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... for a brighter future

Upgrades to Third Generation Synchrotrons:

The Advanced Photon Source

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Associate Laboratory Director for Scientific User Facilities, ANL

Presented at the NSF Panel on Light Source Facilities workshop, Livermore, CA January 9th 2008

U.S. Department of Energy

UChicago Argonne LLC

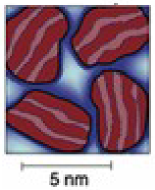
Office of Science U.S. DEPARTMENT OF ENERGY

A U.S. Department of Energy laboratory managed by UChicago Argonne, LLC

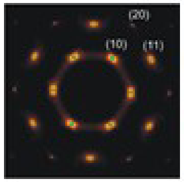
The Advanced Photon Source is a 7GeV 3rd generation synchrotron source producing the brightest x-rays in the US, now operating for 11 years

A scientific tour of the ring

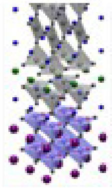
FY '08: 54 operating beamlines
30 operated by APS (XOR)



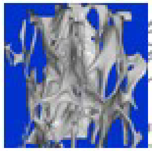
The nanostructure of cement Allen et. al. Nat. Mat. (2007)



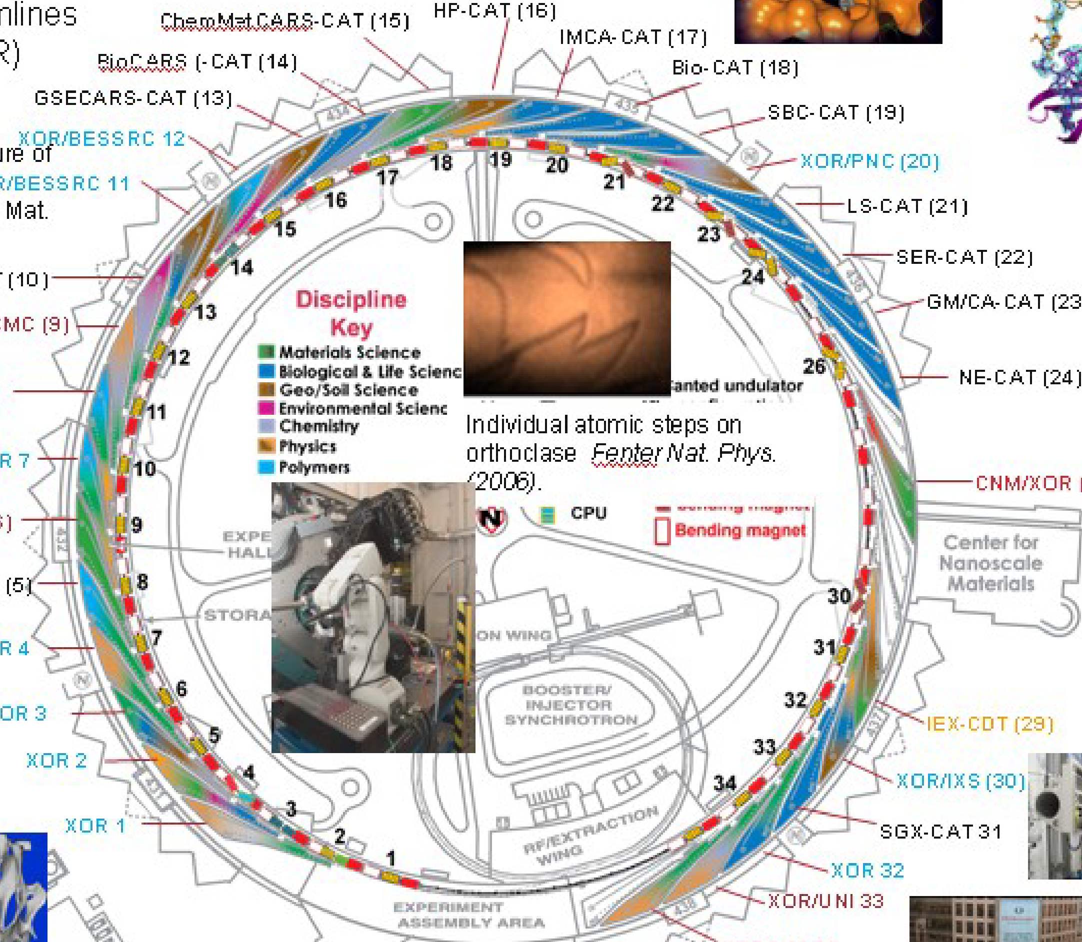
Self-assembling nanostructures Stein et. al. PRL, 2007



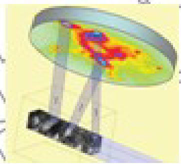
Orbitals at an interface J. Chakalian et. al. Science 2007



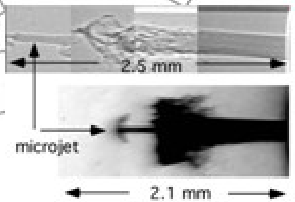
Osteoporosis, Stock et. al.



Individual atomic steps on orthoclase *Fenter Nat. Phys.* (2006).

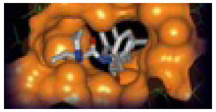


Dislocation walls are lumpy Levine et. al. Nat. Mat (2006)

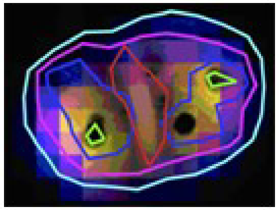


100ps shots of fuel spray (Fezza)

Fighting AIDS with Kaletra™

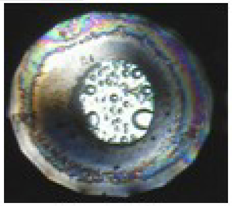


Understanding malaria resistance, Baxter et. al. PNAS, **104**, (2007)

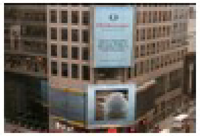


How does radiation kill? Daly et. al., PLoS Biol. **5** (2007).

towards 1 nm probes



New H_2:O_2 alloy at high P-T *Mao et al., Science* ***314***, *636 (2006).*



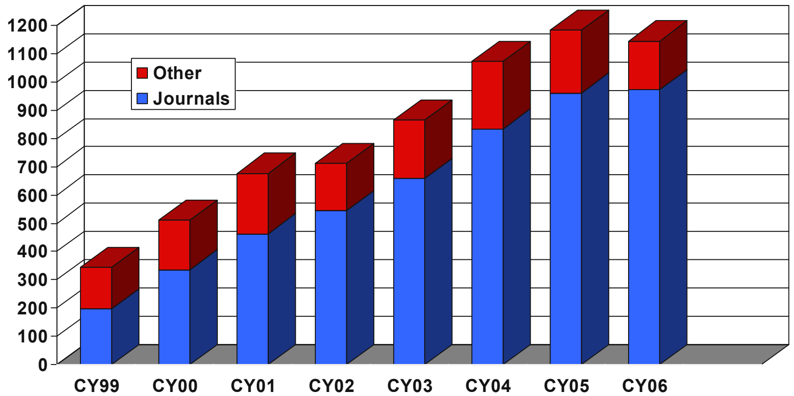
Big Bugs, Socha et. al. Science, (2007)

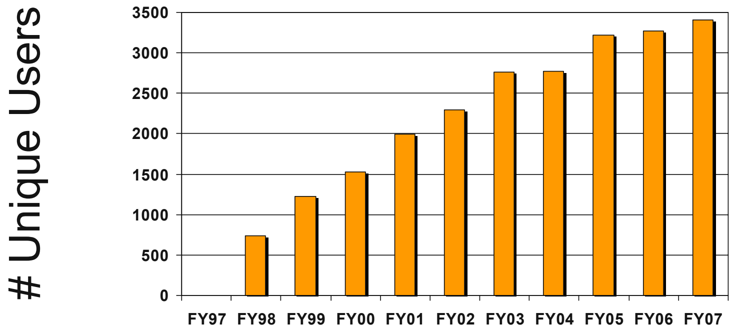
Key
CAT sectors
Current XOR sectors
Transitioning to XOR sector
CDT sector
Operated jointly (APS, CNM)

XOR = X-Ray Operations and Research

APS scientific impact increasing

Refereed publications



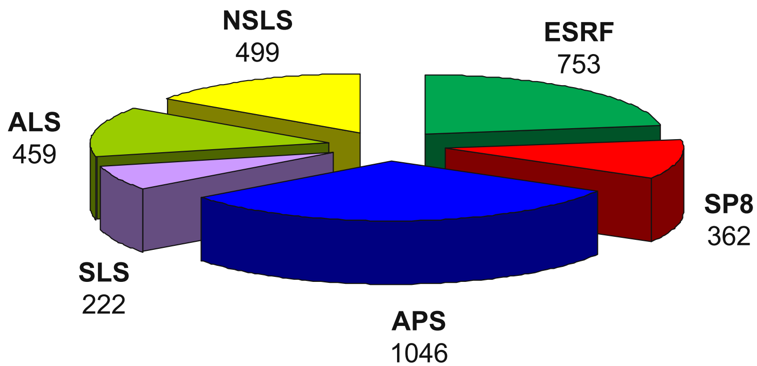


3411 unique users in 2007

Selected high impact stats

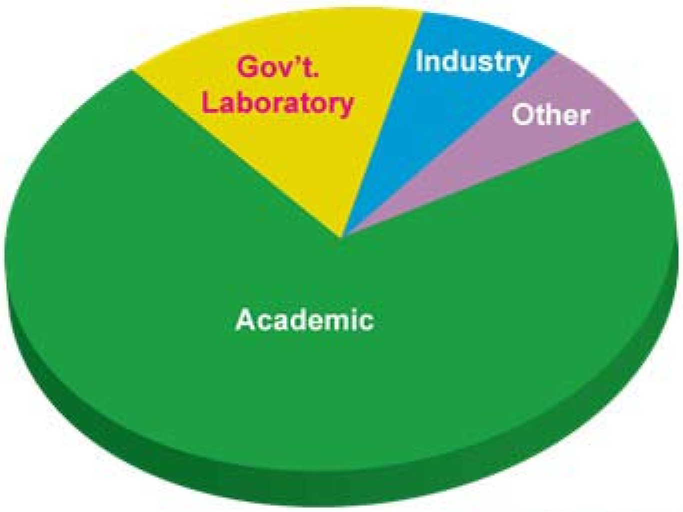
	2004	2005	2006
Cell	7	6	14
All *Nature***	32	37	37
PRL	21	27	37
Science	11	9	20
PNAS	33	44	43

