Status of NSLS II

F. Willeke, BNL

Particle Accelerator Conference 2011, New York City

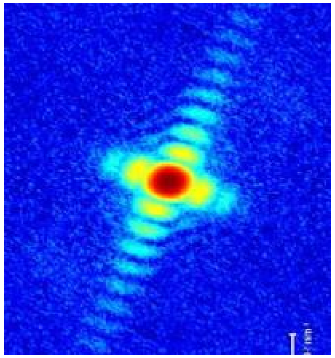
March 29, 2011

Outline

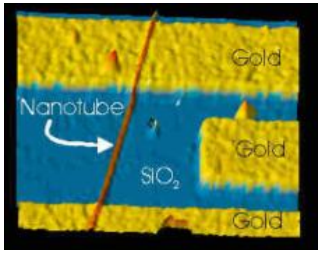
- Requirements
- Design
- Facility Status
- Injectors
- Critical Subsystems
- Insertion Devices
- Photon Beam Lines
- Construction Status
- Summary

Mission

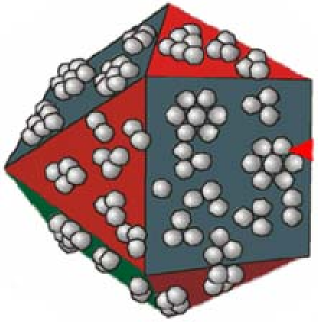
- **NSLS: a very productive light source**
  4^{th} decade of operation
  Strong on-going science program
- **State of the art of accelerator technology:**
  Factor 10^4 increase in brightness,
  Factor 10 increase in flux
  ➔ **More than a quantitative step**
- **2005: DOE acknowledges mission need for a synchrotron radiation facility with**
  1 nm spatial resolution
  0.1 meV energy resolution
- **Start of NSLS-II Project: 2005 CD 0**
  2007 CD 1
  2008 CD2
  2009 CD3
  2015 CD4



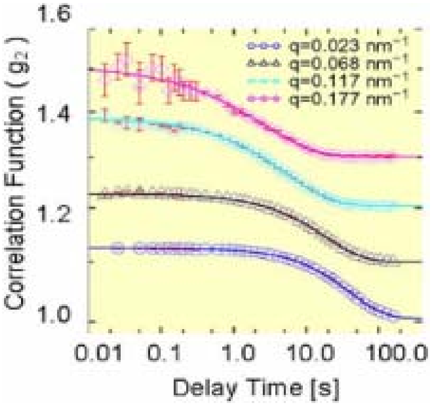
Diffraction Imaging



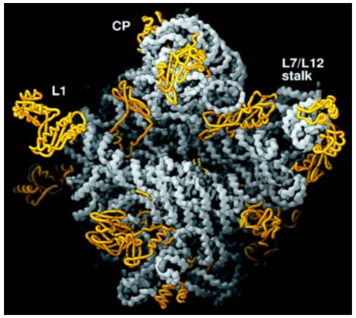
Nanoscience



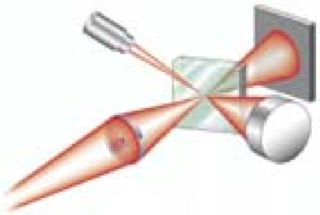
Nanocatalysis



Coherent Dynamics



Life Science



Nanoprobes

Requirements

Average Spectral Brightness: $10^{21} \cdot mm^{-2} \cdot mrad^{-2} \cdot s^{-1} \cdot 0.1\%bw^{-1}$

Spectral Flux Density : $10^{15} \cdot s^{-1} \cdot 0.1\%bw^{-1}$ @ 2 keV

Accelerator Main Parameters

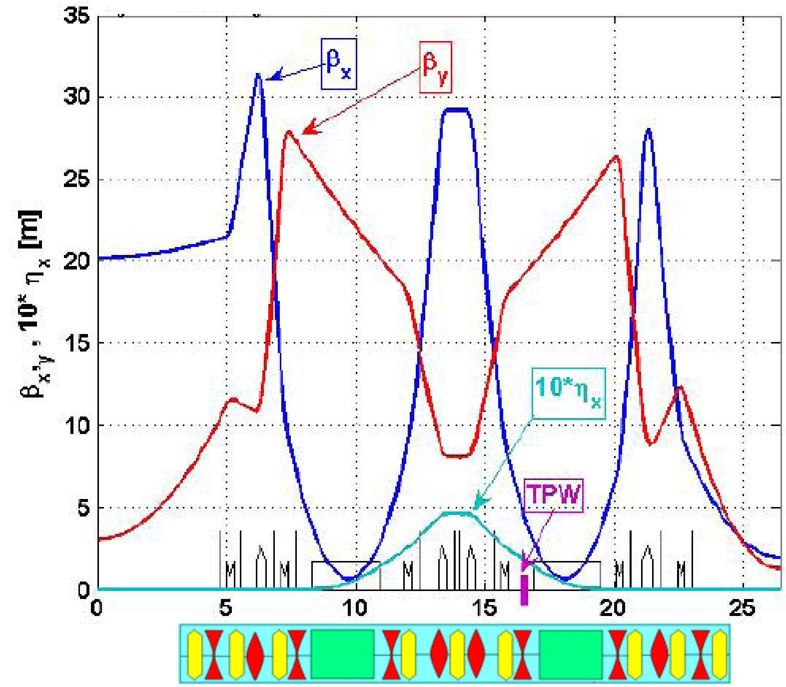
beam energy:	3 GeV
beam intensity:	500mA
Intensity Stability	0.5% ➔ Top-Off Injection mode
small beam emittance:	ε_x = < 1 nm rad,
	ε_y = 8 pm rad
orbital stability:	$\Delta y < 0.3\ \mu m$
RF Phase Stability	0.01 Degree
Number of beamlines	> 60

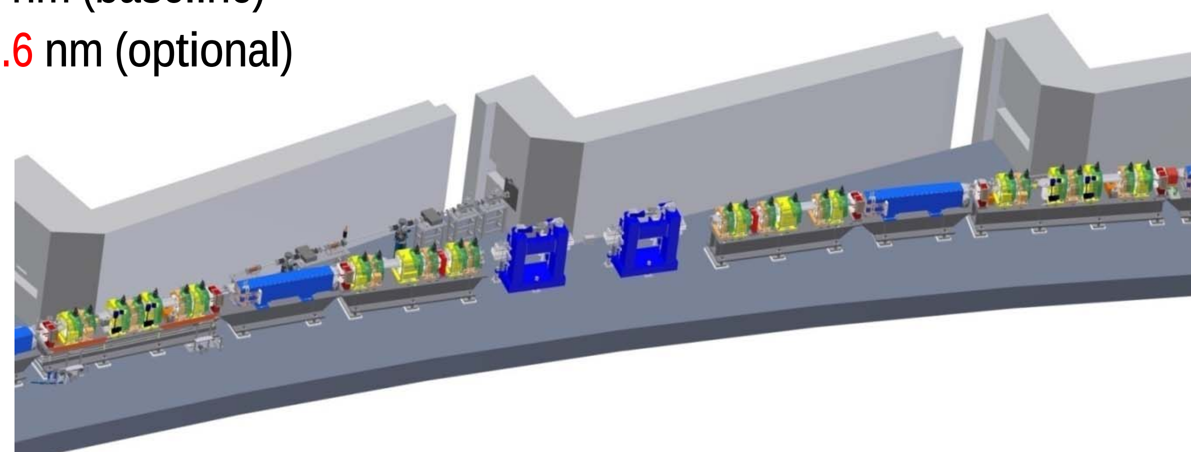
Low Emittance Lattice Design

- **Large Circumference** 792 m
  30 DBA cells $\varepsilon_x \sim N_{cell}^{-3}$

- **Soft Bending Magnet** B= 0.4 T
  $\beta_{x-max} \sim \xi \sim 1 / L_{bend}$
  ➔ Achieve close to theoretical minimum emittance without excessive chromaticity ε_x= 2 nm

- **Soft bend**, low radiation loss Emittance ~ $1/\rho$
  low radiation loss, 283 keV/turn/electron
  ➔ efficient use of **damping wigglers** to reduce emittance by increased betatron damping rate
  3 x 2 x 3.5 m wiggler @ 1.8 T: ε_x= 1 nm (baseline)
  8 x 2 x 3.5 m wiggler @ 1.8 T: ε_x= 0.6 nm (optional)





