Introduction to Synchrotron Radiation and Storage Ring Light Sources.

Monday 22 Nov 2010 at 12:15 (00h55')

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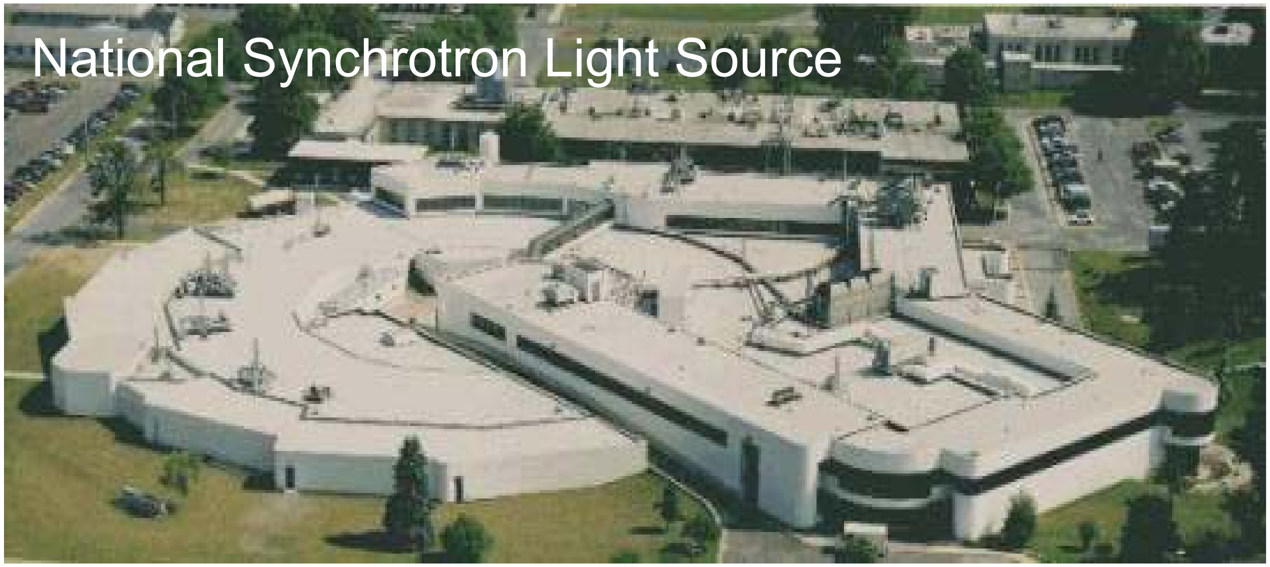
Co-authors :

Presenter : Dr. PODOBEDOV, Boris (BNL)

II Mexican Workshop on Accelerator Physics



NSLS Machines Introduction

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November 24, 2010

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Outline

- Introduction to NSLS
- Accelerator Operations
- Recent Developments & Improvements
- Accelerator R&D
- NSLS-II
- Concluding Remarks

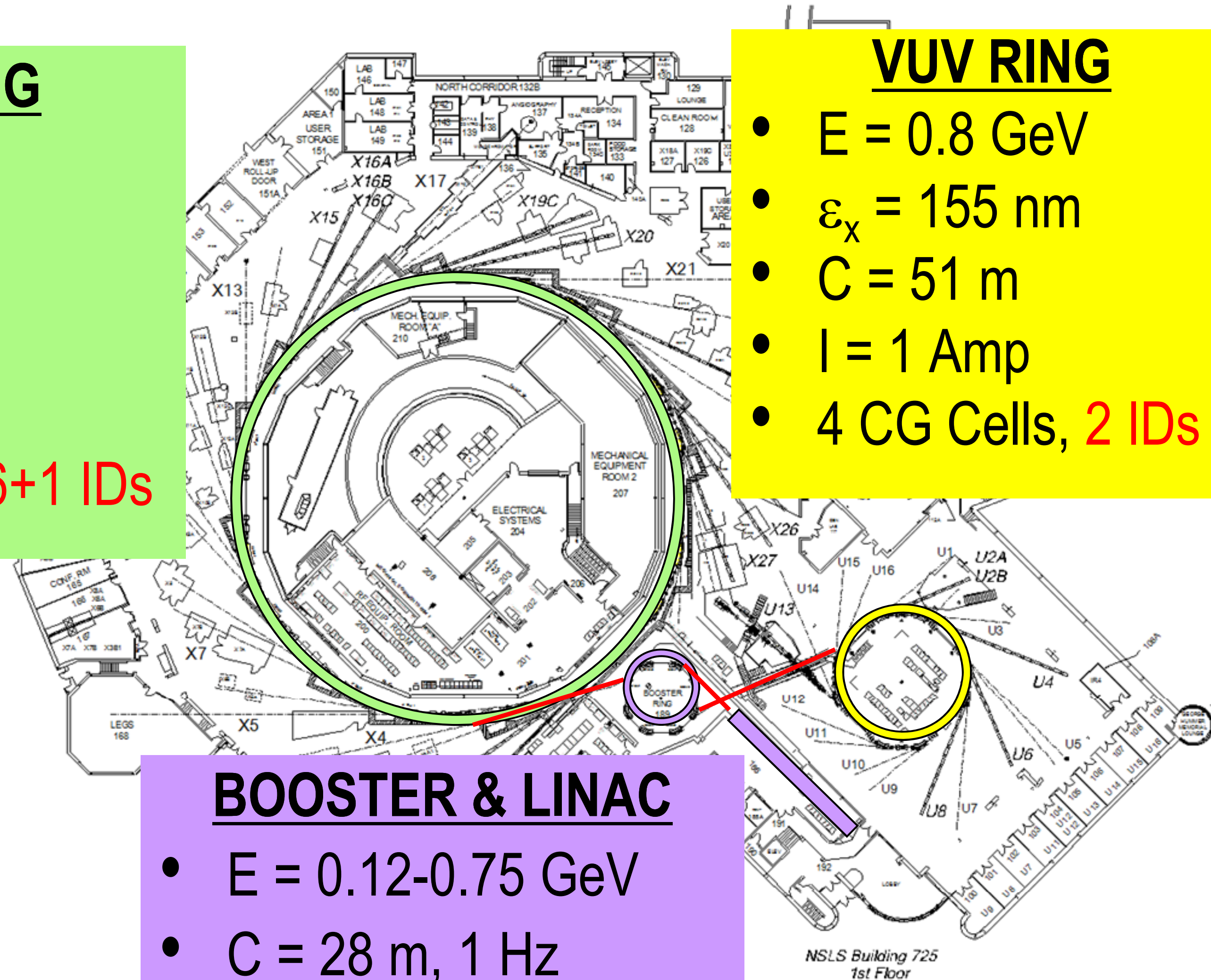
NSLS Accelerator Complex Today

XRAY RING

- E = 2.8 GeV
- ε_x = 65 nm
- C = 170 m
- I = 0.3 Amp
- 8 CG Cells, 6+1 IDs

VUV RING

- E = 0.8 GeV
- ε_x = 155 nm
- C = 51 m
- I = 1 Amp
- 4 CG Cells, 2 IDs



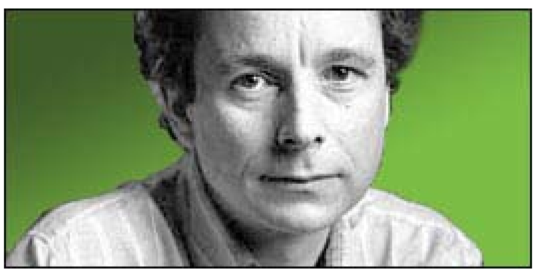
BOOSTER & LINAC

- E = 0.12-0.75 GeV
- C = 28 m, 1 Hz
- I = 0.03 Amp

Nobel Prizes at NSLS

2009 Steitz, Ramakrishnan

2009 Nobel Prize in Chemistry
Venkatraman Ramakrishnan, of the Medical Research Council Laboratory of Molecular Biology in Cambridge, UK, a former employee in Brookhaven's biology department, and a long-time user of Brookhaven's National Synchrotron Light Source (NSLS), and Thomas A. Steitz of Yale University, also a long-time NSLS user, shared the prize with Ada E. Yonath of the Weizmann Institute of Science for studying the structure and function of the ribosome. More



2003 Roderick MacKinnon

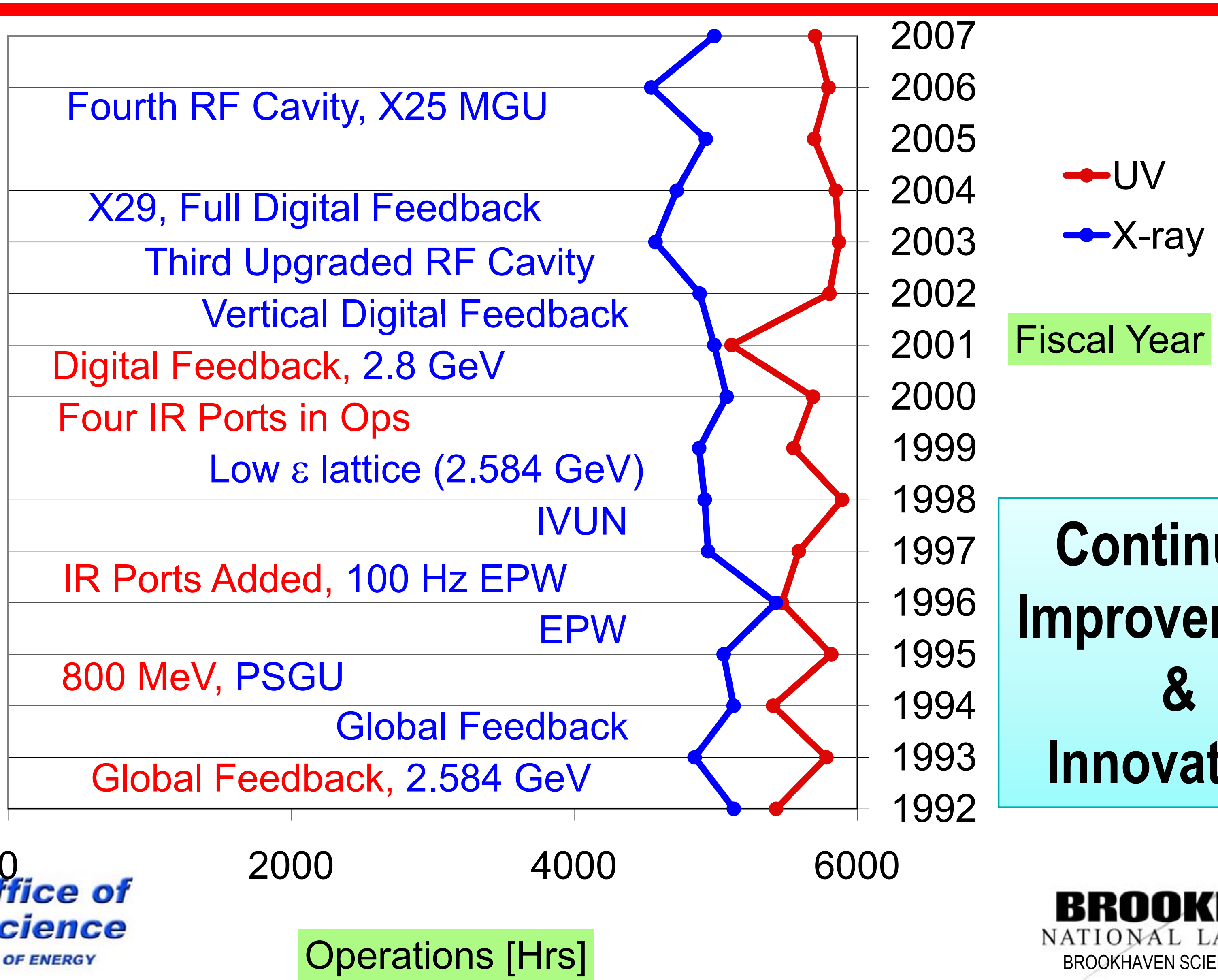
2003 Nobel Prize in Chemistry
Roderick MacKinnon, M.D., a visiting researcher at Brookhaven National Laboratory, won one half of the 2003 Nobel Prize in Chemistry for work explaining how a class of proteins helps to generate nerve impulses -- the electrical activity that underlies all movement, sensation, and perhaps even thought. More

