Introduction to the National Synchrotron Light Source (NSLS)
Outline

• The Facility
• The Users
• The Science
• The Future
Brookhaven National Laboratory

National Synchrotron Light Source
What is a Synchrotron?

A synchrotron is a facility that produces tiny beams of very bright light.

<table>
<thead>
<tr>
<th>Light Spectrum</th>
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<tbody>
<tr>
<td>X-Rays</td>
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<tr>
<td>Ultraviolet Light</td>
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<tr>
<td>Visible Light</td>
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<tr>
<td>Infrared Light</td>
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<tr>
<td>Microwaves</td>
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</table>
First Synchrotrons

- First particle accelerators (cyclotrons) were used to “split the atom”.

- First synchrotron was built in 1947 by General Electric.

- Synchrotron radiation was given off by these accelerators and was seen to be a nuisance.

- In the 1960’s it was realized that this would be a useful source of radiation – a new light source.
Properties of Synchrotron Light

- **Broad band** – a wide energy range of photons is available
- **Polarized** – this minimizes background scattering, improves sensitivity and enables measurement of circular dichroism
- **Pulsed** – the electron bunches produce nanosecond light pulses, enabling process kinetics to be followed and ‘movies’ of reactions to be made.
Properties of Synchrotron Light

**Brightness** – many orders of magnitude brighter than conventional sources, enabling quick experiments on small samples.
The BRIGHTNESS of Synchrotron Light

100 Watts / 1000000 mm\(^2\) (1 m\(^2\)) = 0.0001 Watts / mm\(^2\)

0.005 Watts / 1 mm\(^2\) = 0.005 Watts / mm\(^2\)

30 Watts / 0.01 mm\(^2\) = 3000 Watts / mm\(^2\)
This is Synchrotron Light
How Do We Make Synchrotron Light?

- One of 4 DOE–operated synchrotron facilities
- 2 Electron storage rings that produce synchrotron light
- 65 beamlines operate simultaneously

X–Ray
2.8 GeV
300 mA

VUV–IR
0.8 GeV
1.0 A

Booster Ring
Electron Gun
Building a Synchrotron 101

1) Take evacuated beam pipe

ADD:

2) Bends (dipoles) to form e–beam trajectory (& as SR sources)

3) Quadrupole magnets to focus e–beam transversely

4) Sextupoles for achromatic focusing

5) RF to make up for energy loss; also provides longitudinal focusing (bunching)

6) Injection system

7) IDs into avail. straight sections

8) Beamlines to deliver photons to the Users
Types of Light-Generating Sources

**Bending magnets:**
- Sweeping searchlight
- At each deflection of the electron path a beam of radiation is produced

**Insertion devices** – inserted into “straight sections” of the ring and produce higher intensity of light

**Wiggler:**
- Beams emitted at each pole reinforce each other and appear as a broad beam of incoherent light

**Undulator**
- Produces a very narrow beam of coherent light, amplified by up to 10,000x
Outline

- The Facility
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- The Science
- The Future
• Facility operates 24 hours/day, 7 days/week, ~10 months/year
• >2200 users per year (~1/3 are new users)
• Typical stay is 2–4 days (onsite housing)
NSLS User Distribution

- New York: 816 (32%)
- Foreign: 404 (16%)
- Other Northeast States: 700 (27%)
- Non-Northeast States: 643 (25%)

Non-Northeast States are shown in green, Foreign in blue, Other Northeast States in red, and New York in yellow.
• Large majority of users are from academia
• Industrial participation is small and diverse
NSLS Users by Employment Level

- A large number of students and postdocs work at NSLS

FY 2006
Student Research

Bishnu Panigrahi
college student
“heavy metal transport in plants”
Sayville, NY

Ashley Jones
college student
“Arsenic toxicity in the kidney”
Sayville, NY

Megan Bourassa
PhD student
“metal homeostasis in ALS”
Phoenix, AZ

Jeff Ambrose
college student
“nitrogen fixation in soils”
New Orleans, LA

Matt Engel
PhD student
“protein structure in hepatitis C virus”
Stony Brook, NY

Andreana Leskovjan
PhD student
“metal uptake in Alzheimer’s disease”
Stony Brook, NY

Alvin Acerbo
PhD student
“improving imaging resolution”
The Netherlands

Shirin Mortazavni
college student
“unique methods to crystallize proteins”
Bellport, NY
NSLS User Community

- >2100 scientists*
- >400 academic, industrial, government institutions
- 50% growth in last 12 years
- Strongest growth in life sciences
- Largest groups are materials and life sciences

* users visiting the NSLS in FY 2006. Each year, the NSLS registers approximately 750 new users.
• More life science users, shorter beamtime, high-throughput
• Materials science experiments are more complicated, time-consuming

FY 2006
NSLS Publications

- almost 1000 publications per year
- > 200 publications in premier journals
How to Get Beamtime

• Scheduled in three 4–month cycles
• User access via 2 primary mechanisms:
  • General User Proposals: peer-reviewed proposal system
  • Participation Research Teams
• Some proprietary research is done (full cost-recovery rate)
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What do we do with Synchrotron Light?