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Facility Overview

(1) Accelerator Tunnel 3.7m x 3.2 m x 792m

(2) Experimental Floor, width 17m

(3) 200MeV S-Band LINAC

(4) 3GeV Booster Synchrotron C=158m

(5) RF Building, lq. He Plant

(6) Compressor Building

(7) Central Cooling Tower

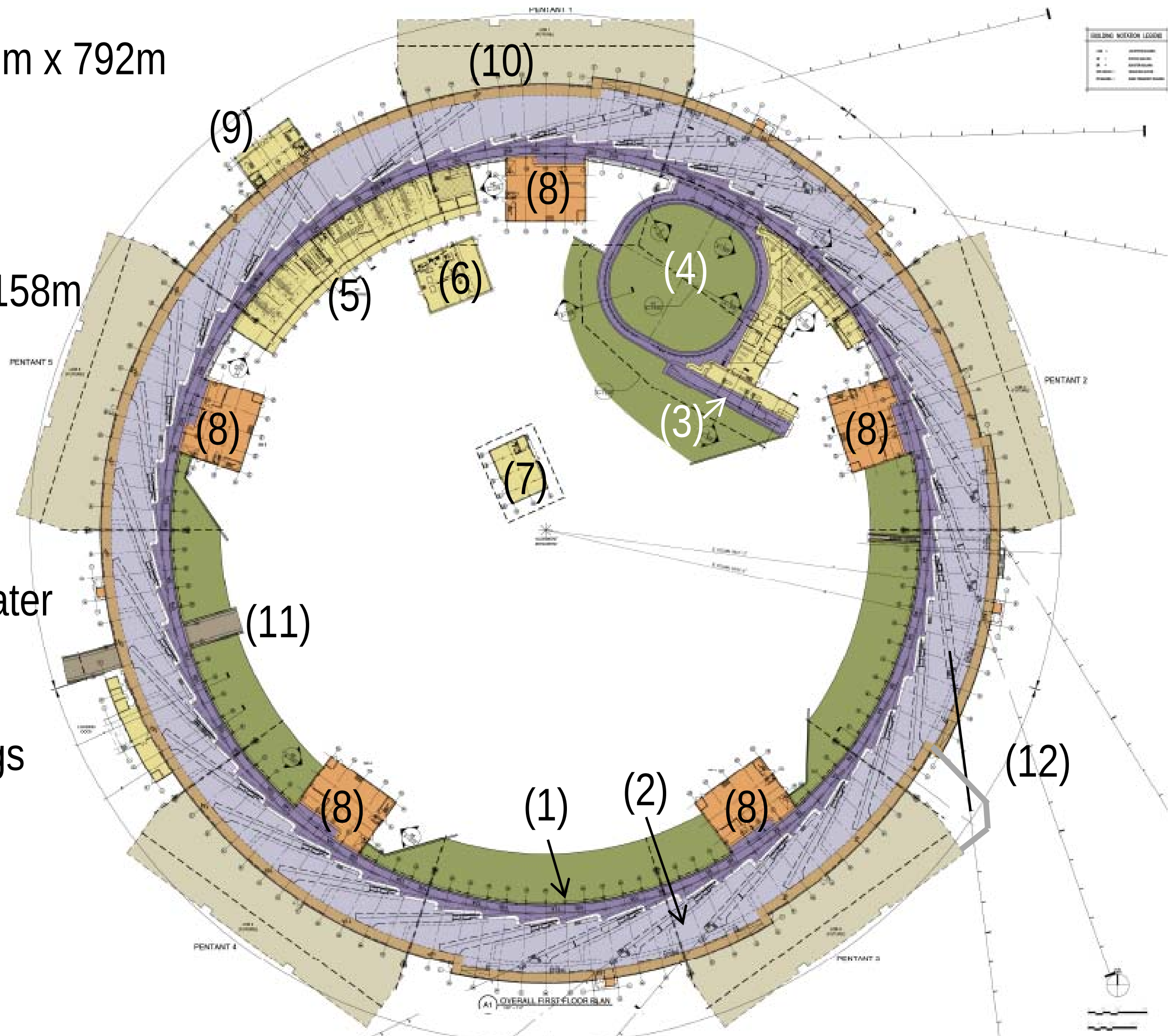
(8) Service Buildings: HVAC, DI water

(9) Lobby

(10) Laboratory and Office Buildings

(11) Vehicle underpass

(12) Extra long beam line



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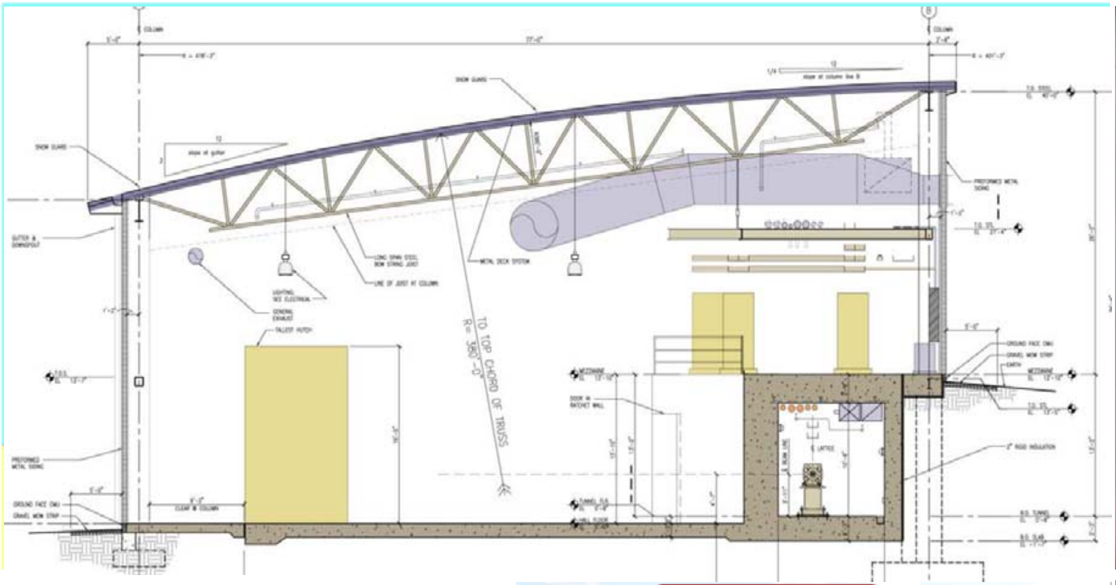
Facility Overview



Staged Availability Building

1st pentant:	Mar 15 ’11
RF	May 18 ’11
Injector	Jul 28 ’11
2nd Pentant	Jun 2 ’11
3rd Pentant	Sep 27 ’11
4th Pentant	Nov 28 ‘11
5th Pentant	Feb 9 ’12

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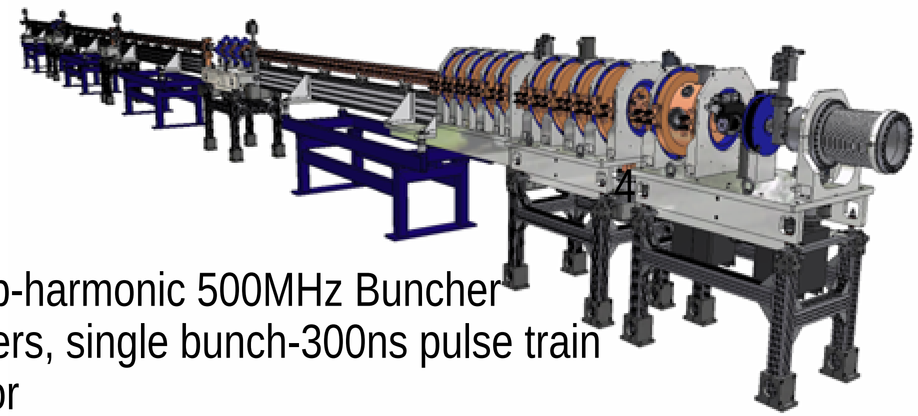
NSLS-II INJECTOR

on-energy top-off injection with 1/min top-off rate



200 MeV LINAC

Frequency	S-Band
Charge	15nC
$\Delta E/E$	<1%

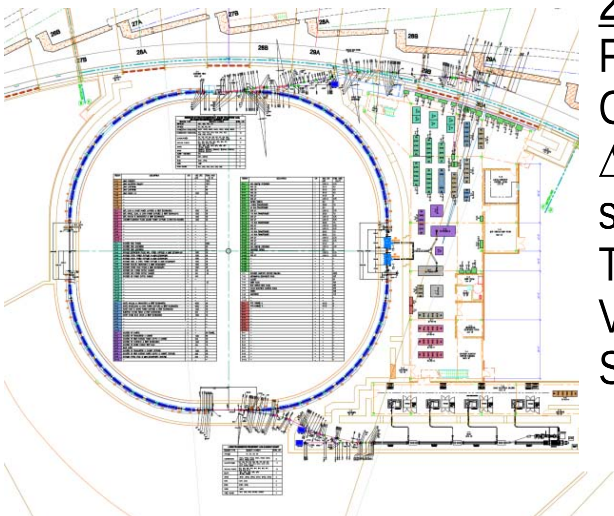
4

sectors

Thermionic Gun Sub-harmonic 500MHz Buncher

Variable bunch patters, single bunch-300ns pulse train

Solid state modulator

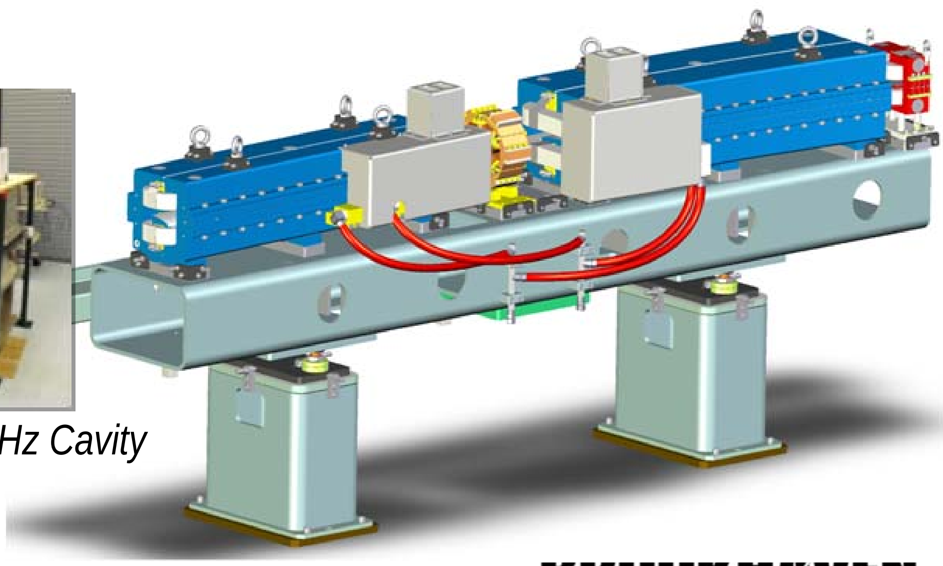


3 GeV Booster

Combined Function Lattice

Circumference	158m
Injection Energy	200Mev
Extraction Energy	3GeV
Cycle Frequency	1Hz
Charge	10-15nC @20-30mA

