Argonne NATIONAL LABORATORY

… for a brighter future

U.S. Department of Energy

THE UNIVERSITY OF CHICAGO

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APS Upgrade Summary Workshop: Introduction to the Workshop, and Goals

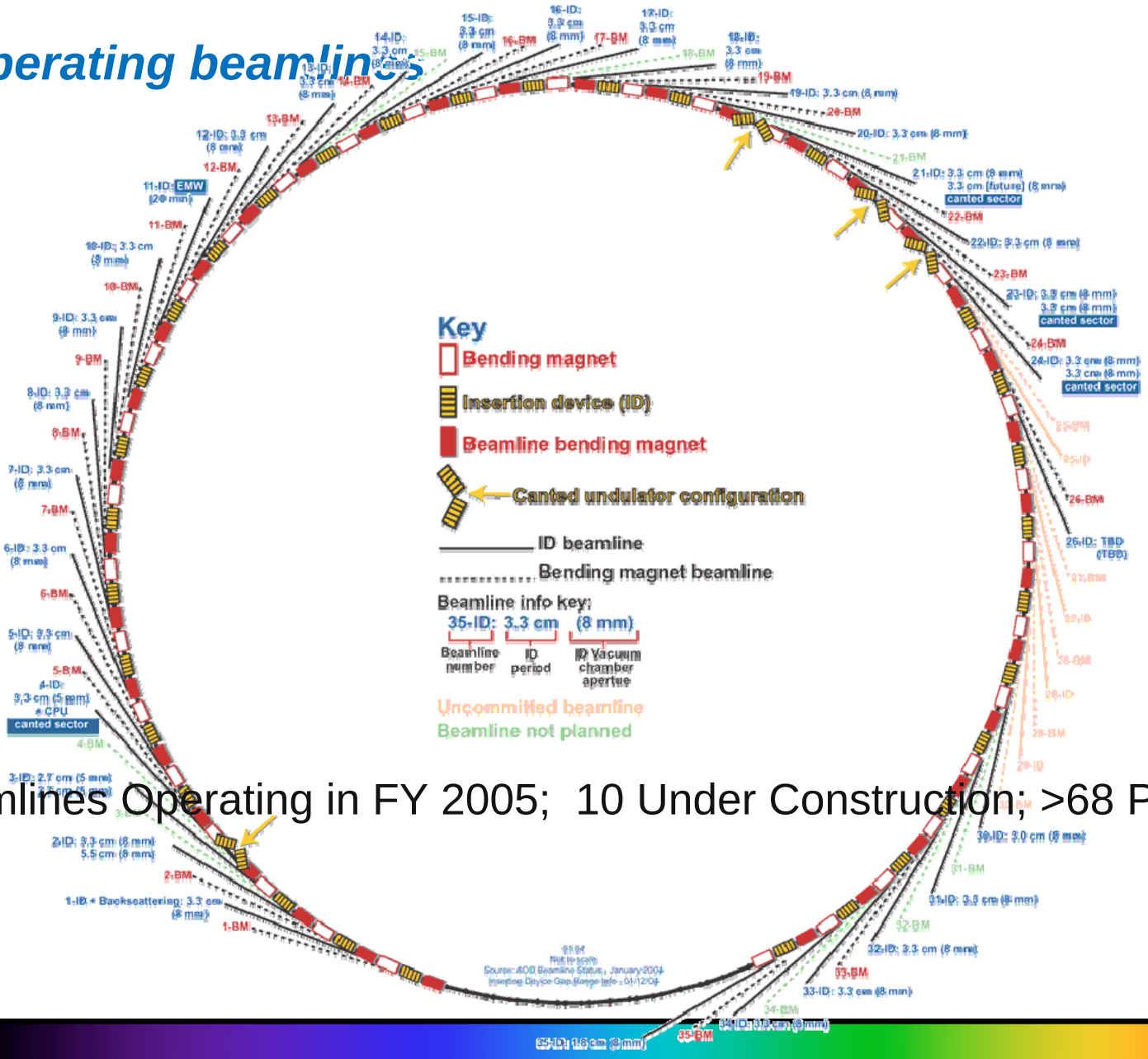
J. Murray Gibson

August 10th, 2006

Fortunately, we're not talking about this kind of upgrade…

The Advanced Photon Source Today

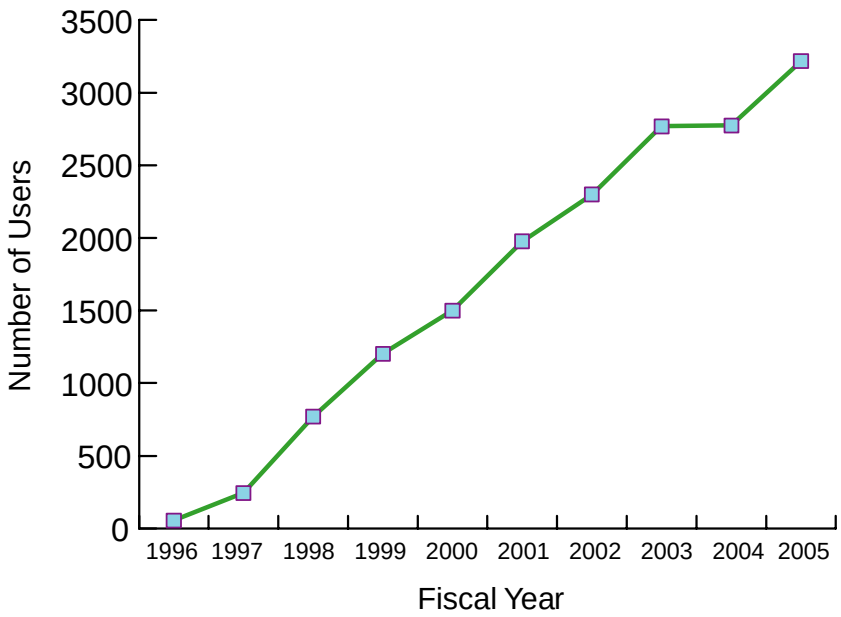
APS operating beamlines



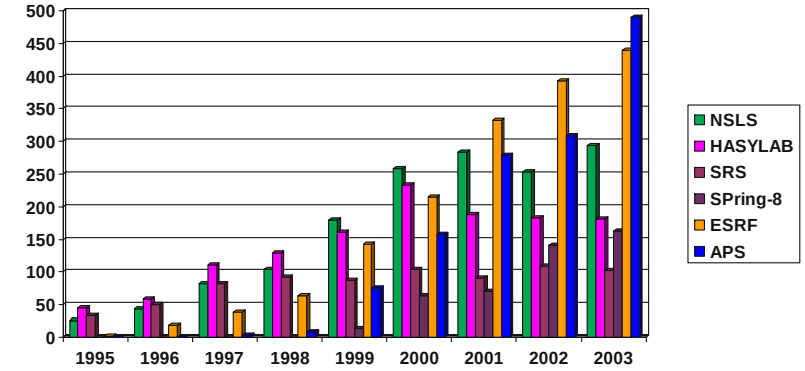
46 Beamlines Operating in FY 2005; 10 Under Construction; >68 Possible

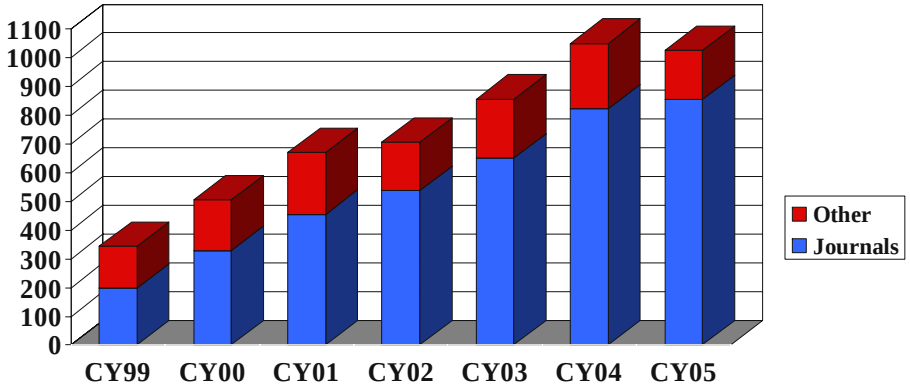
Growing APS user community and scientific impact

Number of unique APS users by fiscal year



APS protein structures in international databank





APS refereed publications by Calendar Year (CY)

So why are we thinking about an upgrade?