Pioneering Light Source R&D at the NSLS

- ✓ Chasman-Green Lattice (NSLS, ESRF, APS, SPRING-8, NSLS-II, …)
- ✓ Global Orbit Feedback Systems for Beam Stability on the VUV & X-Ray
- ✓ Switched BPM Receivers for Improved Beam Position Measurement
- ✓ Longitudinal Coupled Bunch Mode Feedback System on the VUV
- ✓ Actively Powered 4th Harmonic Cavity for Increased Lifetime on the VUV
- ✓ Mini Gap In-Vacuum Undulators (2 x 3.3 mm full gap, 1 x 5.6 mm)
- ✓ Linear Optics from Closed Orbit Response Measurements (LOCO)
- ✓ Alpha Buckets, Coherent CSR & Microwave Emission on the VUV

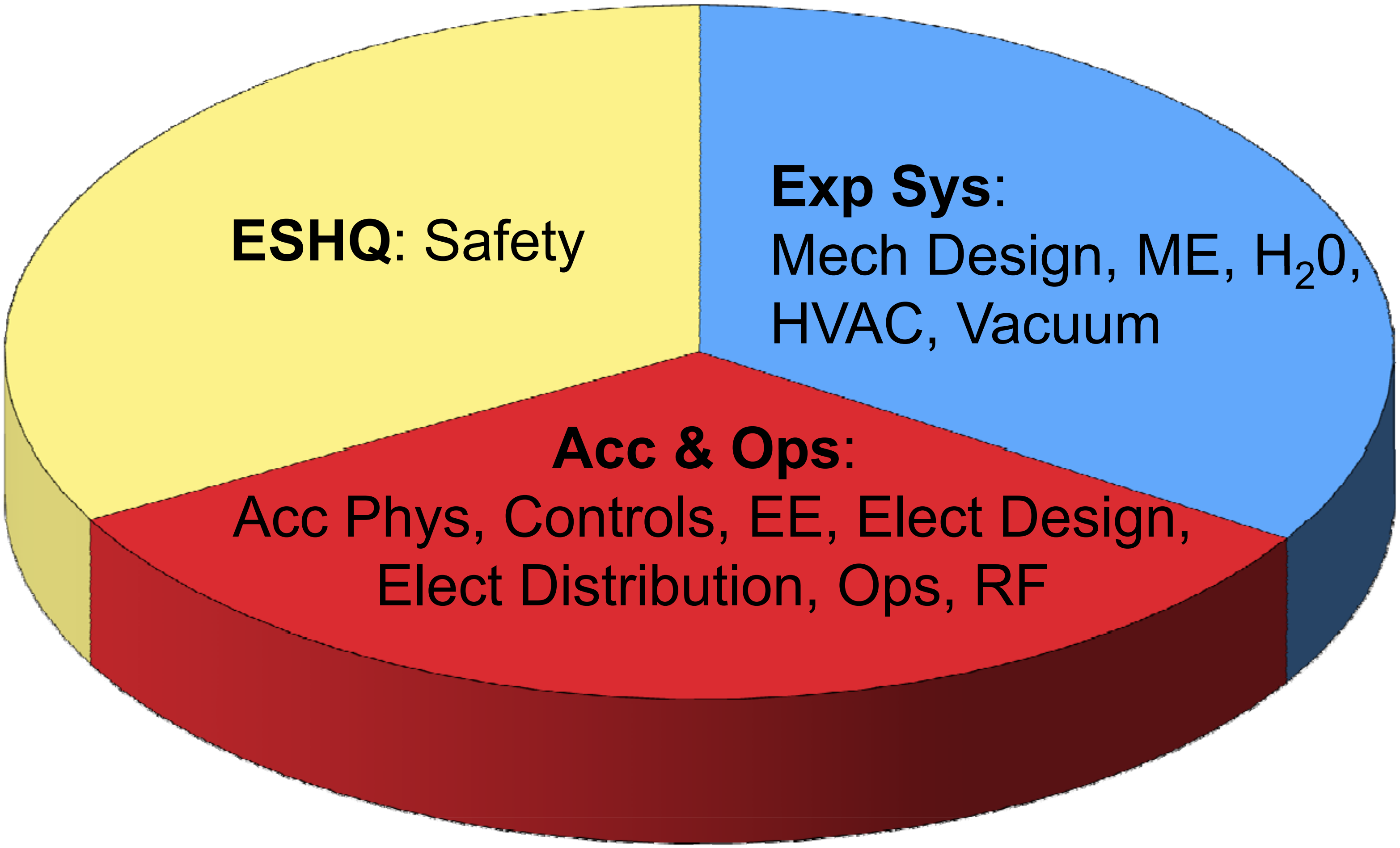
The NSLS storage rings are very mature & already incorporate nearly all of the high impact improvements in the light source arena*!*