PETRA &-cell 500MHz Cavity



Injector Status

- Injector **Building** Ready July 28, 2011

- **LINAC** Turn Key Contract Award   April 2010 (RI)

Design Complete

production of components in progress

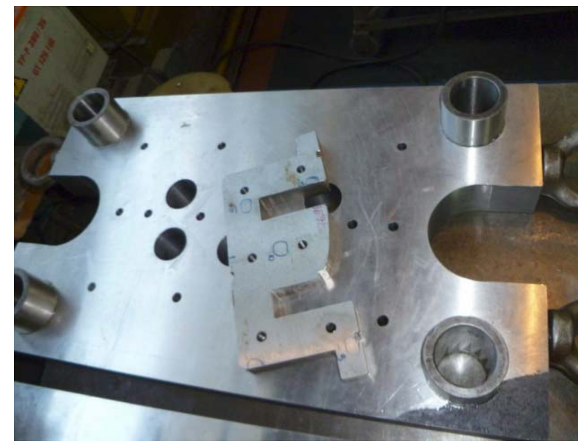
Frontend Delivery: June 2011

LINAC Delivery and start Installation August 2011

- **Booster** Semi-turnkey Contract Award: May 2010 (BINP)

Design Finalized, Prototypes of components being produced

Booster Installation : Spring 2012



Critical Subsystems with Novel Features

Magnet Systems

- high field quality,
- micron mechanical reproducibility,
- 30 micron alignment tolerance
- 25 nm mechanical stability

RF

- High Beam loading,
- High RF phase stability
- bunch lengthening

Instrumentation

- Sub-micrometer BPM
- Pico-meter emittance measurements

Controls

- High speed real time deterministic data communication
- Integrated high level controls
- Integrated equipment database

Power Supplies and Electronics

- High reliability

Insertion Devices

- high field quality
- novel materials

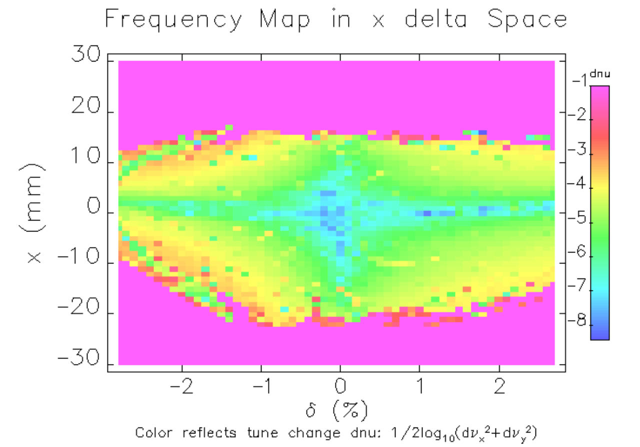
Magnet Field Quality

Medium energy (3GeV) + High intensity (500mA) + low emittance (<1nm, 8pm) beam

➔ Lifetime strongly dominated by Touschek effect

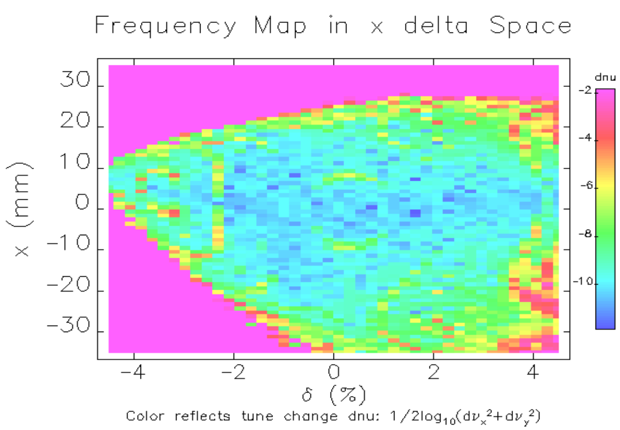
Low emittance lattice with moderate chromaticity and highly optimized sextupole fields
(3 chromatic families, 6 families for nonlinear optimization)

➔ Dynamic aperture fair: 15 mm x 3 mm @ 2.5% momentum deviation @ $\tau_{Touschek}$ =3 hrs



- Large Dynamic Aperture shrinks for quadrupole and sextupoles with "normal field quality

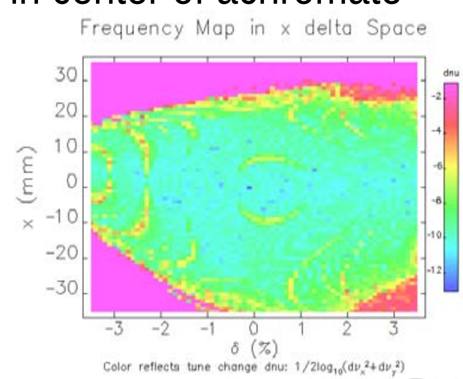
➔ small field errors required: systematic errors $\Delta B/B=10^{-4}$, nonsystematic $\Delta B/B10^{-5}$ @ 25mm



Allowed Relative Field Error Quadrupoles @ r=25, x 10^{-4}

	Normal Aperture		Large Aperture	
n	norm	skew	norm	skew
Symmetry-allowed				
6	3	0	0.5	0
10	3	0	0.5	0
14	3	0	0.1	0
Symmetry-unallowed				
3	2	2	3	1.5
4	2	1	2	1
5	1	1	0.3	0.1
6	-	1	-	0.1
7-9	1	1	0.1	0.1
10	-	1	-	0.1
14	-	1	-	0.1
11-13,15	0.5	0.5	0.1	0.1

Need 90mm aperture quads in center of achromate



Storage Ring Magnet Systems
based on successful prototypes

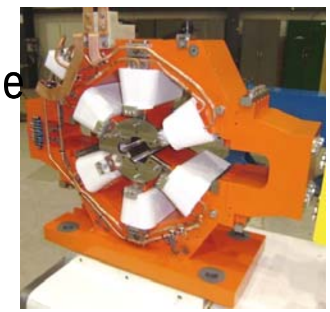
Normal Quadrupole Magnet 120 Units to be built by BINP

Wide Quadrupole 120 Units to be built by TESLA Ltd

156mm and 100 mm DC **dipole correctors** (192 units) to be built by Everson Tesla

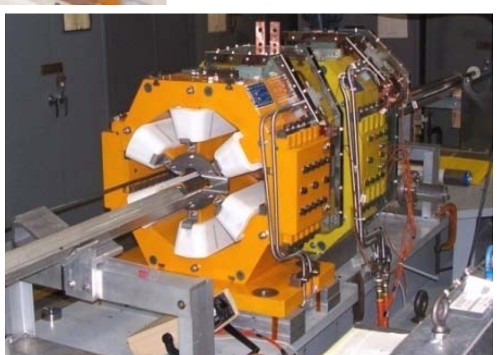
Normal Sextupole 169 Units to be built by Danfysik

Wide Sextupole 75 Units to be built by IHEP



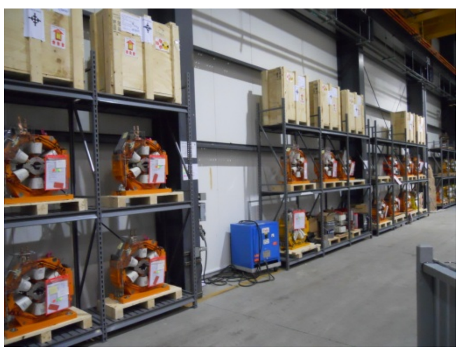
Dipoles 54 units 35 mm gap and 6 units with 90mm gap to by built by Buckley

30 **large aperture** sextupoles and 60 large aperture quadrupoles To be built by Buckley Industries