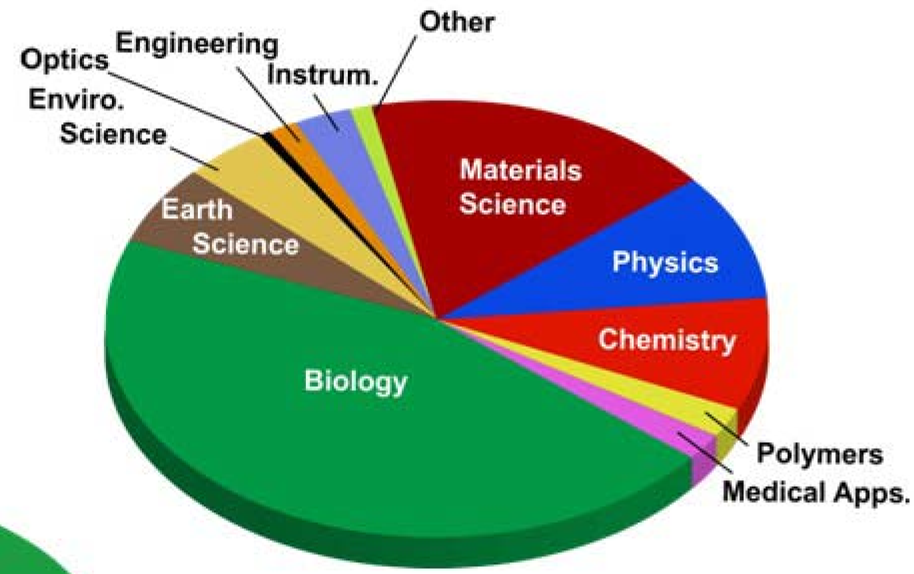
58% journal papers with impact factor > 3.5 (2006)



2006 protein databank deposits

The majority of our users are from academia

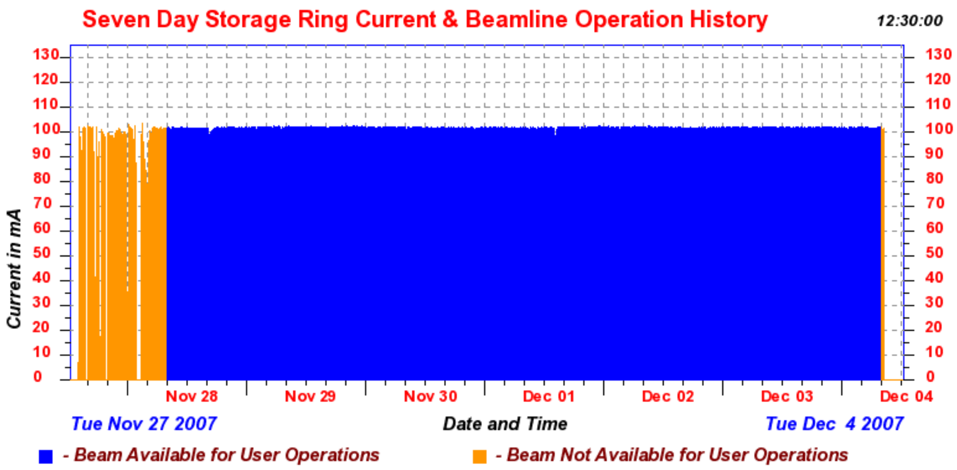




and a significant fraction of their research support comes from NSF

Science possible by a highly performing machine

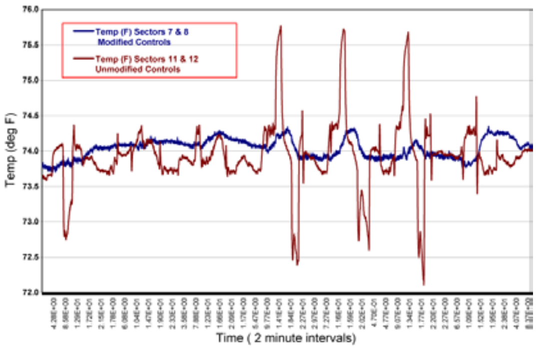
- Over the last three years the average availability has been > 98%
  - And the mean time between faults (MTBF) has been over 90 hours
- These are outstanding metrics
  - The result of many years of a sustained QA approach to faults
    - *Combined with a well-built machine!*
- Our goal has become 97% availability and 70 hours MTBF



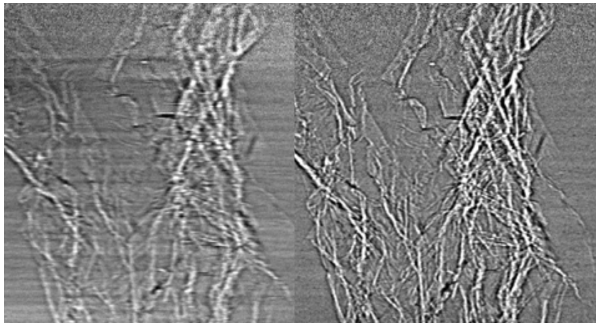
- *We are concerned that our resources have not been adequate to deal with obsolescence, without which sustaining our goals will be a challenge*

Some examples of machine innovation in last three years

a. Improved beam stability



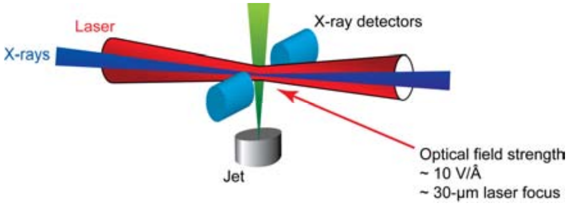
b. Local beta functions



pays off for a dedicated imaging sector (32ID)

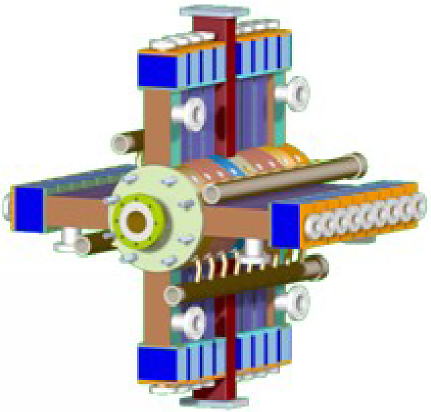
c. Single bunch charge increased by ~2 times to 16 mA

L. Young et al., “X-Ray Microprobe of Orbital Alignment in Strong-Field Ionized Atoms,” Phys. Rev. Lett **97**, 083601 (2006).

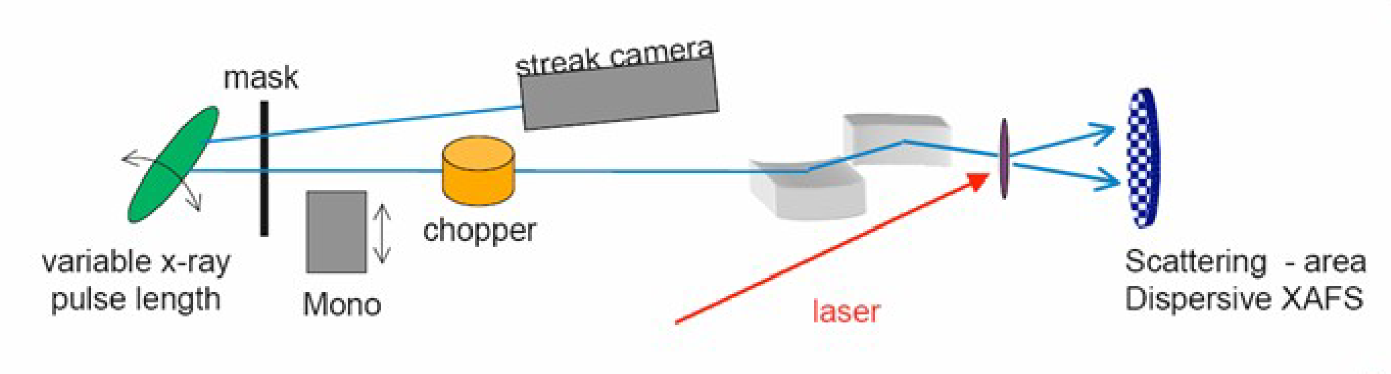


…driven by x-ray science

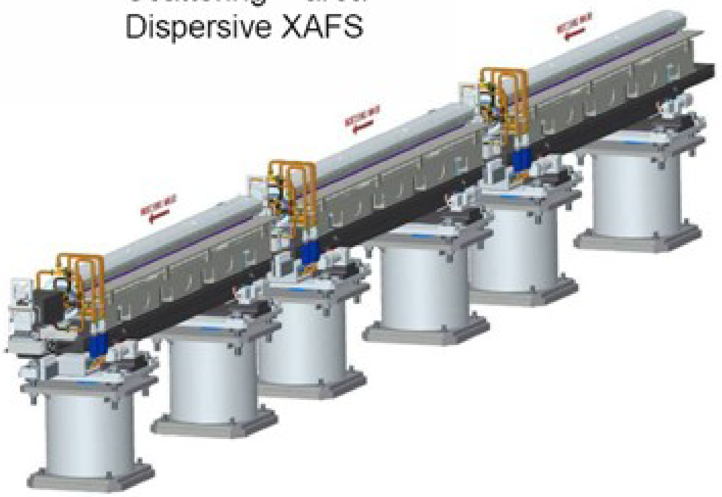
Some medium-term accelerator innovations



- Short Pulse X-Ray Project – ps pulses on Sector 7?