NSLS Operations Evolution

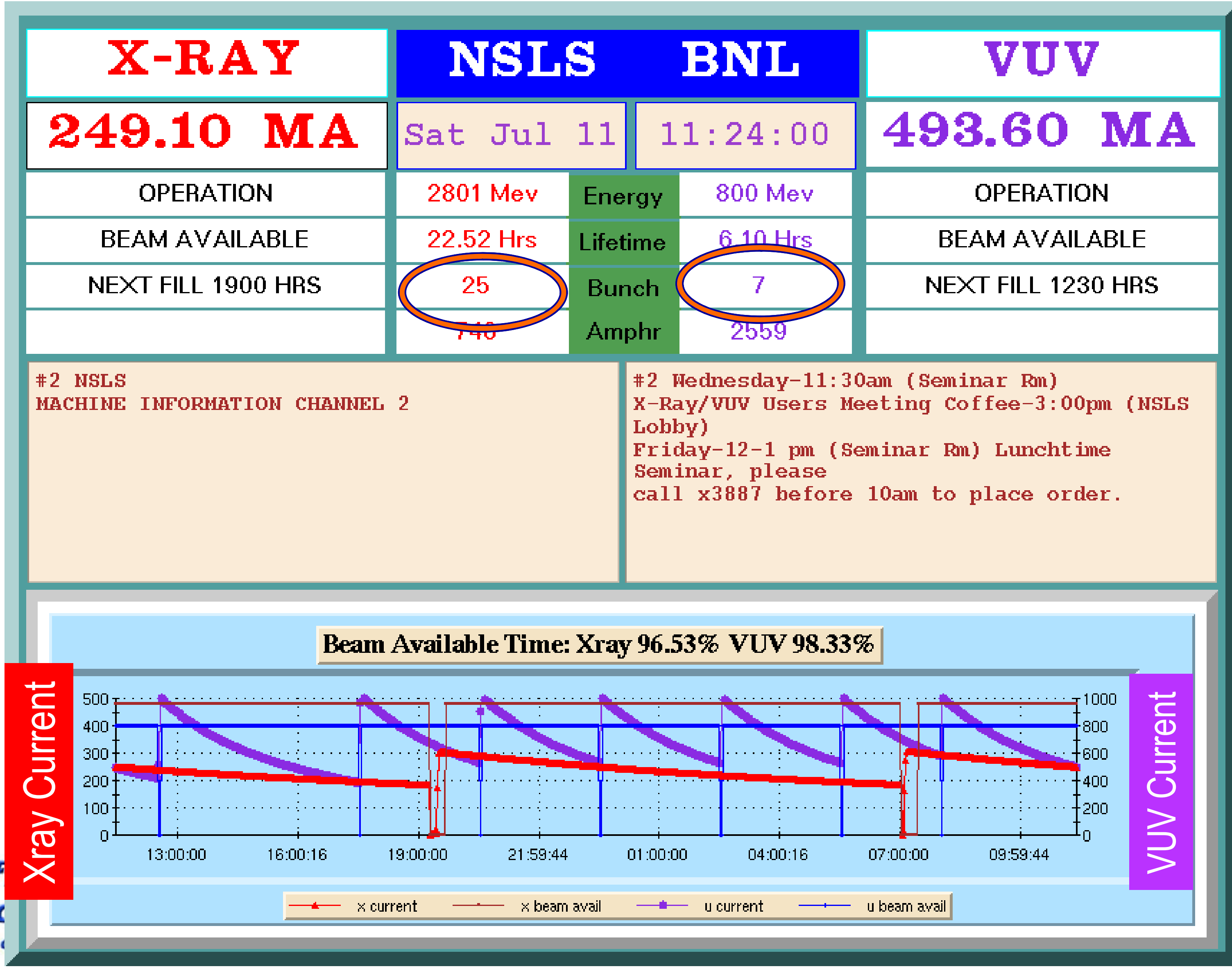


Continuing Improvements & Innovations

NSLS Operations is a Team Effort



Routine Ops: Xray 2 x 300 ma, VUV 7 x 1000 ma



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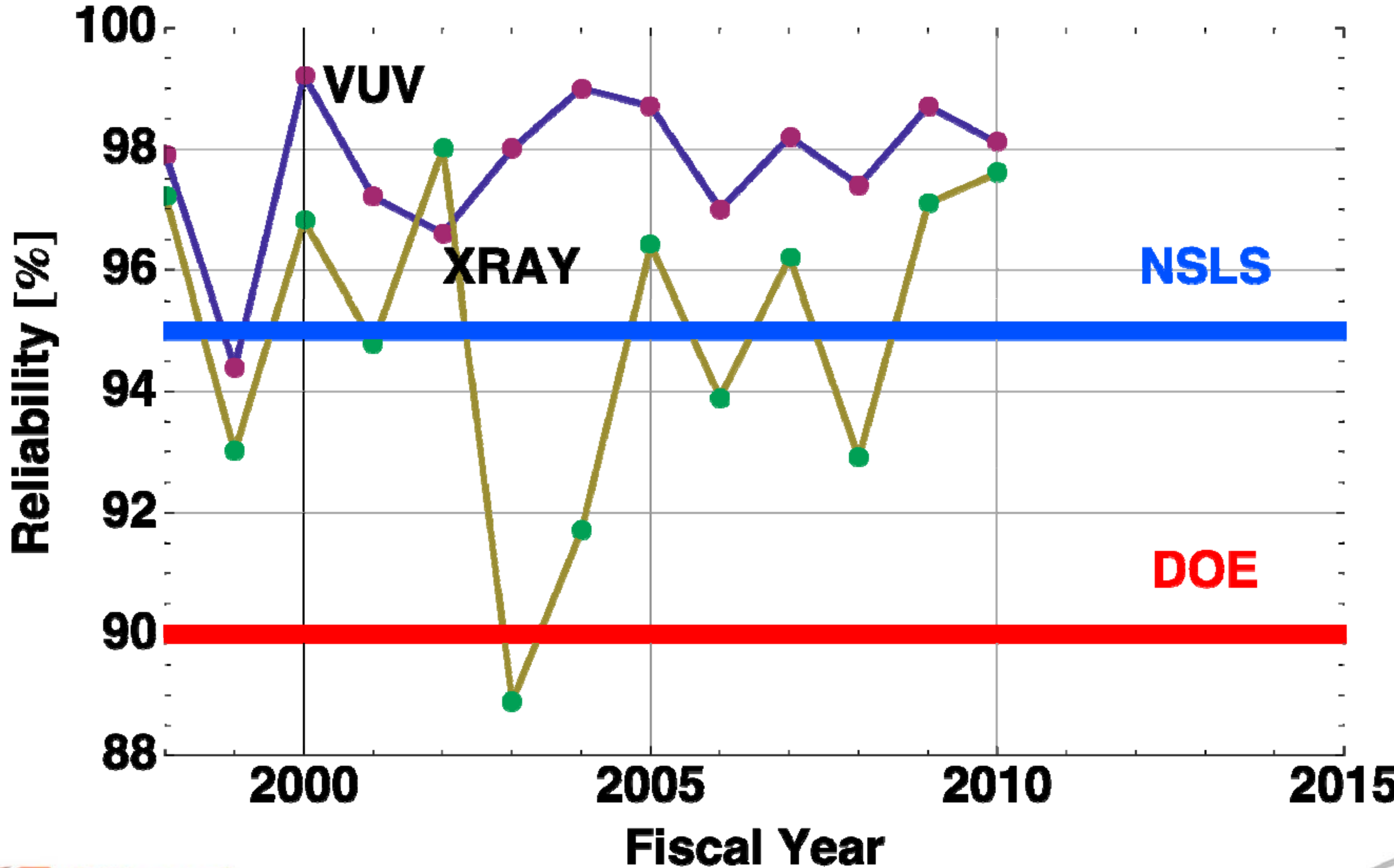
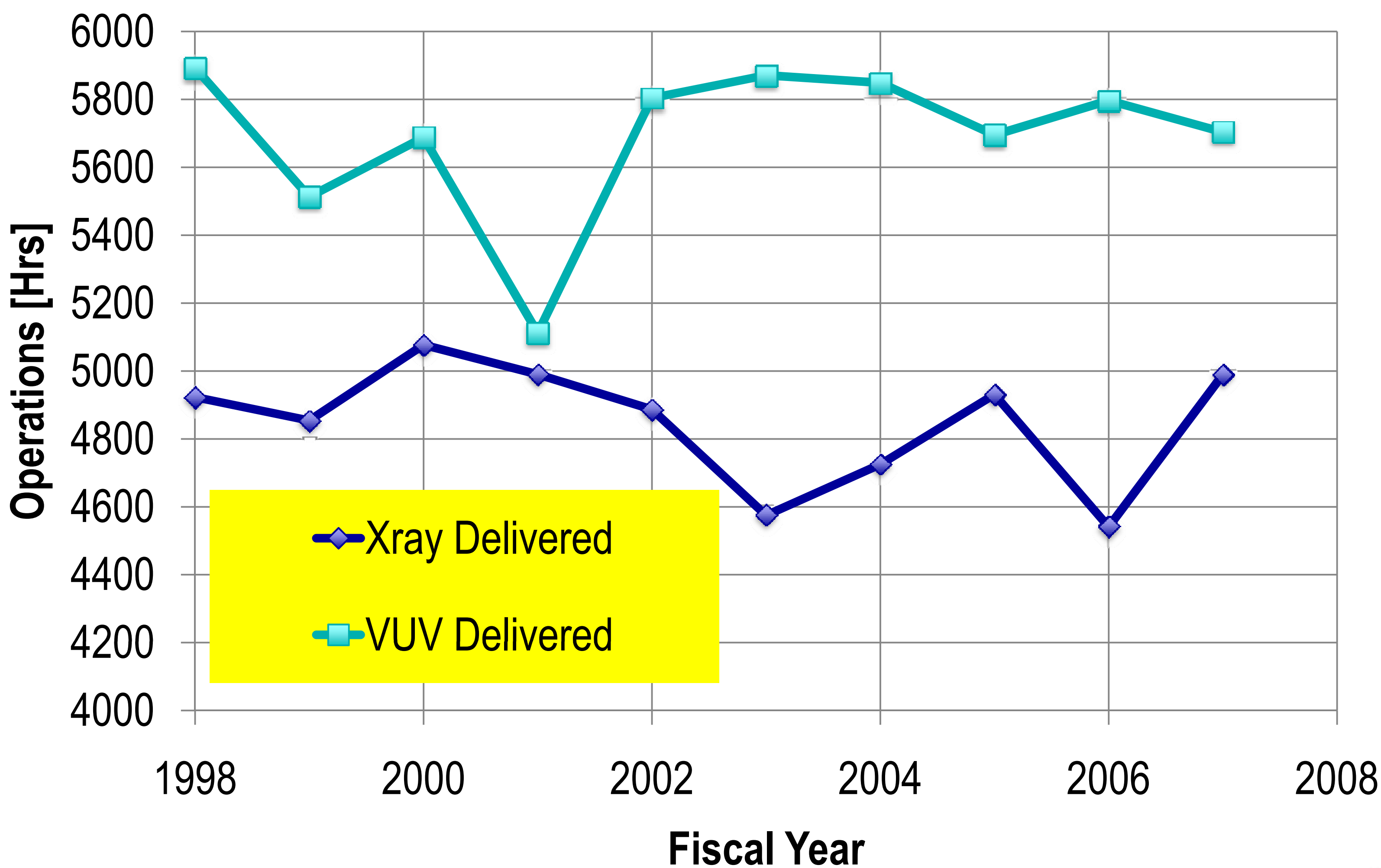
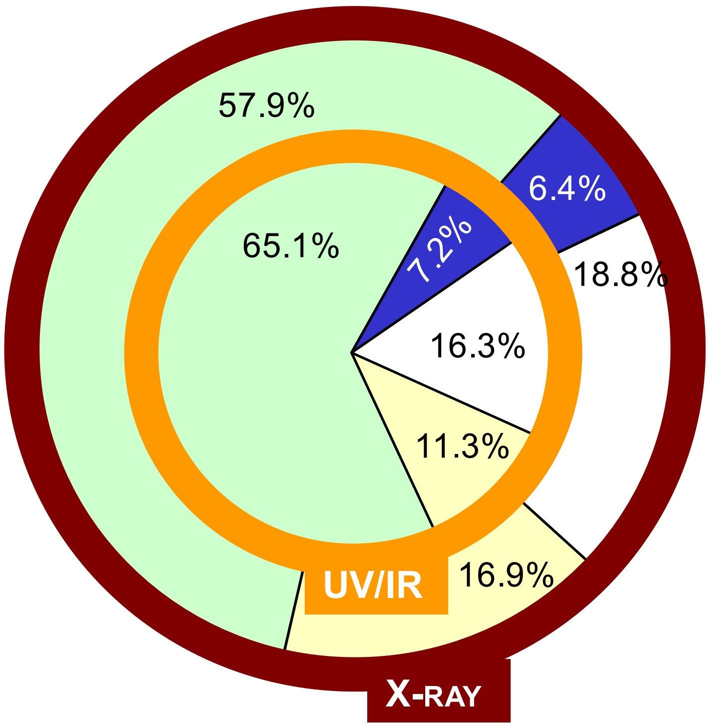
High Reliability Operations



Consistently High Operating Hours for Users

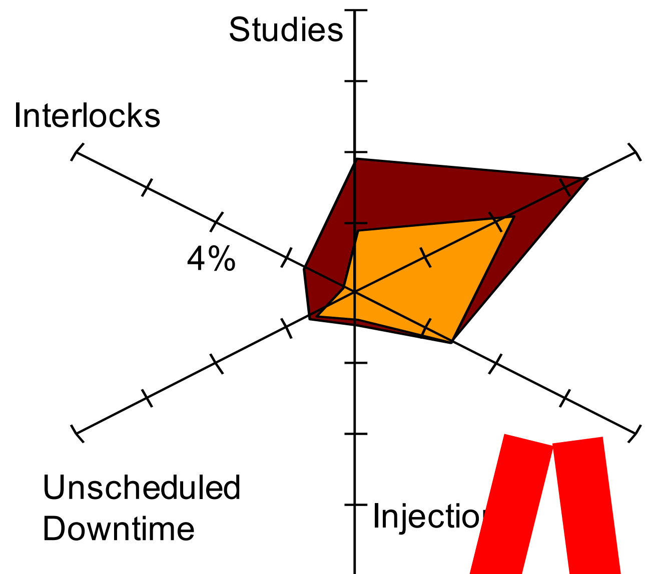


FY2010 Statistics



Other Activities	UV/IR	X-ray
Studies	1.8%	3.9%
Com/Con	4.5%	6.6%
Holiday	2.7%	2.7%
Injection	0.7%	0.8%
Unscheduled Downtime	1.2%	1.3%
Interlock	0.4%	1.5%

YTD 8040 Hrs 100 Hrs= 1.2%



Activity /Hours	UV/IR	X-ray
Operations	5233.2	4655.8
Unscheduled Operations	582.3	517.5
Maintenance	1314.1	1507.8
Other	910.5	1358.9

User Metrics	U [illegible]	[illegible] ay
Reliability	98.1%	97.6%
Availability	109.0%	108.5%

Work In Progress

Hardware & Infrastructure Issues

Ceramic Chambers & Bellows

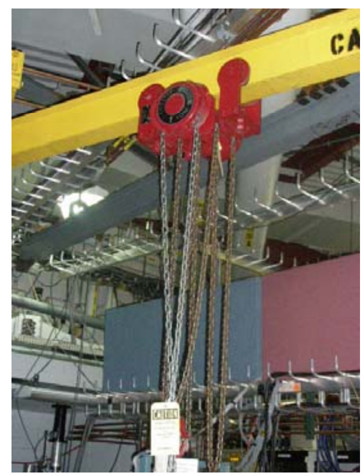
Cracks in Walls & Floors

X17 SCW Cryo System

Pulsed Kicker PS

XRF Power Amplifier Sys

HP/UX WS Micros Software



Crane Docs

MCC Units
10CFR851

Water Tower

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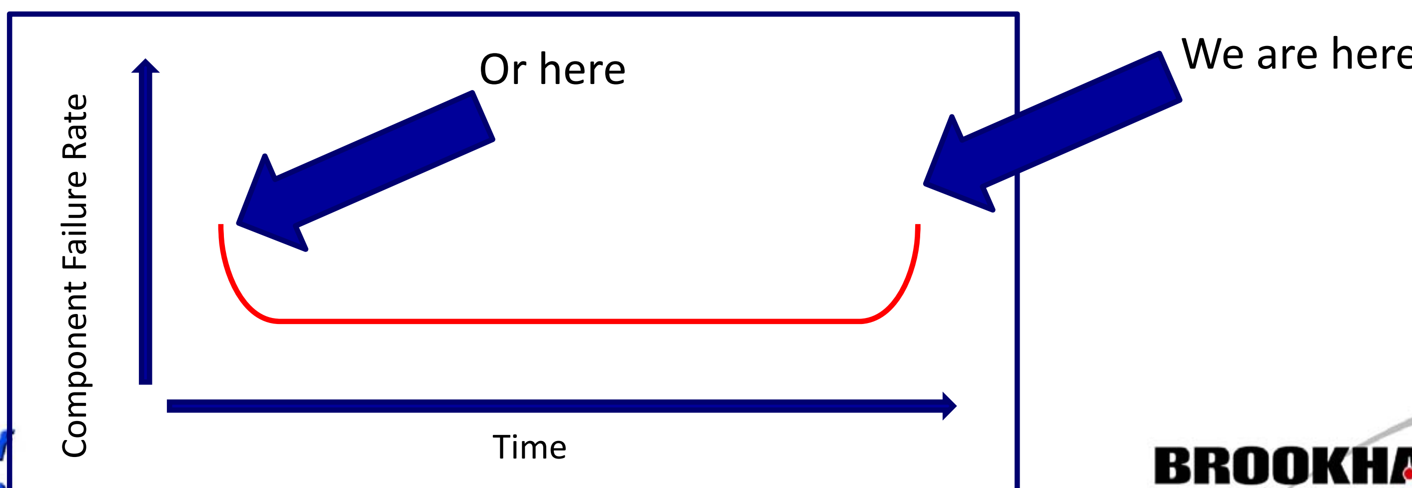
Machine Reliability Issues