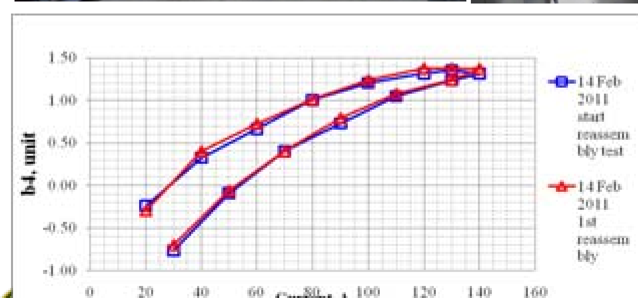


Magnet Production

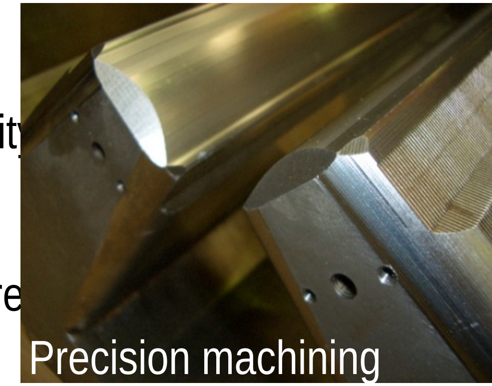
- 7 Contracts awarded in Fall 2009
- All manufacturers made large effort to meet high and reproducible field quality
- ~ 6-12 months development needed before production could start
- Advanced Production methods provide 10 micron precision of pole structure and 3 micron mechanical reproducibility
- Magnet production is taking off and ~15% of production is completed

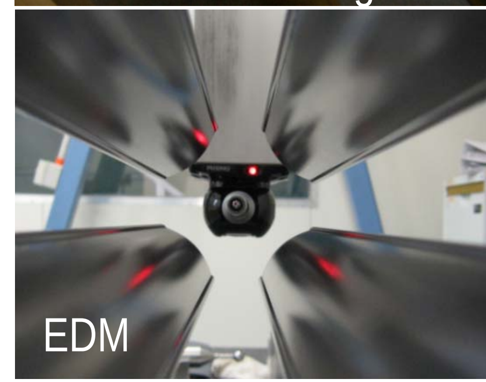


Magnet acceptance Testing at BNL



Remarkable reproducibility after de-assembly-reassembly

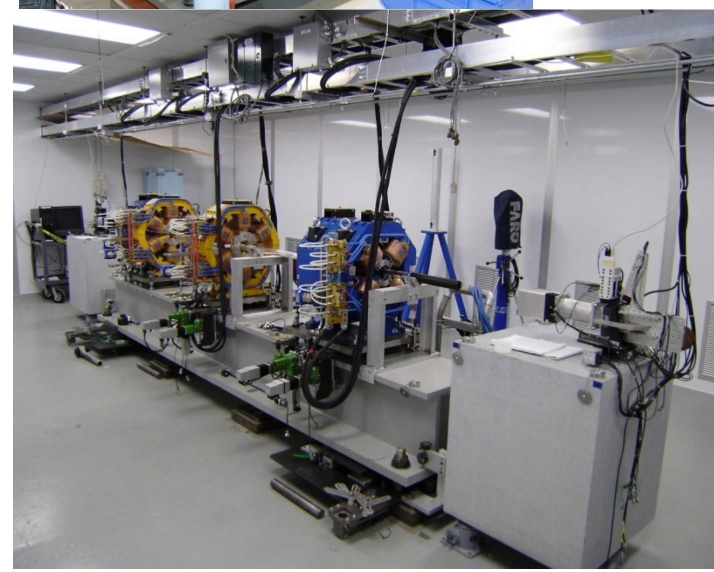

Precision machining


EDM


Fine planking

Girder, Supports and Integration

- Girder girders have been designed and manufactured for low vibration response (f_{res}>30Hz) and high thermal stability
- Visco-elastic layers in supports are an important feature
- A precision alignment procedure based on stretched wire with AC current was developed which allows to measure magnet center with 5 μm precision
- Intricate procedure to align the magnet and secure high precision alignment while girders are transported and installed developed
- Alignment performed in temperature controlled enclosure Which mimics tunnel conditions
- Procedure fully tested
- First girder equipped with magnets, vacuum components and diagnostic equipment



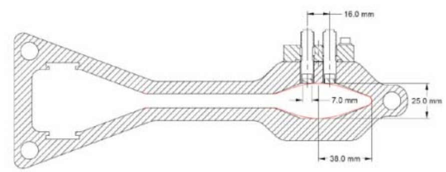
Environmental Room ($\Delta T < 0.1$ C) for 30 μm Precision Alignment

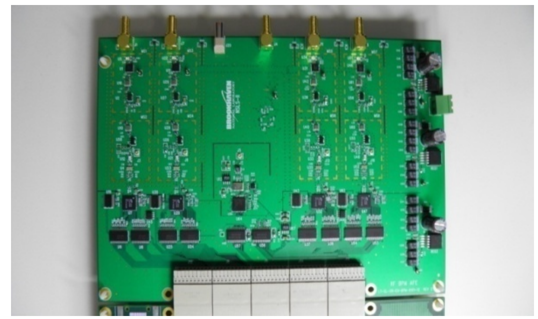
First Fully Integrated NSLS-II Magnet Girder

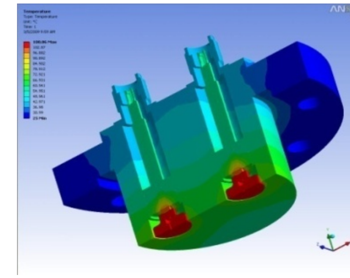
Instrumentation-BPM System

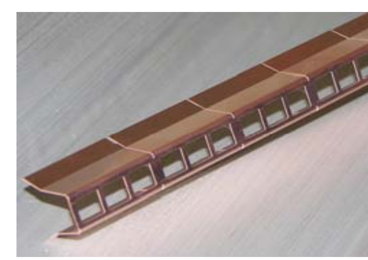
- New improved Button Monitor, Boron-Nitride Heat distribution washers avoid beam heating issues
- In-house development BPM electronics. 500MHz band pass filter, sampling at 117MHz, pilot tone mixed with beam signal for continuous relative calibration of channels
- Beam test at ALS confirm: meet demanding NSLS-II requirements resolution0.2 μm, stability 0.2μm)
- Detrimental TE (H) modes in keyhole-shaped beam pipe exited by beam

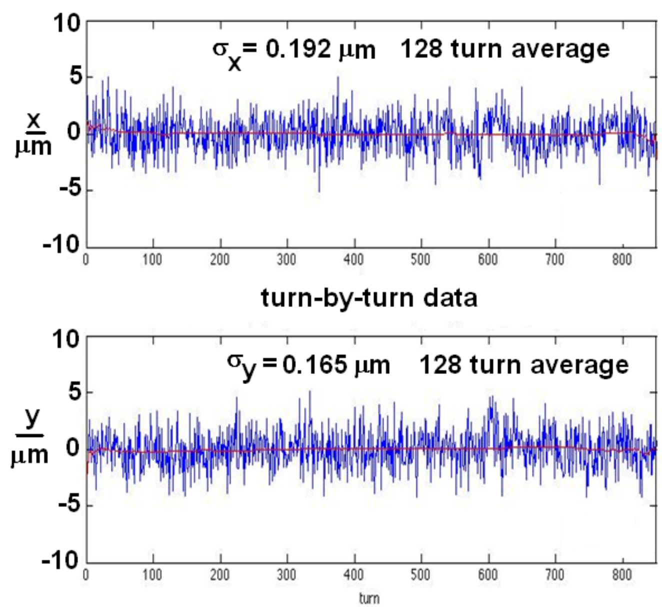
➔ RF shield separates beam- from ante-chamber











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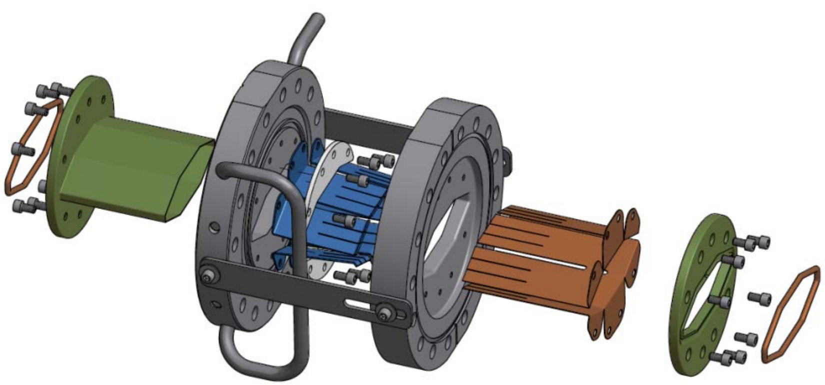
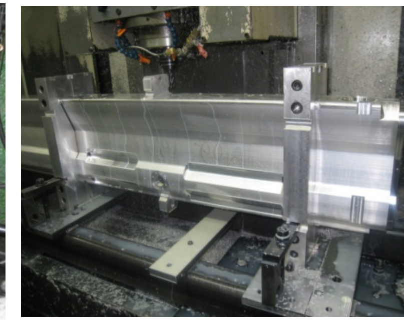
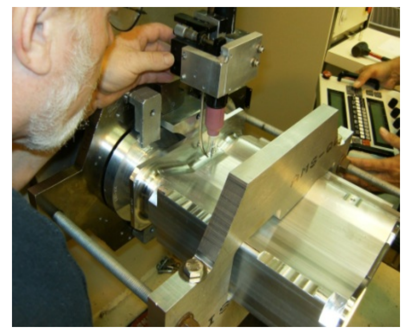
Vacuum System