- APS has been operating over 10 years
  - Our instrumentation is getting old
  - And we need to optimize most of our beamlines and x-ray sources
  - Radically new 4th generation technology, and 3 ½ generation sources are being built around the world
- Brookhaven's NSLS was obsolete in the year 2000, after less than 20 years of operation
- Many of our users demand state-of-the-art capabilities
  - Some, understandably, want a workhorse

"Live only for today, and you ruin tomorrow", Charles Simmons

"The only limit to our realization of tomorrow will be our doubts of today"
Franklin D. Roosevelt

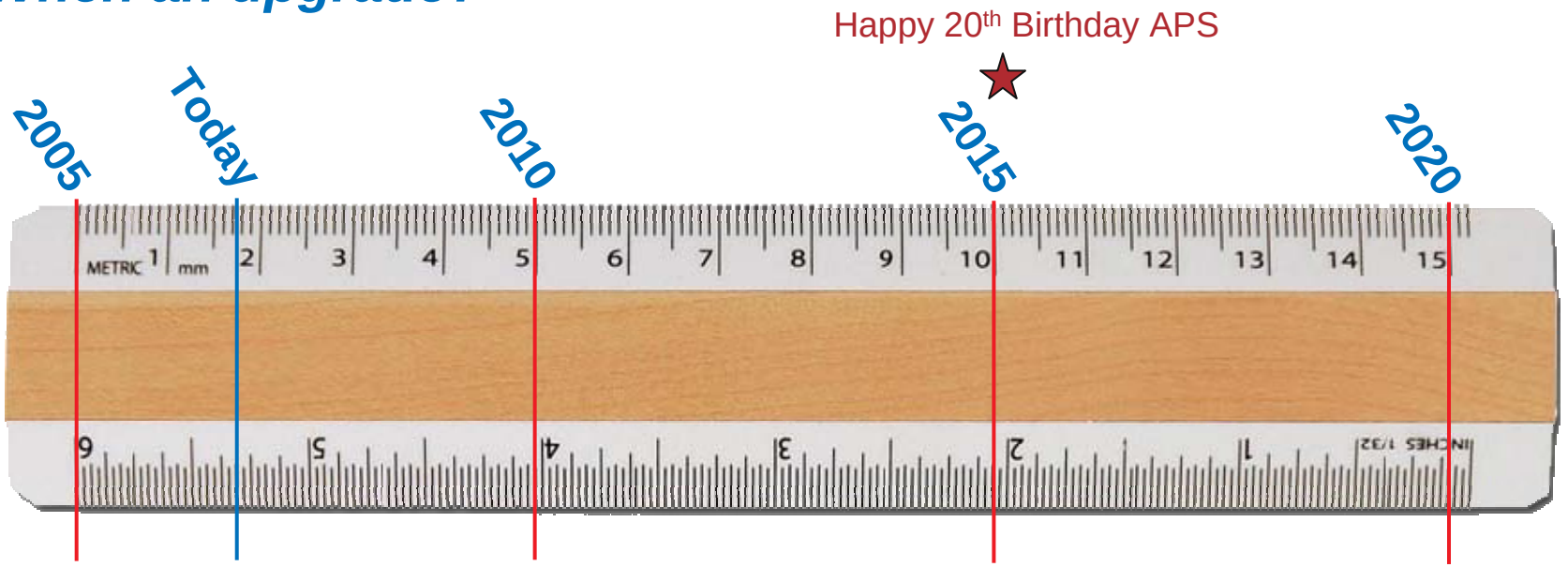
Revolutionary science demanding an upgraded APS

- Chemical excited states studies give insight into photosynthesis for efficient and cheaper solar energy
- Excited states of biomolecules are poorly understood yet critical for biochemical reactions
- Ultrafast dynamics of magnetic and ferroelectric domains for information storage and computing
- Detecting sub zeptogram (10^{-21}g) quantities of metals in cells and soils – health and environment
- In-situ study of nucleation in liquids – leading to better controlled chemical synthesis and catalysis
- Materials under extreme magnetic fields – routes to quantum computing
- …

How an upgrade?

- Our sponsors recognize the need to keep the nation's largest and most productive scientific user facility (APS!) at the state-of-the-art
  - They don't want to repeat the Brookhaven challenge and wait till end-of-life for the facility
  - But that brings a challenge – how do you upgrade a flourishing facility without major disruption?
    - *Any upgrade must deliver revolutionary capabilities, but in a way that minimizes risk or disruption to our users.*

When an upgrade?



