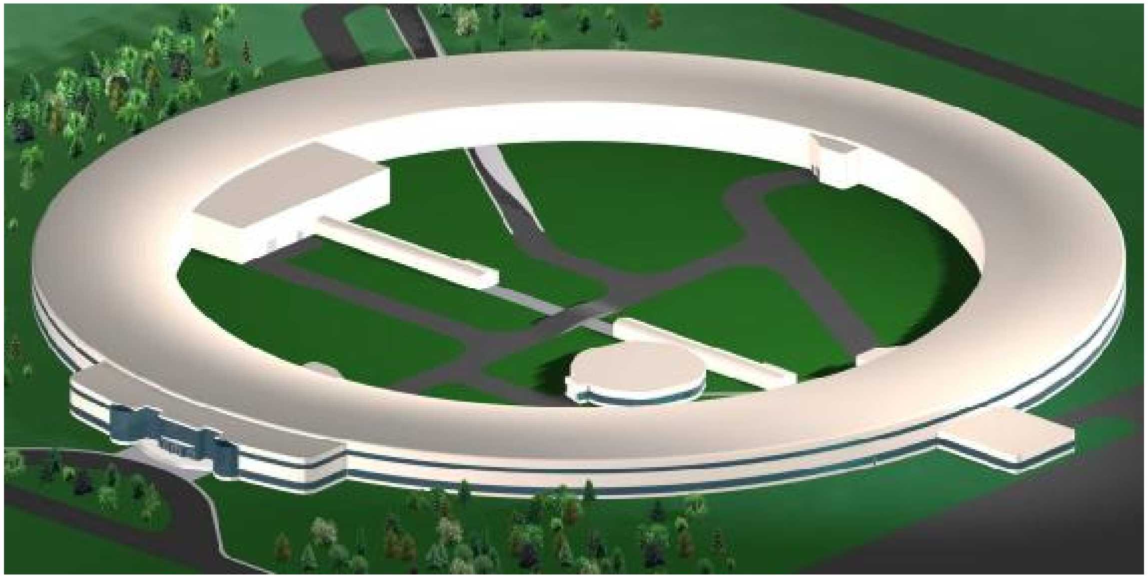
Nanoprobes



Diffraction Imaging



Coherent Dynamics

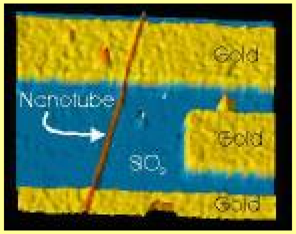


A state of the art ultra-bright medium energy storage ring delivering world leading performance

Steve Dierker
Associate Laboratory Director for Light Sources
Brookhaven National Laboratory

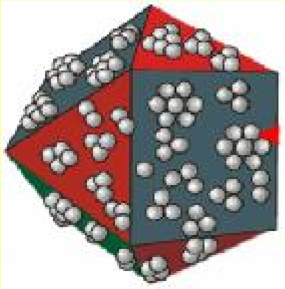
April 6, 2006

New Science



Nanoscience

Life Science



Nanocatalysis

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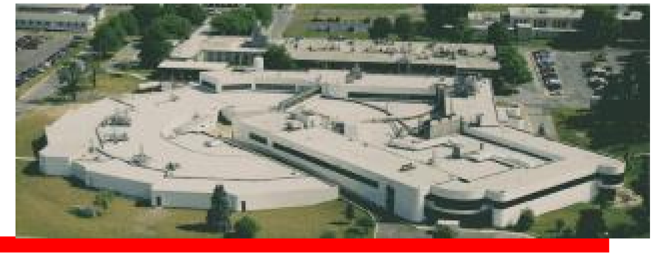
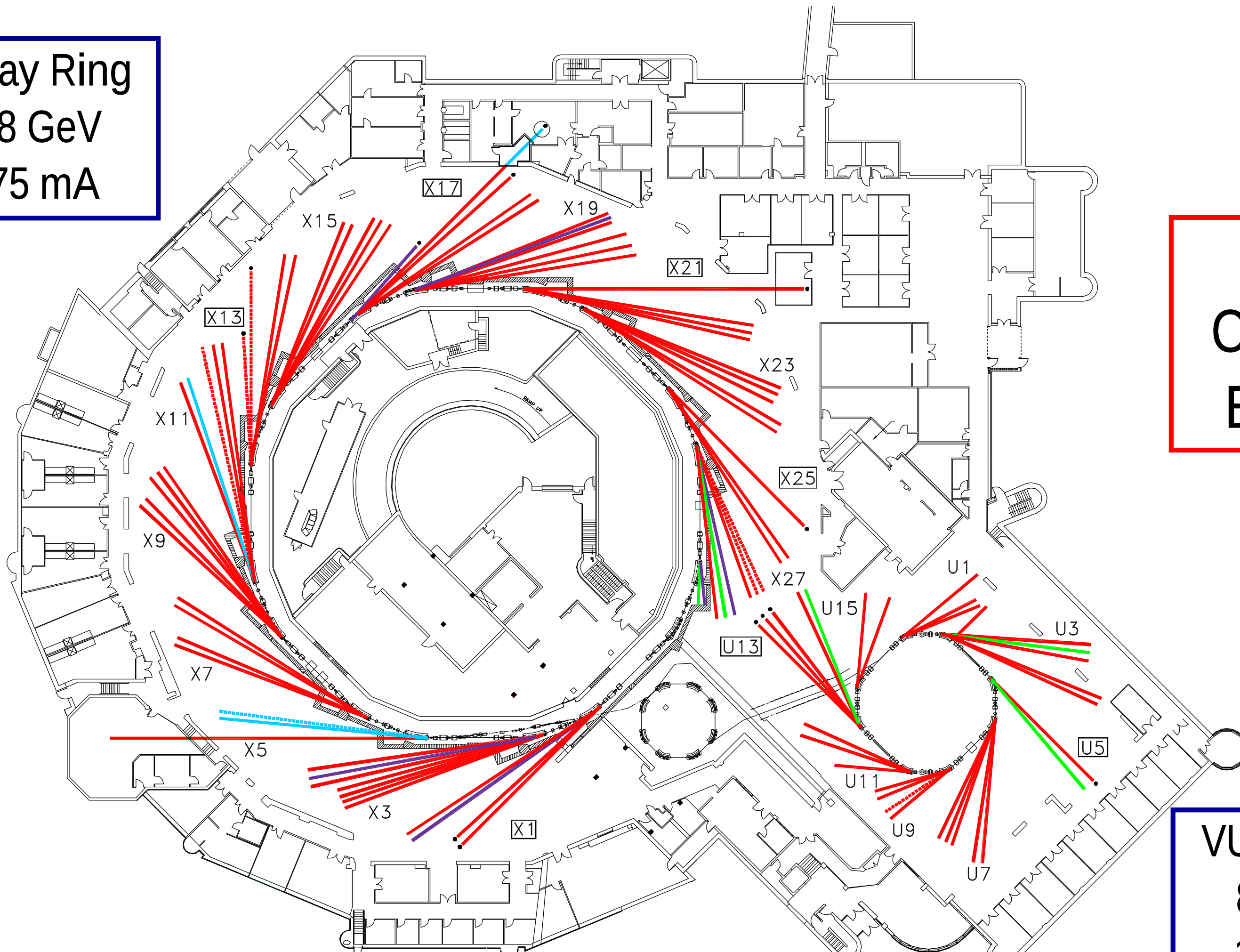
Present NSLS



X-Ray Ring
2.8 GeV
275 mA



65
Operational
Beamlines

VUV/IR Ring
800 MeV
1000 mA

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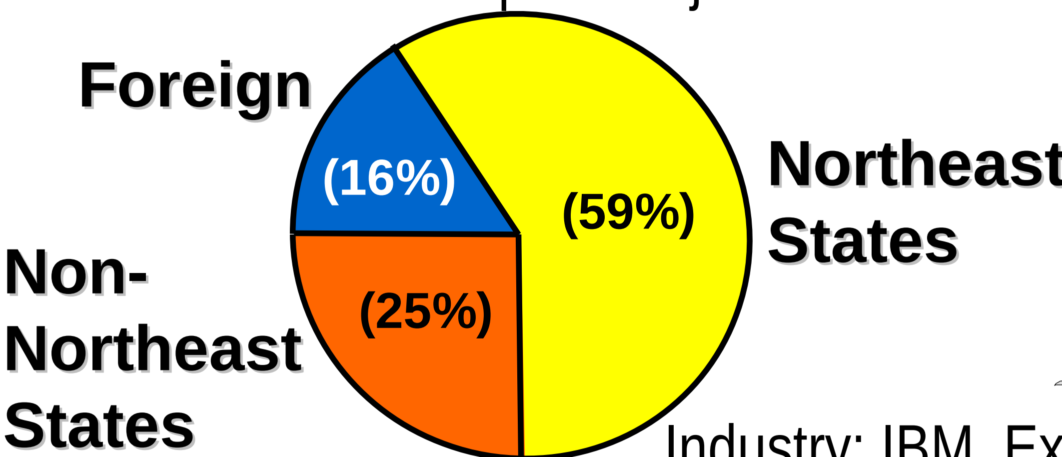
NSLS: A Crucial Resource for the Northeast Region