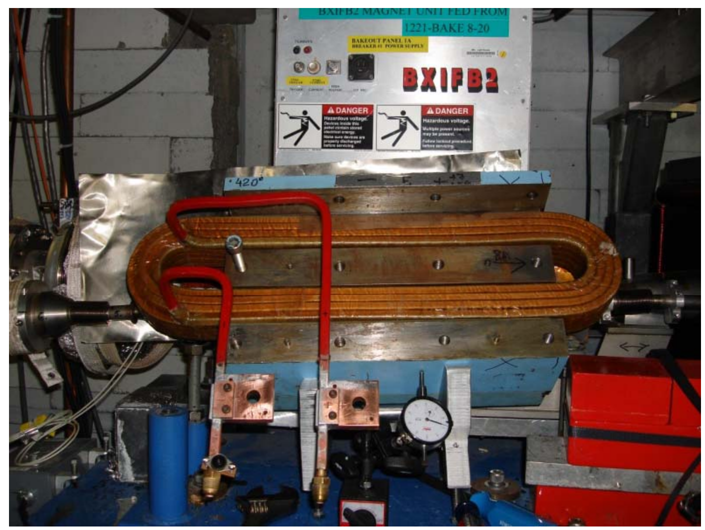
- Machine components are aging and require more preventative maintenance.
- Age-related failures are occurring at a higher rate:
  - RF system failures early CY08
  - VUV kicker magnet failure, summer 08
  - Two significant klystron failures (clocked several days of downtime in June 08)
  - We are on the far right side of the Component Failure Rate vs. Time curve
  - Maintaining robust operations is an increasingly difficult task



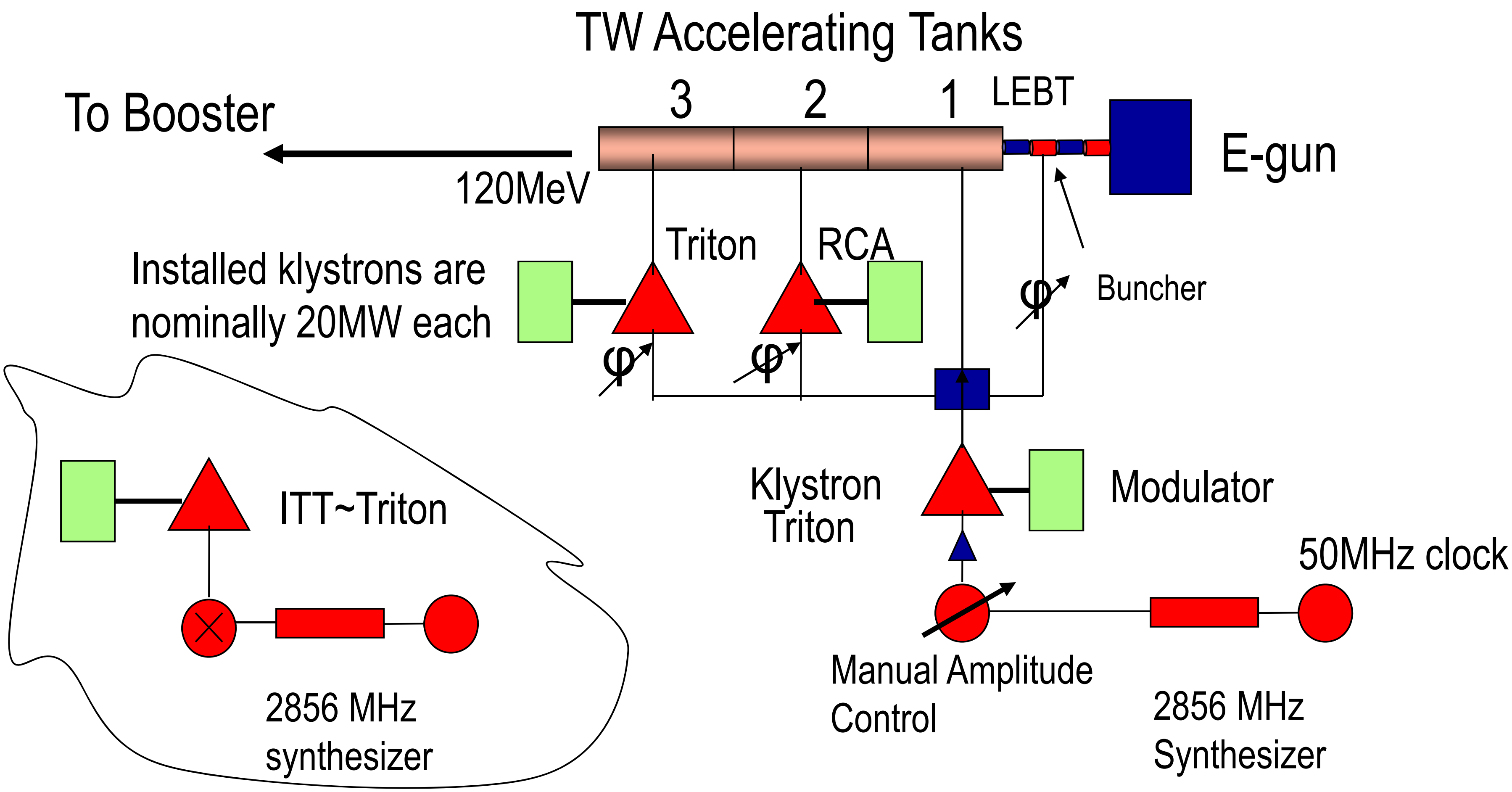
Example of Recent Machine Failure

BXD Magnet Coil Replacement:

- Dipole magnet overheated when a power dip tripped the cooling water off and the power supply remained on due to a faulty relay.
- Mechanical Group handled this very carefully to maintain the same position.
- Task was successful
- Great job by all!

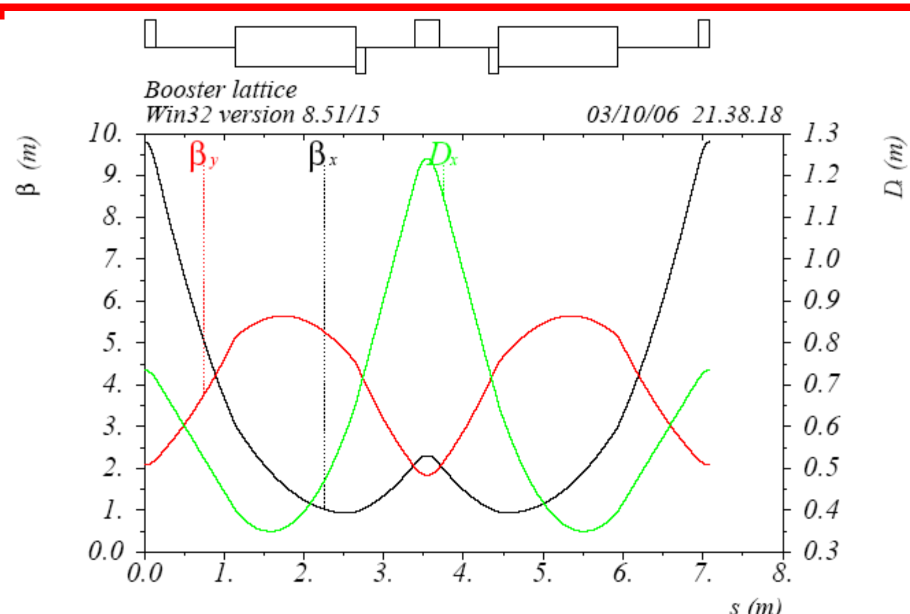


NSLS 120 MeV S-Band Linac



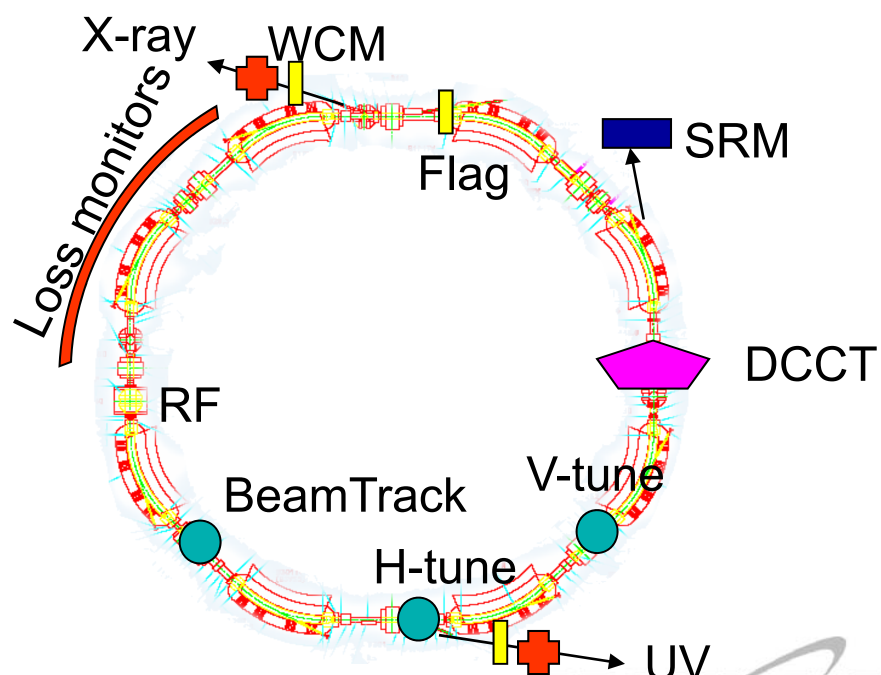
Full "hot spare"of indicated systems in test stand; additional klystrons spares being refurbished

Booster Ops & Diagnostics Improvements



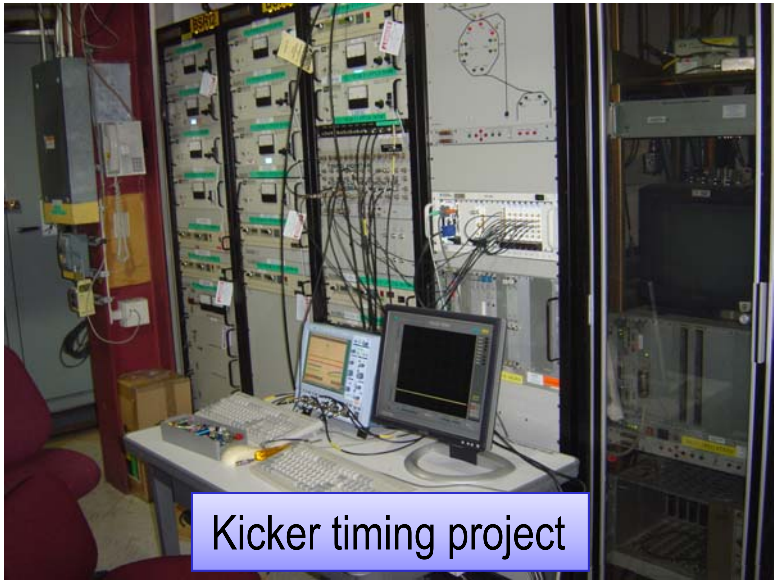
Booster diagnostics:

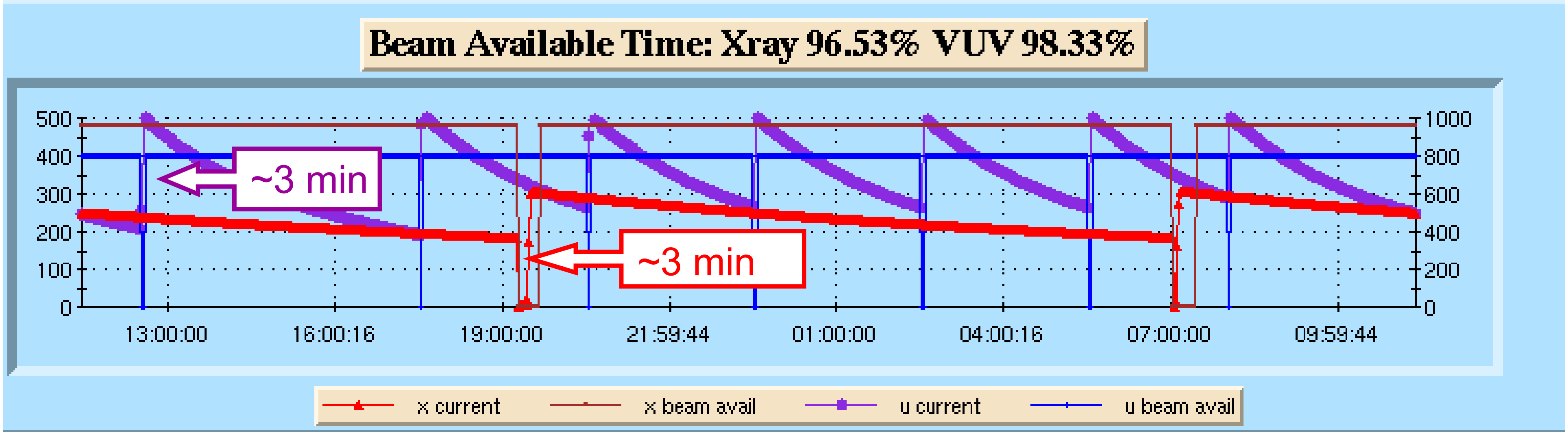
- 8 horizontal & 8 vertical PUEs,
- ✓ only 3 are instrumented
- ✓ Synchrotron Radiation Monitor
- ✓ Tune measurement system
- ✓ DC current transformer
- Loss monitors: not instrumented