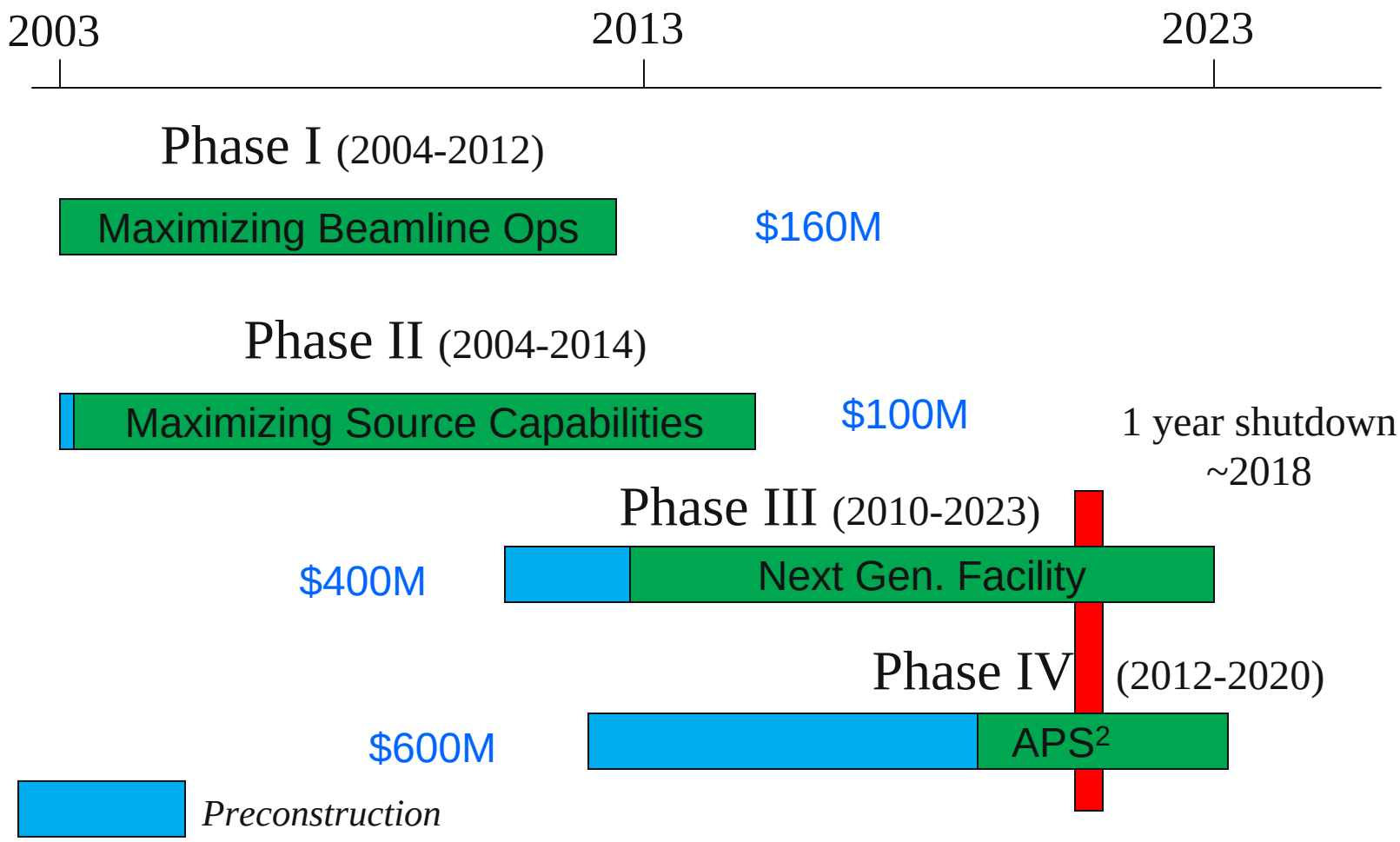
5-6 Year Construction Project

- For construction funding in FY09, need CD-1 in Summer 2008; CD-0 ("mission need") by Fall 2007
  - Scientific and technical proposals to be reviewed Summer 2007
    - *"white paper" on technical design to be submitted February 2007*

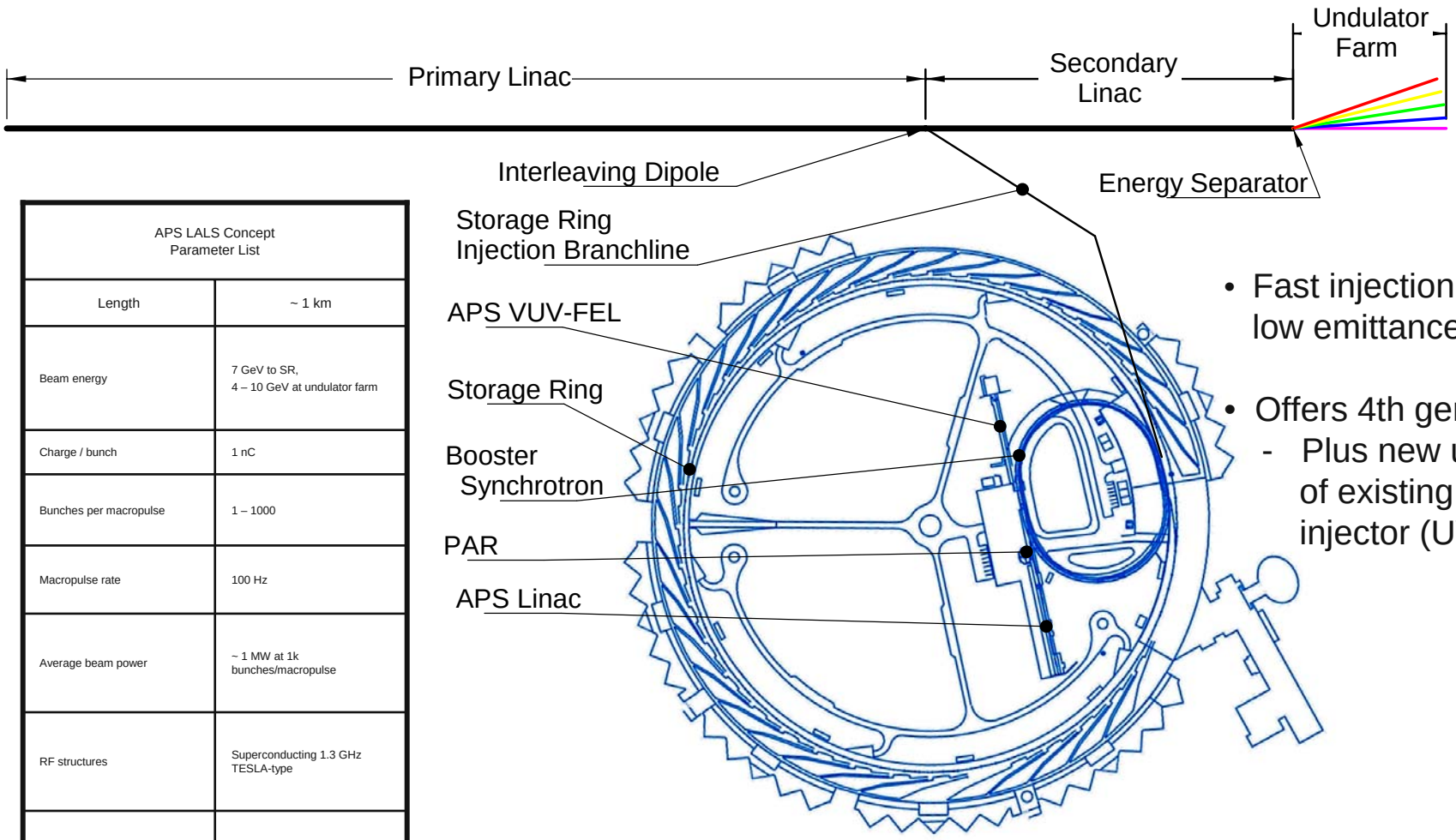
APS Future Planning from the Past….

- DOE-SC holds “20-year planning” for major new facilities
  - BESAC meeting February 2003
- APS began study on “Future Scientific Directions for the Advanced Photon Source”
  - A series of 11 workshops culminating in a strategic planning retreat September 2004
    - *Co-chaired by Sunil Sinha and Gopal Shenoy*
- As APS inherited increasing numbers of beamlines, XOR carried out strategic planning for future APS beamlines
    - *Strategic plan on web, developed in 2005, but a living document*
      - Keen to incorporate planning of independent CATs into our strategic plan

APS Twenty-Year Plan of 2003



PHASE IV – APS^2 – LINAC Augmented Light Source



APS LALS Concept Parameter List	
Length	~ 1 km
Beam energy	7 GeV to SR, 4 – 10 GeV at undulator farm
Charge / bunch	1 nC
Bunches per macropulse	1 – 1000
Macropulse rate	100 Hz
Average beam power	~ 1 MW at 1k bunches/macropulse
RF structures	Superconducting 1.3 GHz TESLA-type
Recirculation?	Possible; not required for low beam power operation

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

An early idea involving direct injection to bring 4th generation capabilities…

Courtesy of J. Lewellen, APS/ANL

APS^2 is on the DOE-SC Roadmap

U.S. Department of Energy

	Priority	Program	Facility
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
		NP	Rare Isotope Accelerator
	Tie for 7	BER	Characterization and Imaging
		NP	CEBAF Upgrade
		ASCR	ESnet Upgrade
		ASCR	NERSC Upgrade
		BES	Transmission Electron Achromatic Microscope
Mid-Term	12	HEP	BTeV
	13	HEP	Linear Collider
	Tie for 14	BER	Analysis and Modeling of Cellular Systems
		BES	SNS 2-4 MW Upgrade
		BES	SNS Second Target Station
		BER	Whole Proteome Analysis
	Tie for 18	NP/HEP	Double Beta Decay Underground Detector
		FES	Next-Step Spherical Torus
		NP	RHIC II
Far-Term	Tie for 21	BES	National Synchrotron Light Source Upgrade
		HEP	Super Neutrino Beam
	Tie for 23	BES	Advanced Light Source Upgrade
		BES	Advanced Photon Source Upgrade
		NP	eRHIC
		FES	Fusion Energy Contingency
		BES	HFIR Second Cold Source and Guide Hall
		FES	Integrated Beam Experiment

Facilities for the Future of Science available from http://www.science.doe.gov/Sub/Facilities_for_future/20-Year-Outlook-screen.pdf

Priority: Tie for 23
Advanced Photon Source (APS) Upgrade

The APS upgrade will greatly enhance the brilliance and power of the facility to enable scientists to study very small sample crystals—important for nanoscience research.