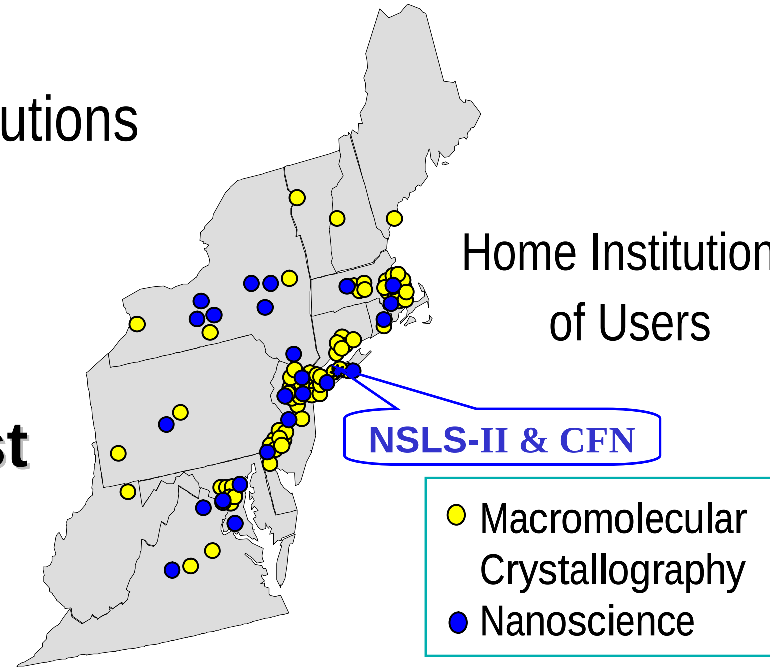
2300 Users/year

> 400 academic, industrial, government institutions

~ 800 publications per year

~ 130 in premier journals





Industry: IBM, ExxonMobil, Lucent, Pharmaceuticals

Vital for BNL programs:
CFN, Catalysis Center, Structural Biology, Environment

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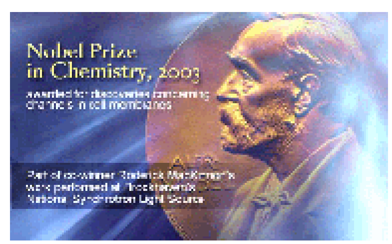

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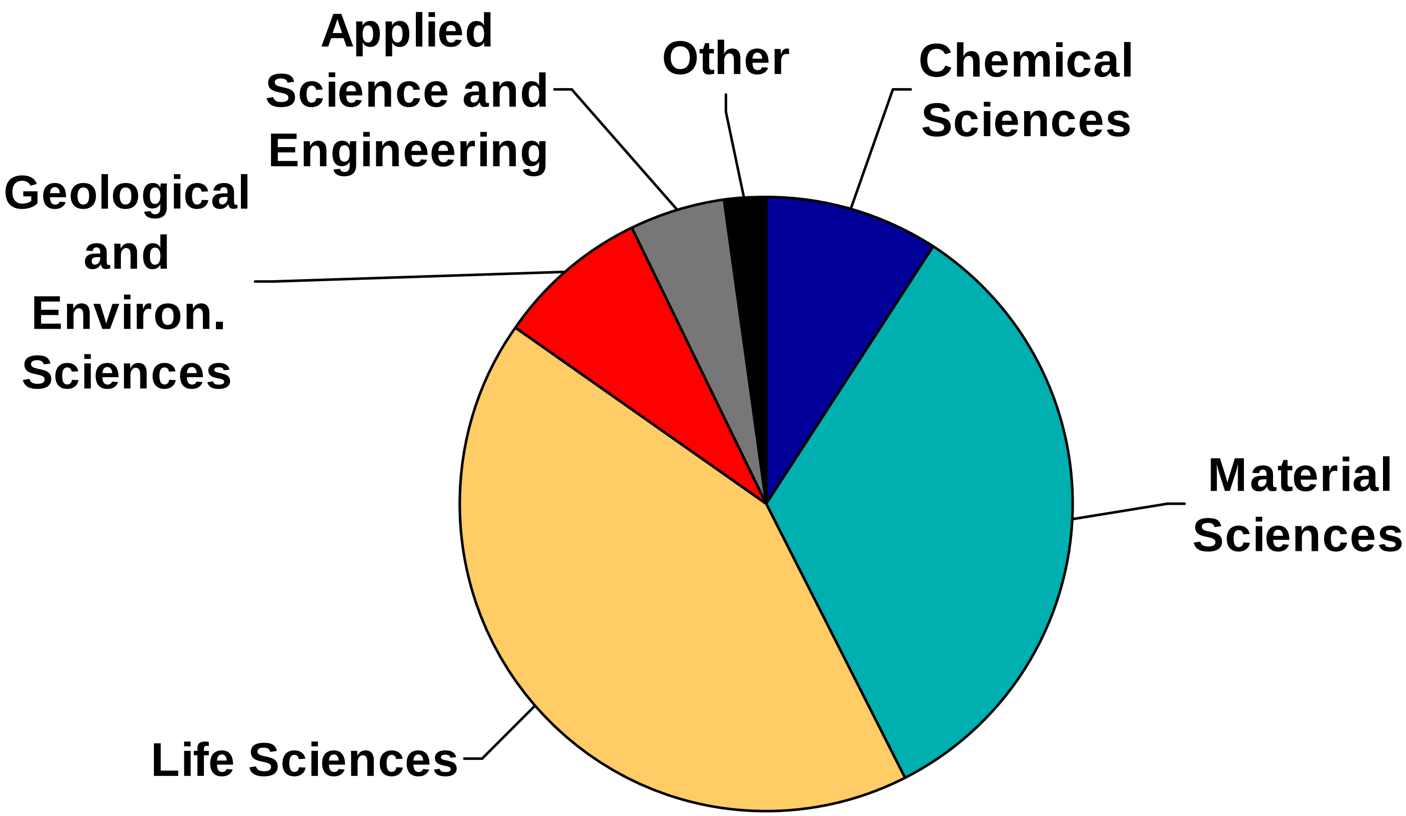
Diverse Science: Users by Field of Research



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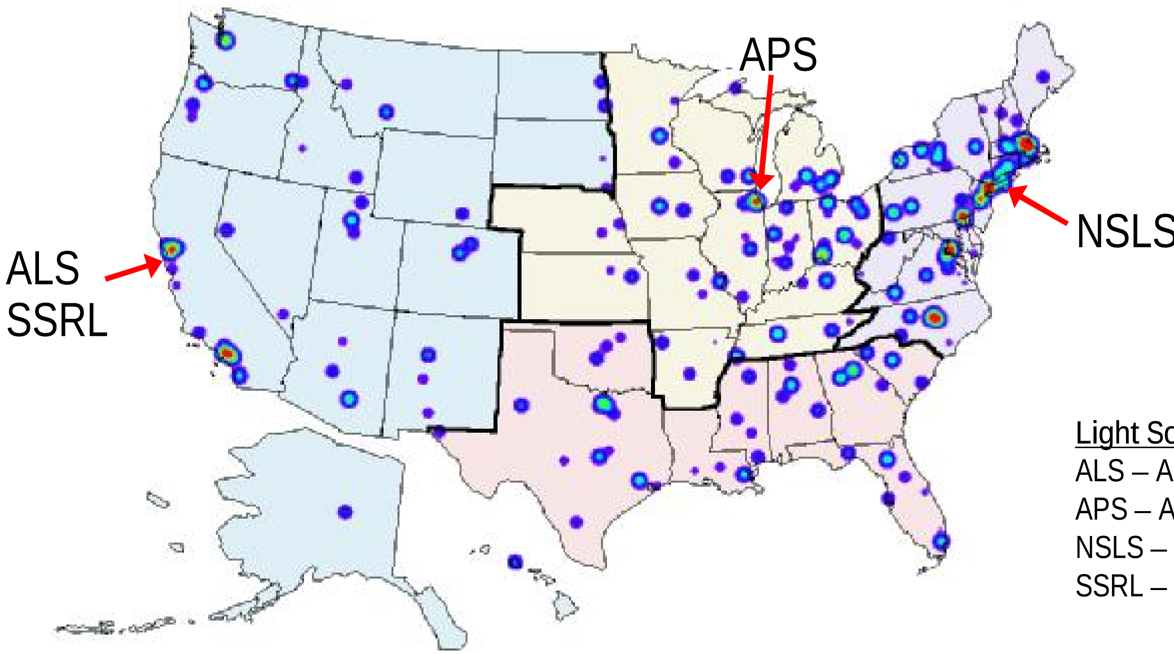
The Northeast User Community

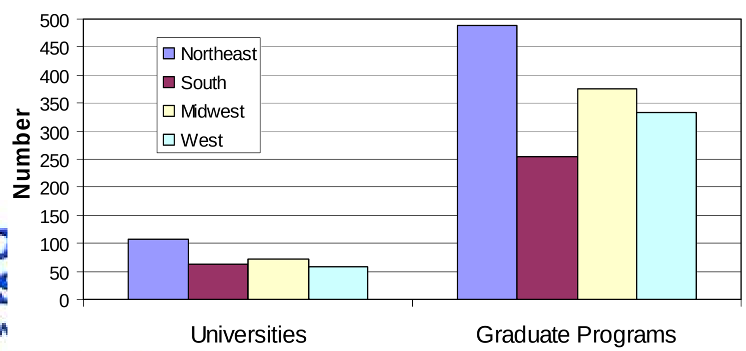
Contour plot of the geographical distribution of faculty and graduate students created by summing the number of faculty and graduate students per city and plotting them on the map. The data were then “smoothed” across each area.

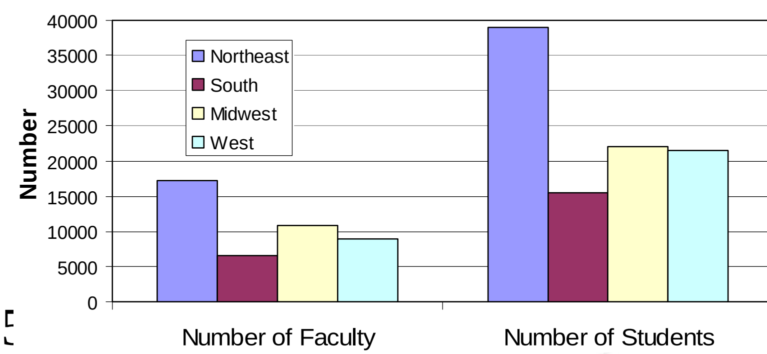


Light Sources operated by DOE Office of Science

ALS – Advanced Light Source
APS – Advanced Photon Source
NSLS – National Synchrotron Light Source
SSRL – Stanford Synchrotron Radiation Laboratory

Faculty and Graduate Student Density





Usage of U.S. Synchrotrons

The majority of synchrotron users visit only one synchrotron.