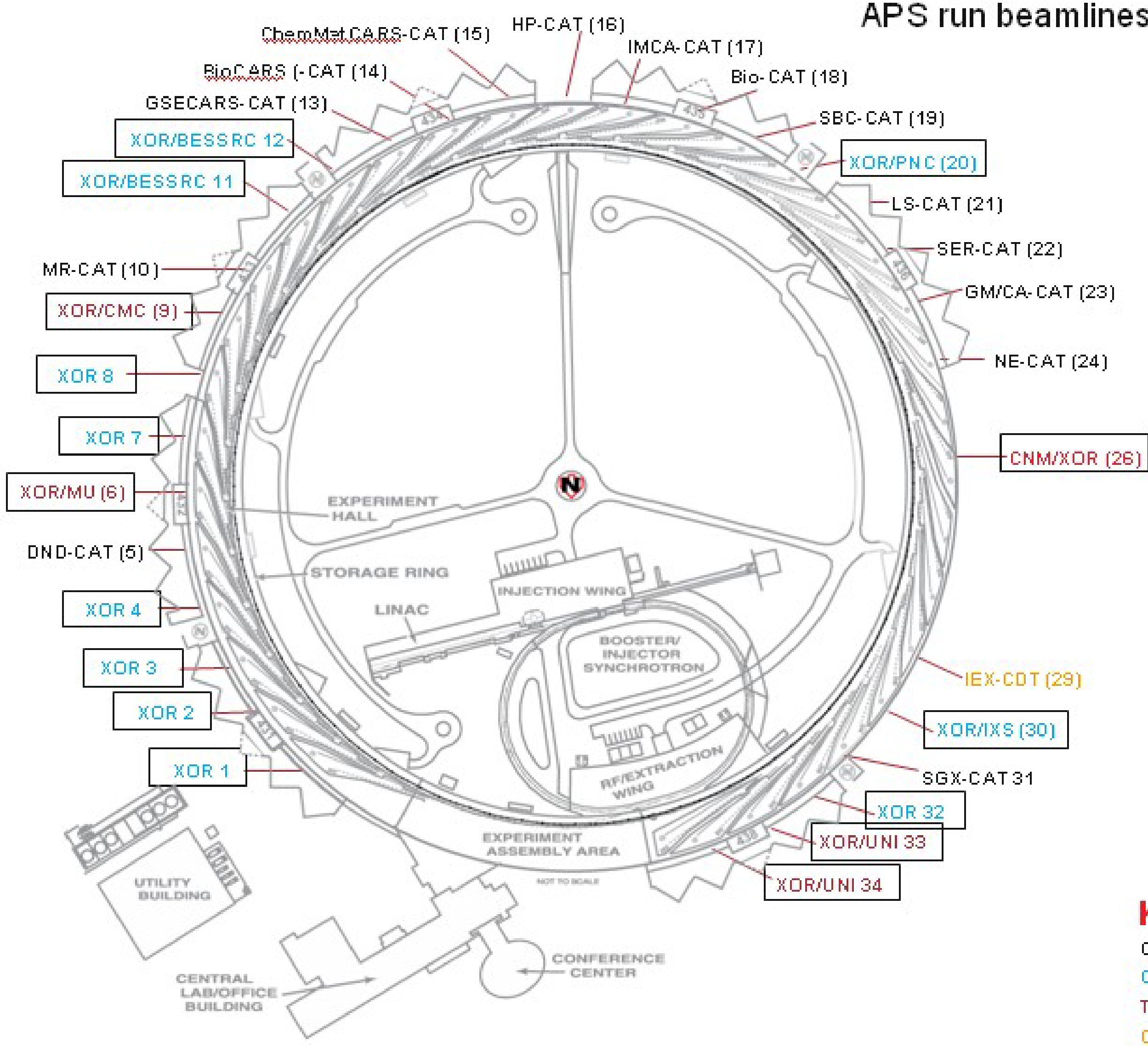


- Responsibility as LCLS partner for undulators in world's first x-ray laser



APS assume operations of more beamlines

X-Ray Operations and Research (XOR)
APS run beamlines (as of end of '07)



Key

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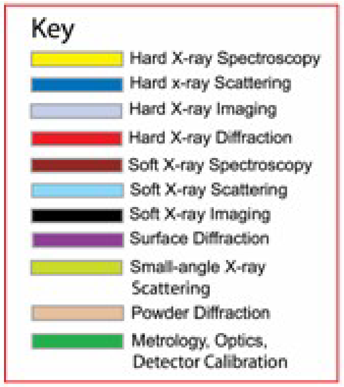
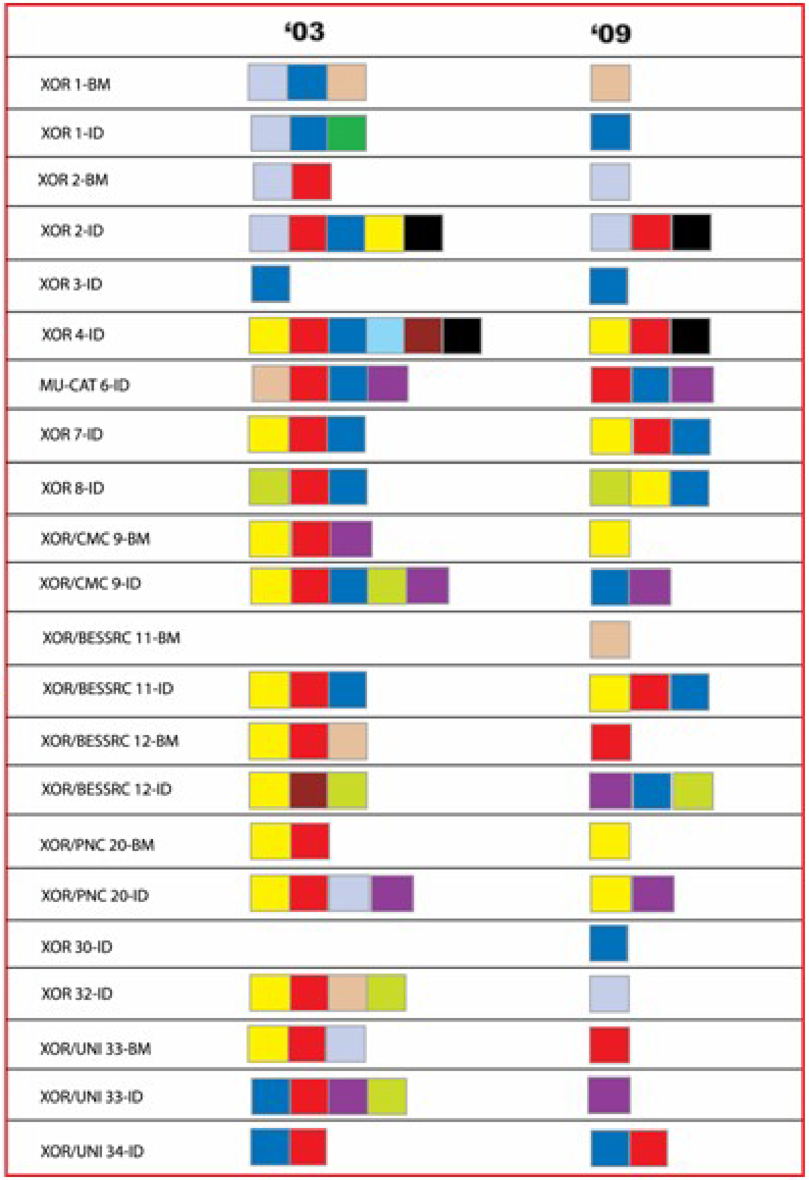
Increasingly optimized XOR beamlines - techniques at the APS – 2003 vs. 2009 (planned)





Single technique beamlines allow tailored undulator sources

New proposals which emerged from strategic planning since 2004 (more than a dozen workshops held..)