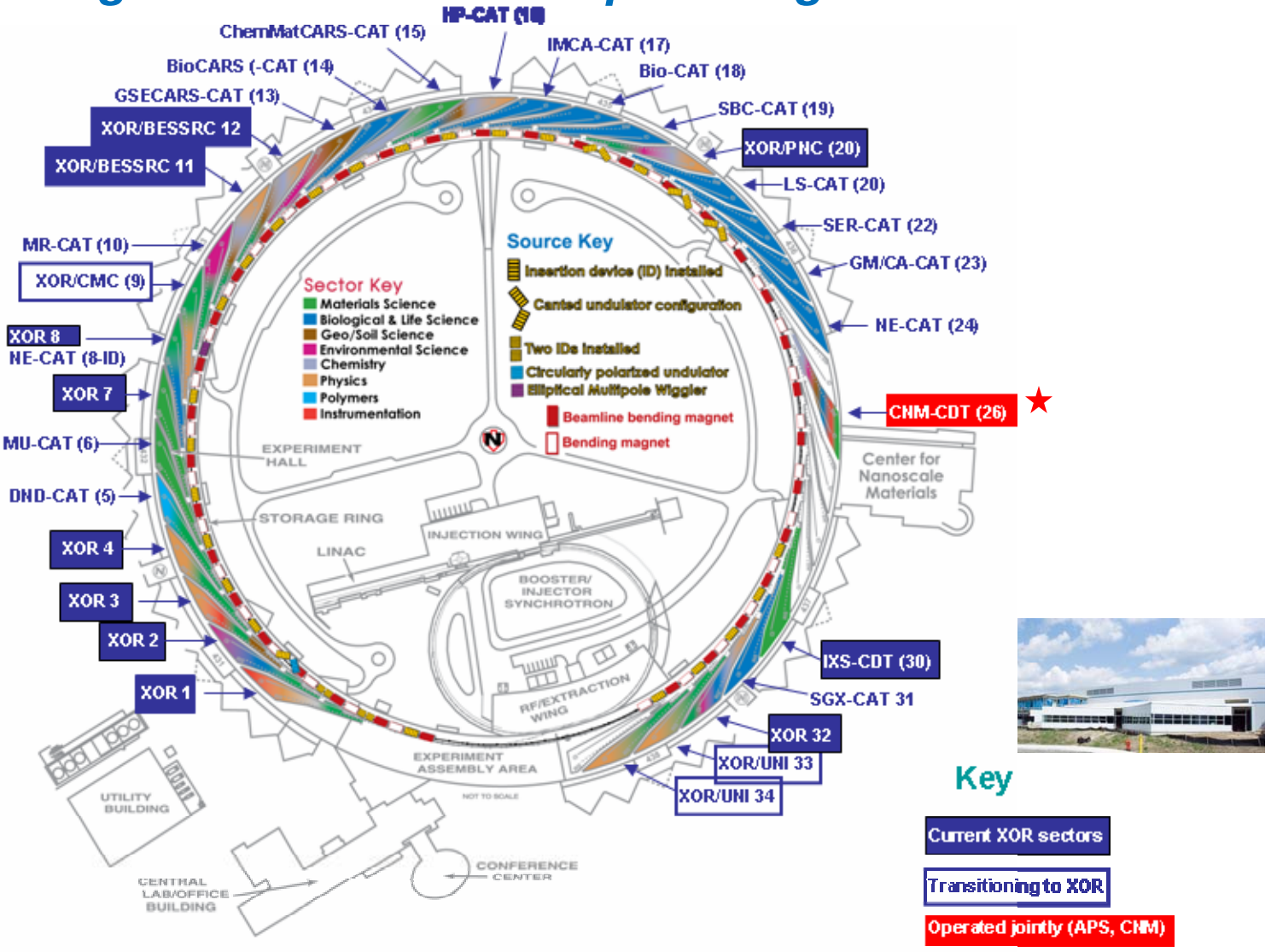
The Facility: The Advanced Photon Source (APS) upgrade will create a "super storage ring" of electrons that will greatly enhance the brilliance of the facility, increasing the power of the device and enabling scientists to work on very small sample crystals. Small samples are important: many current experiments are limited by the fact that the subject materials will not grow into large enough crystals for study.

Background: The APS at Argonne National Laboratory was commissioned in 1996. It currently provides the brightest x-ray beams available in the Western Hemisphere for a wide range of research from materials science to structural biology. The 1,104-meter circumference storage ring of the APS, which is large enough to house a baseball park in its center, produces, accelerates, and stores a beam of subatomic particles that is the source of the x-ray beams that feed numerous experimental stations. The APS will support more than 4000 users on 70 beamlines.

What's New: This eventual APS upgrade will replace and upgrade major components of the accelerator to further increase performance in the hard x-ray region of the spectrum, most notably x-ray photon correlation spectroscopy, coherent imaging, inelastic scattering, and x-ray nanoprobe microscopes. The upgrade will be necessary to keep the APS among the best of the hard x-ray facilities, and ensure that its performance and scientific output continue to be ground-breaking.

Applications: Using high-brilliance x-ray beams from the APS, members of the international synchrotron-radiation research community have achieved major advances in basic and applied research in the fields of materials science; biological science; physics; chemistry; environmental, geophysical, and planetary science; archeology; and innovative x-ray instrumentation.

APS operating more sectors and optimizing beamlines



Key

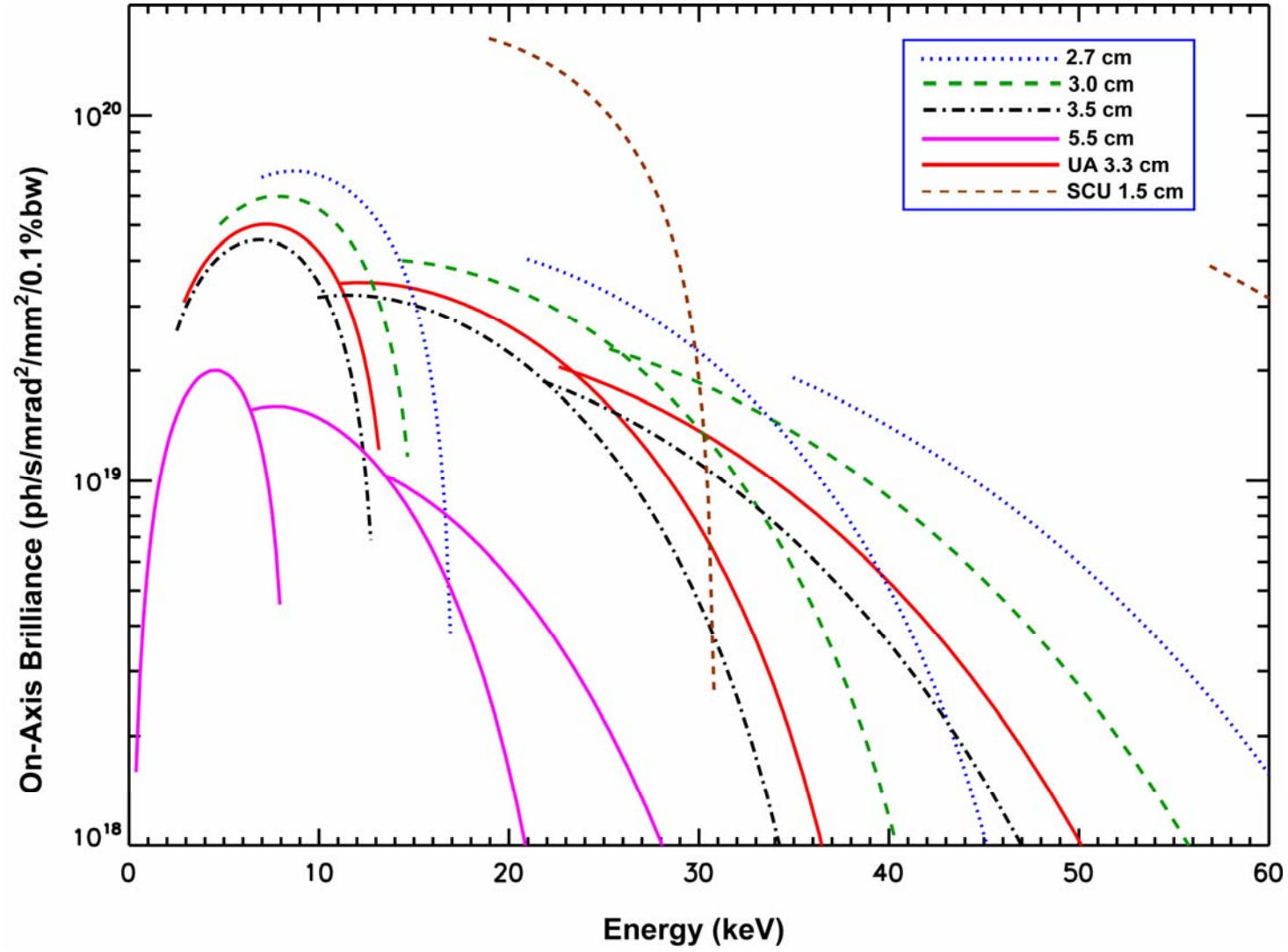
- Current XOR sectors
- Transitioning to XOR
- Operated jointly (APS, CNM)