% of users visiting only one synchrotron in FY 2004

ALS	APS	NSLS	SSRL	
73%	75%	73%	49%	(% visiting only one)
25	25	25	25	→ 25 users visited all 4 SR facilities
66	66	66		163 users visited 3 of the 4 SR facilities
	26	26	26	
20		20	20	
51	51		51	
	367	367		803 users visited 2 of the 4 SR facilities
85		85		
		25	25	
90	90			
	63		63	
173			173	
1402				Unique visits to each SR facility
	2085			
		1668		
			365	

Note: SSRL was in commissioning following the SPEAR3 upgrade completed in late 2003.

Beamline oversubscription is ~2

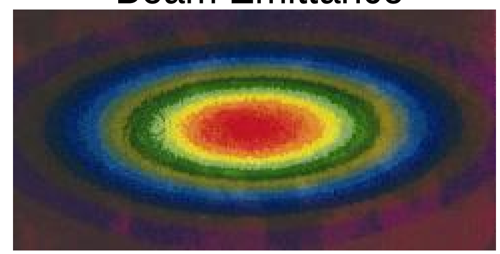
FY 2004 Hours Requested and Allocated for General User Programs at the BES Light Sources

	Requested	Allocated	% Allocated
SSRL	63,382	31,740	50%
NSLS	106,512	62,125	58%
ALS	80,848	39,656	49%
APS	210,248	84,856	40%
TOTAL	460,990	218,377	47%

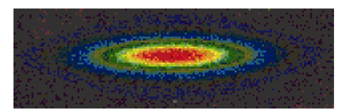
National Synchrotron Light Source

- First Dedicated Second Generation Synchrotron
  and only remaining second generation DOE synchrotron!
- Designed in the 1970's
- Operating Since 1982
- Continually updated over the years
  - Brightness has improved more than 100,000 fold
- ***However***
  - The brightness has reached its theoretical limit
  - Only a small number of insertion devices are possible

Improvement in Electron Beam Emittance



1990



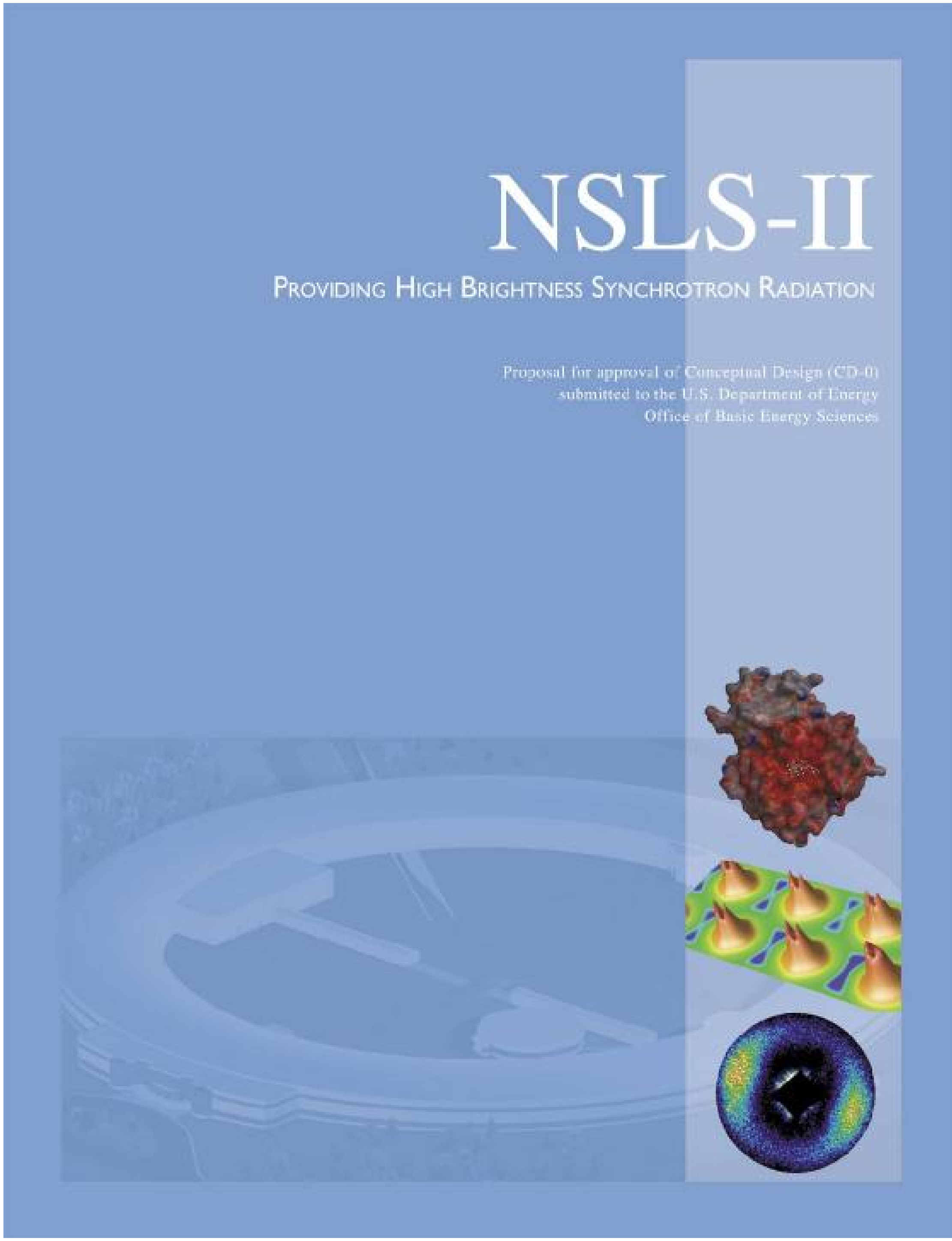
2000

Restricted Capabilities of present NSLS limit the productivity and impact of its large user community

User Community Input on NSLS-II

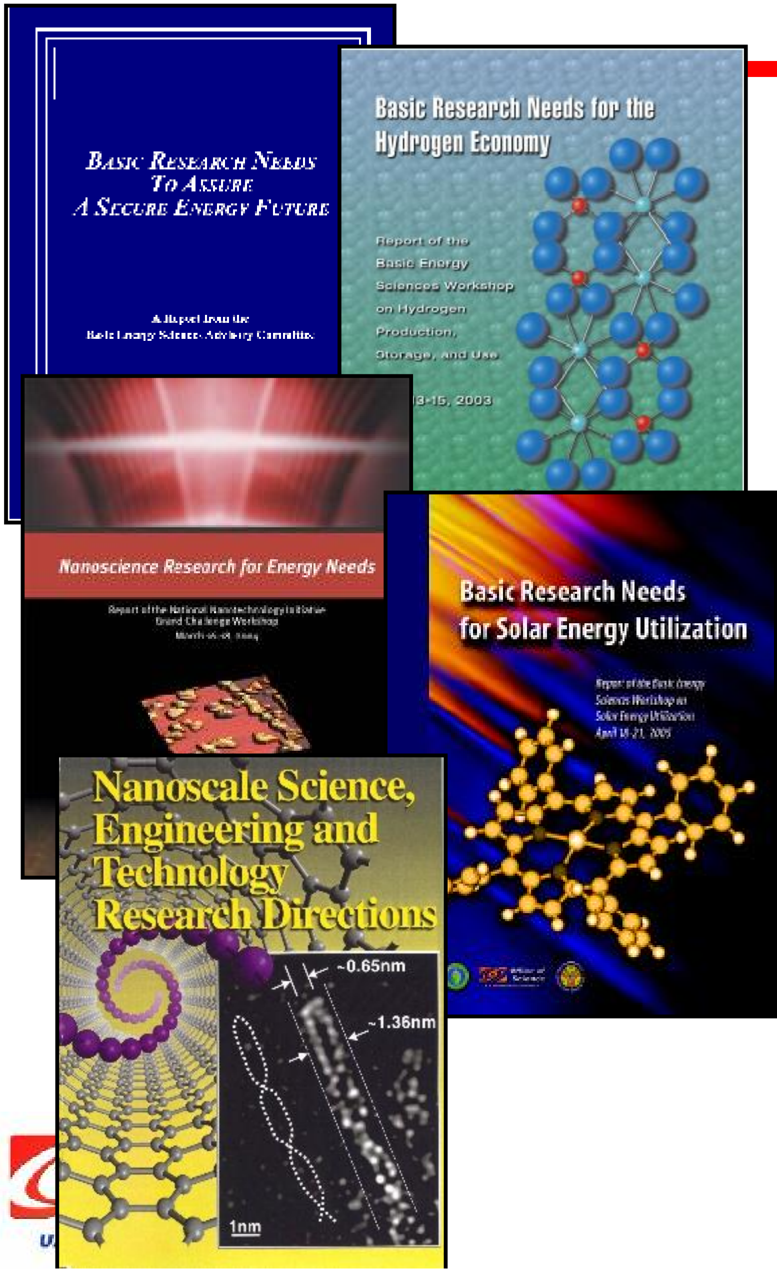
What science will users do in 10+ years and what do they need to do it?

