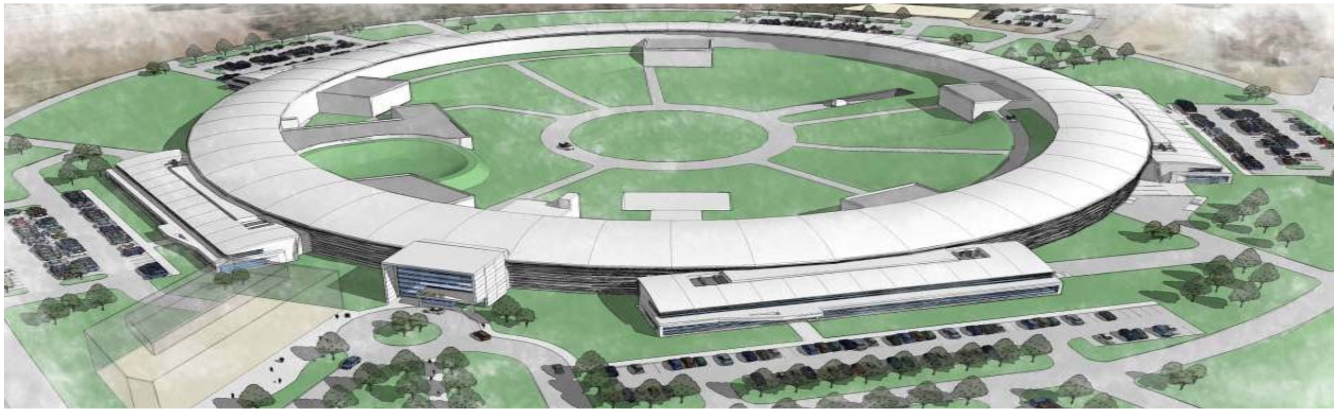
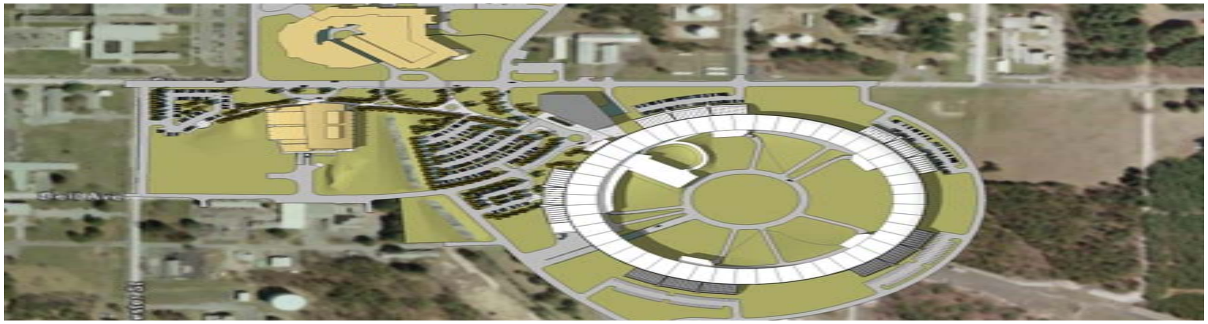
Accelerator Overview



3rd Accelerator Scientific Advisor Committee Meeting
Brookhaven National Laboratory
October 8-9, 2007

F. Willeke,
NSLS-II Accelerator Systems Division

NSLS-II Accelerator Complex



Novel 3rd Generation Light Source

Pushing the Beam and Radiation Parameters beyond State of the Art

Provides Ultra High Brightness and High Flux and Highly Stable Synchrotron Radiation Far IR to hard x-rays for a very large spectrum of applications

Main Design Goals

Beam Energy	$E = 3$ GeV
Quasi Constant High Beam Current	$I = 500$ mA $\Delta I/I = 1\%$
Small Radiation Source Size	
- horizontal Beam Emittance	$\varepsilon_x < 1 \ldots 0.5$ nm
- vertical Beam Emittance @ diffraction limited @12keV	$\varepsilon_y = \sim 8$ pm
Moderate Beam Energy Spread	$\Delta E/E = 0.1\%$ (RMS)
High Orbital Stability	$\Delta z, \Delta z' = 10\% \cdot \sigma_z, \sigma_{z'}$
Large Space for Radiation sources	$L_{UD} = 241$ m (31%) 56 Beam lines

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… Achieved by the following design features

• Large circumference	**C = 791 m**
• Large number of achromats	**N = 30**
• Robust Double bend Achromatic optics	**ε_b = 2nm @ 2 x** theoretical minimum
• Low bend field	**B = 0.4 T**
• ➔ low radiation loss	U_0=286kV
• Damping Wigglers for small emittance	**ε = 1nm** $= \varepsilon_0 \times U_0/(U_0+U_w)$
• Top-Up On-Energy Injection	

NSLS-II Accelerator Complex Overview

Large Storage Ring C = 931m
with 30 Double Bend Achromats

30 Straight Sections

- 15 long (9.3m)
- 15 short (6.6m) Straight

Including:

1 Injection (long) Straight

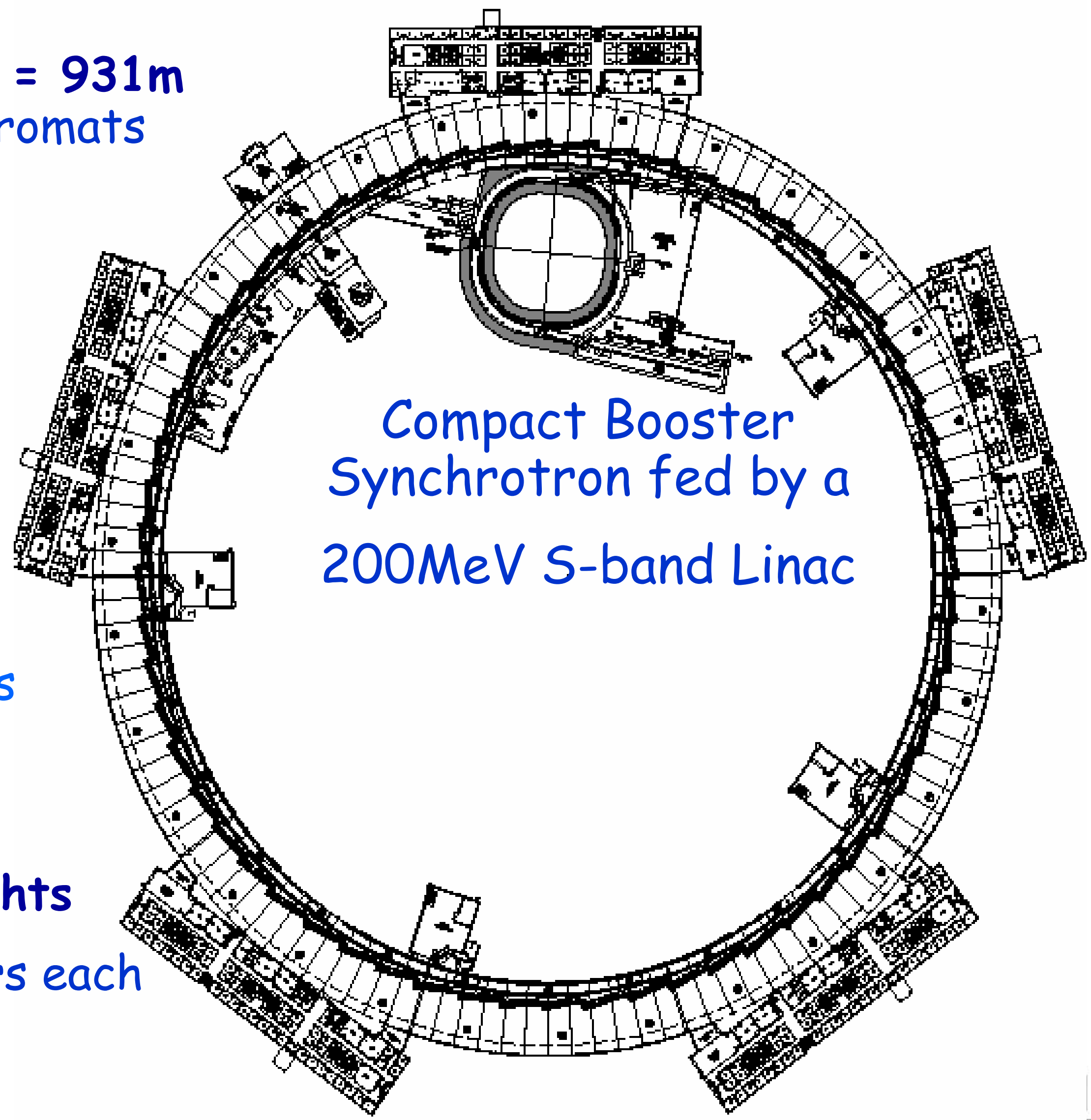
2 RF (long) Straights with

2 SC Single Cell 500 MHz Cavities

1.5 GHz passive S.C Cavity
for bunch lengthening

3-6 Damping Wiggler Straights

2x3.5m 1.8T Damping Wigglers each



Base Line Performance Goals

To support the initial scientific goals of the NSLS-II Project requires the following performance of the accelerator systems:

- Stored electron beam energy of 3 GeV
- Stored charge to provide stored current of 500 mA
- Top-up injection to maintain current stability of better than 1%
- Electron beam emittance ~ 1 nm-radian (horizontal)
- → implies 21 m or 3 x 2 x 3.5m of 1.8 T Damping Wigglers
- Diffraction limited vertical emittance at 12KeV (8pm)
- Electron beam stability to better than 10% of beam centroid
- Six fully equipped Straight sections with insertion devices and front-ends
- Capability to increase number of beam lines to 56

CD4 Design Goals

Necessary deliberate delay of components to match funding profile:

- Only 2 of the 6 baseline beam lines will be installed
- The 2nd RF system will not be available from day 1
  (2 RF cavities but only one transmitter in the baseline)
  this will limit the beam current to 300mA initially
- Damping wigglers will not be installed (but procured) initially

CD4 Accelerator criteria:

Beam energy of 3GeV
Beam Current of 25mA
Two active beam lines

Recent Scope Reductions

- Options to operate at 3.6GeV by margin in PS's, magnets and process water has been given up for cost reasons
- CPMU has been replaced by IVU because of large technical risk to meet baseline requirements and to save costs (CPMU requires independently funded R&D program)
- Three pole wigglers not in baseline funding
- Active RF systems to be supplied by the project reduced from 2 to 1
- Scope reductions in Building: Tunnel roof thickness deduced to 85cm, Tunnel floor thickness reduced to 91cm, 2.5 LOBs, …

Further Scope Contingency: is limited to ~5M$

Injector

Requirements on Injector Complex to support Design Goals include

- Top Energy 3GeV
- Multi-bunch operation
- RF Frequency 500MHz
- Harmonic Number integer fraction of 1320
- High reliability
- Fast Storage ring fill time
- Continuous operation to support 1/min top-up → Low losses
- Bunch to bunch intensity variation in SR → Variable and controllable bunch population
- No impact on Storage Ring Orbital Stability

Injector Progress since April07

- Linac reduced to features which support baseline
- Linac building and klystron gallery optimized
- Preliminary design of booster developed
- Lattice flexibility, orbit correction capability etc ensured
- Instrumentation plan refined
- Procurement plans for booster RF modified
- Booster building optimized
- LTB & BTS Transfer-lines conceptual design completed
- Conceptual design of Injection Straight iterated and completed, preliminary design being developed
- Considerable effort in reassessing the injector cost

Injector Main Specifications

LINAC

Linac Energy	200 MeV
Linac RF Frequency	3 GHz
Linac Charge	15 nC
Linac Pulse Length	300 ns