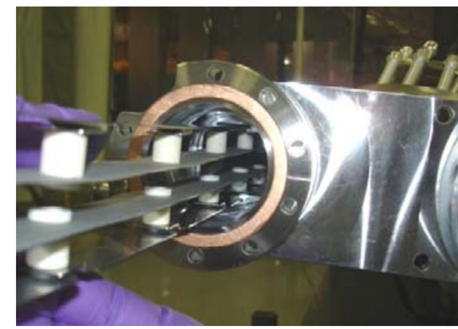
- Vacuum System Based on extruded Aluminum
- Multistage production with final integration in-house
- Status: ~1/3 of chambers ready for installation

- Glidcop masks absorb synchrotron radiation
- New Design Shielded Bellow, Ag+Rh coated sleeves
- First Units being manufactured in-house









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Storage Ring RF

Requirements

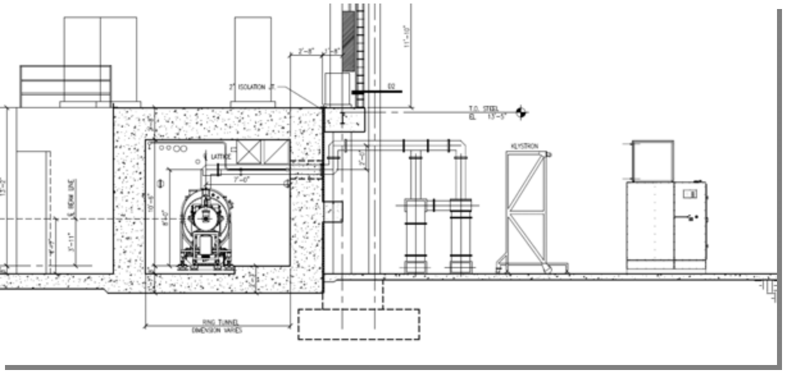
	Baseline Capability with 2 RF Cavity Systems Required Voltage 3.3 MV		Fully Build-out Capability with 4 RF Cavity Systems Required Voltage 5 MV	
	#	P(kW)	#	P(kW)
Dipole	60	144	60	144
Damping wiggler	3 (21 m)	259	8 (56m)	517
Cryogenic-PMU	3	76	6	127
IVU	2	33	4	66
Additional devices	~7	120	~10	200
TOTAL		529		1003
Available RF Power		540		1080

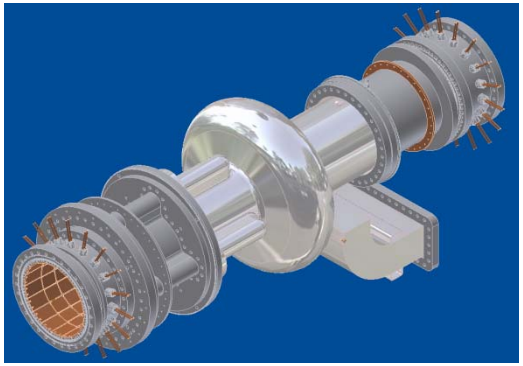
RF Stability Requirements

	$\Delta\varphi$ (deg)	$d\delta$ ($\times10^{-4}$)
Centroid jitter due to Residual dispersion (ID's)	0.81	3
Vertical Divergence (from momentum jitter)	2.4	9
Dipole, TPW (position stability due to momentum jitter)	0.27	1
Timing experiments (5% of 15ps bunch @>500Hz)	0.14	0.5

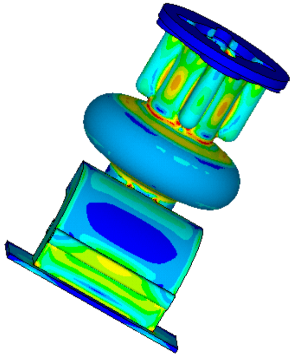
Cavities: Superconducting single cell 500mHz Cavities
Reasons: more economic on the long term, better beam loading performance
RF Power Source: Klystron Amplifiers 310kW
Passive superconducting 3rd harmonic cavity for bunch lengthening

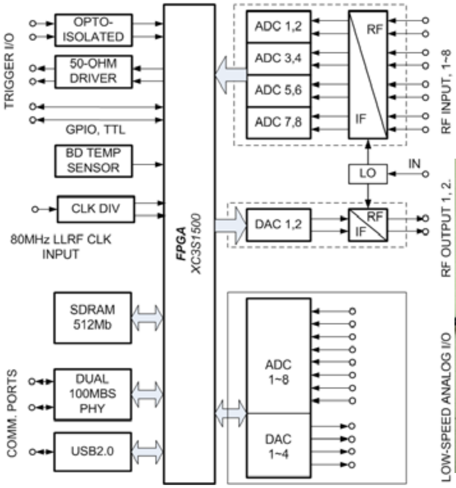
Storage Ring RF System





- Single cell 500 MHz SC Cavity: CESR-B Design
  - Updated design to comply with safety regulations,
  - Input coupler adaption
- 310 kW klystron RF transmitter,
  - Turn-key, - in production
- In-house development LLRF Controls
  - -FPGA based control module, designed, fabricated, tests performed
  - -Extensive LLRF modeling,
  - -Future option for adaptive feedback for optimized control





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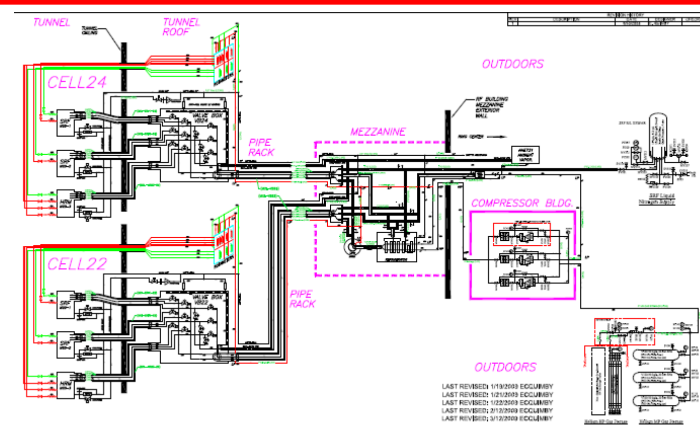
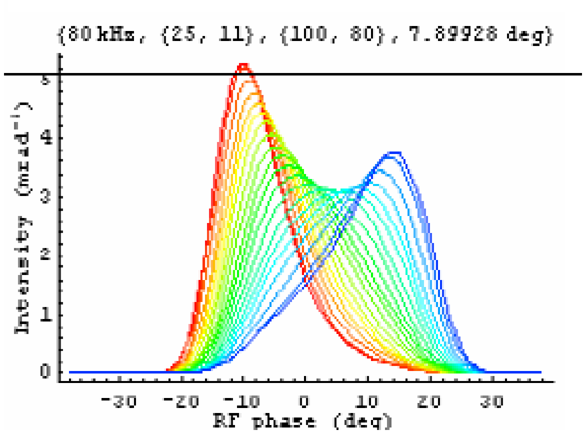
RF Systems



Lq He Cryogenic Plant
900W lq. He Plant
Turn-key system in production

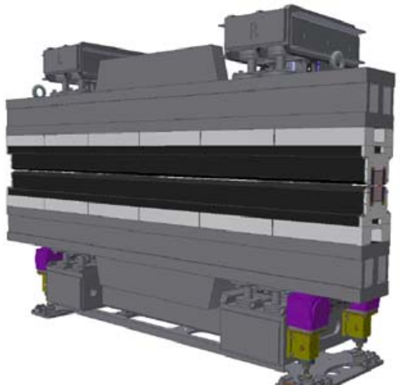
3rd Harmonic Cavity
-Bunch lengthening factor 2-3
-Margin for Touschek lifetime
-New design
-Production in collaboration with Industry (SBIR)
-Low power test successful