NSLS-II Proposal



- Science justification and pre-conceptual design
- Submitted March 2004
- CD-0 (Approval of Mission Need) August 2005
- http://www.nsls2.bnl.gov/

The Mission Need for NSLS-II



- Major studies by BESAC, BES, and the National Nanotechnology Initiative have reassessed the research and the scientific tools needed to advance energy technologies.
- A common conclusion is that the development of nanoscale materials – as well as the methods to characterize, manipulate and assemble them – is critical for the development of future energy technologies.
- The remarkable tools that were developed over the past 30 years for visualizing the nanoworld – in particular, the synchrotron radiation light sources – helped launch the nanorevolution; ; however, none of today's light sources (anywhere in the world) were designed to probe materials with 1 nanometer spatial resolution and with 0.1 meV energy resolution (equivalent to ~1 K).

"Light sources with even more advanced capabilities than the best available today are needed to address the challenges put forward in these and other reports."

Description of NSLS-II

NSLS-II is a highly optimized x-ray synchrotron delivering:

- extremely high brightness and flux*;
- exceptional beam stability; and
- a suite of advanced instruments, optics, and detectors.

Together these enable:

- ~ 1 nm spatial resolution,
- ~ 0.1 meV energy resolution, and
- single atom sensitivity.

NSLS-II will provide:

- the world's finest capabilities both for x-ray imaging and for high-resolution energy analysis, ~10x better than any other synchrotron now operating or under construction, and 1,000x higher sensitivity.

* Flux is a measure of the total beam intensity; high flux is important for experiments that use the entire unfocused beam. Brightness is a measure of the beam intensity per square millimeter of source size, per square milliradian of opening angle, and within a given spectral bandwidth (usually 0.1%); high brightness is important for experiments that need tightly focused, very intense beams.

X-ray Ring

- 3 GeV, 500 mA, top-off injection
- Circumference 630 m
- 24 cell, Triple Bend Achromat
- 24 bending magnet ports
- 21 insertion device straight sections (7 m)
- Ultra-low emittance (ε_x, ε_y) 0.5, 0.005 nm (Diffraction limited in vertical at 10 keV)
- Brightness ~ 7×10^{21} p/s/0.1%bw/mm^2/mrad^2
- Flux ~ 10^{16} p/s/0.1%bw
- Beam Size (σ_x, σ_y) 84.6, 4.3 μm
- Beam Divergence (σ_x', σ_y') 18.2, 1.8 μrad
- Pulse Length (rms) 11 psec

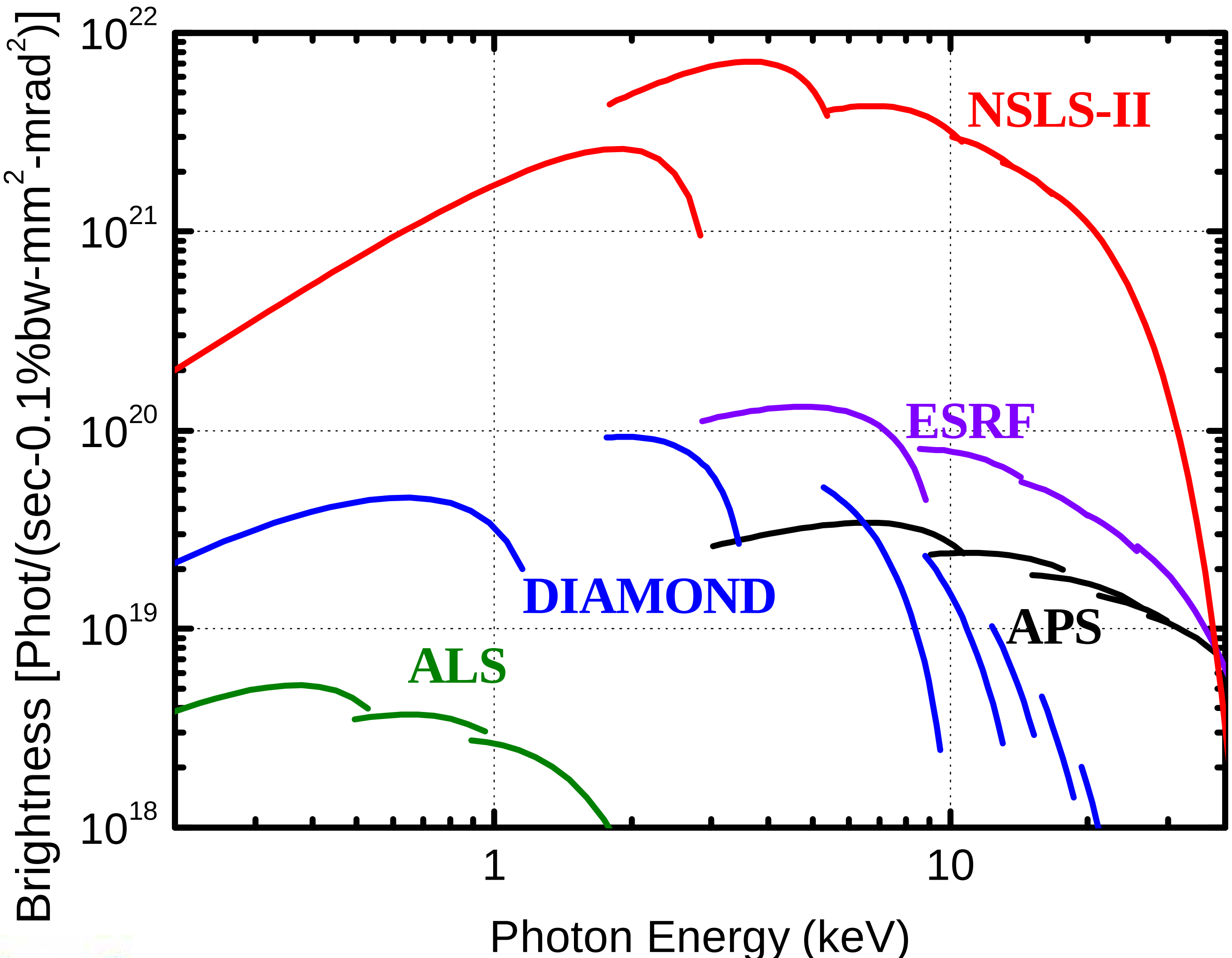
Infrared Ring

- 800 MeV, 1000 mA, top-off injection

Other

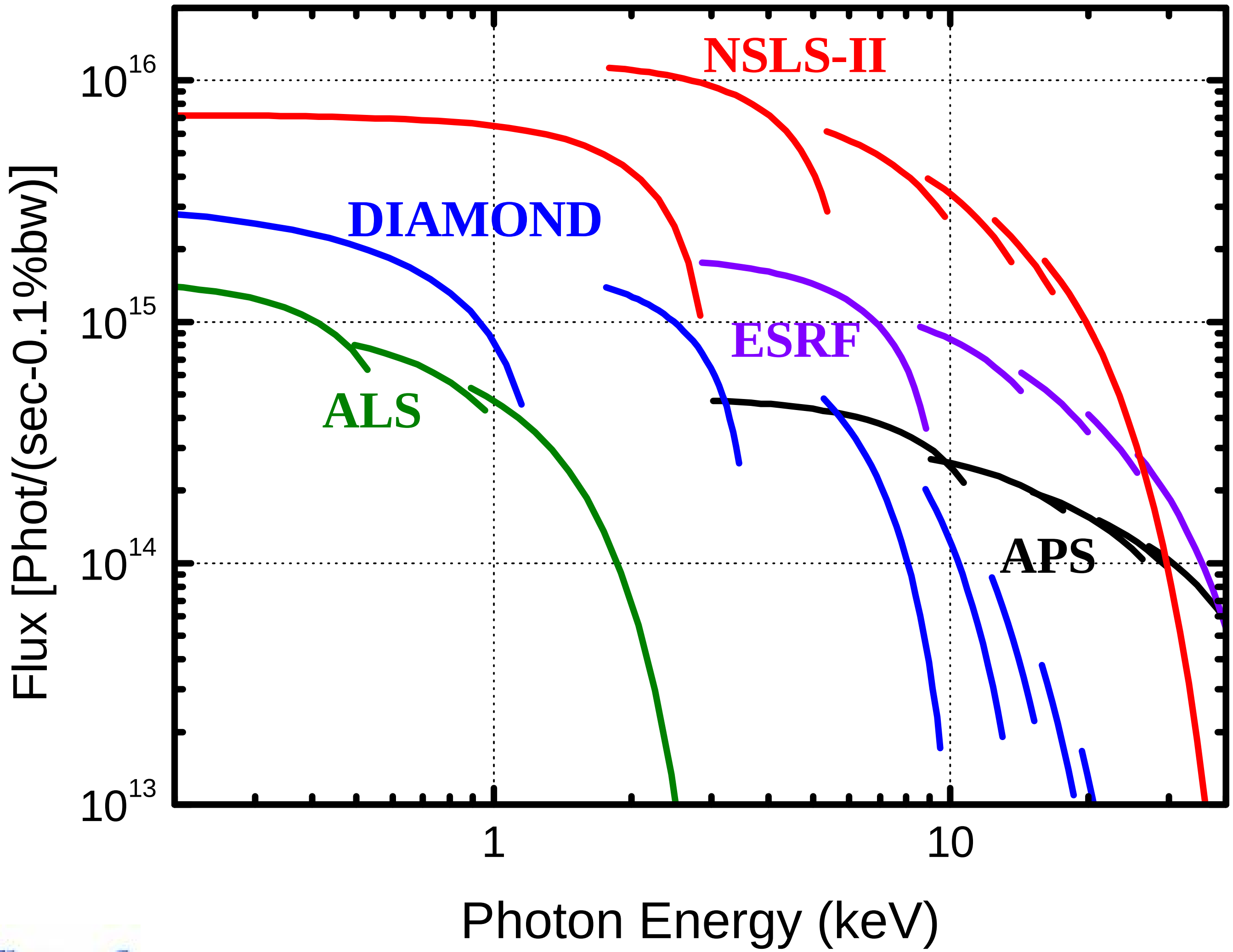
- Instruments, optics, robotics, detectors