100MeV 10nC Soleil-Linac Performance

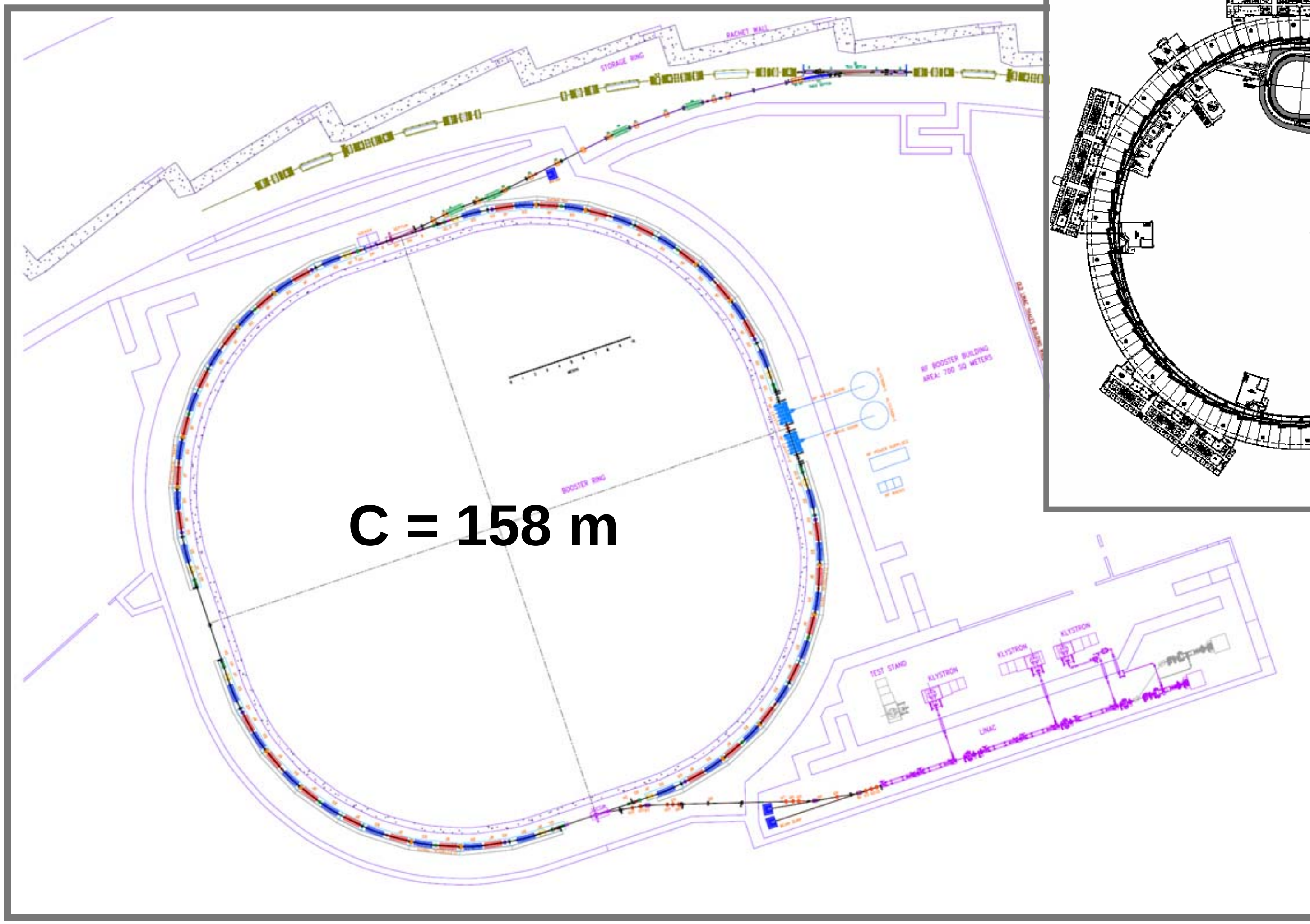
BOOSTER

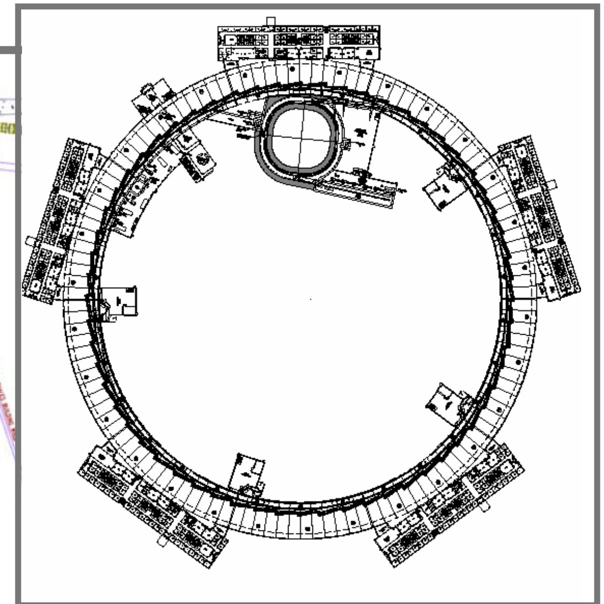
Injection Energy	200 MeV
Injection Efficiency	> 76%
Top Energy	3 GeV
Acceler. Beam Loss	<10%
RF Frequency	499.6 MHz
Beam Current	30 mA ➔ 16 booster cycles to fill S.R.
Bunch Current	142 mA ➔ can support 1/1min top-up