Strategic plan for XOR optimized, dedicated beamlines

1-BM	Variable energy GISAXS, reflectivity, diffraction	MS, LS
1-ID	High-energy scattering, SAXS, powder diffraction, imaging	MS
2-BM	x-ray tomography	MS, LS
2-ID	2-32 keV STXM, microdiffraction, nanodiffraction	MS, LS, ES
3-ID	IXS, NRIXS	MS, LS, GS
4-ID-C	0.5 - 3 keV magnetic spectroscopy	MS
4-ID-D	2.6 - 45 keV magnetic spectroscopy	MS
7-BM	Ultra-fast imaging	Fluids
7-ID-B	Time-resolved white/pink beam imaging	MS, CS
7-ID-C	Time-resolved microbeam scattering	MS
7-ID-D	Laser pump/x-ray probe spectroscopy	CS, MS
8-ID-E	GISAXS	Thin films
8-ID-I	XPCS	Liquids, films
9-BM	XAFS	CS
9-ID-B	Liquid surface scattering	CS
9-ID-C	Resonant IXS	MS
11-BM	Powder diffraction	CS, MS
11-ID-B/C	High-energy powder diffraction, pdf, diffuse scattering	MS
11-ID-D	Laser pump/x-ray probe spectroscopy	CS
12-BM	XAFS, diffuse scattering, diffraction	CS, MS
12-ID-B	SAXS/WAXS	MS
12-ID-C	Time-dependant SAXS	MS, LS
12-ID-D	Surface/interface diffraction	MS
20-BM	XAFS, DAFS	ES, MS, CS
20-ID-B	Micro-XAFS	ES, MS, CS
20-ID-C	DAFS, XRR, surface-XAFS, laser pump-XAFS	ES, MS, CS
26-ID	Hard-x-ray nanoprobe	MS
30-ID	IXS, resonant IXS	MS
32-ID	Advanced full-field x-ray imaging	MS, LS
33-BM	Diffraction	MS
33-ID	Diffraction, surface/interface scattering	MS
34-ID-C	Coherent diffraction imaging	MS, LS
34-ID-E	3D-x-ray diffraction micro (and nano) scope	MS
New BM	Catalysis research (XAFS and WAXS)	CS
New ID	0.2 keV - 2.5 keV ARPES, resonant scattering, diffraction	MS
New ID	Hard-x-ray magnetic scattering (35 T magnet)	MS
New ID	ps-pulse science	CS
New ID	BioNanoprobe	LS

more on our web site www.aps.anl.gov

Tailored x-rays for optimized beamlines



APS Announcement of Competition for new IDs

- Letters of intent ("white papers") for new insertion devices from sectors will be evaluated by our SAC in Spring of 2007, with a priority list to be announced in May of 2007.
  - DEADLINE FOR SUBMISSION December 1st 2006
  - Must explain role in the APS strategic plan
  - Must identify source of funds for related beamline upgrades
    - *APS expects to support the cost of IDs and front ends for all sectors outside the life sciences (NIH)*
      - Can support development costs, cost sharing for exciting developments in life sciences
  - We could support installation of additional new IDs by Fall of 2007
    - *In any case, all decisions will be based on evaluation of scientific impact for APS as a whole, recommended by our SAC*

Exciting recent developments – the future is in sight..

- In June, DOE encouraged us to prepare a proposal for a major upgrade to APS
  - Initially we were focusing on a lattice upgrade, with a constrained budget
  - Proposal was to have been submitted in October, 2006
  - We held a series of planning meetings this summer to examine opportunities in several scientific areas (thanks to all the participants, and George Srajer for shepherding the process)
    - *Primary focus on overall facility upgrades, including beamlines and storage ring; some, but little discussion of alternates such as ERLs*
- Last week DOE supported and encouraged us in looking more broadly at options, specifically including the possibility of an Energy-Recovery LINAC (ERL):
  - Mantra: *Seek revolutionary enhancements while minimizing the disruption to existing users*

What does our past future planning tell us…

- We know where many of the exciting science opportunities are
- We are in need of new beamlines, optics, detectors
  - And tailored x-ray sources for each sector
- We have evaluated many novel machine upgrades for APS and are ready to narrow to more serious options
- Our 20-year plan recognized that a direct LINAC injector offered an exciting 4th generation upgrade path for APS with possibility of minimized disruption

ROBUST PLANS, NEED TO BE
FURTHER EXAMINED IN NEW CONTEXT

Summer Planning Meetings (most will be summarized here)

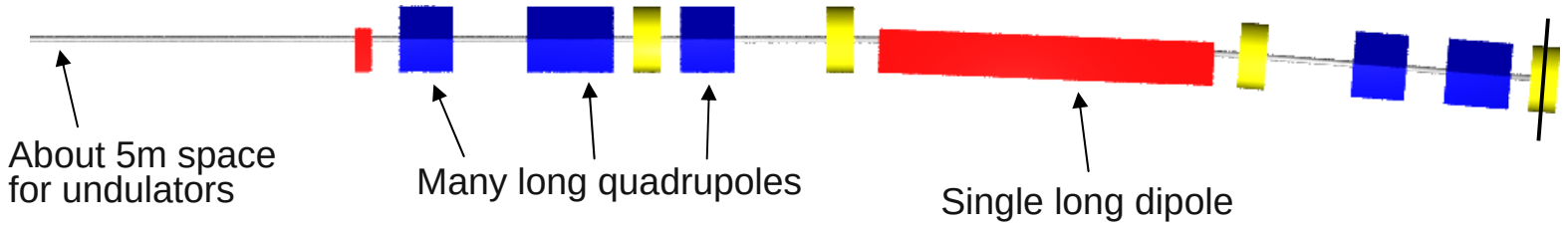
- Ultrafast SAXS
- Split-gap high-field Magnets
- Intermediate energy
- Coherence/imaging
- Interfacial and surface science
- Novel science with polarized x-rays
- Picosecond science
- New structural science emerging from improved high-energy x-ray sources
- Biology and life sciences
- Microscopy
- Sub-meV resolution
- Detectors
- New applied materials research from improved high-energy x-ray sources
- Scientific software (future)