Absorption

Scattering

Diffraction
Major Synchrotron Techniques

**SPECTROSCOPY**
- Infrared spectroscopy
- Photoelectron spectroscopy
- X-ray absorption spectroscopy
- X-ray emission spectroscopy

**DIFFRACTION/SCATTERING**
- Protein crystallography
- Small molecule crystallography
- Powder diffraction
- Small-angle x-ray scattering
- X-ray microdiffraction
- High momentum resolution x-ray scattering

**IMAGING**
- Infrared microspectroscopy
- Soft X-ray scanning microscopy
- Hard X-ray microprobe
- X-ray microtomography
- Diffraction-enhance imaging

**OTHER**
- Micro-machining
- X-ray footprinting
Physics and Materials Science

Data storage

Liquid crystal displays

Improved polymers

Nonstick coatings

Nanomaterials
Chemistry

Corrosion

Rechargeable batteries

Catalytic converters
2003 and 2009 Nobel Prizes in Chemistry

Rod MacKinnon
Venkatraman Ramakrishnan
Thomas Steitz
Geology and Environmental Science

Environmental cleanup

Mars meteorites

Space dust

Earth’s core
Biology and Medicine

- Anthrax
- Malaria
- Lyme’s disease
- Arthritis
- Osteoporosis
- HIV
- Alzheimer’s disease
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NSLS–II: Brighter Light for the Future

- new synchrotron under construction at Brookhaven Lab
- $912 M project to be completed in 2014
- x-rays ~10,000 times brighter than current NSLS
- will be the brightest synchrotron in the world

http://www.bnl.gov/nsls2/cam/
How is NSLS–II Different?

Highly optimized synchrotron delivering:
• extremely high brightness (10,000x)
• exceptional beam stability
• advanced instruments, optics, & detectors that capitalize on these special capabilities

Together, these enable:
• ~ 1 nm spatial resolution
• ~ 0.1 meV energy resolution
• single atom sensitivity
NSLS–II Design Features

**Design Parameters**
- 3 GeV, 500 mA, top–off injection
- Circumference 791.5 m
- 30 cell, Double Bend Achromat
  - 15 long, hi–β straights (9.3 m)
  - 15 short, lo–β straights (6.6 m)

**Novel design features:**
- Damping wigglers
- Soft bend magnets
- Three pole wigglers
- Large gap IR dipoles

**Ultra–low emittance**
- Small beam size \( \frac{e_x}{e_y} = 0.6 / 0.008 \text{ nm–rad} \)
- \( \sigma_x / \sigma_x = 28 \mu \text{m} / 2.6 \mu \text{m}, \sigma_x' / \sigma_y' = 19 \mu \text{rad} / 3.2 \mu \text{rad} \)
- Diffraction limited in vertical at 10 keV

**Pulse Length (rms) ~ 15 psec**

Total Project Cost = $912M
NSLS-II Site Plan

NSLS-II
With Full LOB Build-Out
Lab–Office Building (LOB) Floor Plan

33,600 Gross Square Feet

- 120 Offices
- 10 labs
- Machine shop
- Conference Rooms
- Interaction Areas
- Loading/storage area

Current project scope:
- 2 built–out LOBs
- 1 shell (maybe 2–3)
NSLS–II Beamlines

- 19 straight sections for undulators
- 8 straight sections for damping wigglers
- 27 BM ports for IR, UV and Soft X-rays
- 4 Large Gap BM ports for far-IR

At least 58 beamlines
More beamlines by canting multiple IDs per straight
Multiple end-stations/beamline are also possible

For comparison, NSLS has 60 operating beamlines
Six Beamlines in Scope of Project

Coherent hard x-ray scattering

Coherent soft x-ray scattering

Inelastic x-ray scattering

High-energy powder diffraction

Hard x-ray nanoprobe

Sub-micron resolution x-ray spectroscopy
<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Status</th>
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<tbody>
<tr>
<td>Aug 2005</td>
<td>CD–0, Approve Mission Need</td>
<td>(Complete)</td>
</tr>
<tr>
<td>Jul 2007</td>
<td>CD–1, Approve Alternative Selection and Cost Range</td>
<td>(Complete)</td>
</tr>
<tr>
<td>Jan 2008</td>
<td>CD–2, Approve Performance Baseline</td>
<td>(Complete)</td>
</tr>
<tr>
<td>Jan 2009</td>
<td>CD–3, Approve Start of Construction</td>
<td>(Complete)</td>
</tr>
<tr>
<td>Feb 2009</td>
<td>Contract Award for Ring Building</td>
<td>(Complete)</td>
</tr>
<tr>
<td>Aug 2009</td>
<td>Contract Award for Storage Ring Magnets</td>
<td>(Complete)</td>
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<tr>
<td>Mar 2010</td>
<td>Contract Award for Booster System</td>
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<tr>
<td>Feb 2011</td>
<td>1st Pentant Ring Bldg Beneficial Occupancy; Begin Accelerator Installation</td>
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<tr>
<td>Feb 2012</td>
<td>Beneficial Occupancy of Experimental Floor</td>
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<tr>
<td>Oct 2013</td>
<td>Start Accelerator Commissioning</td>
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<tr>
<td>Jun 2014</td>
<td>Early Project Completion; Ring Available to Beamlines</td>
<td></td>
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<tr>
<td>Jun 2015</td>
<td>CD–4, Approve Start of Operations (NSLS ceases operations)</td>
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