Injector Repetition Frequency 1 Hz

LINAC planned as turn-key procurement

Injector Footprint





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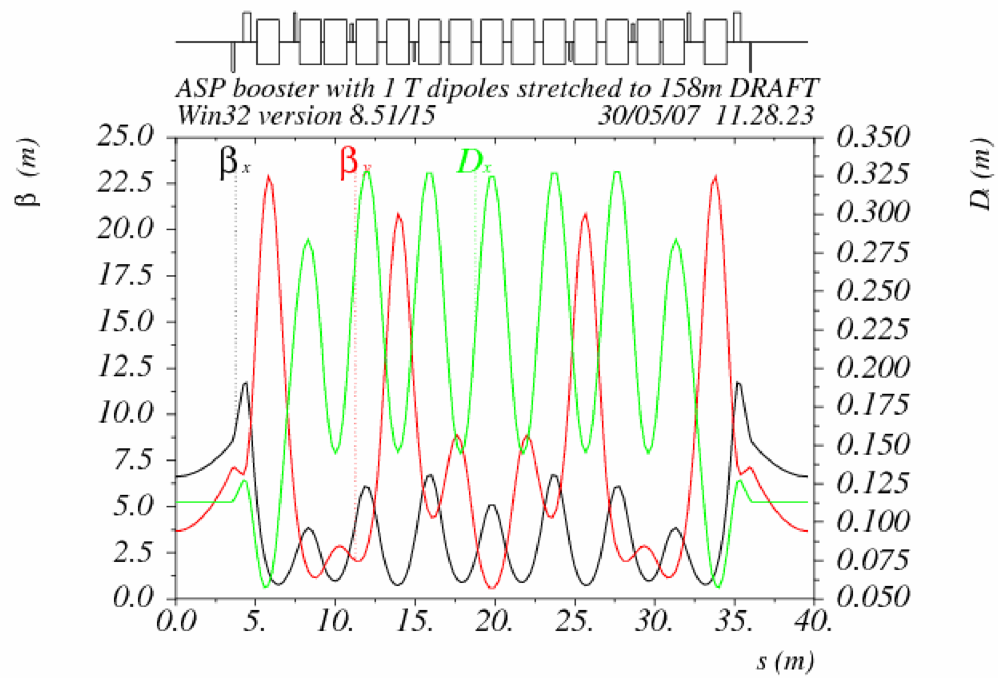
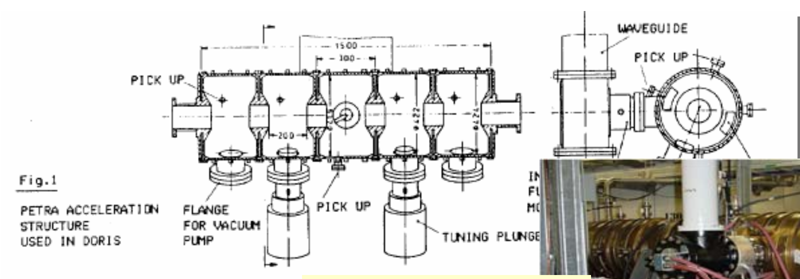
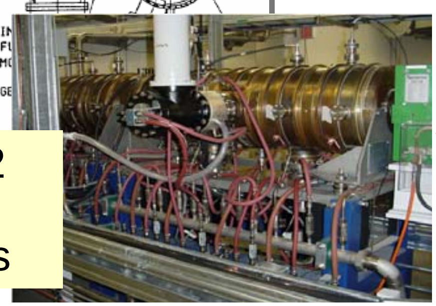
3 GeV Booster Features

Emittance, nm	26.6
Circumference, m	158.4
RF frequency, MHz	499.654
RF voltage, MV	1.2
tunes x/y	10.91/6.69
Natur. Chromaticities x/y	-14 /- 19
Momentum Compaction	0.0072
Energy loss per turn, keV	625
X/Y/Z damping time, ms	5.4/5.1/2.5
Damped energy spread, %	0.078
Damped bunch length, mm	13.9







RF: IOT+ 2 PETRA 5-cell cavities

Scaled from ASL Booster Lattice using combined function magnet lattice

Present Plan: Pursue Booster as turn-key procurement

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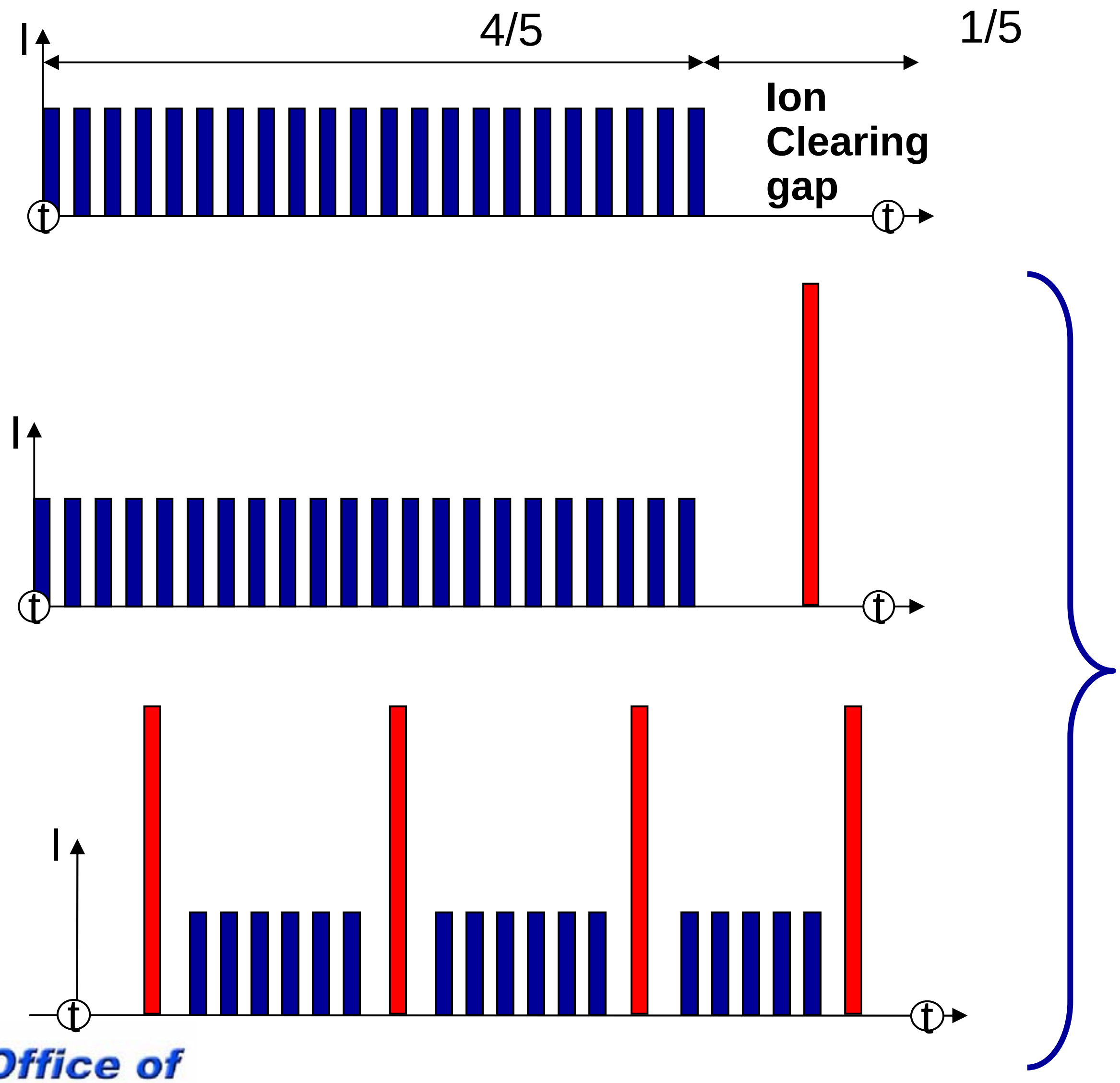
Supported Storage Ring Bunch Pattern