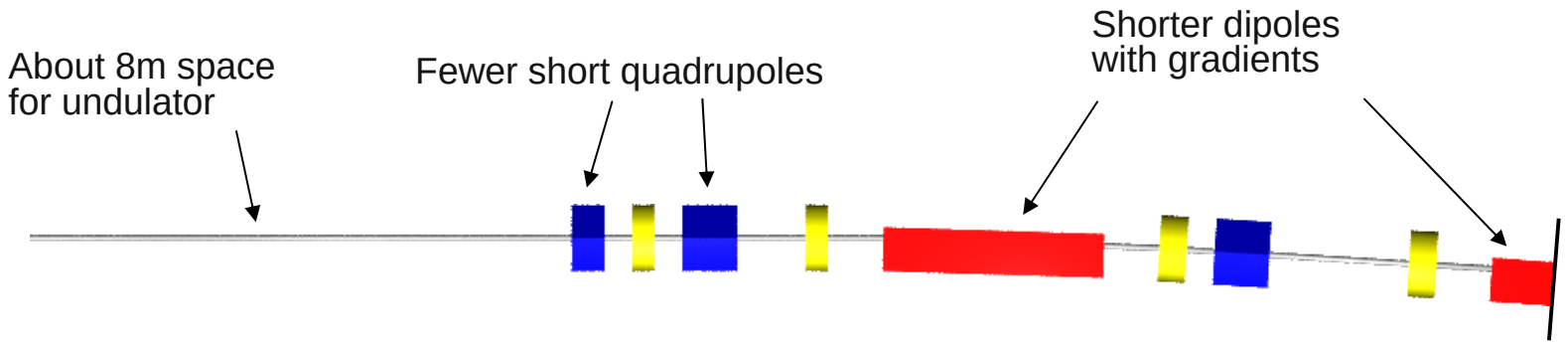
State-of-the-art 3rd Generation Sources

- APS has emittance of 3nm
- New 3 ½ generation sources have emittance in same range, but some (in design) approach 1nm (NSLS-II)
- Lower emittance benefits brilliance and microfocussing, but a factor of three alone is not a revolutionary improvement
  - but could be tied in to longer straight sections, new lower-k insertion devices to give 10-100 x performance
  - further gains from coupled detector, software and optics developments

- Other comparable sources are proposing major upgrades – SPring-8 is building an FEL; ESRF plans many new beamlines focusing on imaging, nanoscience and time-resolved science. ESRF has considered, but does not plan a lattice upgrade.

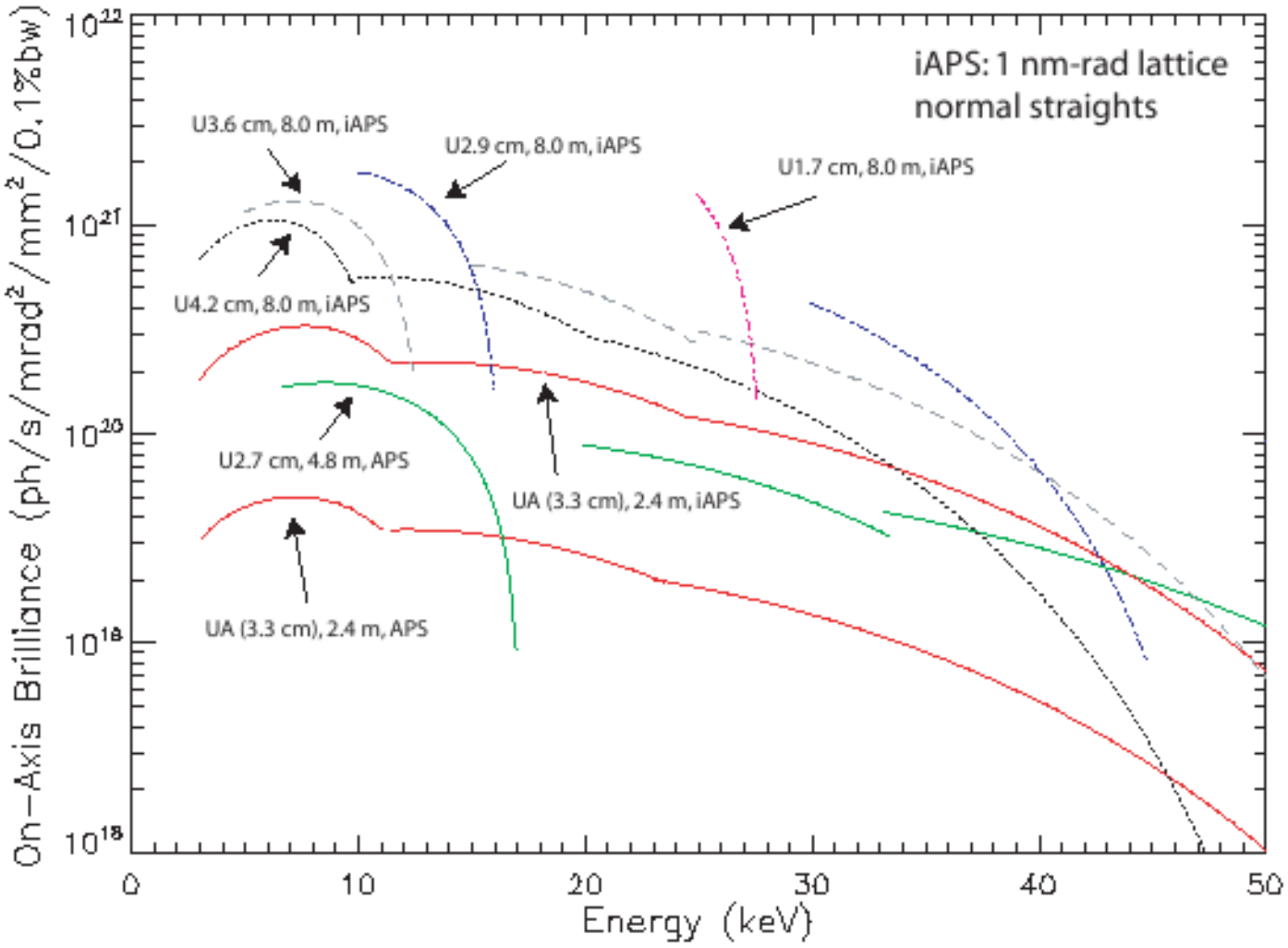
Our first serious option to be considered – a 1nm lattice upgrade





Graphics courtesy L. Emery.

Spectral Brightness Predictions from a 1nm New Storage Ring Lattice



Assumes 200mA beam current and 1% coupling.

Care taken to ensure power and power density are within reasonable limits.

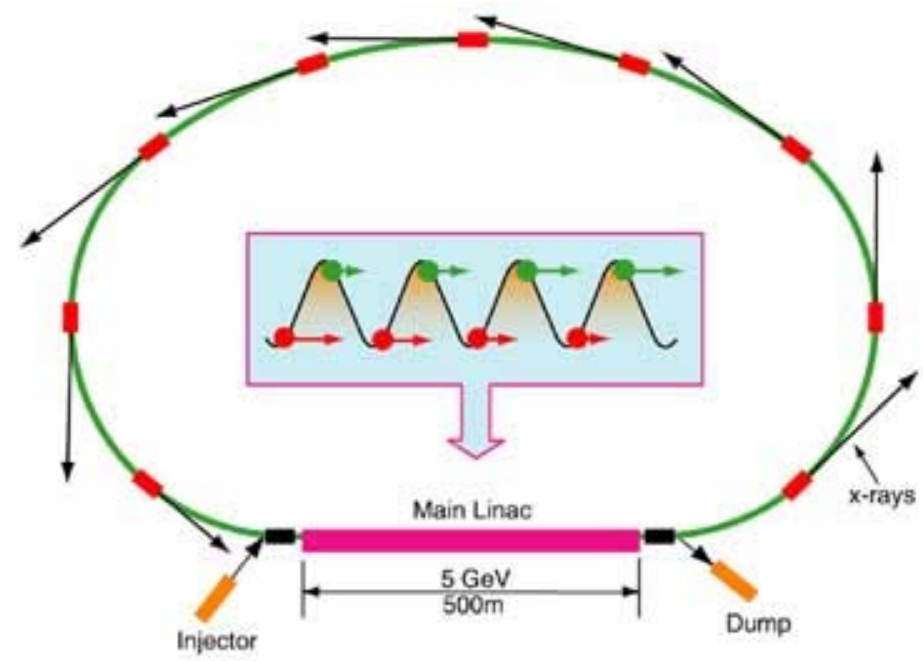
R. Dejus

Issues with lattice upgrade

- Can deliver revolutionary enhancements only through coupled developments of lattice, insertion devices and beamlines
- Involves ~1 year shutdown, but could consider alternate less disruptive approaches to reducing emittance, such as damping wigglers (NSLS-II approach)
- But does not offer 4th generation level capabilities
  - Much shorter intense pulses with high average brilliance
  - High coherence and small beams
- For that, the most promising approach appears to be an Energy-Recovery LINAC…