Brightness:
NSLS-II vs Other Synchrotrons



NSLS is below this chart

Flux:
NSLS-II vs Other Synchrotrons



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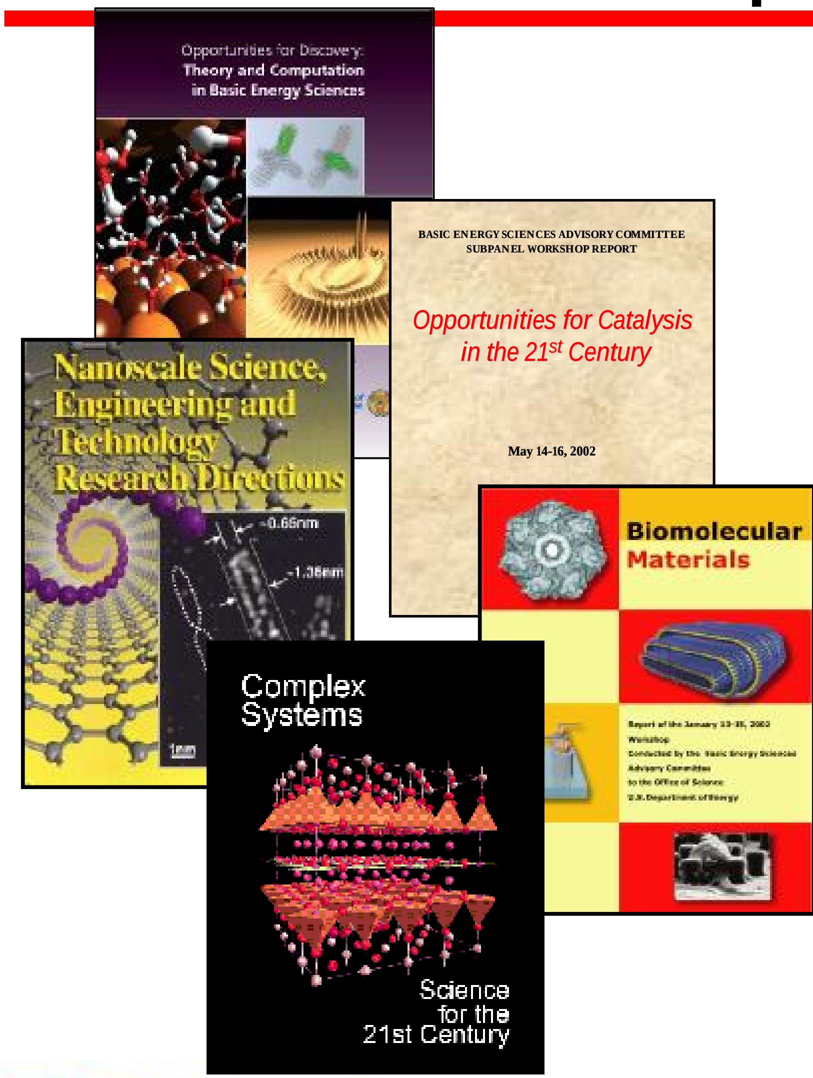
What Research will NSLS-II Uniquely Enable?



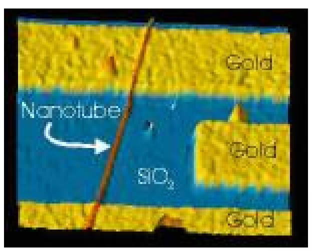
- The "nanoscale" covers the length range from 1 to 100 nm, but the low end of this scale is particularly important for many fundamental studies.
- Research at the NSLS-II will focus on some of the most important challenges at the lower end of the nanoscale size range, including:
  - *the correlation between nanoscale structure and materials properties (requiring high spatial resolution) and functions (requiring high energy resolution);*
  - *the mechanisms of molecular self-assembly, which produces exquisite molecular structures in both the living and nonliving worlds; and*
  - *the science of emergent behavior, which arises from cooperative behavior of individual components of a system.*

What Research will NSLS-II Uniquely Enable?

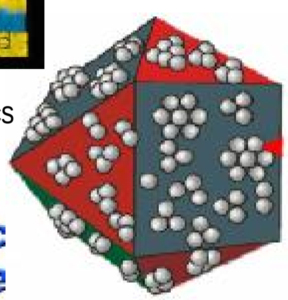
Structure & properties/functions

Observe fundamental material properties with nanometer-scale resolution and atomic sensitivity

- Physical, chemical, electronic, and magnetic structure of nanoparticles, nanotubes and nanowires, e.g. new electronic materials that scale beyond silicon
- Designer catalysts, e.g., in-situ changes in local geometric, chemical, and electronic structure of active catalytic site in real-time and under real reaction conditions



Molecular Electronics

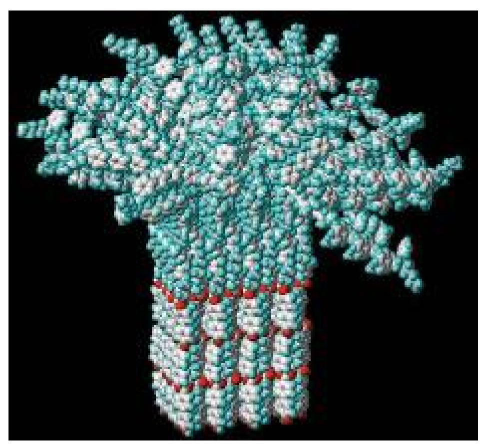


Nanocatalysis

Self-assembly

Understand how to create large-scale, hierarchical structures from nanometer-scale building blocks

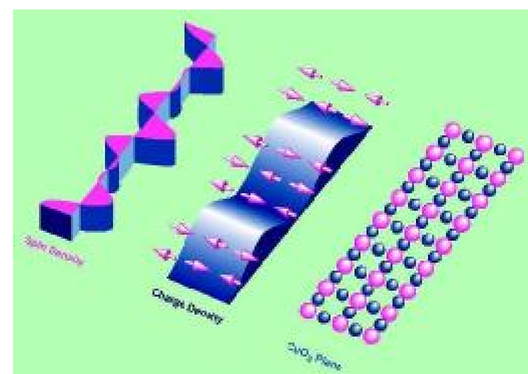
- Interactions between nanoscale building blocks
- Kinetics of nanoscale assembly
- Structure of hierarchical materials from nanometers to microns
- Mechanisms of directed assembly (by templating or external fields)
- Molecular interactions in nano-confined environments



Emergent behavior

Probe nanometer-scale materials that display emergent behavior

- Direct 3D imaging of domain structures and dynamics, e.g., in random field magnets and spin glasses
- Colossal magnetoresistance for high-sensitivity magnetic sensors or high-density information storage
- Dynamics of charge and spin stripes in high temperature superconductors



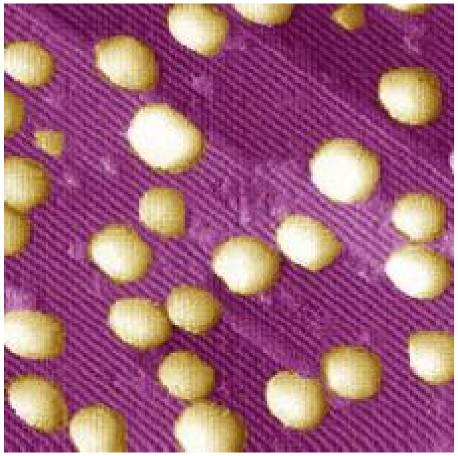
Charge and spin stripes in complex oxides

Science with nm Spatial Resolution

Catalysis by Gold Clusters on Supports

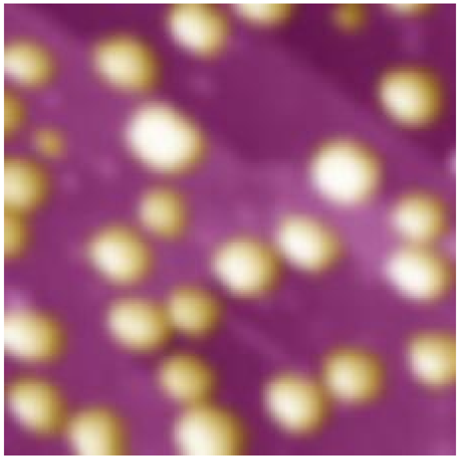
Gold nanoparticles a few nm in diameter on porous supports are highly active catalysts, with 10x greater efficiency than today's automotive catalytic converters. NSLS-II will enable these to be imaged in-situ, inside porous hosts and under real reaction conditions

30 nm x 30 nm



Scanning tunneling micrograph of gold clusters on titanium

Simulated 10 nm Resolution (Capability of best light sources today)



Simulated 1 nm Resolution (Capability of NSLS-II)

With NSLS-**II**, it will also be possible to do *spectroscopy on a single atom*. This will provide the elemental electronic structure, including oxidation state and symmetry of chemical bonds, as well as the local geometric structure surrounding the atom.

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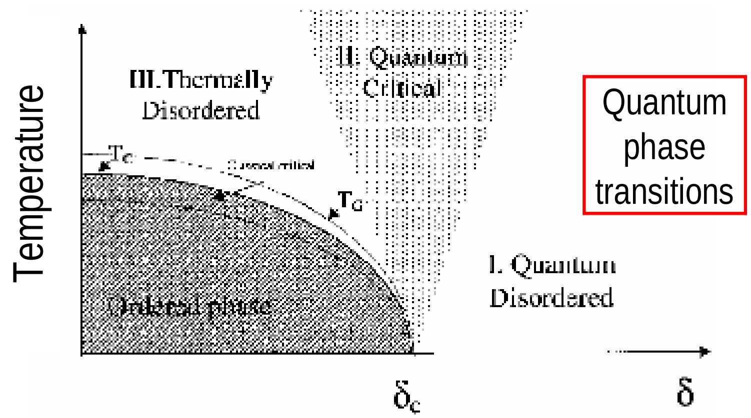
Studying Emergent Phenomena with 0.1 meV Energy Resolution

- Quantum mechanical effects are enhanced in bulk materials when the interactions are strong and have reduced dimensionality.
- This leads to new states of matter with unusual properties.