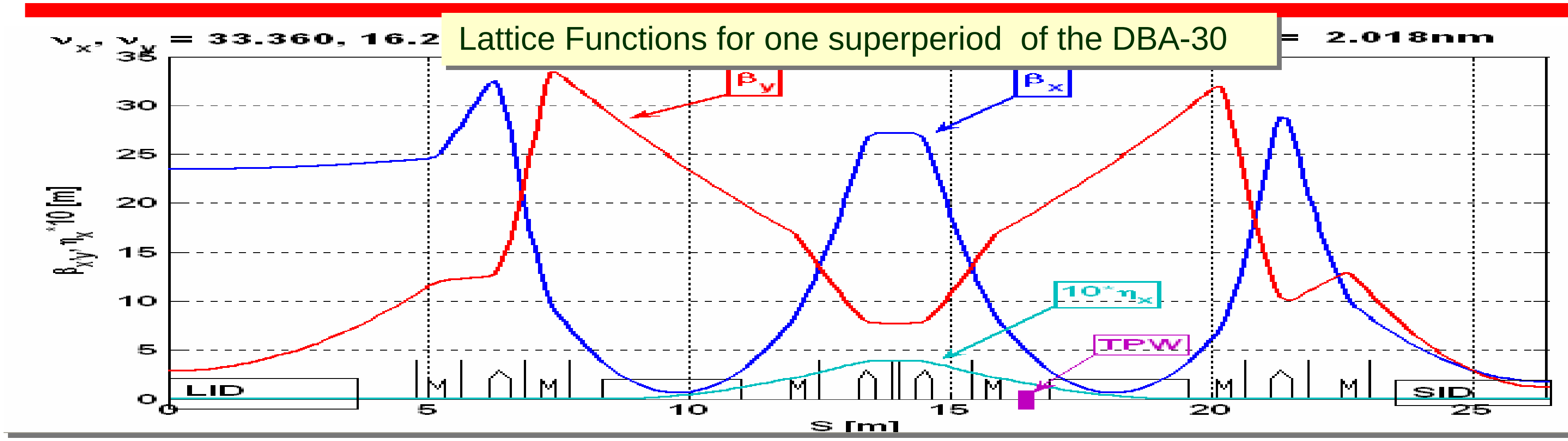
Base Line

Addressed in R&D Program

Storage Ring Parameters

Energy	3.0 GeV	Energy Spread	0.094%
Circumference	792 m	RF Frequency	500 MHz
Number of Periods	30DBA	Harmonic Number	1320
Length Long Straights	6.6 & 9.3m	RF Bucket Height	3%
Emittance (h,v)	<1nm, 0.008nm	RMS Bunch Length	15ps
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

Lattice Developemnt since April 07



<u>Unchanged:</u>

Bare Emittance: 2.02 nm-rad
15 fold Symmetry
Dispersion free ID Straights

Changed: Drifts for Insertion Devices 6.6m/9.3m

- Triplet Focusing for Achromats
- Triplett focusing around straights
- Beta-Functions in ID Straights
  9.3m Straight β_x / β_y = 24m / 2.9 m
  6.6m Straight β_x / β_y = 2.0m / 0.8 m
- 2 Chromatic Sextupole families for chromaticity correction in each achromat
- 7 non-chromatic Sextupole families for optimization of D.A. and ID compens. around each ID straight
- Decker Distortions and Canting integrated