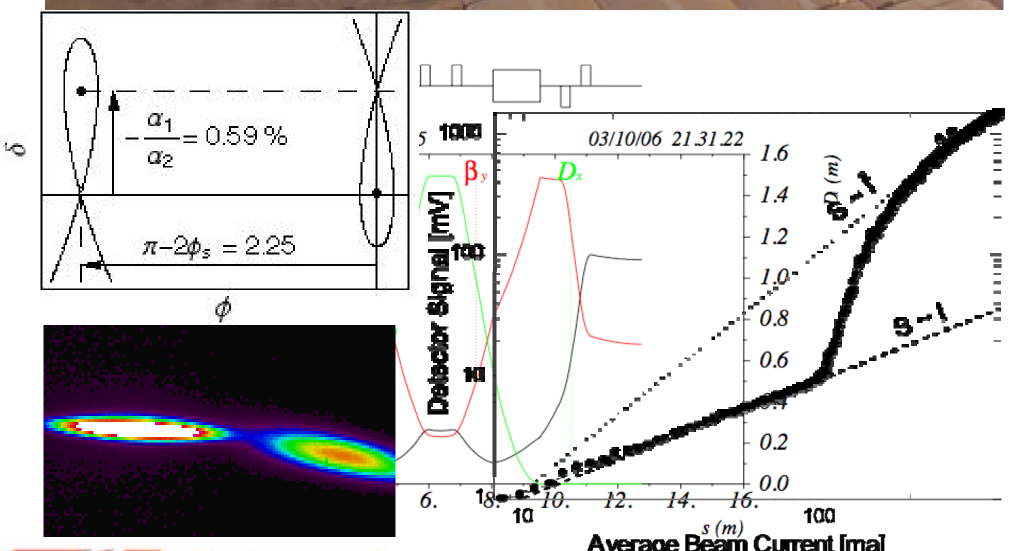
Injection System Improvements

- Motivation: faster injections, reduce radiation to staff/users, faster troubleshooting
- What: new/improved diagnostics (orbit, efficiency, etc) modeling and studies
- Progress: booster shot-to-shot variations reduced, extraction loss reduced
- X-ray injection time & radiation losses reduced a factor of 3





NSLS VUV Ring



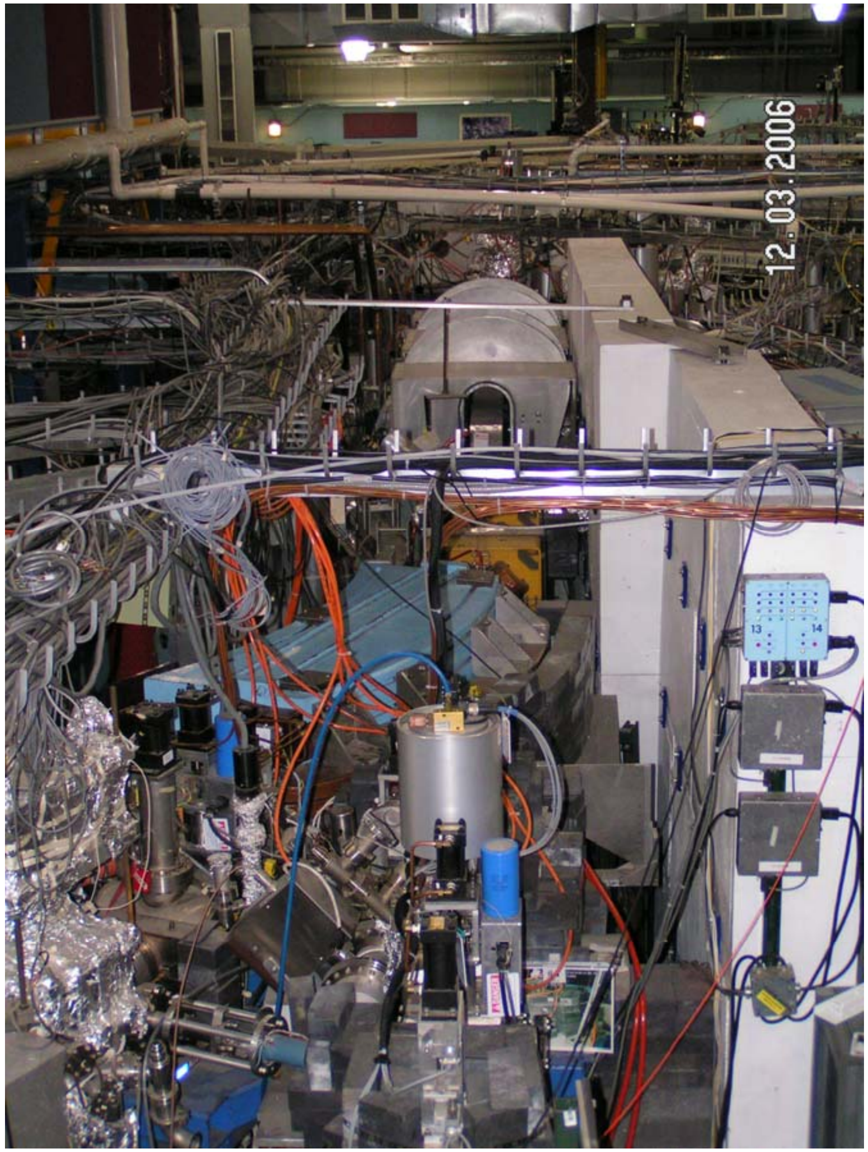
Operations

- •Reliability exceeding 95% at 808 MeV
- •High Current ~ 1 Amp in 7/9 bunches
- •4th Harmonic Cavity for Lifetime
- •Both Straights have IDs for Decades
- •Longitudinal Coupled Bunch Feedback
- •H&V Global Orbit Feedback
- •90 x 90 mrad IR ports

R&D

- •Alpha Buckets (PRL)
- •Bursting CSR & Microwaves (NIM)

Present View of VUV Floor

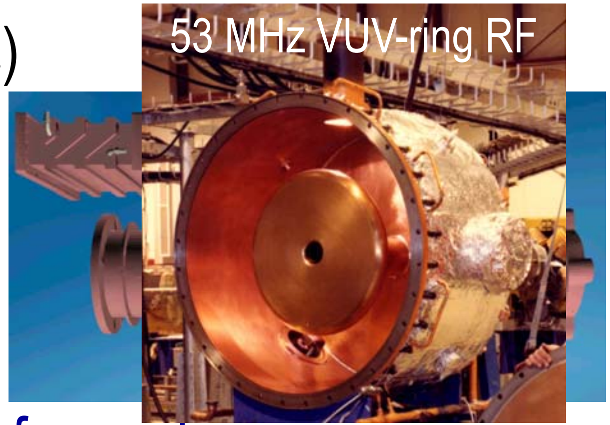


Possible VUV / IR Ring: Coherent IR Development

- Goal is to add short pulse capability and to boost coherent IR flux
- Short bunches require high RF gradient (& low α)
- Need to replace 53 MHz RF cavity (σ_τ(I)~0.3-1 ns)
- Take 2.5 MV CESR-B & 800 MeV:

  present (α_0=0.0235) => σ_τ=10 ps rms

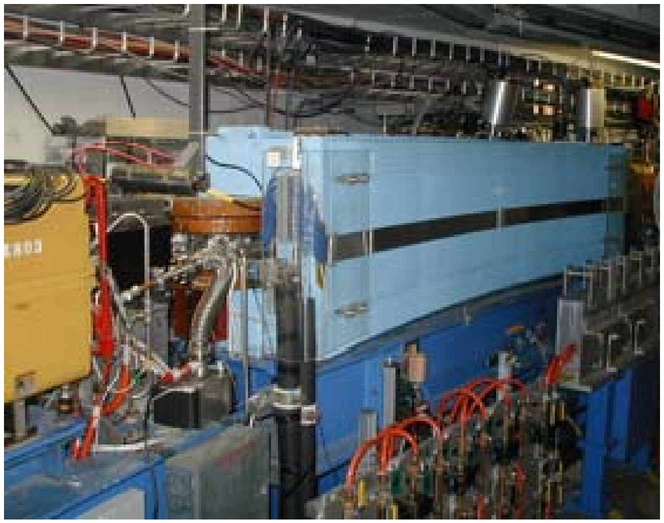
  $\alpha = \alpha_0/100$ => 1 ps for CSR mode

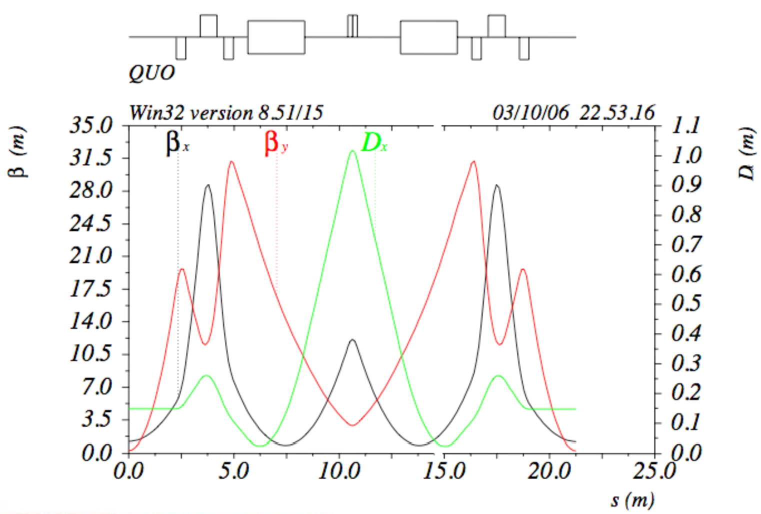


- Lattice needs minor modification for CSR mode of operations
- Scaling CSR instability threshold for VUV ring with CESR-B cavity results in flux/mrad higher than @ BESSY-II
- Issues include collective effects, lifetime, feedbacks & diagnostics, …

CESR-B RF cavity should work well & fits into existing VUV-ring
Will shorten the pulse 1-3 orders of magnitude, and boost IR flux for the Users
Will jumpstart NSLS-II SC RF & beam dynamics R&D efforts

X-Ray Ring





Operations

- Reliability of 90-98% at 2.8 GeV
- High Current ~ 0.3 Amp in 25/30 Bunches
- Inject @ 0.75 GeV and Ramp Up
- Four New RF Cavities Provide 1 MV
- Six of Eight Straight Sections have IDs
- H&V Global Orbit Feedback

R&D

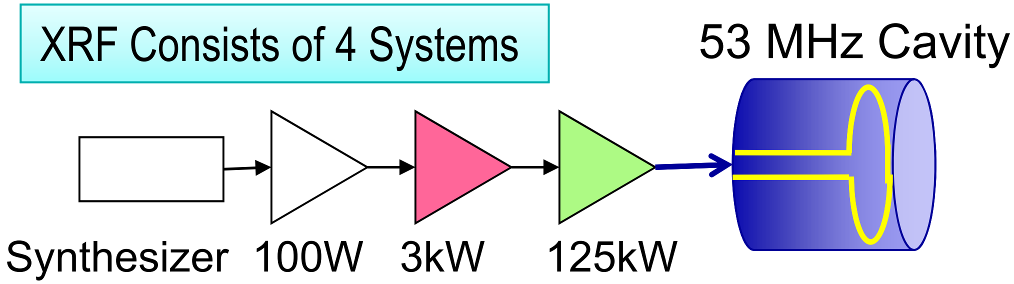
- Small Gap Insertion Devices
- Dynamic Aperture with EPU + IDs
- Improve injection modeling for X5 ID