Insertion Devices

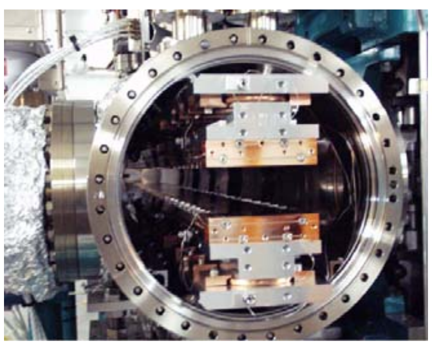
Damping Wiggler 1.8T

6 x3.5m in production

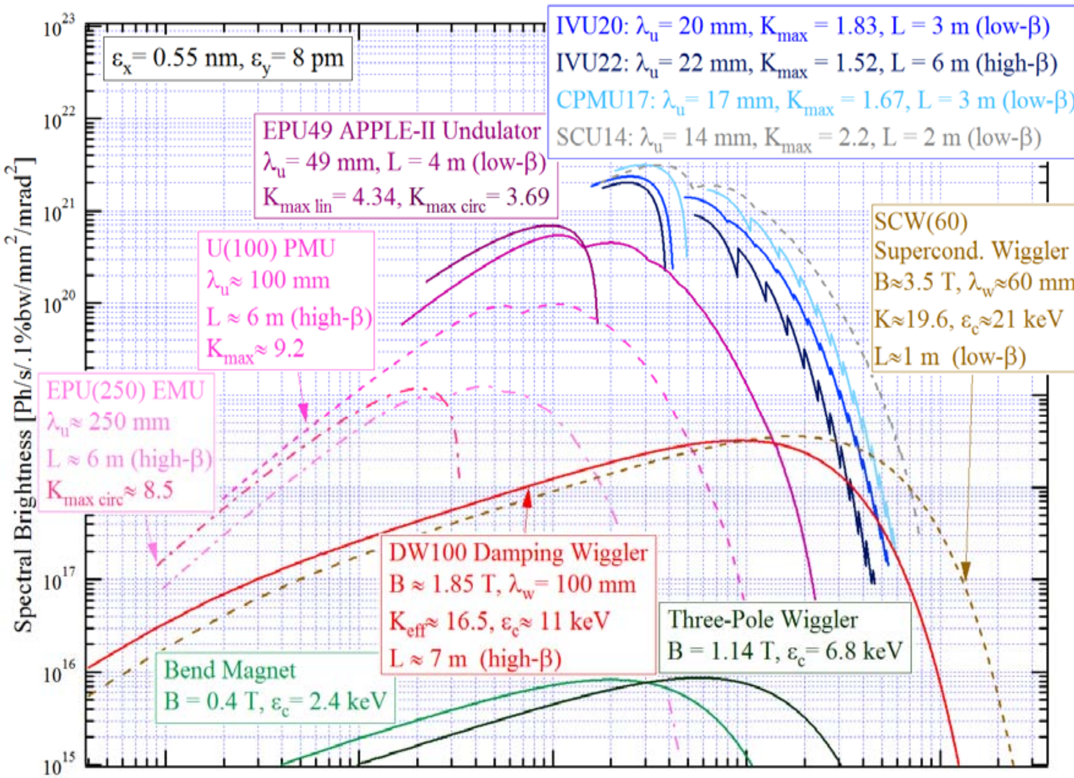


IVU 20,21,22

Design complete



Brightness of NSLS-II radiation devices

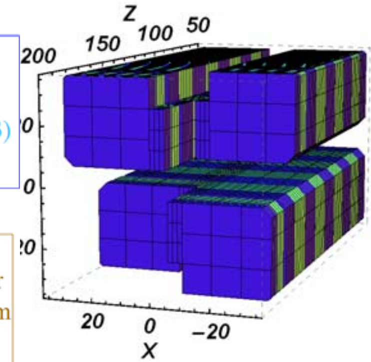


10 eV 100eV 1 keV 10keV 100 keV

Photon Energy

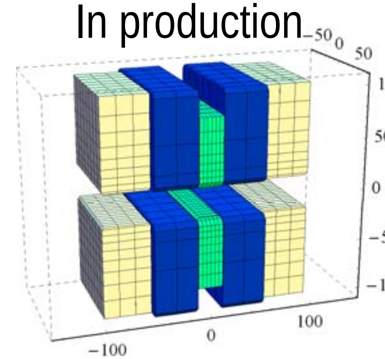
EPU

contract award



3 Pole Wiggler

In production



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NSLS-II Insertion Devices

Name	U20	U22(IXS)	EU49	U21(SRX)	DW-1.8T	3PW
Type	IVU	IVU	EPU	IVU	PMW	PMW
Photon energy range	Hard x-ray (1.9-20keV)	Hard x-ray (9.1keV)	Soft x-ray (250eV-1.7keV)	Hard x-ray (1.9-20keV)	Broad band (<10eV-100keV)	Broad band (<10eV-100keV)
Type of straight section	Short	Long	Short (canted)	Short (canted)	Long (in-line)	near 2nd Dipole
Period length (mm)	20	22	49	21	100	-
Length (m) & Number of Devices	3.0 x 2	3.0	2.0 x 2	1.5	3. 5 x 6	0.25
Number of periods	148	135	36 x 2	69	34 x 2	0.5
Magnetic gap (mm)	5	7.0	11.5	5.5	15.0	28
Peak magnetic field strength B (T)	1.03	0.78	0.57(Heli) 0.94 (Lin) 0.72(vlin) 0.41 (45°)	0.9	1.80	1.14
Keff	1.81	1.52	2.6(Heli) 4.3 (Lin) 3.2(vlin) 1.8 (45°)	1.79	18.0	-
hν fundamental, eV	1620	1802	230 (Heli) 180 (Lin) 285(vlin) 400 (45°)	1570		
hν critical, keV					10.7	6.8
Total power (kW)	8.0	4.7	8.8	3.6	64.5	0.32