1. Transition of several multi-purpose to dedicated APS beamlines:

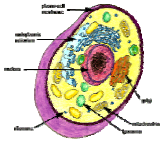
- High-energy (E>50 keV) beamline: 1-ID ☑
- Imaging beamline: 32-ID ☑
- Small/wide angle x-ray scattering: 12-ID-B
- *Time-resolved picosecond scattering: 7-ID-C* ***(NEW)*** ☑

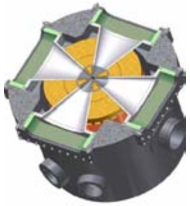
2. Several groups formed partnerships to develop new beamlines:

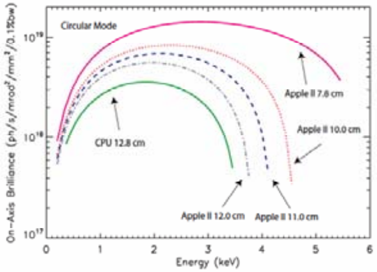
HP-Sync – a virtual beamline for high-pressure studies ☑

- Intermediate X-ray Energy Spectroscopy and Scattering ☑
- BioNanoprobe
- Diffraction in High Field

others under development

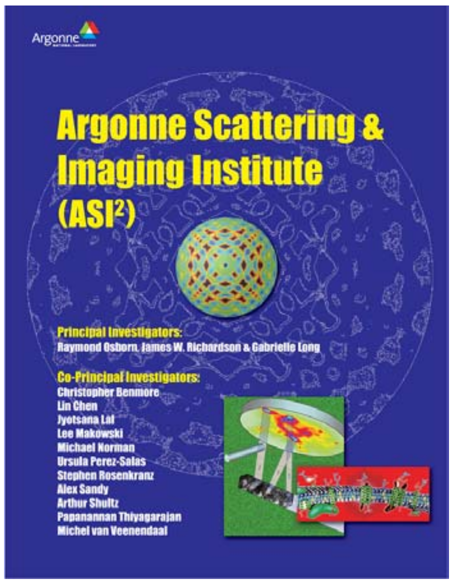






Software and instrumentation

Software is a critical "weak link" in accessibility to APS



BEAMLINE TECHNICAL SUPPORT
P. FERNANDEZ
GROUP LEADER

J. BALDWIN
K. BEYER
L. GADES
H. LEE
T. LUTES
T. MADDEN
A. MICELI
D. MORGAN (6)
C. PIATAK
S. ROSS
R. SPENCE
J. WEIZEORICK

Detector development supported by ANL laboratory strategic LDRD in 2007

and ASI^2 would make this a national asset for x-ray and neutron grand challenge science (*follows on from NSF funded DANSCE*)

Future growth areas

- Biology outside protein crystallography
- Magnetism
- Inelastic x-ray scattering for Condensed Matter Physics, Geophyiscs, Biophysics
- Nanoscience
- Intermediate energy x-ray scattering
- Catalysis…

- Tactics:
  - Increasingly dedicate beamlines
  - Create new beamlines, with user partners
  - Facilitate scientific portals, not necessarily beamline specific
  - Especially focus on imaging (broadly defined) and ultrafast science
  - Develop detectors, scientific software and theory
  - Plan for long-term machine upgrade to support new science

Status of Facilities for the Future: 20-Year Outlook – By the End of FY 2008

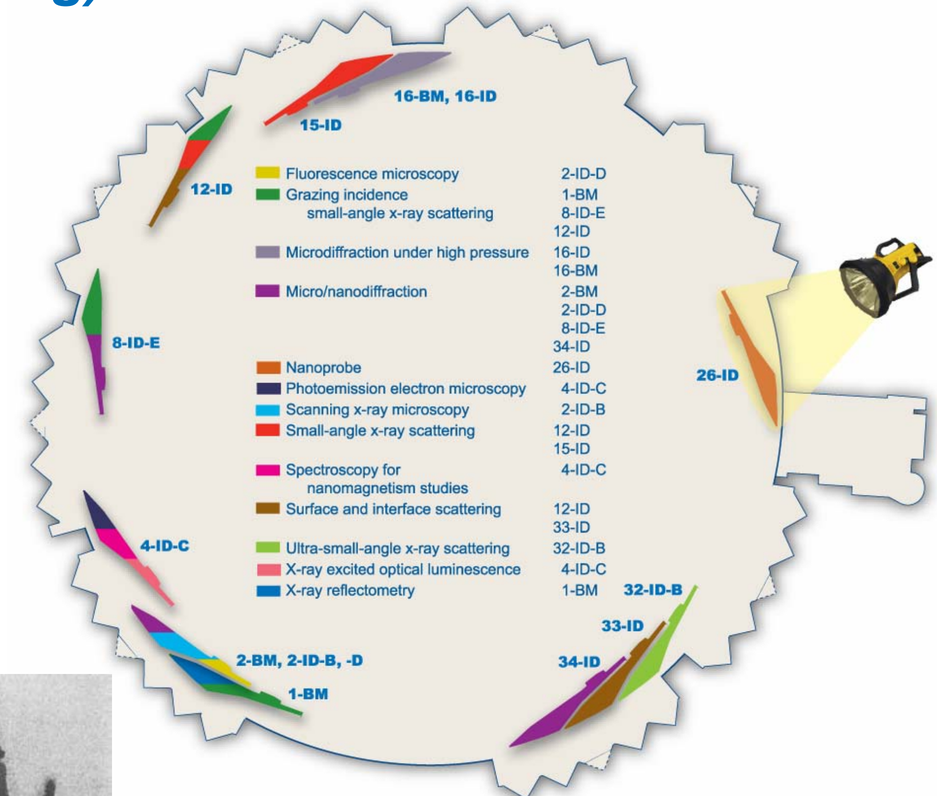
Term	Priority	Program	Facility		R&D	Conceptual Design	Engineering Design	Construction	Operation
Near-Term	1	FES	ITER						
	2	ASCR	UltraScale Scientific Computing Capability						
	Tie for 3	HEP	Joint Dark Energy Mission						
		BES	Linac Coherent Light Source						
		BER	Protein Production and Tags →	Bioenergy Research Centers*					
		NP	Rare Isotope Beam Facility (previously RIA) #						
	Tie for 7	BER	Characterization and Imaging →	Bioenergy Research Centers*					
		NP	CEBAF Upgrade						
		ASCR	ESnet Upgrade						
		ASCR	NERSC Upgrade						
		BES	Transmission Electron Aberration Corrected Microscope						
Mid-Term	12	HEP	BTeV #		Terminated				
	13	HEP	International Linear Collider						
	Tie for 14	BER	Analysis/Modeling of Cellular Systems →	Bioenergy Research Centers*					
		BES	SNS 2-4 MW Upgrade						
		BES	SNS Second Target Station						
		BER	Whole Proteome Analysis →	Bioenergy Research Centers*					
	Tie for 18	NP/HEP	Double Beta Decay Underground Detector						
		FES	Next-Step Spherical Torus						
		NP	RHIC II						
	Tie for 21	BES	National Synchrotron Light Source Upgrade*						
		HEP	Super Neutrino Beam						
Far-Term	Tie for 23	BES	Advanced Light Source Upgrade						
		BES	Advanced Photon Source Upgrade						
		NP	eRHIC or eLIC or Electron Ion Collider						
		FES	Fusion Energy Contingency						
		BES	HFIR Second Cold Source and Guide Hall						
		FES	Integrated Beam-High Energy Density Physics Experiment						

75-100% 50-75% 25-50% > 0% complete

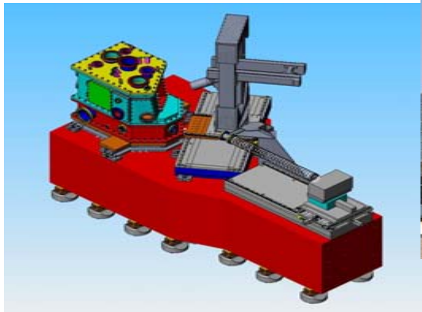
Ray Orbach
9/21 update to
BESAC

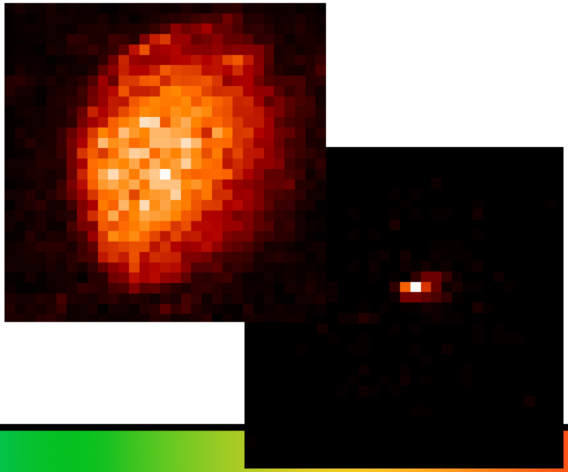
*Technology readiness changed
Changed due to planned facility abroad

APS science at the nanoscale (predominantly imaging or focusing) will benefit from increase source brilliance



New nanoprobe jointly with Center for Nanoscale Materials
~10nm resolution aim in hard x-ray region





110 years

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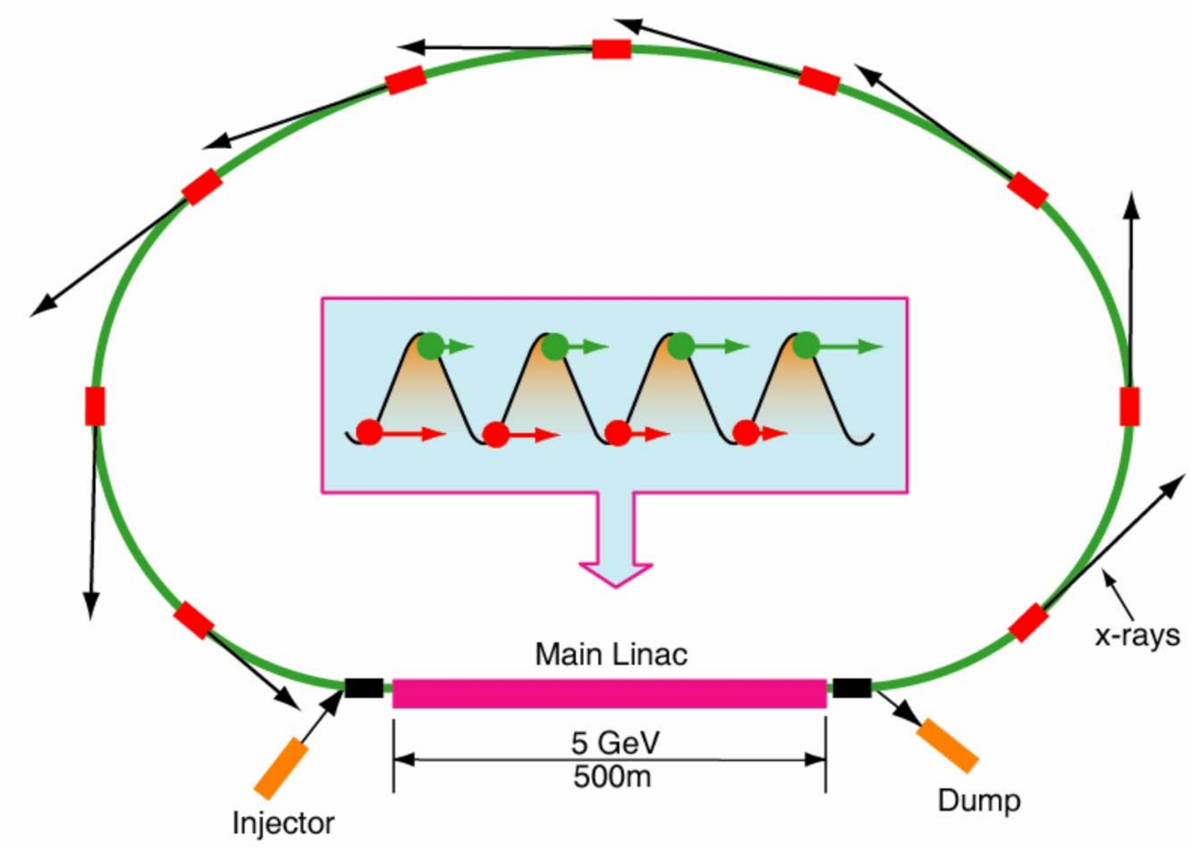
Energy Recovery Linac