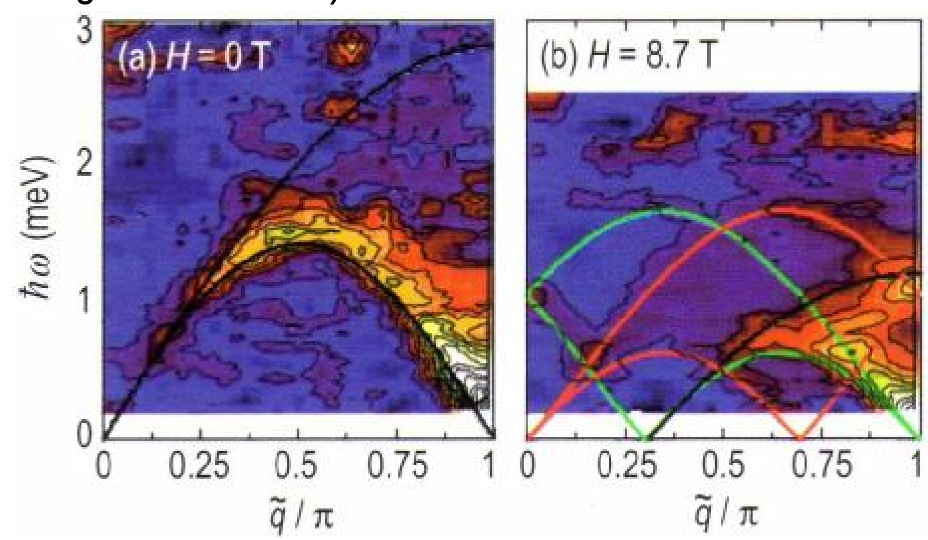


- Discovering and understanding these new properties requires the ability to study the excitations of minute quantities of nanoscale systems with high energy resolution and high spatial resolution.

Example: "spin chain" compounds

$Cu(C_4H_4N_2)(NO_3)_2$

Neutron scattering studies of 'spinons' in these materials requires very large samples (several grams or more).



With NSLS-II it will be possible to study collective excitations of nanoscale systems, enabling the discovery and understanding of new properties and functionality.

What is the Structure and Function of Molecular Machines?

High brightness is essential for projects with small crystals and large unit cells, such as large asymmetric complexes, particles like ribosomes, and membrane proteins.

Bending Magnet
B ~ 10^{15}

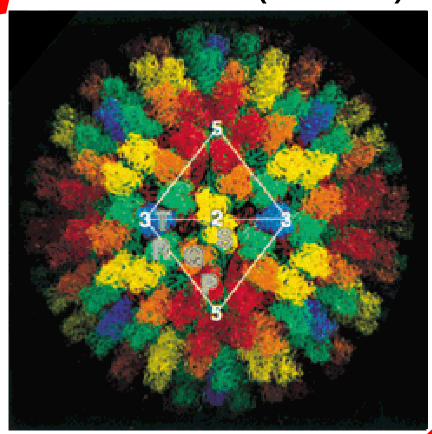
Protein
(~100 Å)

Ribosome
(~250 Å)

Wiggler
B ~ 10^{17}

Increased Brightness

Virus
(~750 Å)

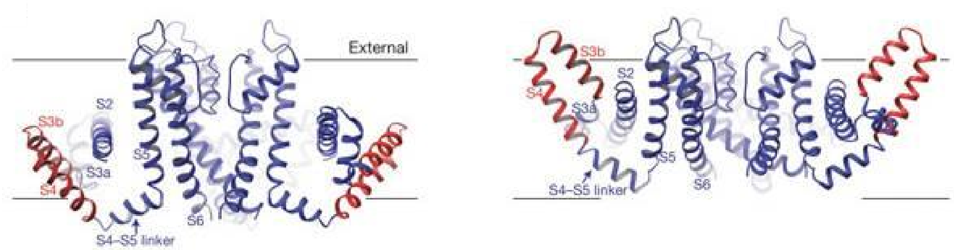


NSLS-II Undulator
B ~ $7x10^{21}$

Molecular Machinery

Requires:

- Large unit cells (> 1000 Å)
- Small crystals (< 10 mm)
- High resolution (< 1.0 Å)



Ion Channel Membrane Protein

Structural Genomics
Genomes to Life

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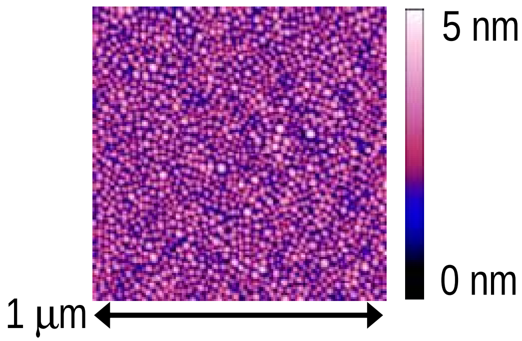
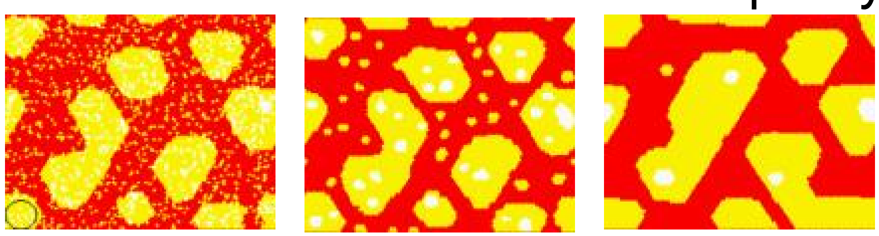
How do Proteins Fold and Materials Grow?

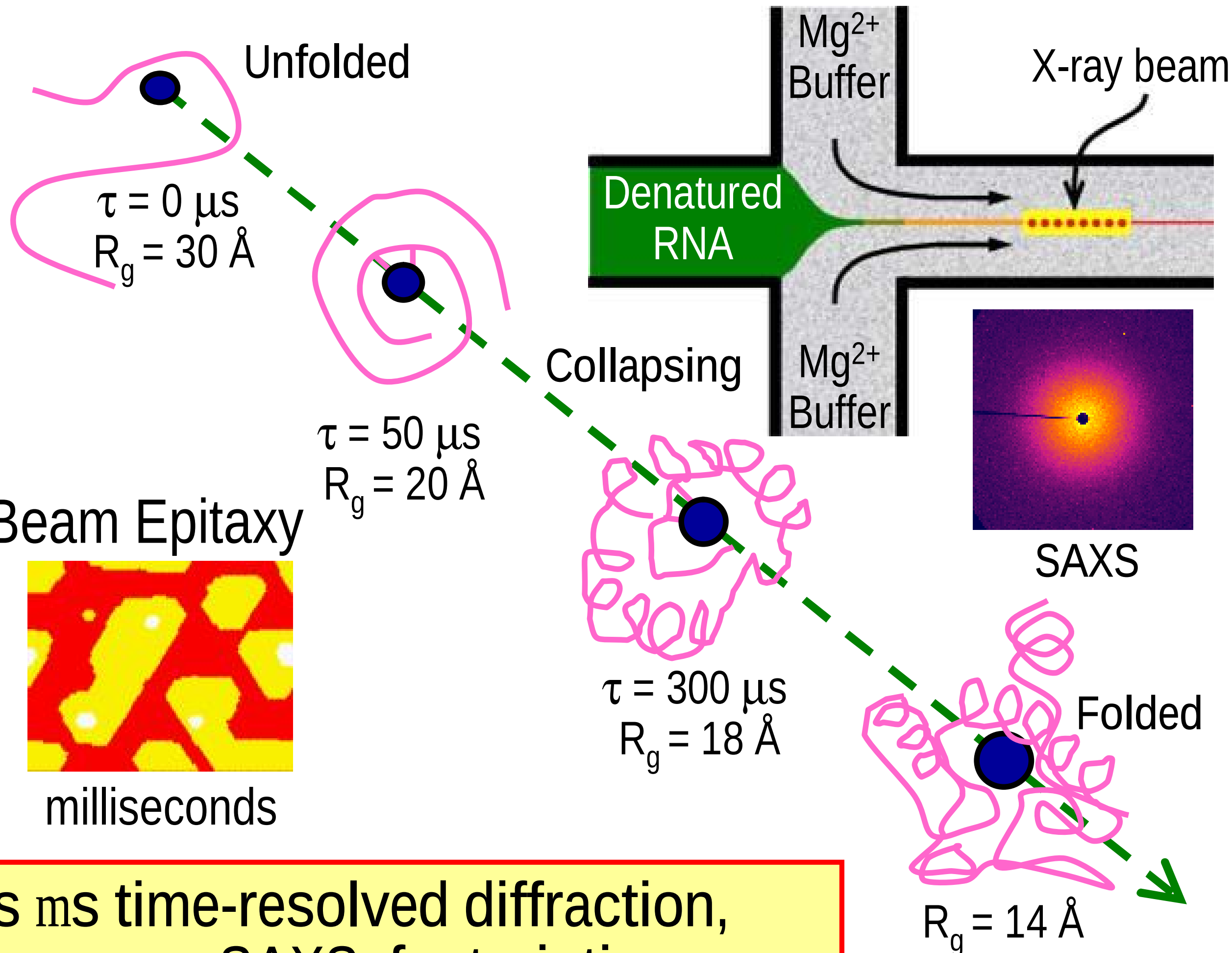
Self Organized Nanoscale Surface Structures