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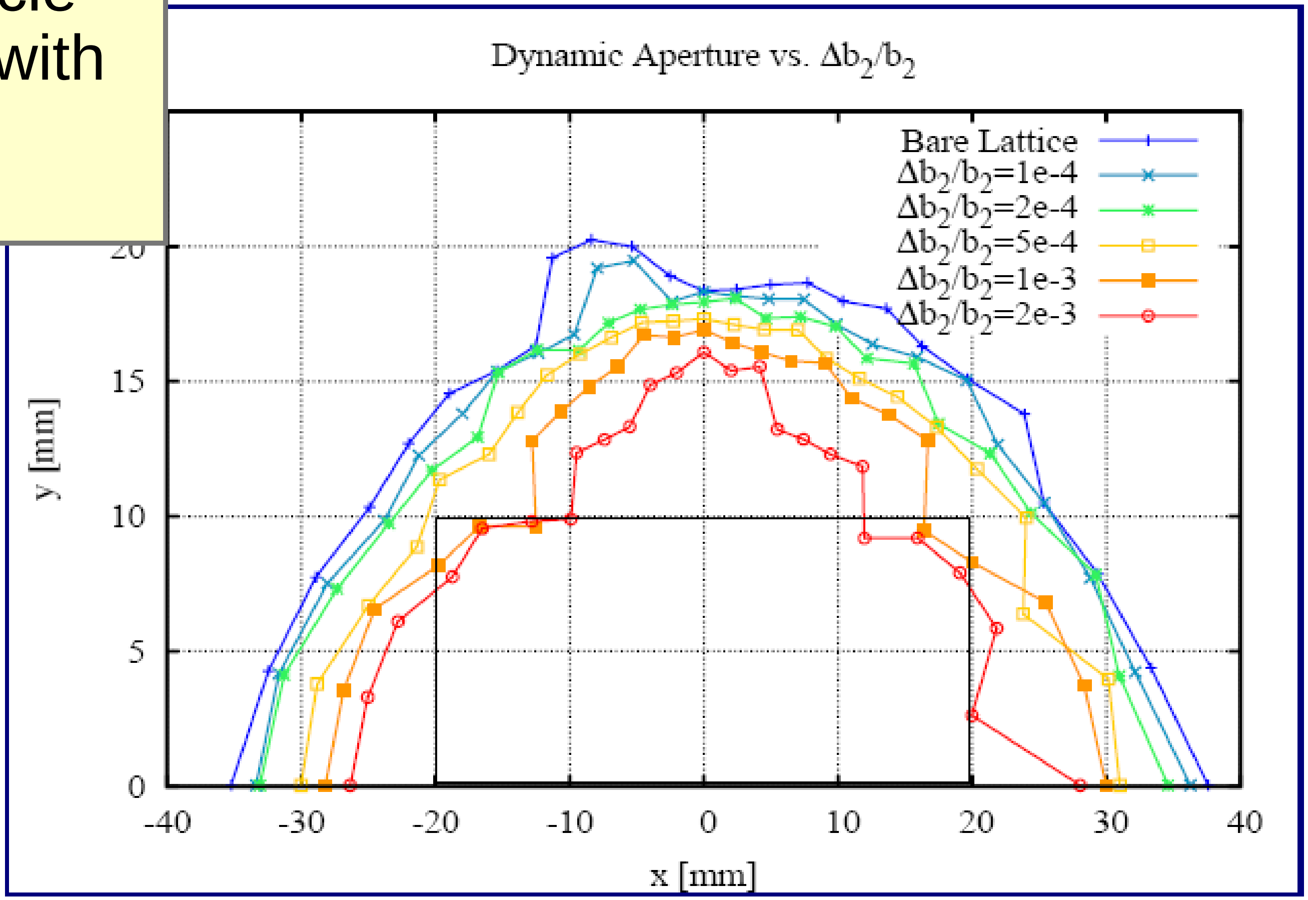
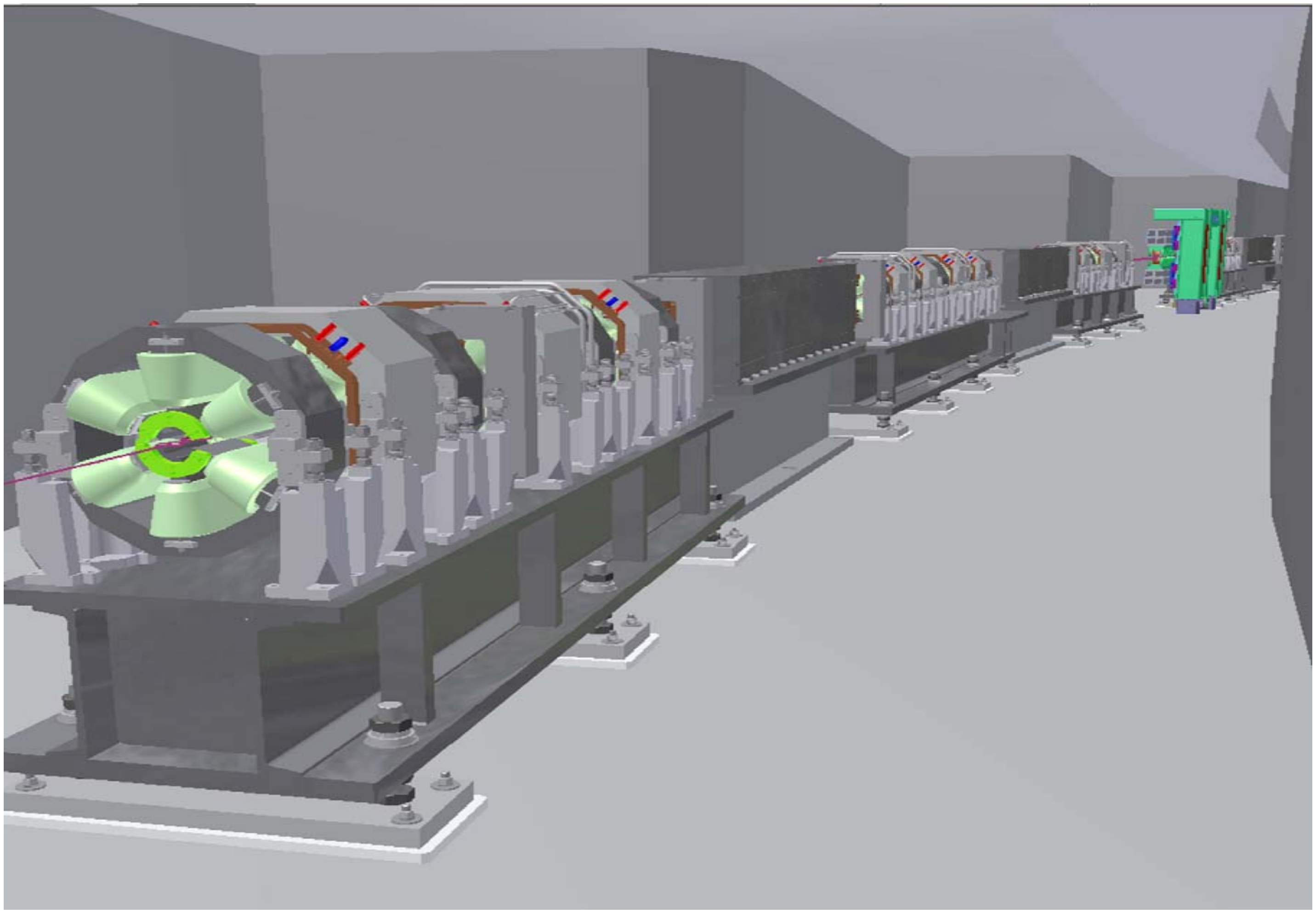
Robust Dynamic Aperture