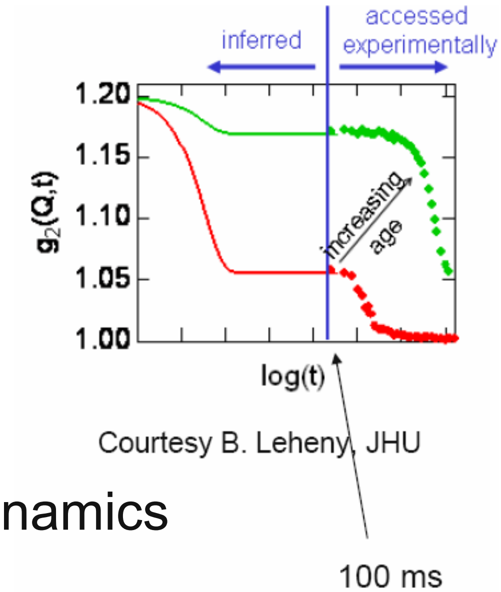
Accelerating bunch

Returning bunch

A superconducting LINAC is <u>required</u> for high energy recovery efficiency

An ERL would produce almost fully-coherent illumination (transversely) => probing complex materials dynamics by x-ray photon correlation spectroscopy (XPCS)

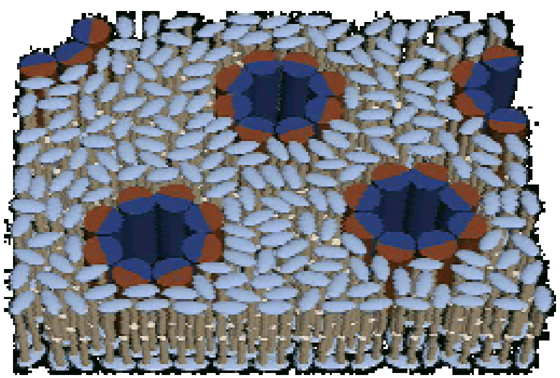
e.g. Photon correlation spectroscopy becomes 4 orders of magnitude faster



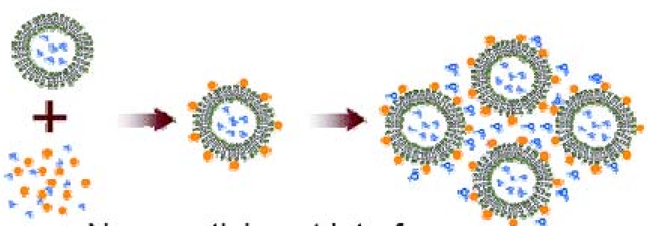
Glassy dynamics

$$S / N \propto I\sqrt{t}$$

EXAMPLE



Dynamics of membranes

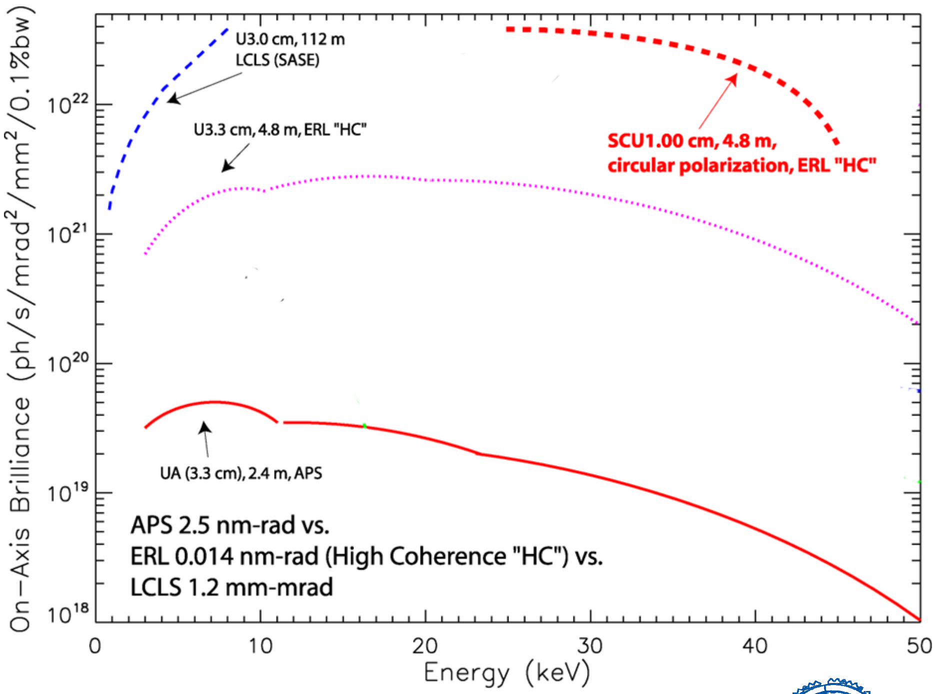


Nanoparticles at interfaces

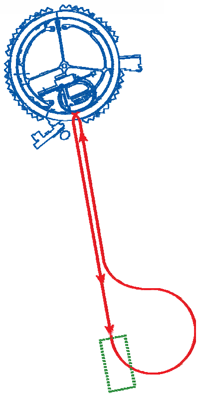
[L. Zhang and S. Granick, Nano Lett. **6**, 694 (2006)]

Better detectors will reach sub-μs

What would an ERL offer?



- Substantially spatially-coherent source ("like a laser")
  - It can put >100 times more flux into a <10nm probe and improve phase contrast compared with a storage ring
  - And deliver to many users
- It offers pulses 100 times shorter or less (in the sub-ps regime)
  - Does not rival FEL for peak brilliance
  - But compatible with FEL upgrade as well
- Natural upgrade path for storage ring such as APS
  - Could be done without compromise or major disruption

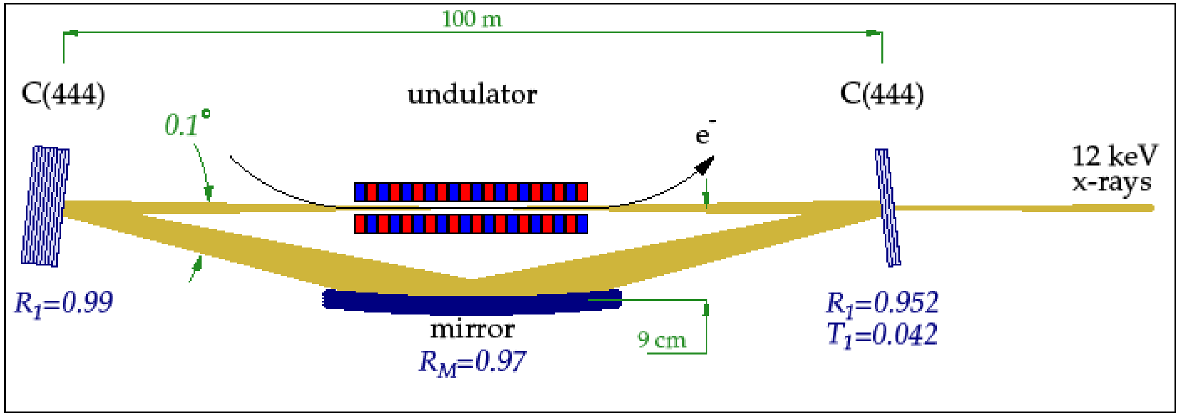


We continue to consider other options, but are now targeted on the ERL

R&D Hilite: Cavity laser might become possible with ERL beam

K.J. Kim and Y. Shvydko

Diamond cavity for the X-FEL Oscillator

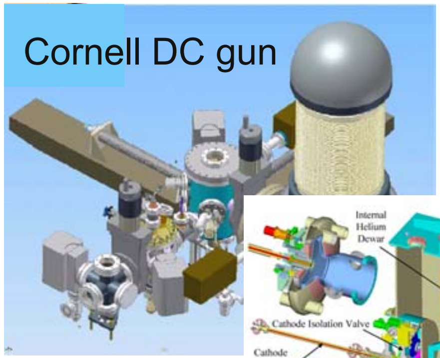


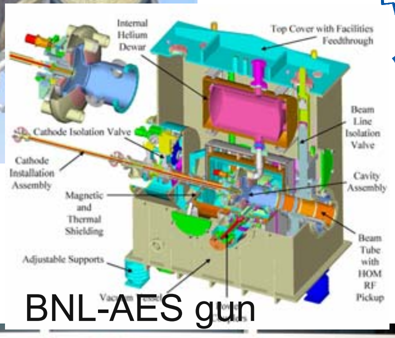
$$R_1 \times R_2 \times R_M = 0.91 \quad T_1 \simeq 0.042$$

Fully coherent (temporal and spatial) x-ray laser source!