Pulsed Laser Molecular Beam Epitaxy

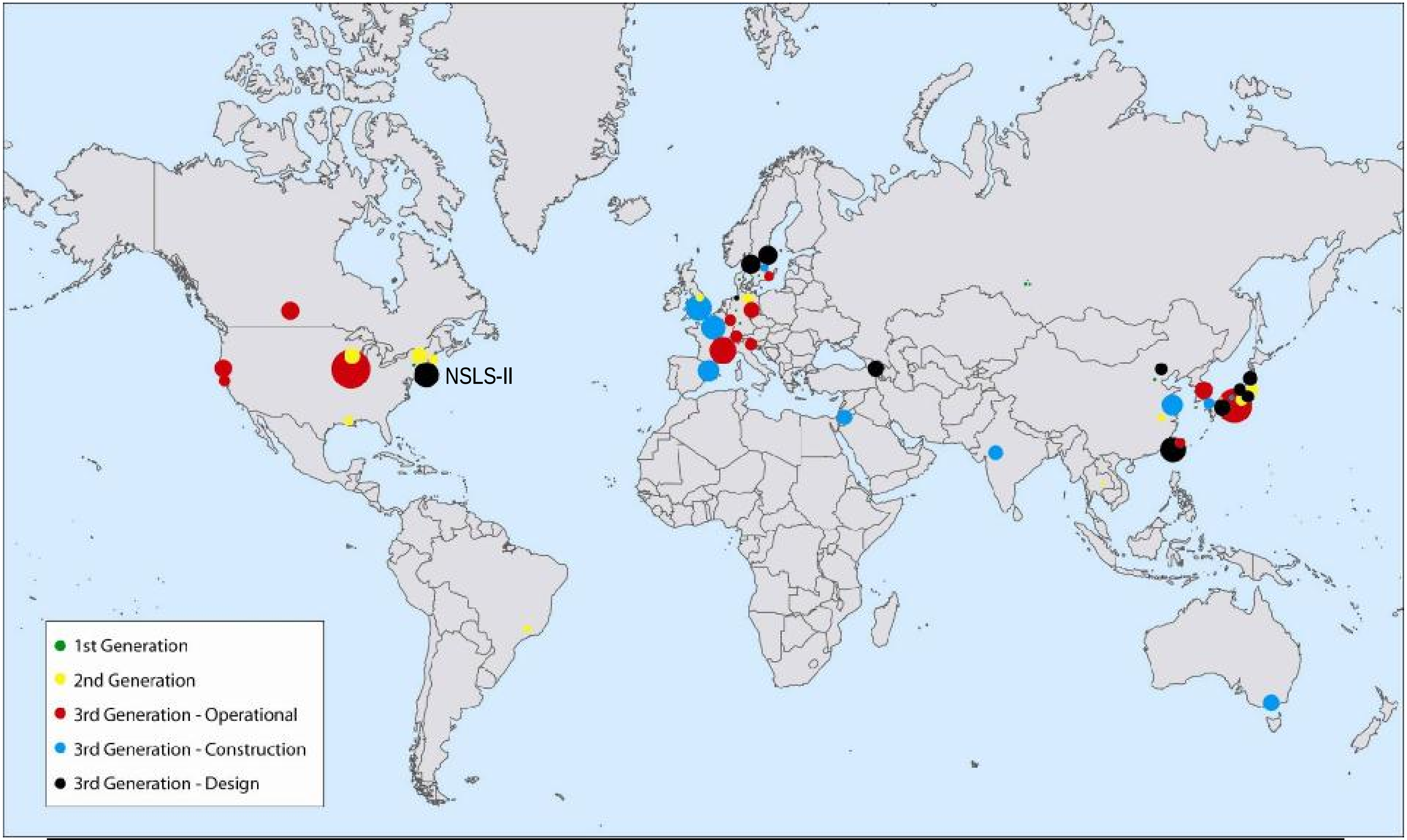


Instantaneous microseconds milliseconds



Requires ms time-resolved diffraction, spectroscopy, SAXS, footprinting

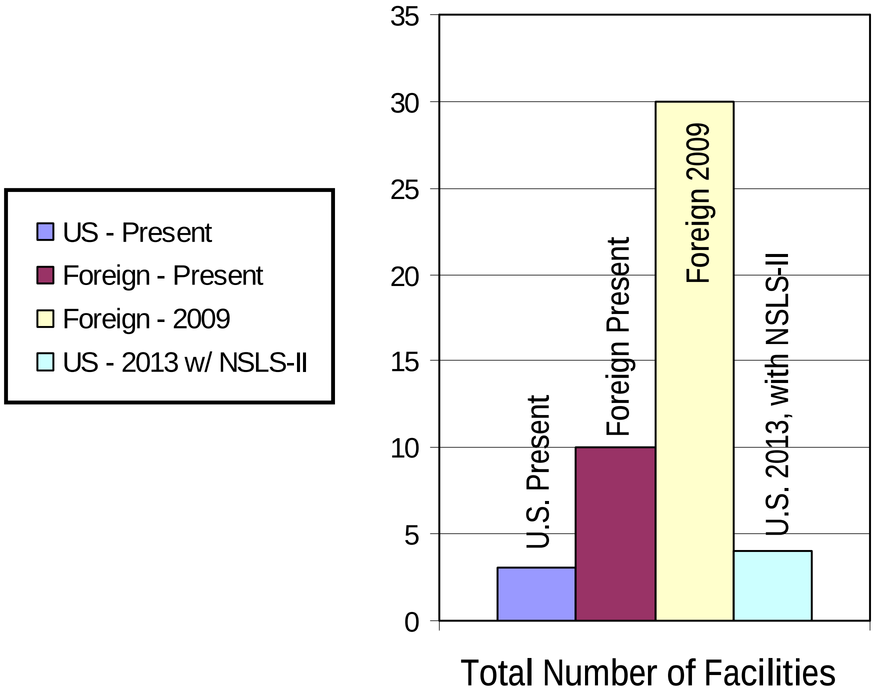
Synchrotrons Worldwide

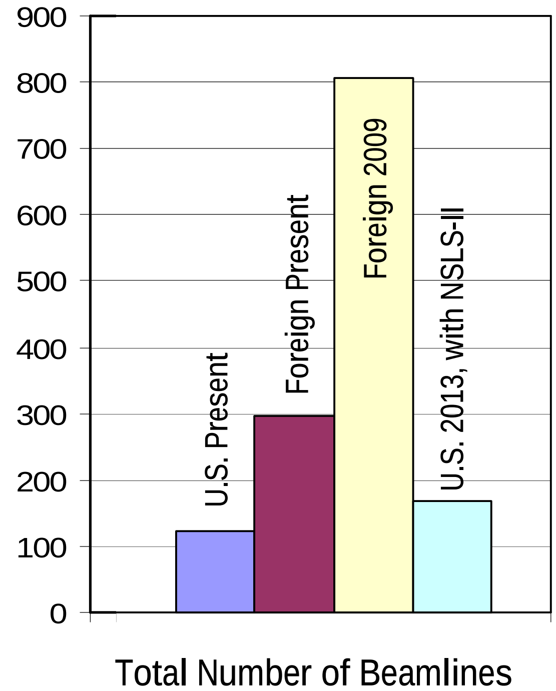


The dots show all 1st, 2nd, and 3rd generation light sources worldwide that are operational, under construction, and in design. (Compact synchrotrons are excluded.) The dot diameter is proportional to the total number of beamlines at each facility. The number of users that a facility can host scales with the number of beamlines.

Red, blue, and black dots show 3rd generation machines. The numbers of beamlines for these machines are shown on the next chart.

3rd Generation Synchrotrons Worldwide





Considering only 3rd generation sources, we see that the U.S. currently has 123 beamlines. In the rest of the world, there are currently 296 beamlines on 3rd generation synchrotrons. By 2009, this number will increase to 806. The U.S. will be outnumbered by the rest of the world by 7:1.

NSLS-II will increase the number of beamlines to 168. With NSLS-II in 2013, the U.S. will still be outnumbered by the rest of the world by 5:1.

Milestone Schedule

DATE	Milestone	Activity
August 2005	CD0	Approve Mission Need; Commence Conceptual Design
January 2007	CD1	Approve Alternate Selection and Cost Range; Commence Title I Design
December 2007	CD2	Approve Performance Baseline; Commence Title II Design
September 2008	CD3	Approve Start of construction
2009		Civil construction underway, 18 months to beneficial occupancy. Systems procurement and fabrication underway.
2011		Installation and subsystem integration. Start commissioning of injector while ring installation continues
2013	CD4	Complete construction, installation, and commissioning. Begin operations.