Energy Recovery LINACs

- Offer very short and coherent pulses
- With time-averaged brilliance like
  3rd generation sources
- Upgrade path could be minimally disruptive

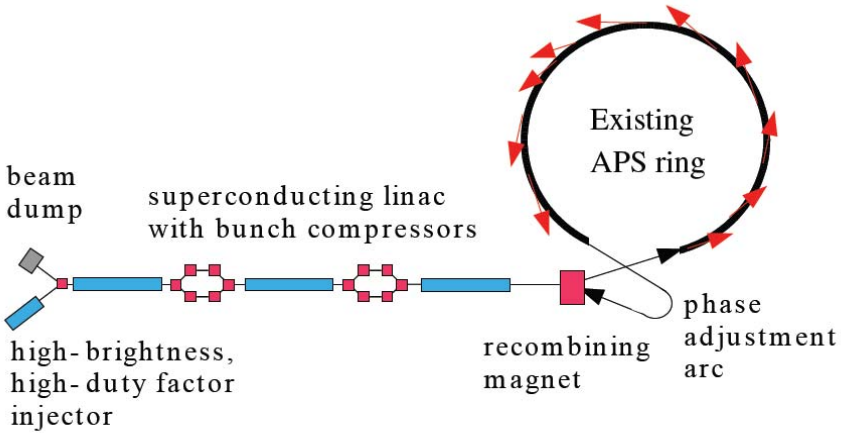


Cornell Design for ERL

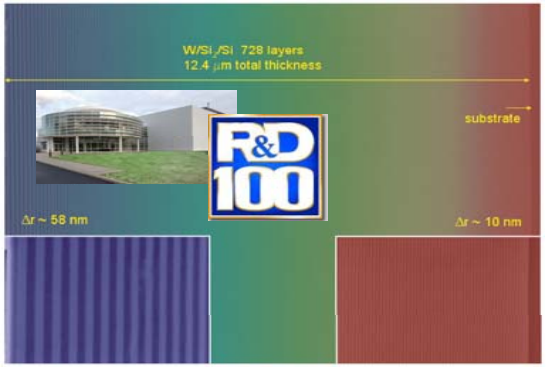
Advantages to Energy Recovery LINAC

- Similar time-averaged brilliance/flux to storage ring
- Ultra-low emittance of ~0.010nm (Cornell design at 5GeV) c.f. 1nm of best storage rings
  - With a round, small beam (100% coupling)
  - Emittance is close to diffraction limit at 1 Angstrom
    - *beam has very high coherence ideal for imaging, nano-focussing*
- Individual pulses are very short (<1ps)
    - *well suited for ultrafast science*
- In principle, this is both a revolutionary and minimally disruptive path
  - Primary changes to injector
  - Could continue to operate in a storage ring mode
- Challenges:
  - Gun R&D needed to reach “storage ring” average current
  - Short pulses are very closely spaced in time at high average current
  - Issues with preserving emittance in one turn around ring, and energy recovery
  - Stability questions

Scientific Strategy – New Directions which relate to the advantages of an ERL



- Imaging, nanofocussing and ultra-fast science were high on our strategic plans
- All would benefit radically from an ERL



- Recognize that many other limitations: detectors, optics, endstations, IDs will be required to take full advantage of upgrade (even for APS today!)

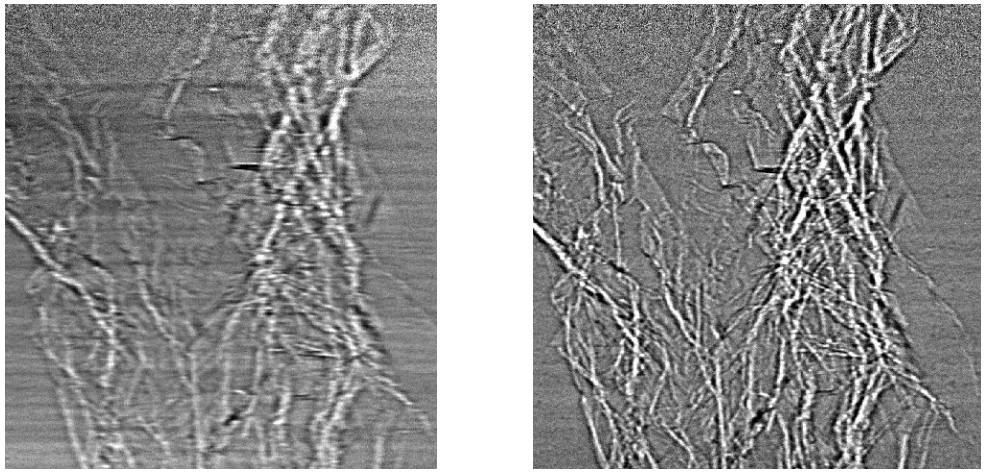
Steps toward an upgraded APS:

Making a smaller x-ray source at Sector 32 – improved imaging

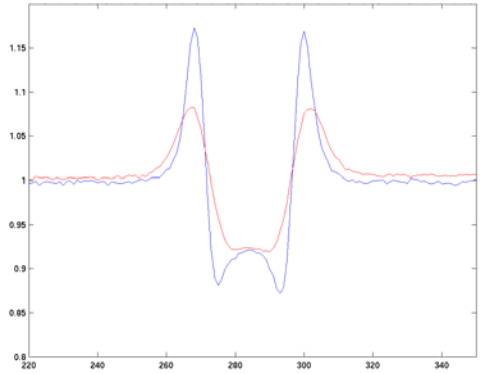
APS has unique flexibility to control beta functions by sector