Where are we now on upgrade planning?

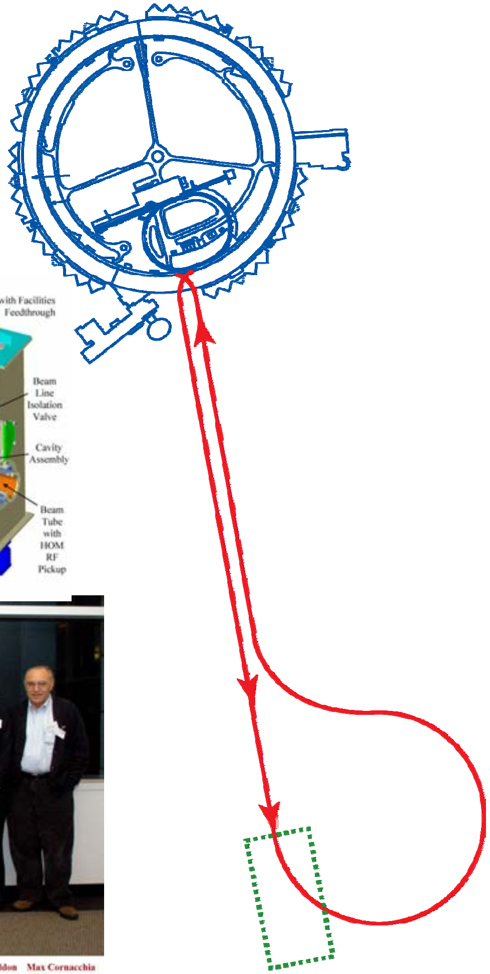
- Serious R&D is required for APS upgrade (esp. gun and RF)
- R&D proposal submitted to DOE strengthens international effort
  - Leveraged by ANL LDRD and accelerator institute
- During R&D phase there is time to consider all options
- Major workshop with users planned for October 20-21 2008
- Meanwhile, BESAC plans to evaluate user community needs which will drive DOE-BES plans
- Of equal priority to us is development of new and dedicated beamlines, instrumentation, detectors and software to expand imaging and ultrafast capabilities





Sam Krinsky (NSLS) Klaus Balewski (DESY) Annick Ropert (ESRF) Vic Suller (Chair) (CAMD) Georg Hoffstaetter (Cornell U.) Andrew Hutton (JLab) Elaine Seddon (Daresbury) Max Cornacchia (SLAC, retired)
Not pictured: John Galayda (SLAC)

Advanced Photon Source Machine Advisory Committee
Argonne National Laboratory
November 15-16, 2006



The big three

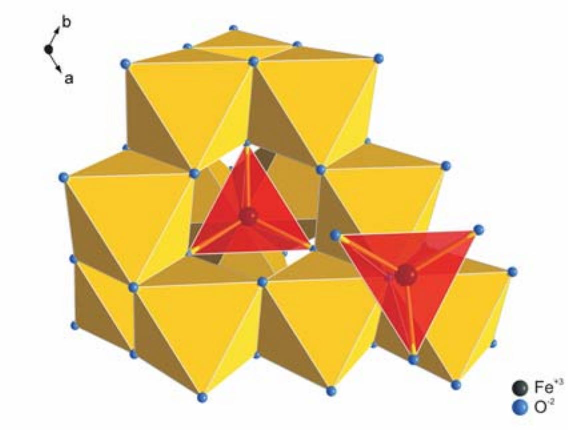
High energies chosen for x-ray brilliance and tunability based on insertion devices of the time – machines pioneered high heat-load optics, better insertion devices, top-up etc. which made “3- ½ generation” possible

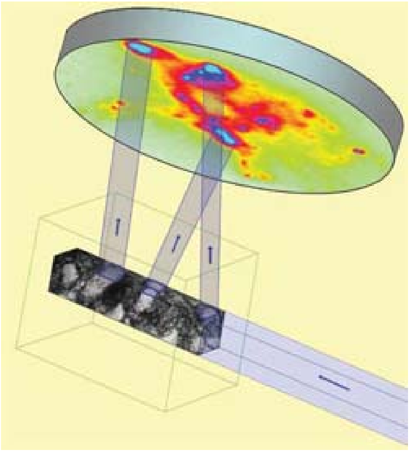
New ~3GeV "3 ½ generation" sources are flourishing

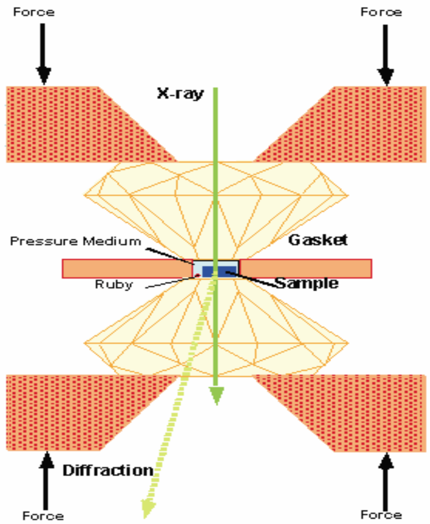
Existing or planned x-ray synchrotron light sources

I believe that the future for the big three is secure even with growing beamports at "3½ generation" sources nearby

- They will be uniquely suited for applications needing ~15keV or higher







ESRF, APS and Spring-8 planning major upgrades

The role played by NSF to date (seen from a large DOE facility)

- Support of research program for users
- Training of people – users and staff at large facilities
- Investment in instrumentation through the academic user community at DOE facilities – stimulating partnerships between the facility and "super" users, and improving capabilities for the general user
- Development of novel techniques at NSF facilities, later applied at DOE facilities
- Facility construction and operation for 1st and 2nd generation sources

NSF Facilities trained key APS employees

Dennis Mills
Scientific User Facilities
Deputy Associate Laboratory Director
X-ray Science

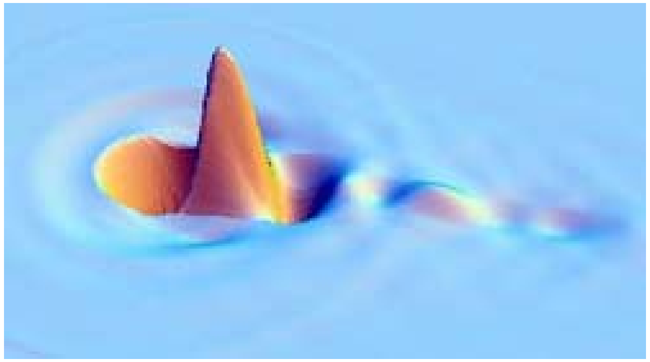
Glenn Decker
Accelerator Systems Division
Diagnostics
Group Leader

Qun Shen
X-ray Science Division
X-ray Microscopy and Imaging
Group Leader

Just a few of those from Cornell (and Wisconsin)

Lights, Camera, Electrons – an example of the role of NSF facilities

- Fastest movies ever made of electron motion
- Created by scattering x-rays off water at CMC-CAT (APS) and CHESS (initial results)
- Movies show electrons sloshing in water molecules
- Each frame lasts 4 attoseconds (quintillionths of a second)
- Results could let researchers "watch" chemical reactions even faster than those viewable with today's "ultrafast" pulsed lasers



courtesy of P. Abbamonte, Brookhaven National Lab, University of Illinois

Difficult experiment was developed at CHESS and then brought to APS

Imaging Density Disturbances in Water With a 41.3-attosecond Time Resolution
P. Abbamonte, K. D. Finkelstein, M. D. Collins, and S. M. Gruner
Phys. Rev. Lett. 92, 237401
(issue of 11 June 2004)

Abbamonte et al., Phys. Rev. Lett. **92**, 237401

The role of NSF facilities – developing new instruments

- IEX (SRC Wisconsin pioneered design)