Insertion Devices-New Materials

Successful Tests with Pr-Fe-B

Will be operated at

Lq N2 temperature,

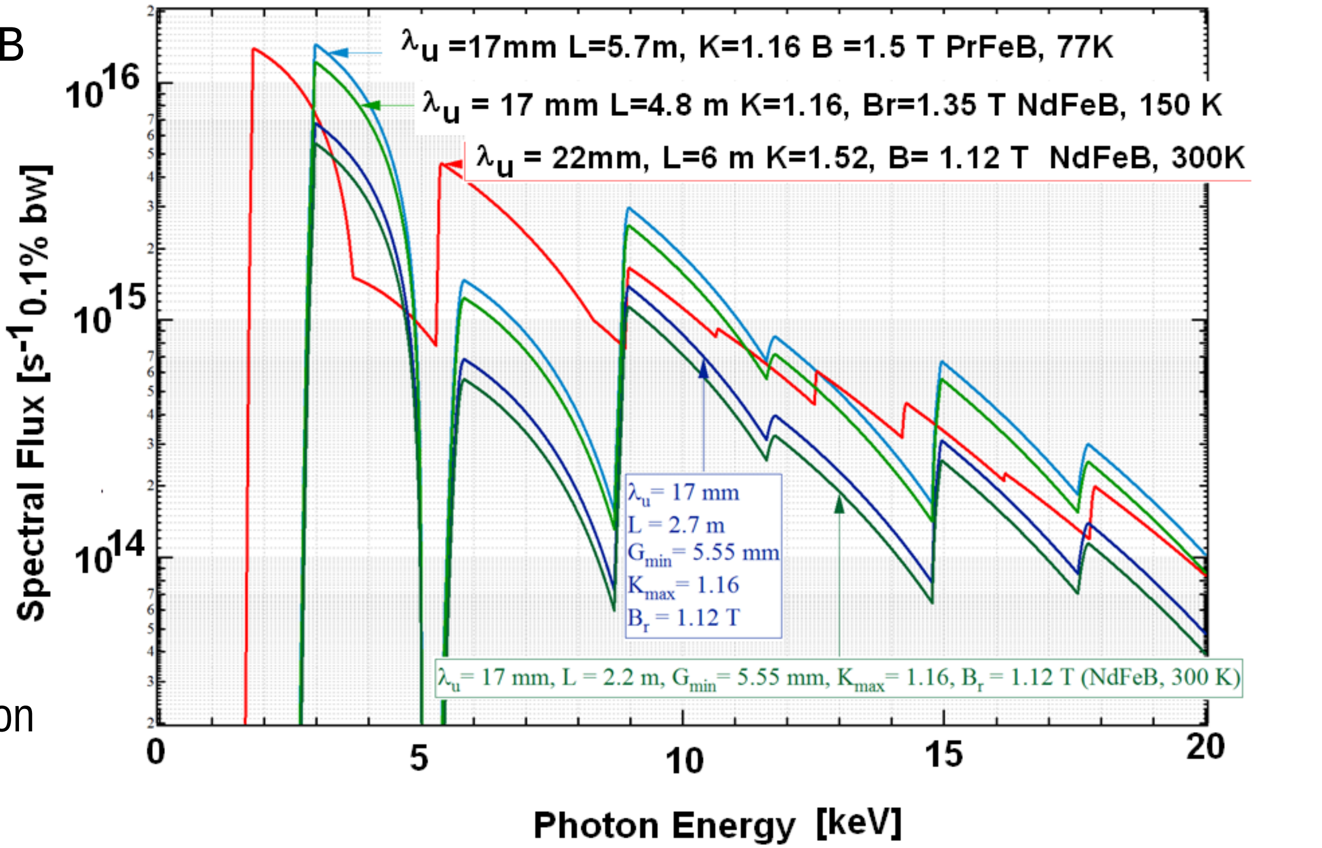
Fairly flat temperature coefficients

➔ Stable operation with enhanced B_r

Vacuum bakeout tests in

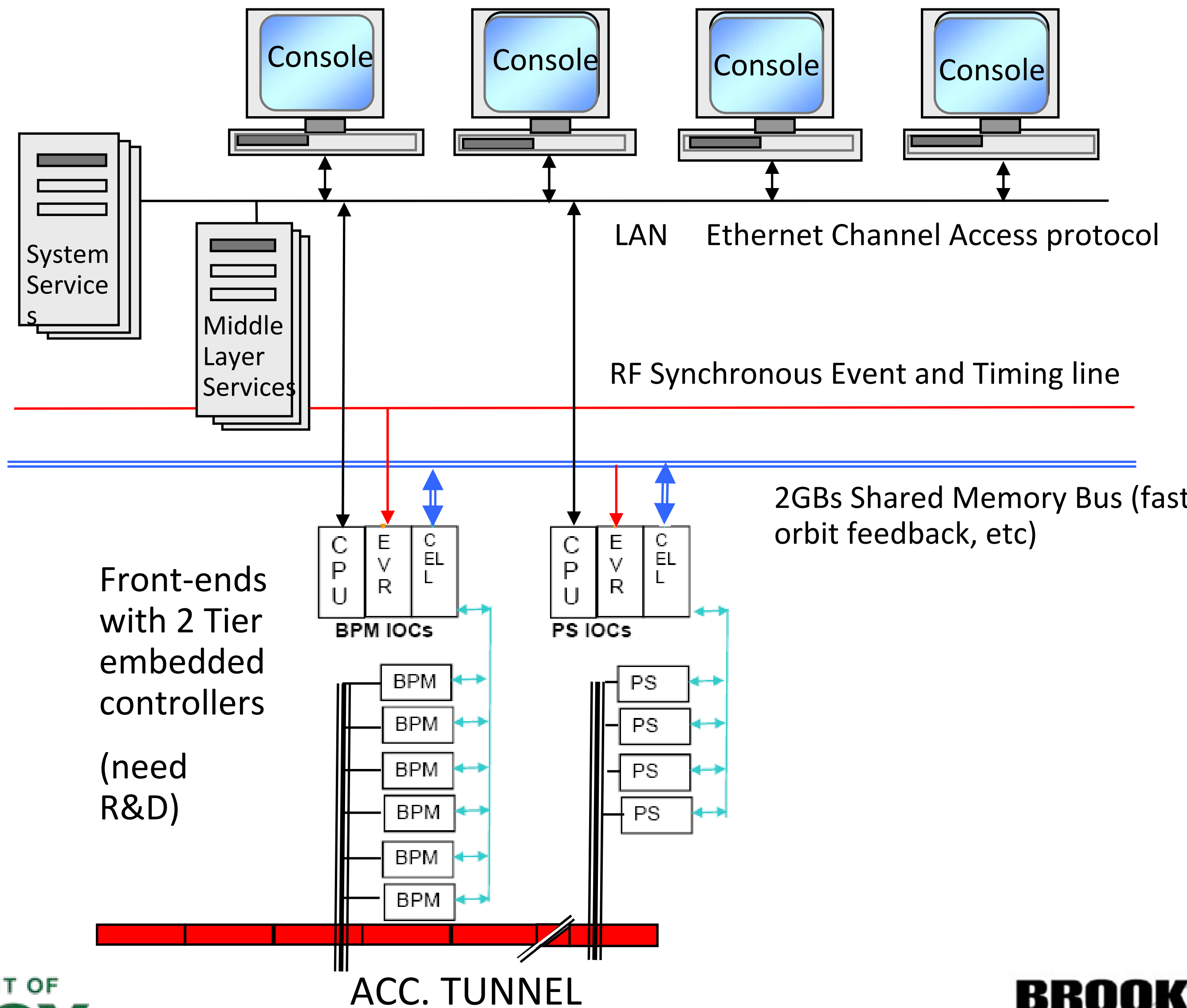
Progress

Magnet test araay in production



Control System

EPICS protocol



Front-ends with 2 Tier embedded controllers

(need R&D)

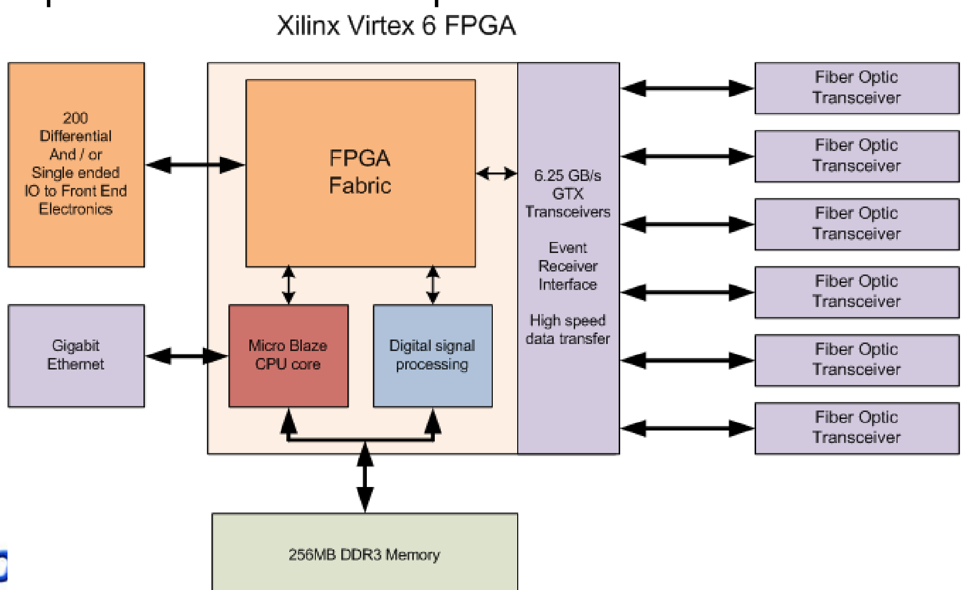
Digital Front End Electronics

BPM Application:

- Calculates beam position from Raw ADC inputs at 117MHz
- Stores 1 million Turn By Turn data points, 10KHz data points and raw ADC measurements
- Provides 10kHz position data for Fast Orbit Feedback

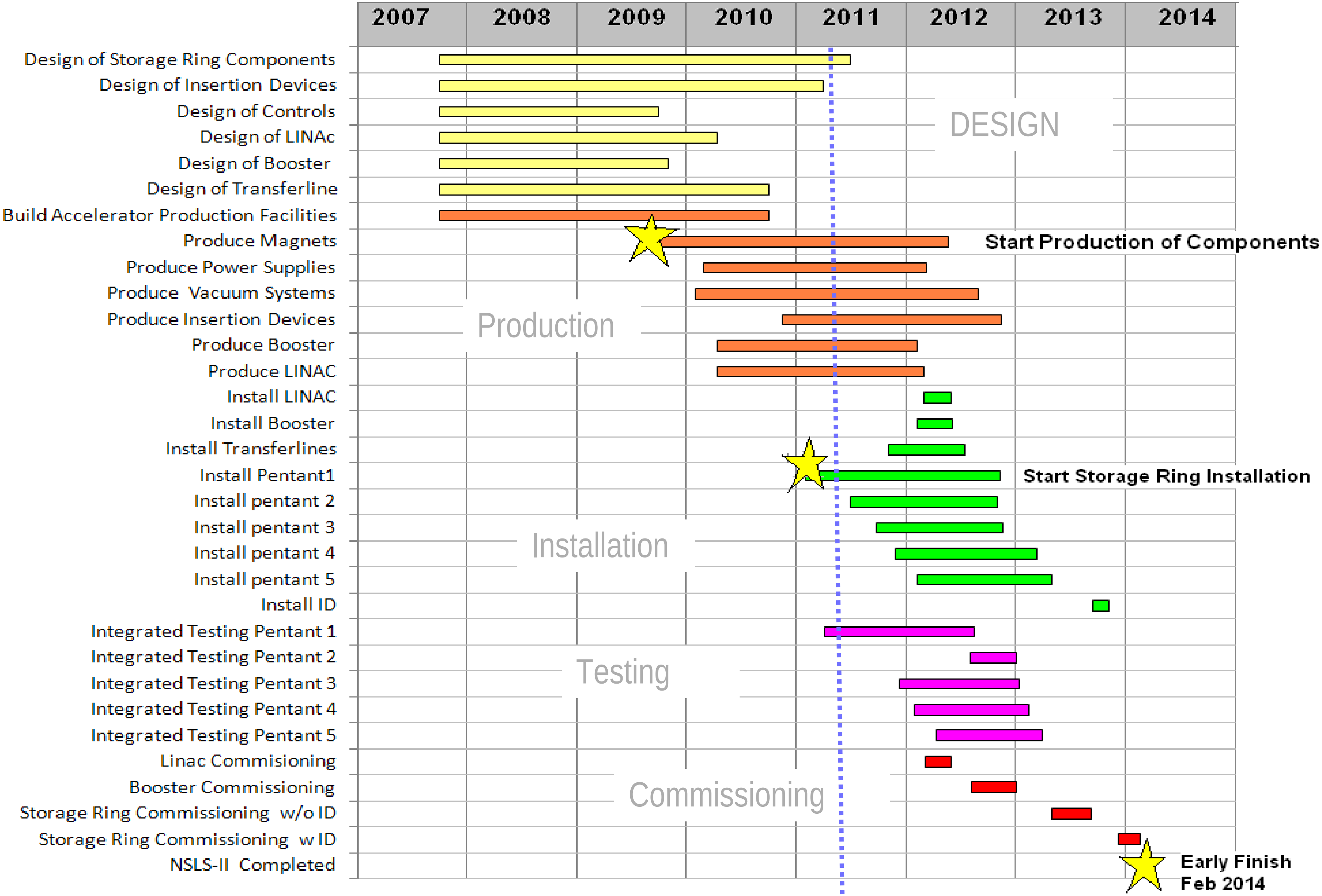
Cell Controller Application:

- Transfers all BPM measurements to all cells in less than 15us over redundant fiber optics
- Computes 90 parallel Eigenvectors in less than 4us for fast orbit feedback
- Responds to beam envelope violations in less than 100us for machine protection