Annual Funding Profile

(in $ millions)

	FY05/6	FY07	FY08	FY09	FY10	FY11	FY12	FY13	Totals
Other Project Costs	1	25	20	5	5	10	20	50	136
Project Engineering and Design		20	55						75
Construction				127	165	150	100	47	589
Totals	1	45	75	132	170	160	120	97	800

Joint Photon Sciences Institute (JPSI)

Founded to serve as an intellectual center for development and application of the photon sciences and a gateway for users of NSLS-II

- $30M building construction funding commitment from NYS
- Office space, meetings areas, & laboratories
- Collaborative, interdisciplinary R&D in areas of physical and life sciences that are united in employing synchrotron-based methods
  - advanced materials
  - energy sciences
  - biomedical imaging
  - structural biology
  - advanced instrumentation (optics, detectors, robotics)
- Develop new methods & applications to exploit unique capabilities of NSLS-II
- Establish now so projects & teams mature in time to benefit NSLS-II development

Scientists

JPSI

NSLS-II

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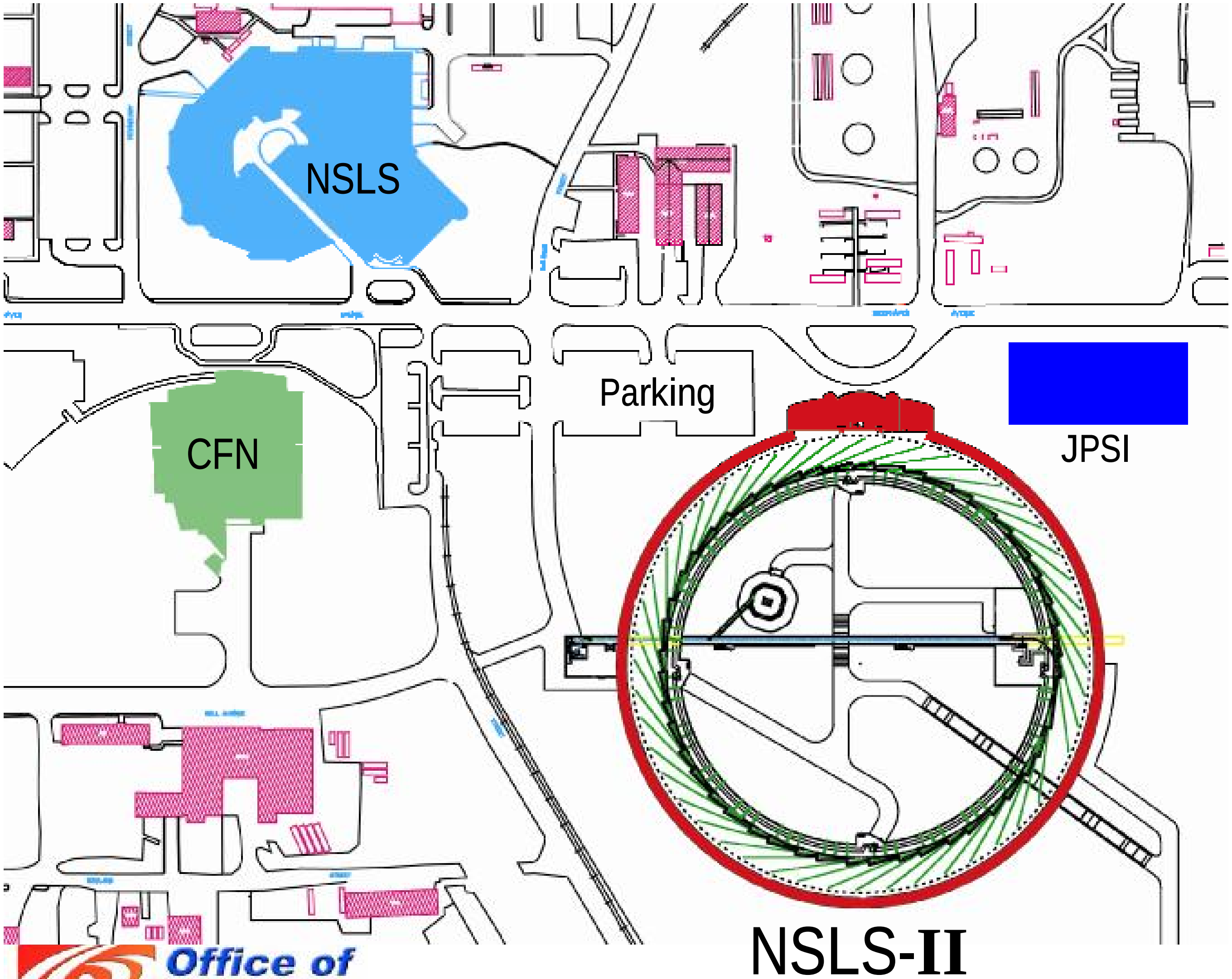
Siting



Site Features

- Grade ~ 4 ft
- Glacial sand
- Largely undeveloped
- Stability
- Low Site Prep Costs
- Proximity to CFN, Core Programs & Future JPSI

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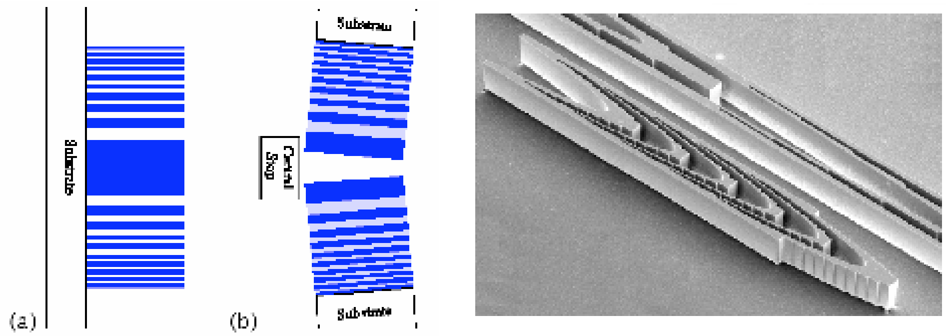
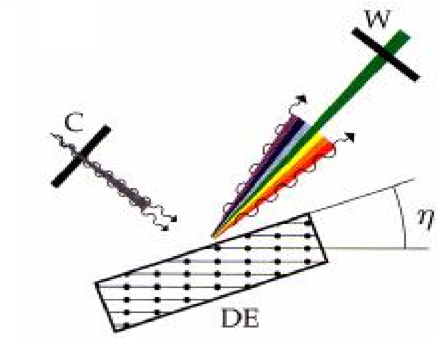
Transitioning Operations From NSLS to NSLS-II

- Continue operations of NSLS until NSLS-II operational
- Move NSLS programs to NSLS-II
  - Overlap operations while programs transfer over (< 1 year)
- NSLS Staff Transfer to NSLS-II
- Present NSLS Building Renovated for Other BNL Programs

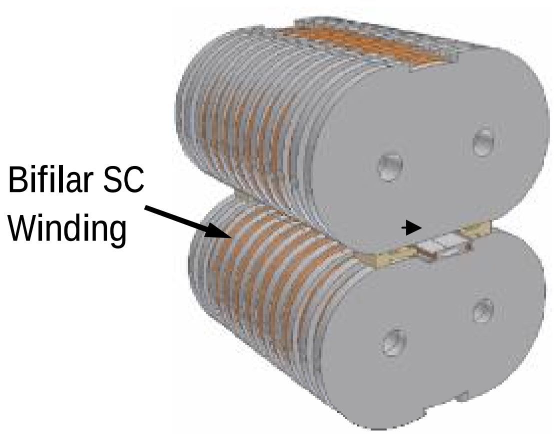
Principle R&D Areas



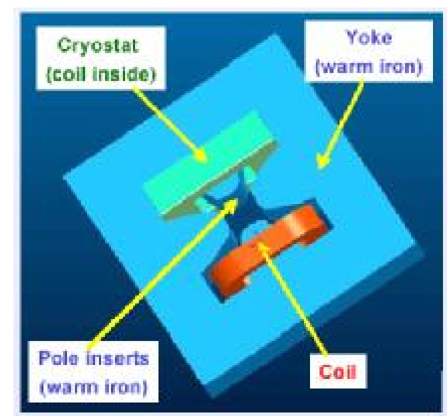
X-ray Focusing Optics



High Resolution Monochromators



Superconducting Undulators



High Temperature Superconducting Storage Ring Magnets

Mechanism for Beamline Development

- Spallation Neutron Source and Linear Coherent Light Source model
  - Coordinate users to define scientific case and instrumentation specifications for each beamline
  - Users and/or facility submit proposals to funding agencies
  - Facility constructs and operates the beamlines and instruments
- Partner user
  - Research resources and others funded by NIH and NSF
  - Industrial research
  - Others

Preliminary NSLS-**II** Beamline Plan

X-ray Insertion Device Beamlines (total: 27)

5 Macromolecular Crystallography
1 X-ray Micro-beam diffraction
1 Materials science/time-resolved
1 Resonant/Magnetic x-ray scattering
4 Soft x-ray undulator beamlines
1 Coherent X-ray Scattering
1 Small angle x-ray scattering
1 Inelastic x-ray scattering
2 Superconducting Wiggler (8 beamlines)
4 To be determined

X-ray Bending Magnet Beamlines (total: 22)

5 X-ray Spectroscopy
4 Soft x-ray spectroscopy
3 Small angle x-ray scattering
3 X-ray powder and single crystal diffraction
4 X-ray microprobe and imaging
4 To be determined

IR Beamlines (total: 12)

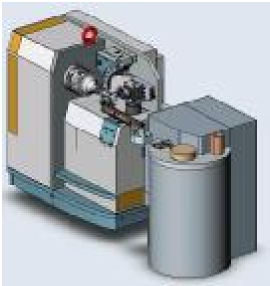
2 Extended Source IR Imaging Beamlines (Biological and Environmental)
2 Far-infrared / THz Beamlines (High Magnetic Field and Time-resolved)
4 IR Microprobe Beamlines (Materials, Biological, and High Pressure)
4 ports to be determined

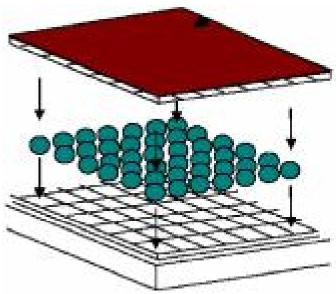
Five Insertion Device Beamlines Included in Initial Project Scope

NSLS-II Instrumentation

Optimized and Unique Endstation Instrumentation

Automation, Robotics
Ultra-High Pressures
Ultra-High Magnetic Fields
Very Low Temperatures
Advanced, efficient, high throughput, large area detectors





Pixel Array Detector

Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Summary

NSLS-II will deliver world leading performance

- U.S. will regain world leadership
- Essential for energy security
- A competitive advantage for U.S. industry
- Will enable ‘grand challenge’ science in many diverse fields