Normal beta $FWHM_x$ = 560 μm Reduced beta $FWHM_x$ = 280 μm

200 μm ⟷

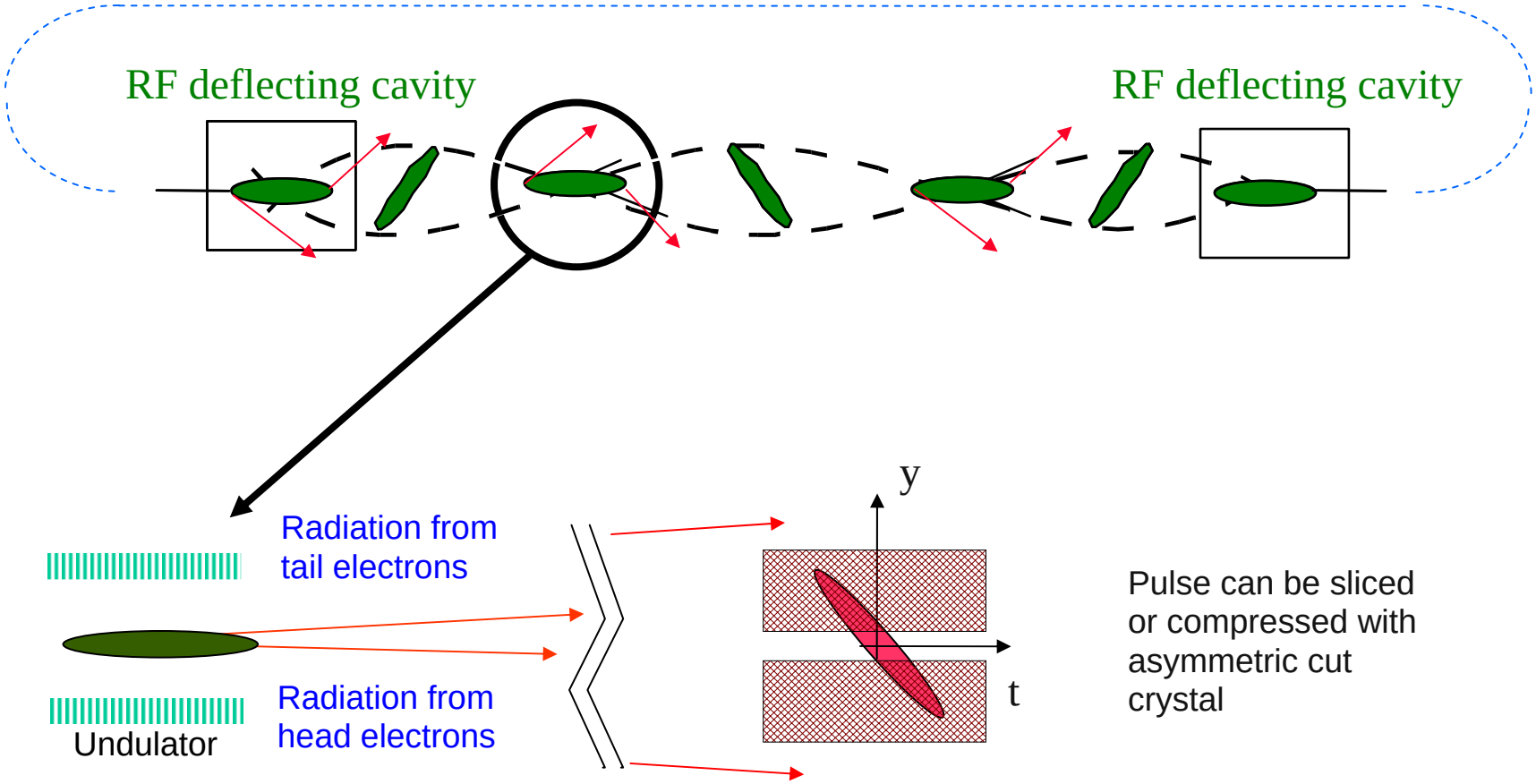


Aluminum stress crack sample, ~3mm thick



Effect of reduced beta function (blue line) on fresnel fringes around a carbon fiber

Zholents' Transverse Rf Chirp Concept – ps pulses from APS



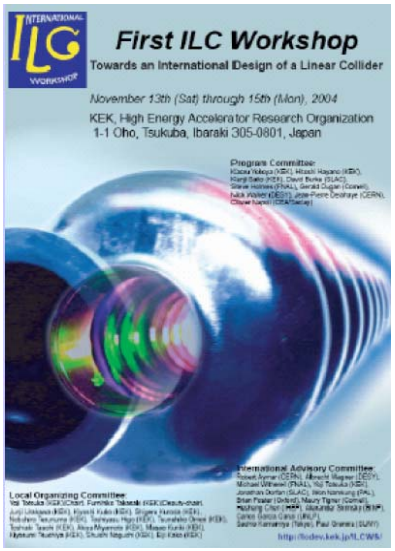
Pulse can be sliced or compressed with asymmetric cut crystal

~1ps FWHM possible for existing APS
(K. Harkay *et al*., PAC 05, p. 668.)

(Adapted from A. Zholents' August 30, 2004 presentation at APS Strategic Planning Meeting.)

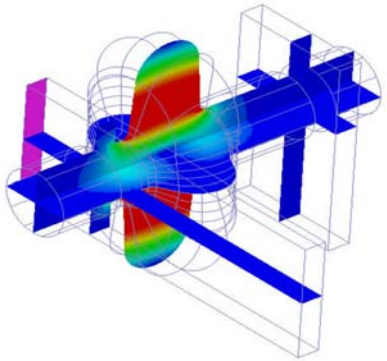
Accelerator and Detector Initiative at Argonne

- Accelerator technology is critical to the current and future facilities at Argonne: APS, IPNS, ATLAS, RIA…
- Benefits major upgrade of the APS
- Argonne and Fermi will team to secure the International Linear Collider project in Illinois
- Argonne has set up an Accelerator Institute to fertilize accelerator research with external partners
- This includes a component on **detectors**, critically important in most of Argonne's facilities



In the nearer future…

- We expect a $10M dollar increase in operating budget this year, and hope for further increases in FY'08
  - Helps us in beamline staffing and upgrades
- We have a plan for ps pulse production which we plan to implement on one sector within the next two years
- We will aggressively seek, with partners, to leverage funds for new beamlines, detectors, etc. before the upgrade



Goals for this workshop

- Have changed a little due to further DOE guidance

- Wish to collect input from summer workshops on revolutionary science
  - Recognize this was prepared with focus on upgraded storage ring, but also solicit input on ERL option and other ideas
  - Many beamline related improvements will be pursued under either model, but ERL emphasis will be on imaging, focusing and ultra-fast science

- Wish to get user feedback on the directions to go in preparing detailed options
  - *The playing field for upgrade options is leveled*

- Seek support and guidance for our next steps

Next Steps

- Prepare a menu of options for revolutionary machine upgrades based on this workshop's discussion
  - Develop a few of these as a "menu" of choices
- Convene international Machine Advisory Committee to advise on best option (aim for meeting late this calendar year):
  - Revolutionary *technical* performance, feasibility, and minimal disruption
- Obtain initial scientific input on technical choice from scientific advisory committee in January
- Submit white paper to DOE in February
- Hold further scientific workshops in the spring, with a summary meeting (retreat or user's meeting?) in early summer, aiming to submit scientific proposal in Summer '07

Agenda – August 10 (a.m.)

8:30	Welcome	Don Joyce
8:40	Introduction to the Workshop and Goals	Murray Gibson

Facility Upgrade Plans:

9:10	Possible Accelerator Upgrades	Michael Borland
9:35	Insertion Device Possibilities	Liz Moog
10:00	Beamlines, Detectors, Optics, Software	Gabrielle Long
10:30	*Break*	
10:45	Discussion of Proposed Facility Upgrades	

Science Planning Meeting Summaries:

11:15	Science Opportunities and Requirements with Ultrafast SAXS	Pappannan Thiyagarajan
11:35	Scientific Opportunities with Synchrotron Radiation and High-Field Magnets	Jonathan Lang
12:00	*Lunch*	

Agenda – August 10 (p.m.)

Science Planning Meeting Summaries (continued):

1:30	Science with Intermediate-Energy X-rays	Juan Carlos Campuzano
1:50	New Opportunities in Interfacial and Surface Science at the APS	Paul Zschack
2:10	Novel Science with Polarized X-rays	John Freeland
2:30	*Break*	
3:00	APS Upgrade: Optimal Beam Properties for Macromolecular Crystallography and Other Biological Applications	Andrzej Joachimiak
3:20	Opportunities for X-ray Microscopy with the APS Upgrade	Stefan Vogt
3:40	Scientific Opportunities with Improved Coherence and Imaging Capabilities at the APS	Qun Shen
4:00	Discussion	
5:15	PUC Meeting (A5000)	

Agenda – August 11

8:30	Short Pulses--Accelerator and Optics Perspective	George Srajer

Science Planning Meeting Summaries (continued):

9:00	Picosecond X-ray Science	Linda Young
9:20	Future Prospects for sub-meV Spectroscopy	Harald Sinn
9:40	High-Energy X-ray Enhancement Possibilities from an APS Upgrade	Dean Haeffner
10:15	*Break*	
10:30	Discussion	
11:45	Closing Remarks	Murray Gibson

Conclusion

- APS has a brighter future!
  - Conditions for our upgrade:
    - *Revolutionary new science*
    - *Minimize disruption to existing users*

- Seeking guidance and moving towards consensus on the best option(s)

- Thanks for coming!