6-D particle tracking with gradient errors



CAD Model of Storage Ring in the Tunnel

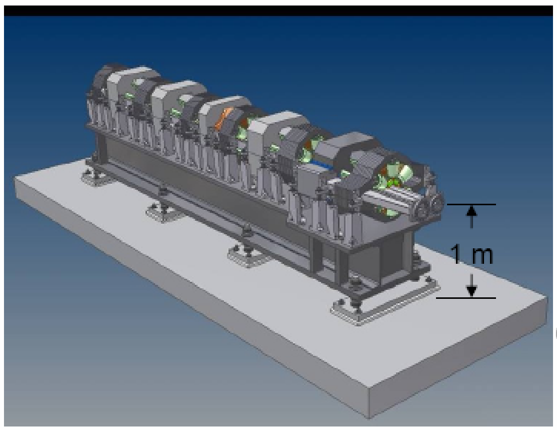


Girder System

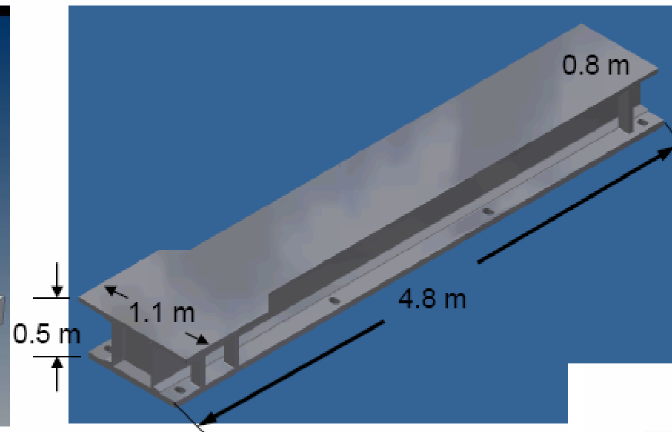
Tolerances on Magnets' Motion

Tolerance Limits	ΔX RMS Quads	ΔY RMS Quads
Random magnet motion	< 0.15 μm	< 0.025 μm
Random girder motion	<0.6 μm	< 0.07 μm

Over- constraint girder-ground connection
8 studs



Long Girder-Magnets Assembly

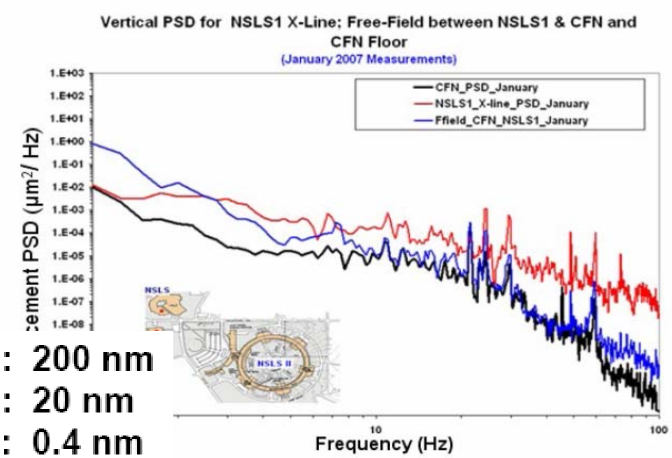


Long Girder

Mechanical Resonant frequencies >50 Hz

Main Design Features:

- 1-meter beam height.
- The long girder is supported on eight 2-inch diameter studs.
- No built-in precision alignment mechanisms.
- Welded construction with stiffeners.
- Standard machining tolerances.



(0.5-4) Hz : 200 nm
(4-50) Hz : 20 nm
(50-100) Hz : 0.4 nm

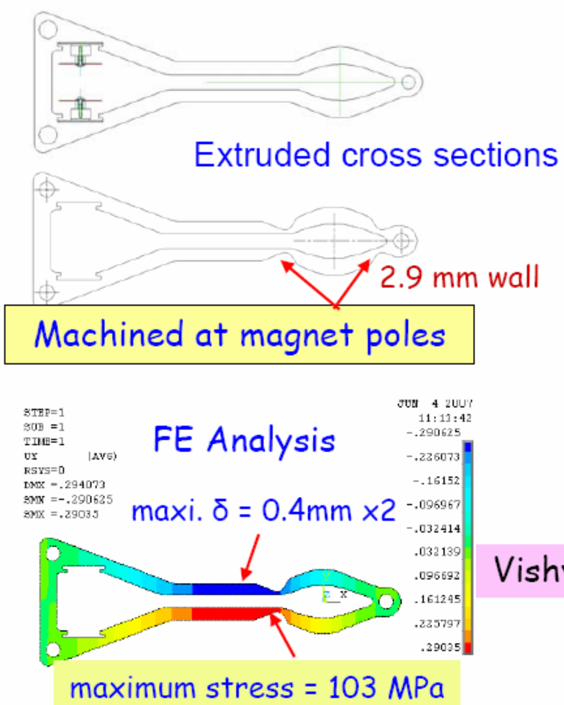
Vacuum System Technical Choices

Extruded Aluminum Profiles

NEG-strip based pumping

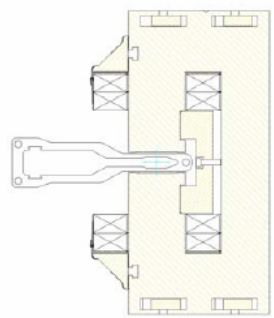
Minimum wall thickness required for

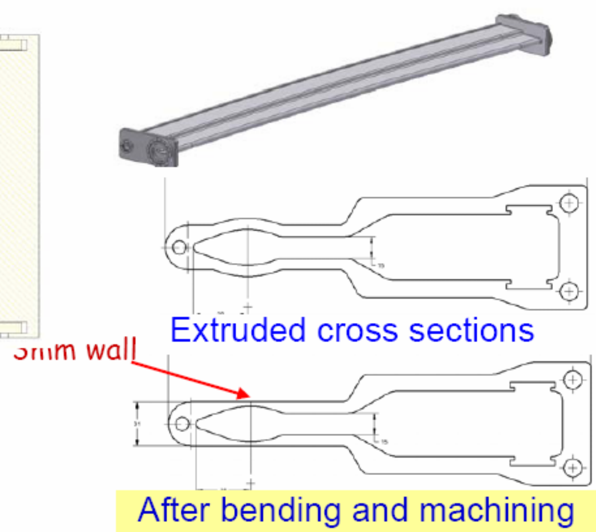
- balanced Al flow during extrusion
- no chamber porosity ⇨ low Q, no leaks
- welding by APS robotic machine
- large cooling channels for extrusion die lifetime