Corrector Magnet Power Supplies

Quad and Corrector with Skew Coils

XRAY RF Amplifier Upgrade Projects

XRF Consists of 4 Systems



<u>125 KW Anode Rectifier & Power Supply</u>
Two systems to upgrade (2009, 2010)

<u>3 KW Solid State Amplifier</u>
4 systems to upgrade

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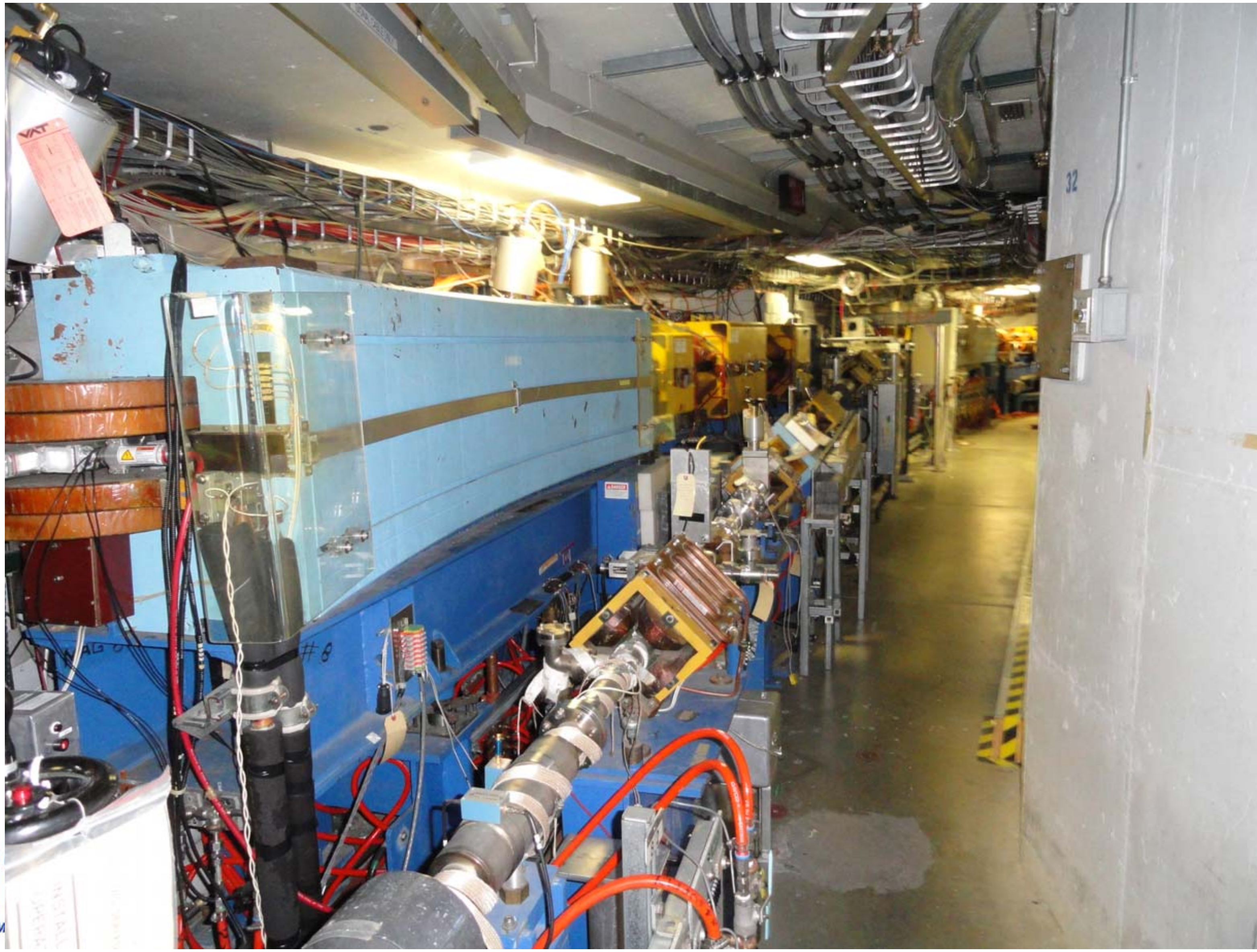
X-ray Injection Line



Sextupole Power Supply

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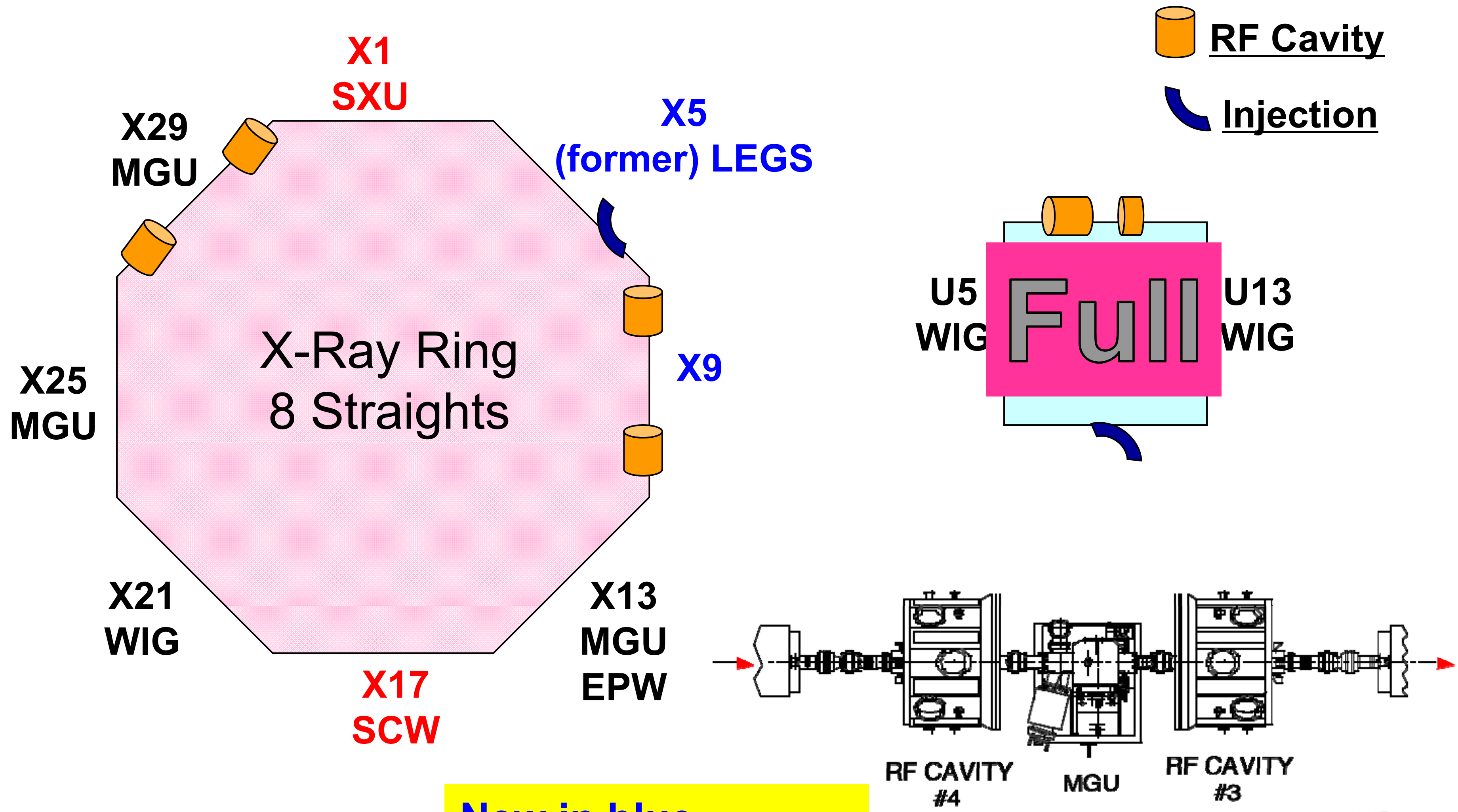
Matching Triplet

NSLS Insertion Devices: Near Capacity



New in blue
Replacement in red

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NSLS Leads the Way with In-Vacuum IDs

	X13			X29	X25	X9
Device Parameters	**PSGU** (1993)	**IVUN** (1997)	**MGU** (2002)	**MGU** (2003)	**CPMU** (2005)	**MGU** (2008)
Type	Pure PM in Air	Pure PM In-Vacuum	Hybrid PM In-Vacuum	Hybrid PM In-Vacuum	Cryo-Ready PM Hybrid	Hybrid PM In-Vacuum
Period (mm)	16	11	12.5	12.5	18	14.5
Length (m)	0.33	0.33	0.36	0.36	1	0.36
No. Periods	18	30.5	2	27	53	23
Min.Mag.Gap (mm)	6.0	3.3	3.3	3.3	5.6	3.3
Peak Field (T)	0.62	0.68	0.95	0.95	0.96 **(warm)**	1.28 **(warm)**
K_{eff}	0.93	0.7	1.1	1.1	1.5	1.63
E_{fund} @ 2.8 GeV	3.2	5.4	3.7	3.7	1.9	2.2

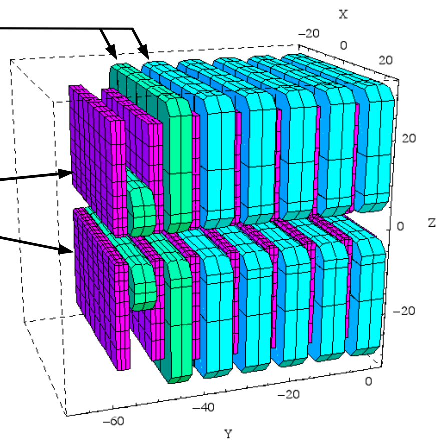
G. Rakowsky

New In-Vacuum Undulator Replaced X25 Wiggler

NdFeB Magnets:
new "hybrid car motor" grade

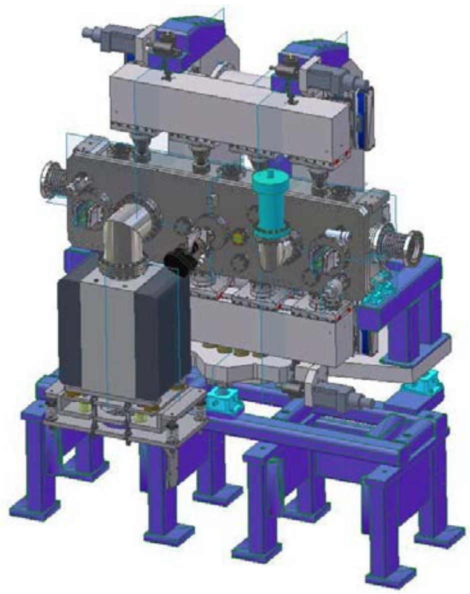
Vanadium Permendur Poles

<u>Magnetic Design:</u>
NSLS



Provision for future cryo-cooling of magnet arrays to -120ºC

<u>Mech. Design</u>:
Advanced Design Consulting, Inc.