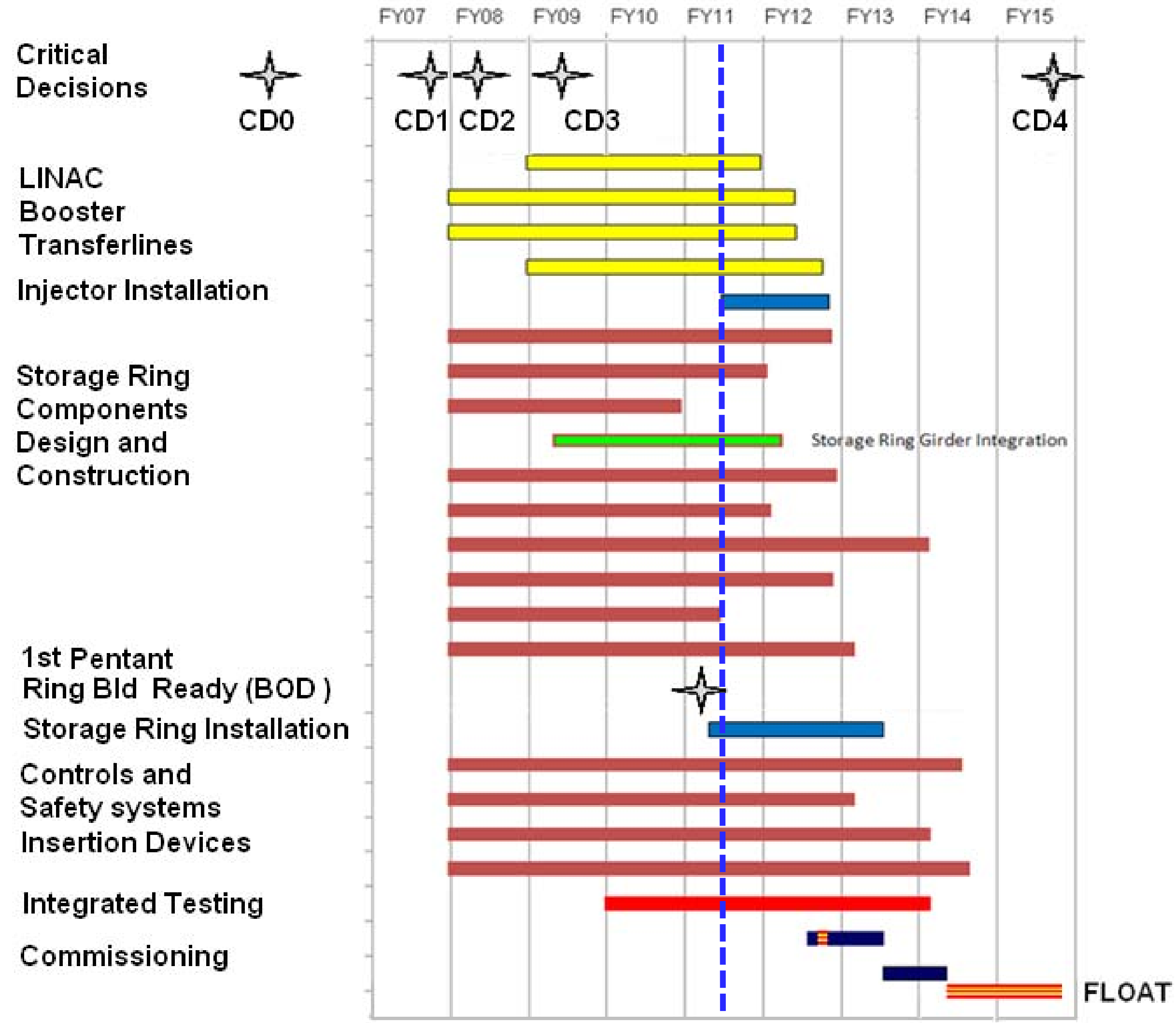


- High speed Serial Communication
- Gigabit Ethernet
- Large Memory
- On board CPU
- Digital Signal Processing

Accelerator Schedule



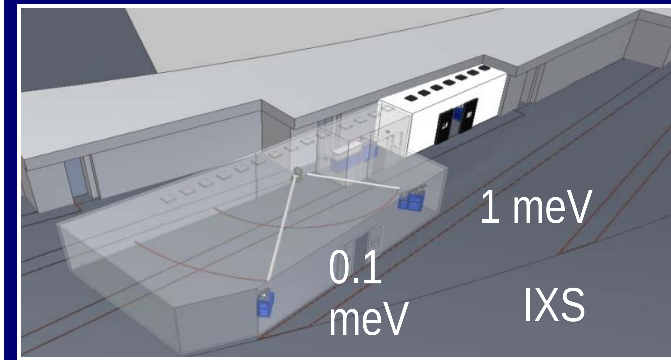
Schedule



U.S. DEPARTM ENERGY

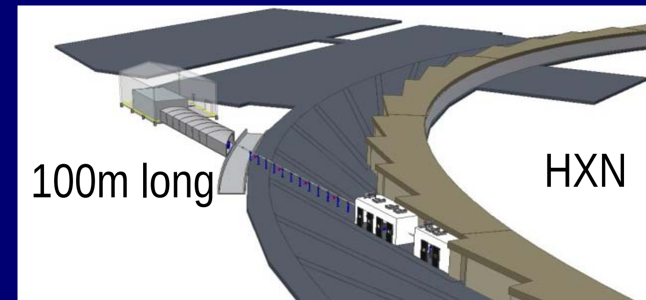
BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

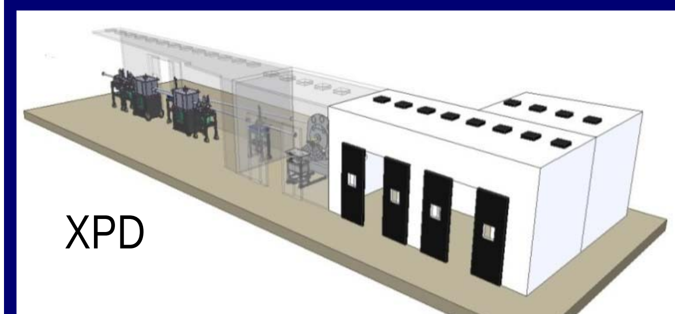
The Six Initial NSLS-II Beamlines



inelastic
x-ray scattering

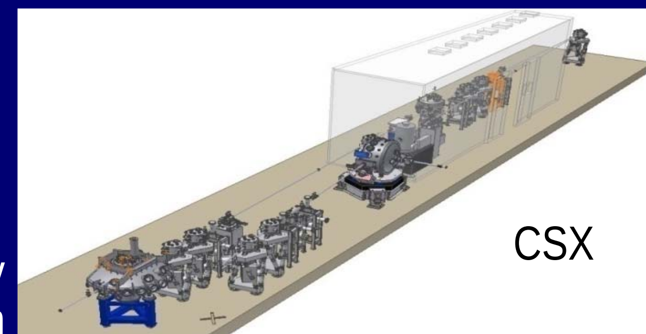
hard x-ray
nanoprobe

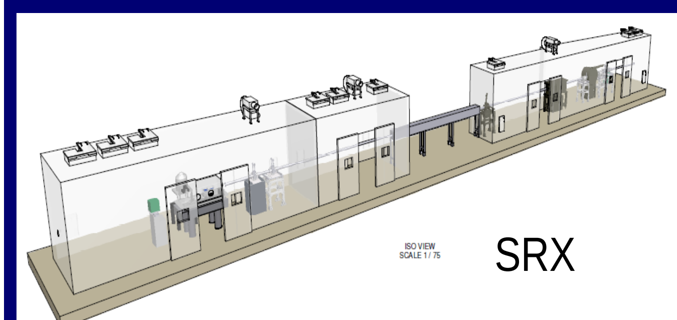




x-ray powder
diffraction

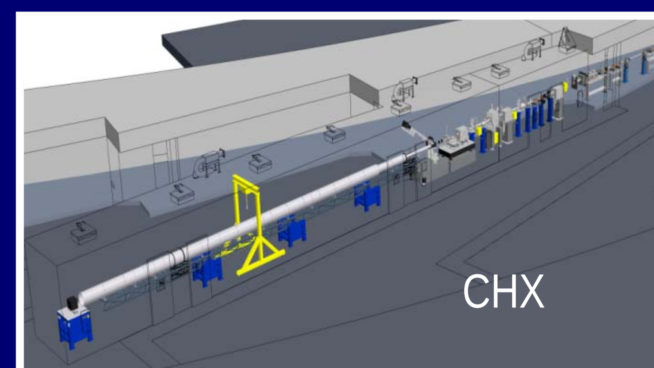
coherent soft x-ray
scattering/polarization





sub-µm resolution
x-ray spectroscopy

coherent hard
x-ray scattering



Conclusion

- NSLS-II is a 3rd generation light source using cutting edge accelerator technology
  - Magnet production
  - Alignment
  - instrumentation
  - Insertion devices
  - Controls

to meet the desired performance, a brightness of 10^{21} 2keV photons per (mm^2mrad^2sec,0,1%bw) needed to achieve 1nm spatial resolution and 0.1meV energy resolution

- Most of Accelerator Components are in production
- First Part of Ring Building available for installation
- Installation of components has started
- Linac will be installed and commissioned this year
- Storage Ring Commissioning will start in May 2013
- Project Early completion is envisioned for February 2014

NSLS-II PAC'11 Contributions

Lattice Design: THP189, THP190, THP129,

Accelerator Physics: WEP176, MOP192, WEP217,THP127, THP193, MOP276

Safety Systems: MOP274,

RF: FROBS4, TUP055,

Instrumentation: MOP211,MOP199, MOP198, MOP193, MOP266

Controls: WEODN4, MOP165

Injection systems: TUP211,THP131-135, THP215,WEP282-283

Insertion Devices: THOPS4,

Vacuum: THP216