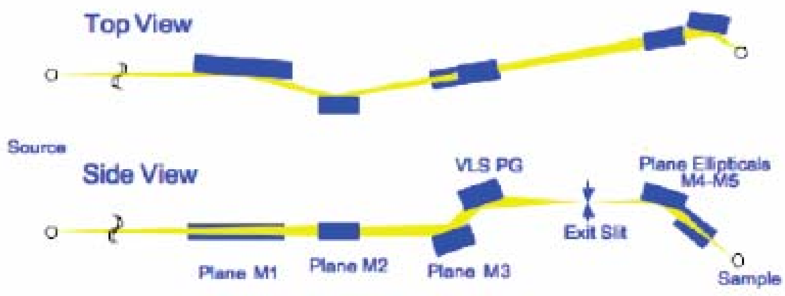
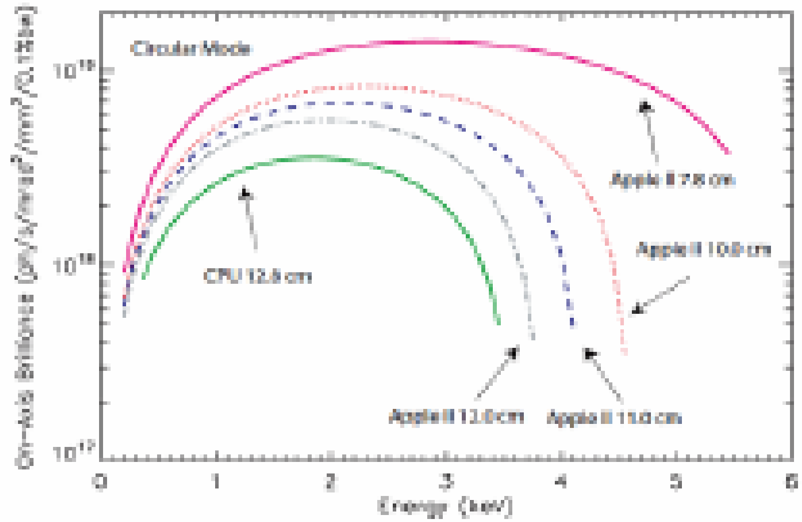
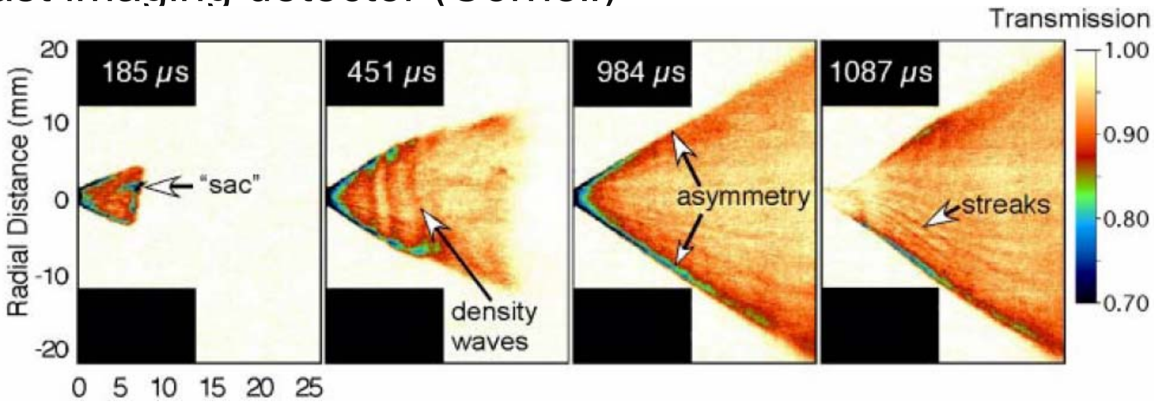


Figure 4.3: Cartoon of the proposed beamline



- Ultrafast imaging detector (Cornell)



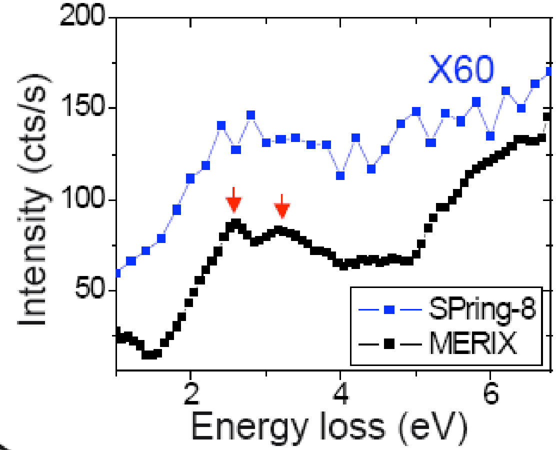
NSF Direct Investment in APS Beamlines and Users

- We estimate that ~ $50M of capital investment has been made by NSF in instrumentation (beamlines) at the Advanced Photon Source alone
  - Recent examples are ISX and IEX (just funded)
- Does not include operating funding to Collaborative Access Teams at the level of $2-3M per year, and most likely much larger research funding for academic users of the facility

New inelastic x-ray scattering beamline IXS (joint with DOE at Sector 30)

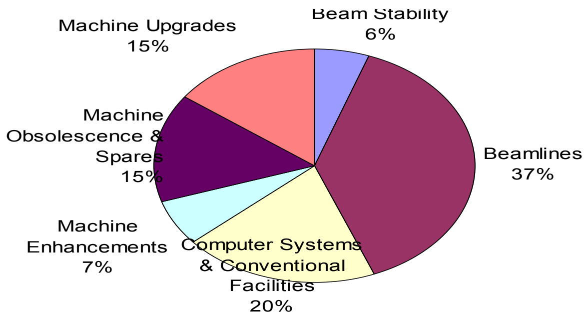
MERIX clearly resolved excitonic modes in a 1D cuprate chain for the first time Wray et al. (2007)

Comparison of MERIX and SPring-8 data with energy and polarization tuned for optimal enhancement of the 2 - 4 eV signal:

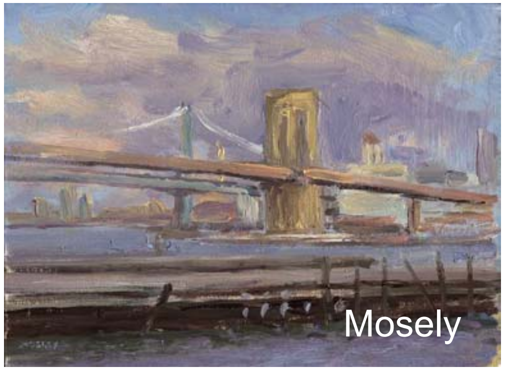


Short term challenge at APS – reduced operating hours driven by essential maintenance needs and inadequate budget

- Allocation of resources to accelerator and beamline improvements, repairs:

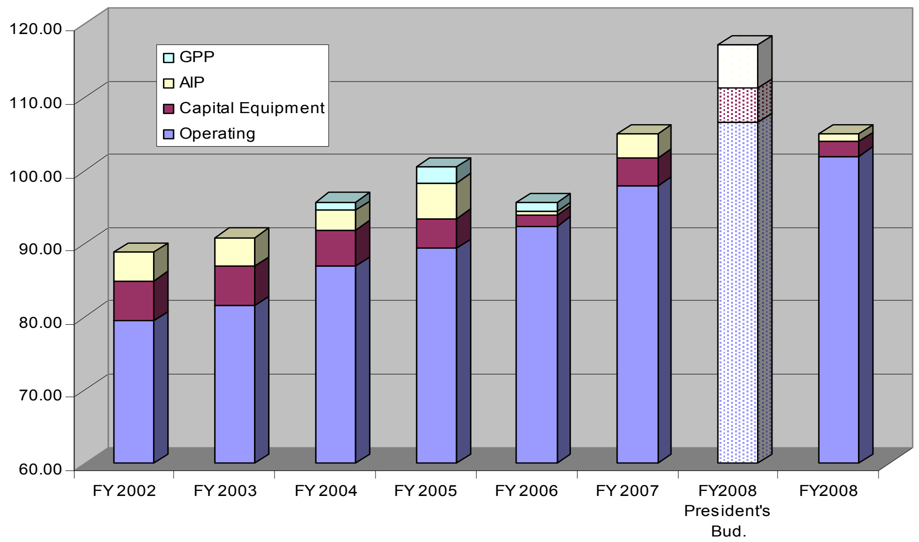


- Can no longer defer painting the bridge



For 2006,7,8 we have allocated only $12M capital and accelerator improvements (4% ops)!

DOE-BES APS Operating Budget



Strategy will be to make repairs with fewer staff and so reduce operating hours (to 4000 in FY09 -20%!)

Conclusions

- APS is a flourishing source which is currently the largest in the western hemisphere and growing
- Despite gloomy national budget picture, we have plans for the short-term, medium-term and long-term including a major upgrade
- The Energy-Recovery LINAC, developed by Cornell and also planned by KEK, seems the most promising upgrade path for APS
  - R&D is ongoing
  - Major user workshop planned for this fall
- NSF has played a key role in developing the synchrotron science community, and continues to directly benefit DOE sources
  - Especially education, technique and instrumentation development
  - We hope that they NSF will play an important role in future

Extras

A short history of partner users at APS

- When the APS was constructed only 4 sectors were operated by the facility
- Most sectors were constructed and operated by independent teams, Collaborative Access Teams (CATs)
  - The CATs brought
    - *Strong intellectual partnerships*

    - *Leveraged construction funding*

    - *Diverse ideas and approaches*
    - *Versatile multipurpose beamlines*
    - *Insecure operating funding*

The XOR (APS X-Ray Operations and Research) system

- Offers funding stability
- Dedicated beamlines
- Partnerships possible (for intellectual drivers)
- Involves change!