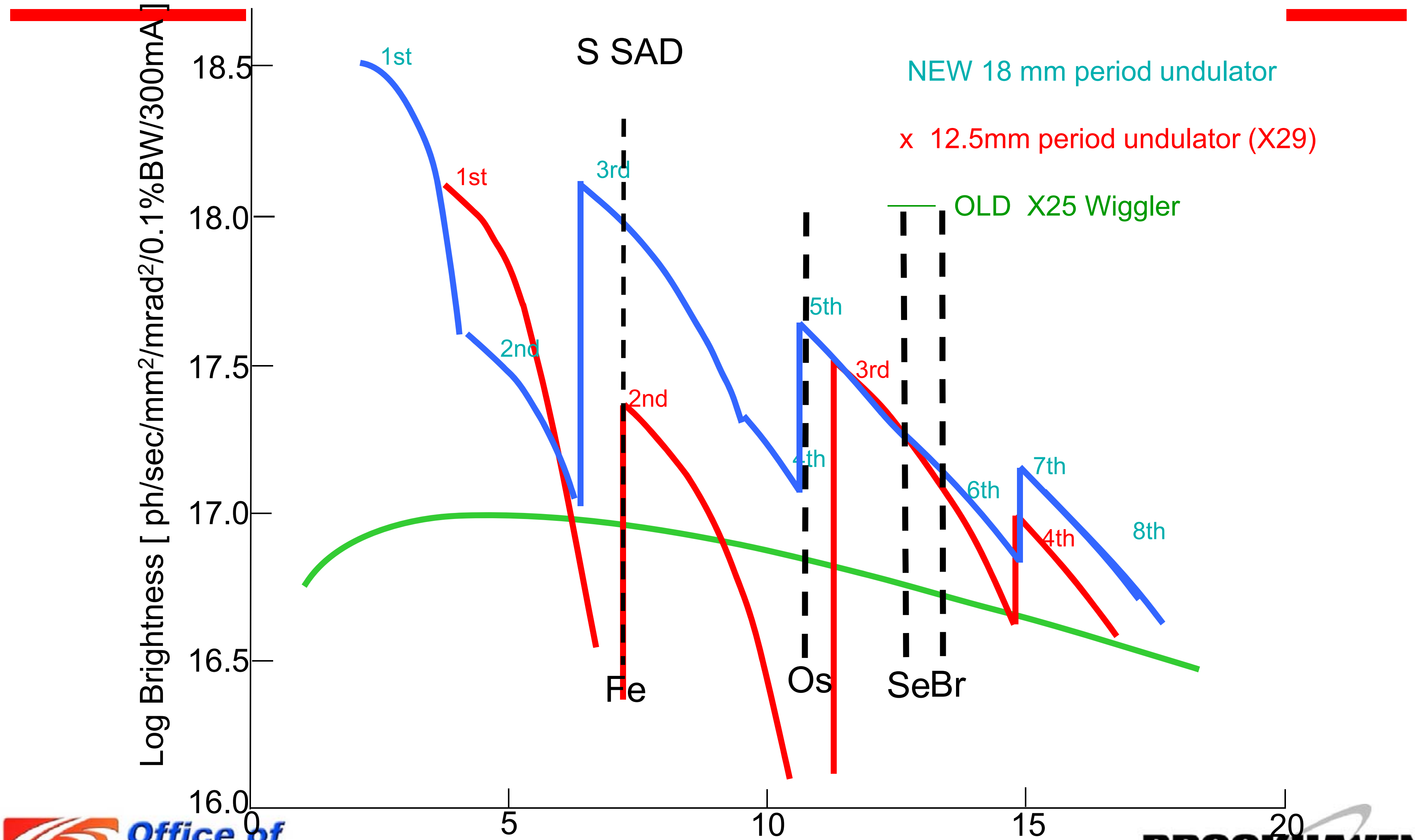
<u>Expected performance</u>

Length (m)	1
Period (mm)	18
Gap (mm)	5.6 - 12

Operation: Warm (20C), Cryo (-120C)

Installed Dec. 2005

MGU Spectra

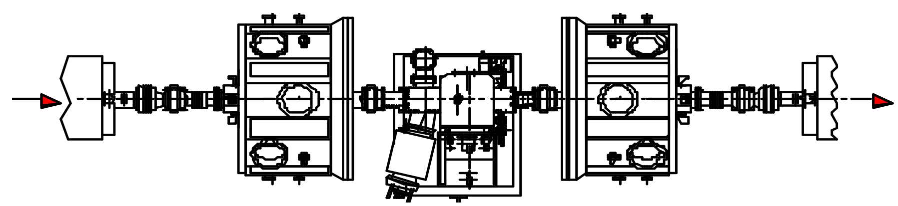


S SAD
NEW 18 mm period undulator
x 12.5mm period undulator (X29)
OLD X25 Wiggler
1st
1st
2nd
3rd
2nd
5th
3rd
4th
6th
7th
4th
8th
Fe
Os
SeBr
Log Brightness [ph/sec/mm²/mrad²/0.1%BW/300mA]
18.5
18.0
17.5
17.0
16.5
16.0
0
5
10
15
20
Energy [keV]

Installed in the Ring

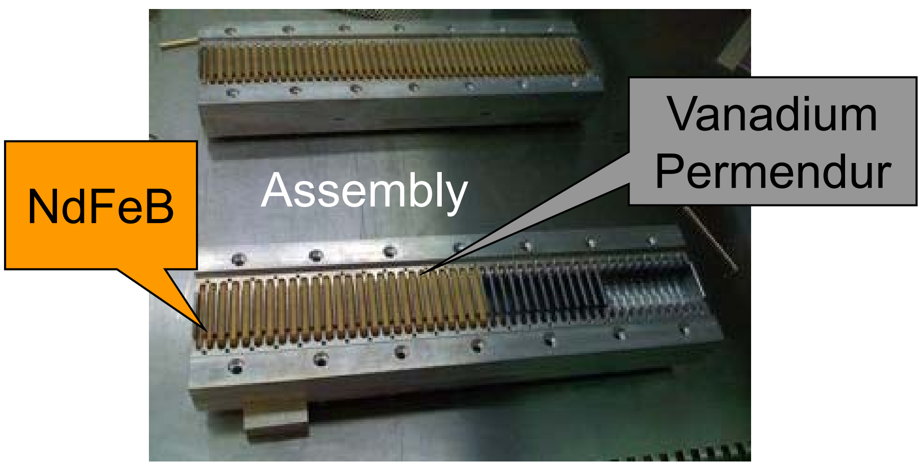
CFN X9 Undulator

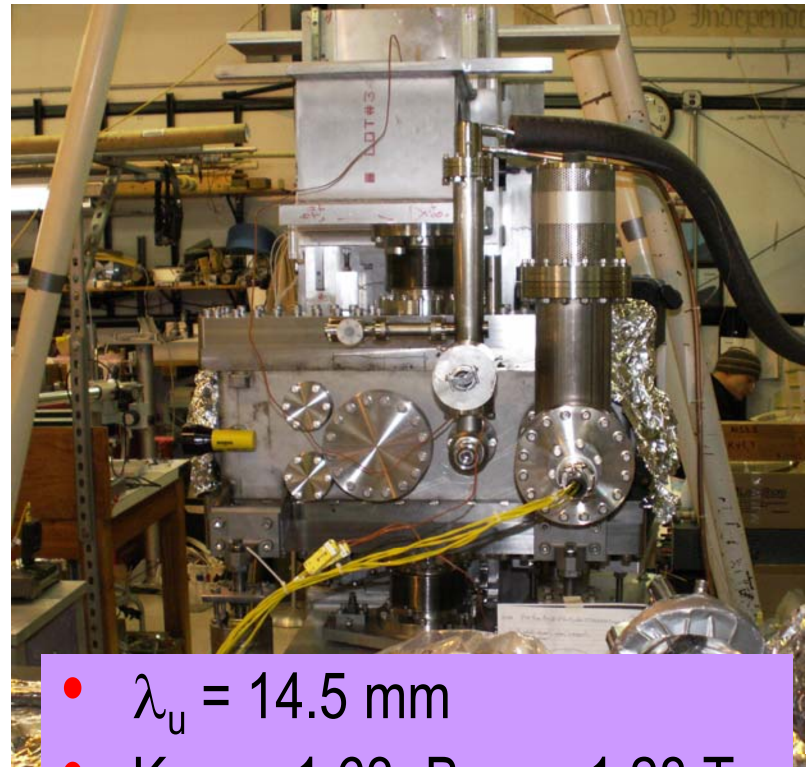
- X9 MGU for CFN beamline is under construction in-house
- Coverage 2.2-20 keV (use up to 7th harmonic, $0.5<K<1.7$)
- 36 cm long, 14.5 mm period, min. gap 3.3 mm, B_{pk}=1.3 T
- Fits between RF1 and RF2 cavities in the X-ray ring
- To be installed in May 2008
- Challenges due to out-of-spec magnet material limiting baking temperature. Required extensive thermal testing and magnetic measurements



CFN X9 Undulator Installation

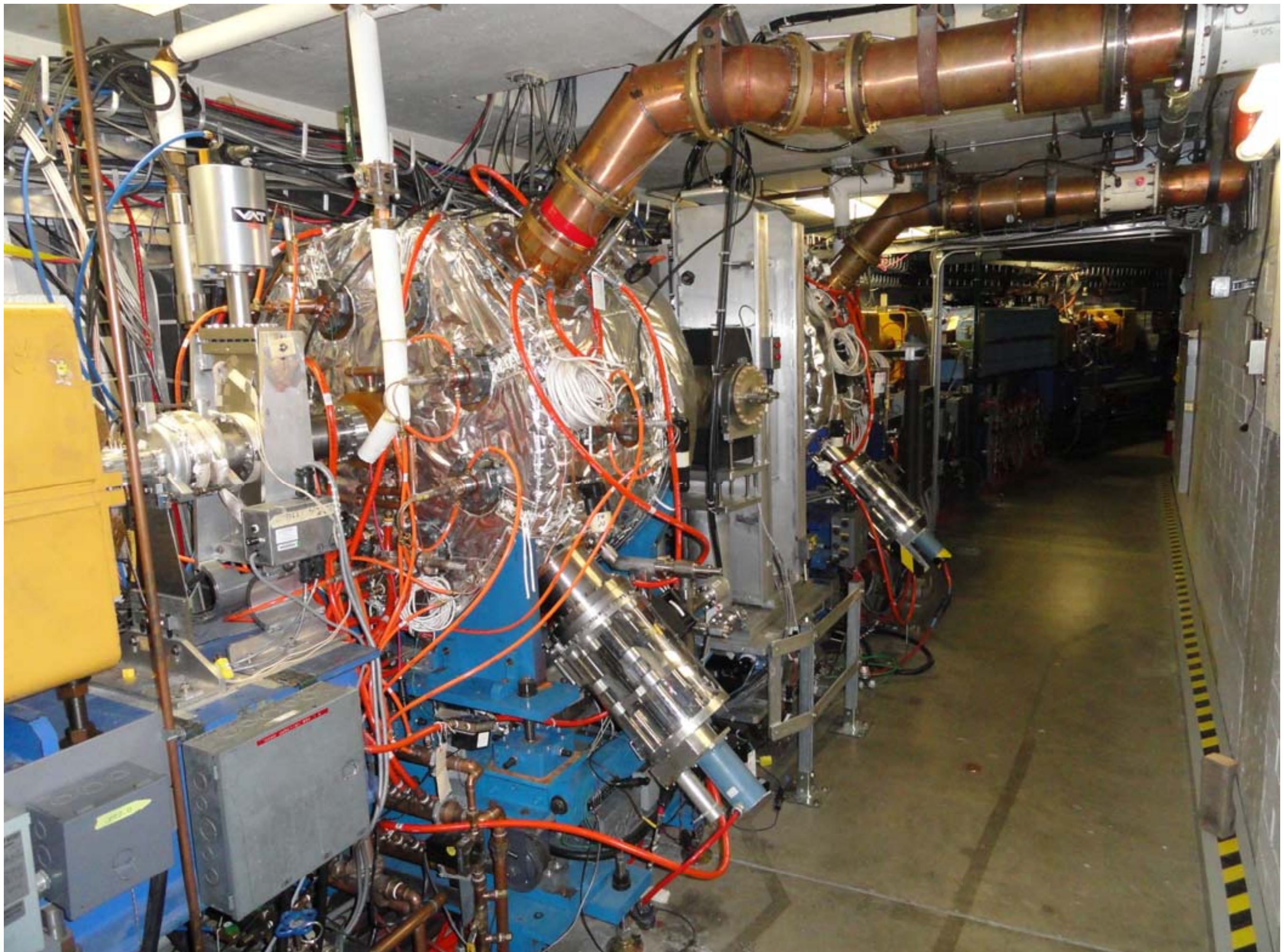
- Magnetic assembly completed
- Magnetic measurements done, performance is within specs
- Additional work on vacuum integrity
- Bakeout temp must not exceed 90º C
- Ring installation in August 2008



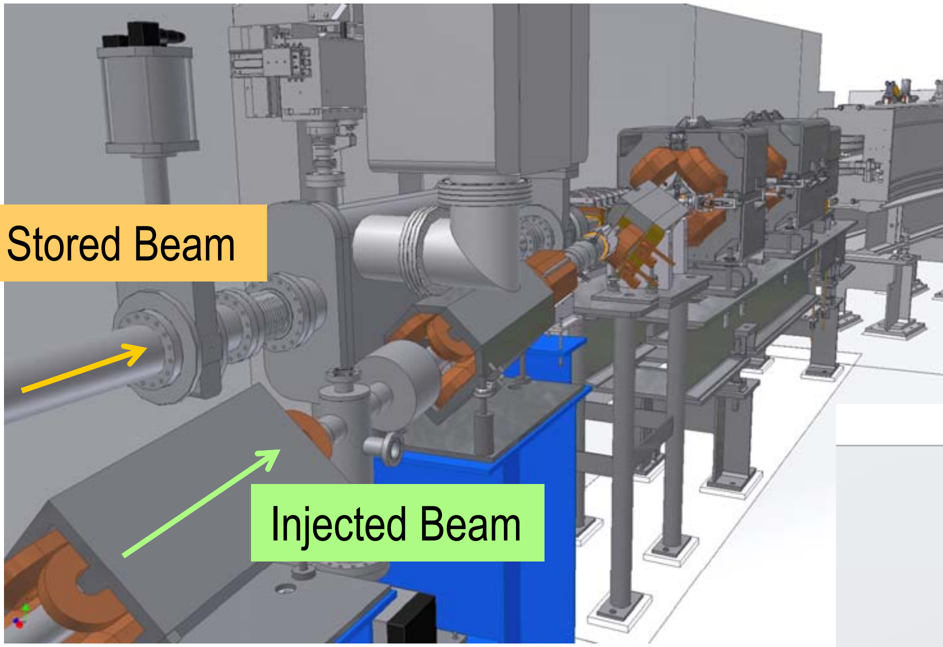


- λ_u = 14.5 mm
- K_{max} = 1.63, B_{max} = 1.28 T
- $N_{periods}$ = 23, L = 0.36 m
- Minimum full gap = 3.3 mm

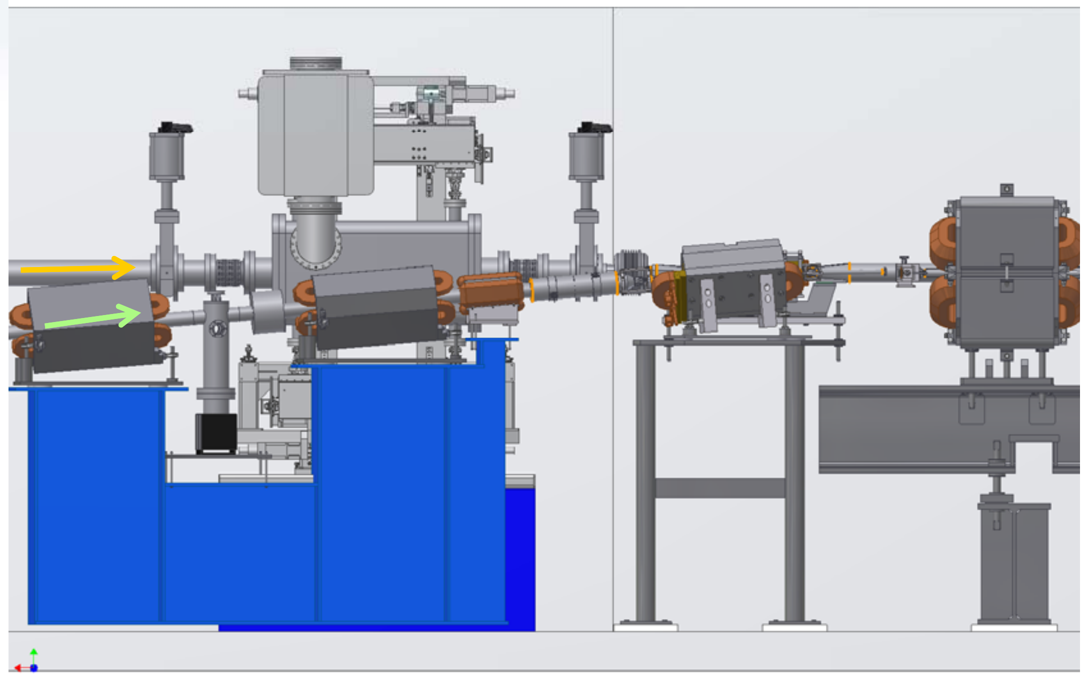
RF Cavities and Undulator in Between



New MGU is a Snug Fit For X5 Straight



- New 50 cm MGU or EPU?
- Interest from PX & Physics
- Cost & schedule being done
- Timeline depends on budget



✓ X5 straight section was freed from LEGS. It is crowded with injection hardware, but….

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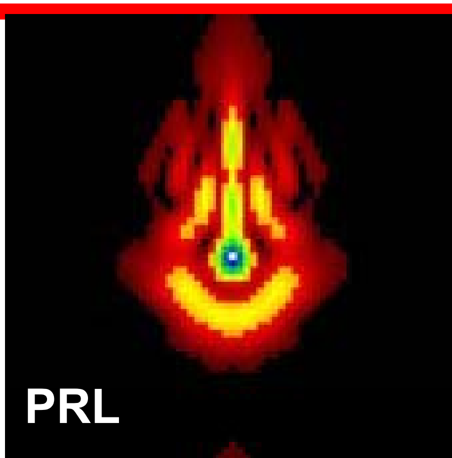
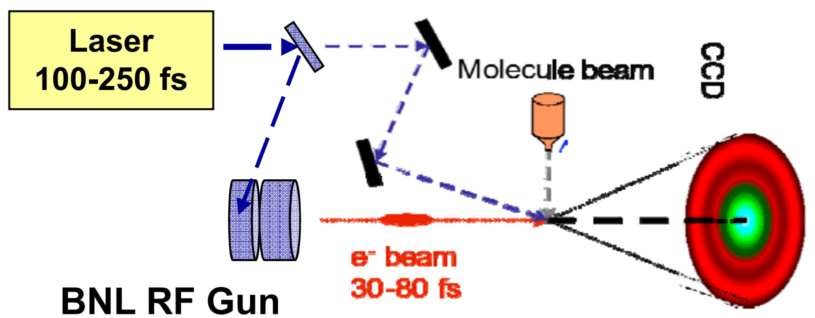
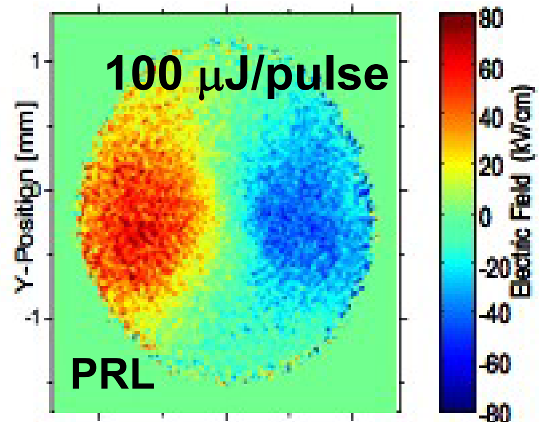
S. Pjerov Artwork

Ultrafast: SDL is a World Class FEL & e-Beam R&D Lab



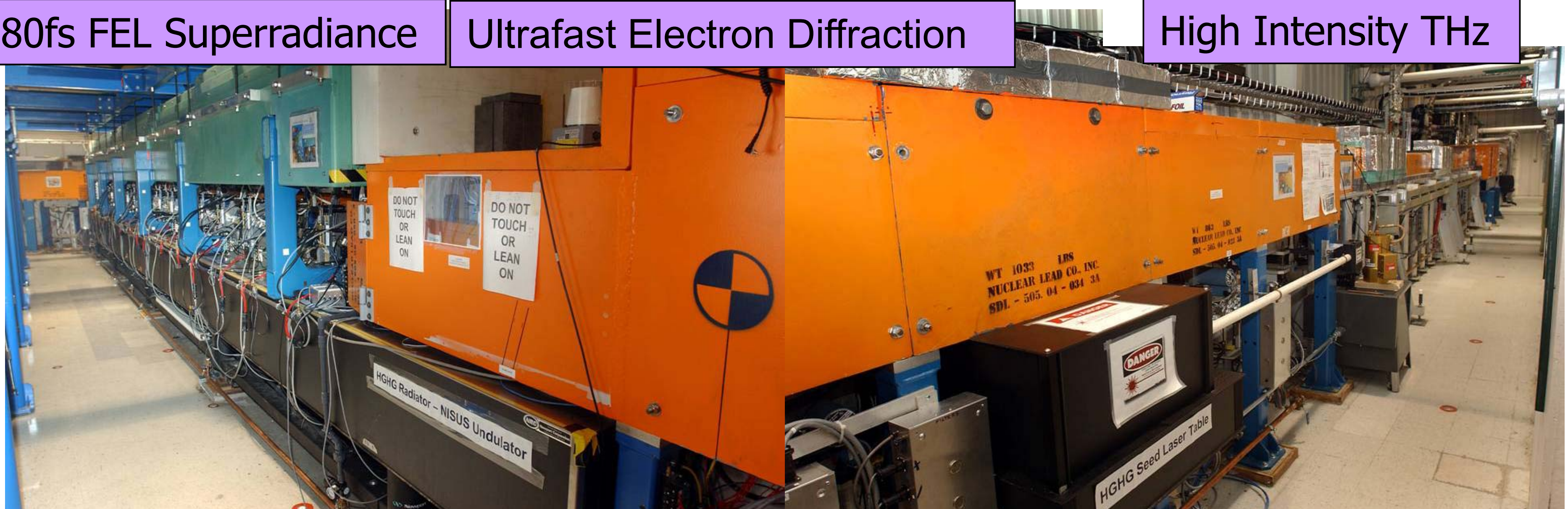




80fs FEL Superradiance

Ultrafast Electron Diffraction

High Intensity THz



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NSLS-II: Our Future Light Source

NSLS-II Design Features

Design Parameters

- 3 GeV, 500 mA, top-off injection
- Circumference 792 m
- 30 cell, DBA
  - 15 high-β straights (9.3 m)
  - 15 low-β straights (6.6 m)

Novel design features:

- Damping wigglers
- Soft bend magnets
- Three pole wigglers
- Large gap IR dipoles

Ultra-low emittance

- ε_x, ε_y = 0.6, 0.008 nm-rad
- Diffraction limited in vertical at 12 keV
- Small beam size: σ_y = 2.6 μm, σ_x = 28 μm, σ'_y = 3.2 μrad, σ'_x = 19 μrad, σ_z=15-30 ps

NSLS-II Design Parameters & Specifications

Energy	3.0 GeV	Energy Spread	0.094%
Circumference	792 m	RF Frequency	500 MHz
Number of Periods	30 DBA	Harmonic Number	1320
Length Long Straights	6.6 & 9.3m	RF Bucket Height	>2.5%
Emittance (h,v)	<1nm, 0.008nm	RMS Bunch Length	15ps-30ps
Momentum Compaction	.00037	Average Current	500ma
Dipole Bend Radius	25m	Current per Bunch	0.5ma
Energy Loss per Turn	<2MeV	Charge per Bunch	1.2nC
		Touschek Lifetime	>3hrs

Summary and Conclusions

NSLS Storage rings are highly optimized but still improving

- **In Place**: Mini-gap & variable polarization IDs, digital feedback, 4th harmonic cavity, EPICS-like controls …
- **To Be Done**: improved injection, stability & reliability, …

NSLS-II Storage ring is the future of NSLS

- **Will Provide**: much higher brightness, many straight sections filled with advanced IDs, high beam stability, unprecedented energy resolution, etc
- **Many Potential Synergies with Present NSLS**

A wealth of accelerator physics and engineering expertise at NSLS and NSLS-II (Photon Sciences Directorate of BNL)