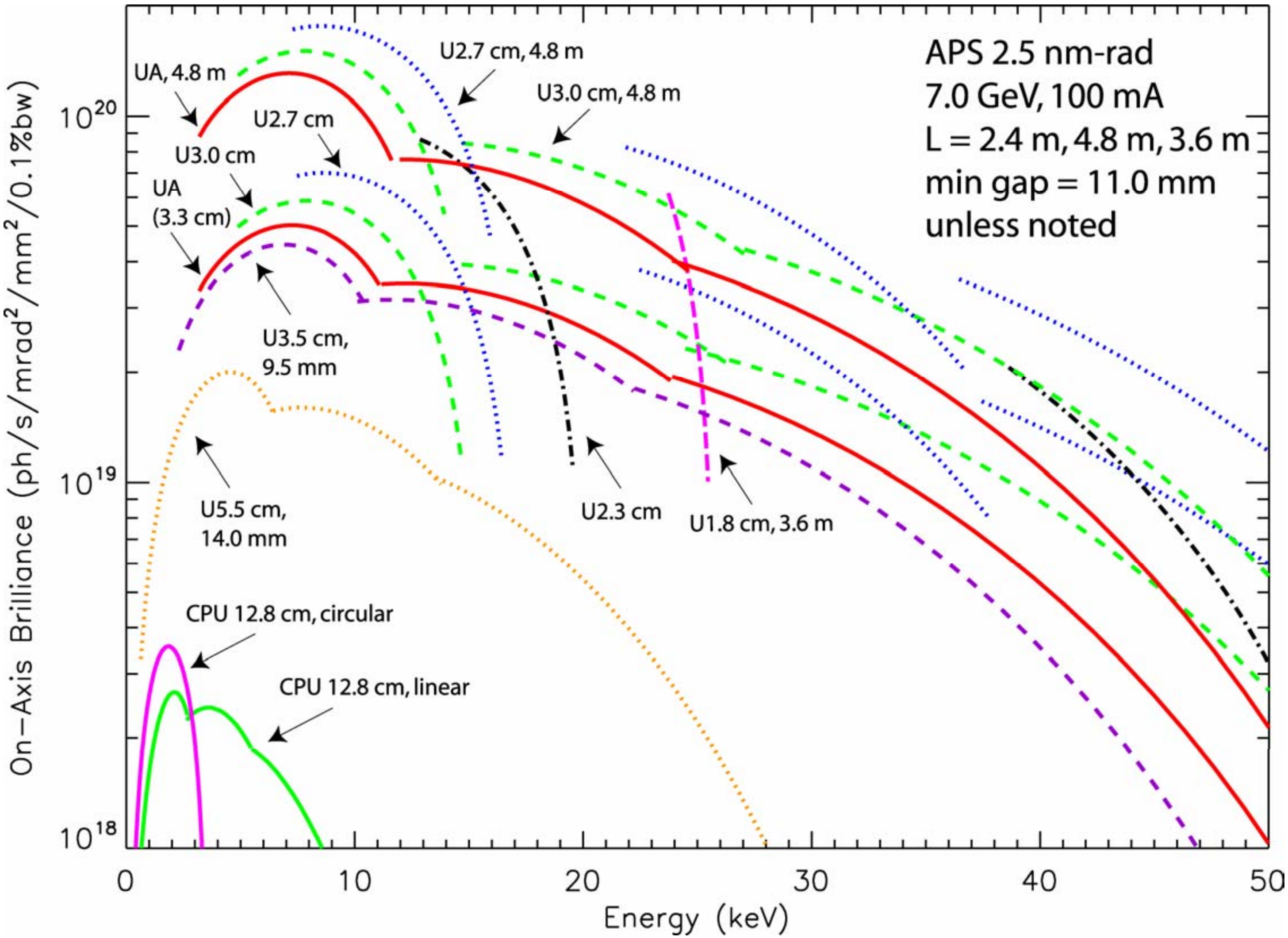
More beamtime available to general users (> 50%)

Today we have 31 sectors under construction or operating

- 17 are or will be operated by XOR
  - (of which 10 were former CATs, 3 are or were CDT's*)
- 9 Protein Crystallography (CATs)
- 5 operating physical sciences CATs

CDT – Collaborative Development Team = CAT - operation
is our preferred mode of beamline development and construction

On-axis brilliance tuning curves for existing undulators

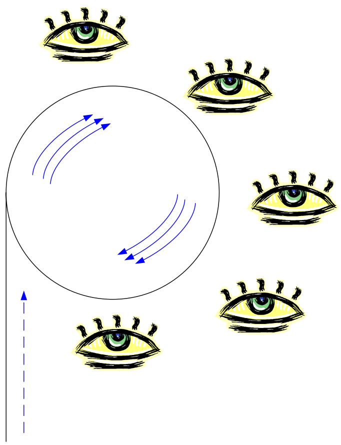


- Beam energy 7.0 GeV, beam current 100 mA, emittance 2.5 nm-rad, and coupling 1%.

What is the fourth generation revolution in x-ray sources?

$\tau_{lifetime} \gg \tau_{relaxation}$

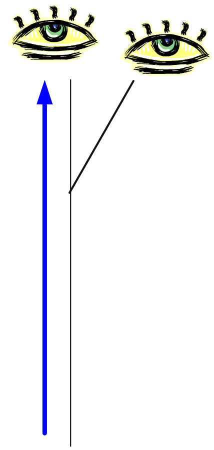
Storage ring



•Many users
•Ready tunability
•High flux
•Low brilliance
•Long pulses

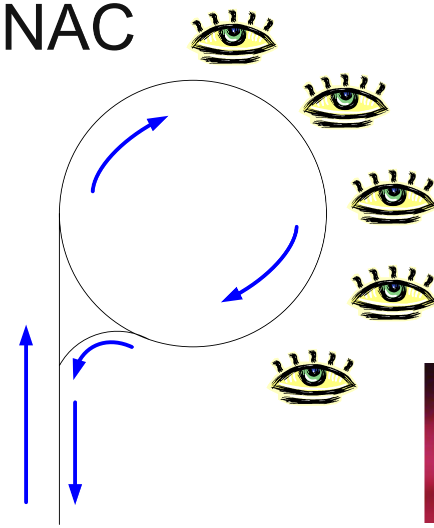
$\tau_{lifetime} \ll \tau_{relaxation}$

LINAC source (=> FEL)



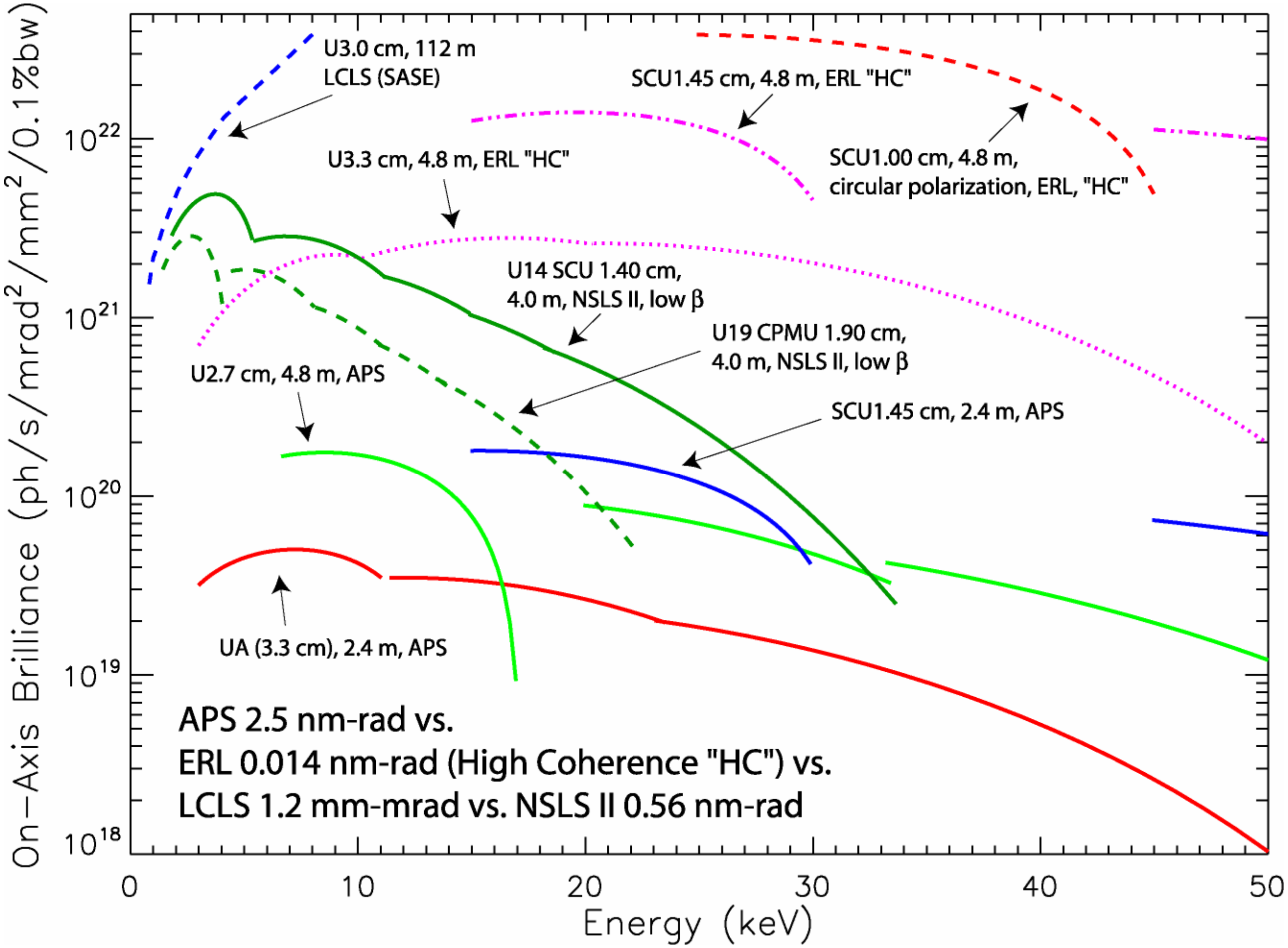
•Extremely high peak brilliance
•Full spatial coherence
•Ultrashort pulses
•Temporal coherence with seeding in future
•Relatively low pulse rep rate
•Fewer users

Energy-Recovery LINAC



•High average brilliance
•Full spatial coherence
•Many users
•Ready tunability
•High flux
•Short pulses but closely spaced and lower # of photons per pulse

On-axis Brilliance Tuning Curves for Current APS Lattice vs. ERL High-coherence Mode vs. LCLS vs. NSLS II



- Beam energy: 7.0 GeV (APS), 4.3 – 13.6 GeV (LCLS), 3.0 GeV (NSLS II)
- Beam current: 100 mA (APS), 25 mA (ERL High Coherence “HC”), 500 mA (NSLS II)