Vishy's talk

Dipole chamber, 6° bend, 3m long





Diverse Beamlines from NSLS-II

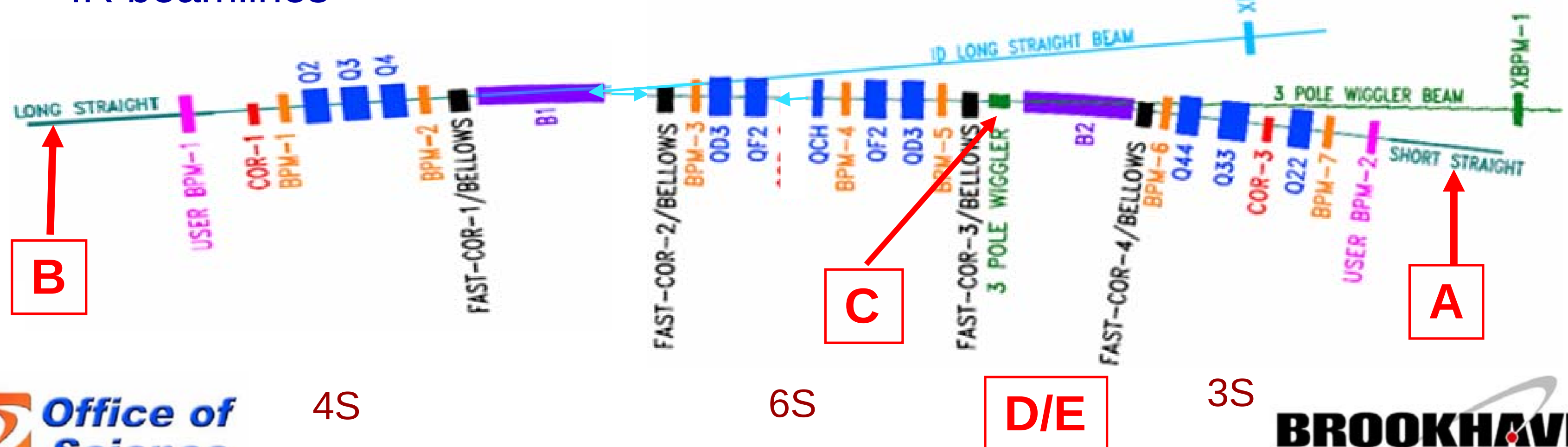
A. Short ID straights (low β): high brightness hard X-rays beamlines
- IVU for ultra-bright hard x-ray beamlines
- EPU for polarized x-ray beamlines

B. Long ID straights: damping wigglers and their high power beamlines and other insertion devices
- Study in progress for canted DW's to generate two beamlines from 1 straight

C. Three-Pole Wiggler (TPW) in dispersion straights for hard x-ray beamlines, similar in flux as NSLS dipole radiation but ~100 times brighter (< 15)

D. Soft bend dipoles for soft x-ray and UV beamlines

E. Three pairs of wide-gap dipoles to provide large aperture beam ports for far IR beamlines



Insertion Device Changes and Progress

- CPMU has been replaced by IVU
- CPMU and new magnetic material planned to be developed together in an off-project R&D program
- Damping wiggler parameters fixed: 90mm period, 3.5m, 12.5mm gap
- Design study for damping wiggler has been launched
- 3PW design based on permanent magnet

RF System

- CESR-B SCRF cavities chosen for ring RF
  - low impedance better for beam stability
  - higher AC power efficiency
  - Reliability and costs well established
- KEK-B SCRF cavity as option
  - Higher power per coupler attractive
  - minimal impact on conceptual design
- 310 kW Klystron amplifiers chosen for baseline:
  - Well established at other LS facilities
  - Reliability and costs well established
  - Combined IOT's as option
- Passive SCRF Landau cavity
  - Demonstrated performance at SLS, ELLETRA

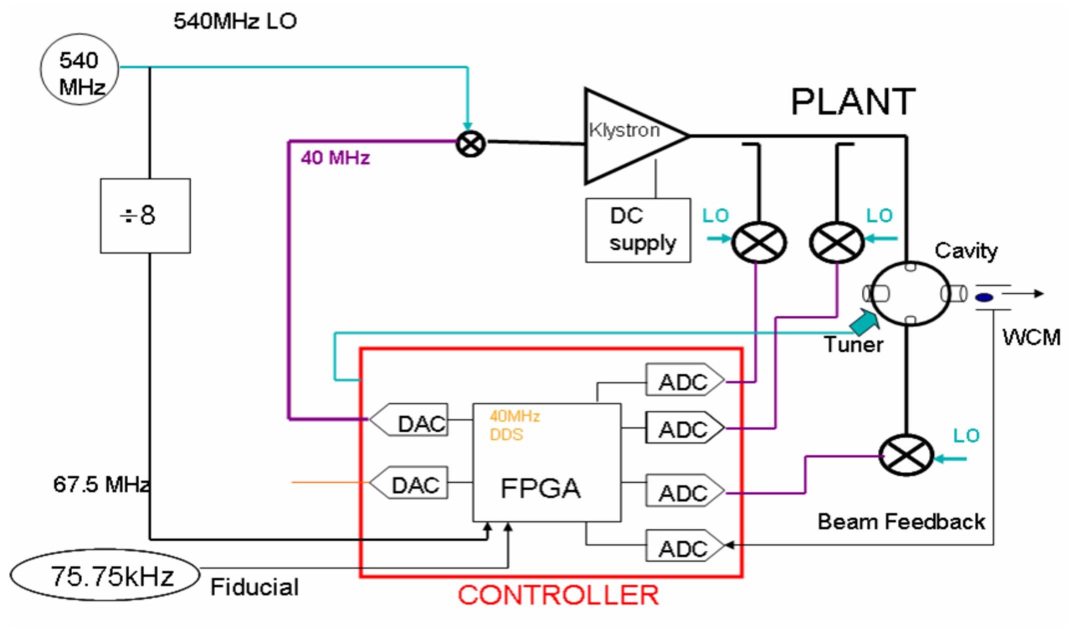
CESR-B SC cavity

RF System Changes

- Low Level RF system changed to fully digital FPGA based system
- R&D program launched for alternative power sources (IOT, solid state)
- Efforts underway to validate second vendor
- Will start with only one RF station (2 sc cavities procured

Storage Ring RF Parameters

Frequency	500 MHz
Beam energy gain/cav	>2.4 MV
Eacc	>8 MV/m
Unloaded Q	$>7 \cdot 10^8$
Standby (static) losses	< 30 W
Dynamic + static losses	<120W
Operating Temperature	4.5 K
Max. beam power/cavity	<250 kW

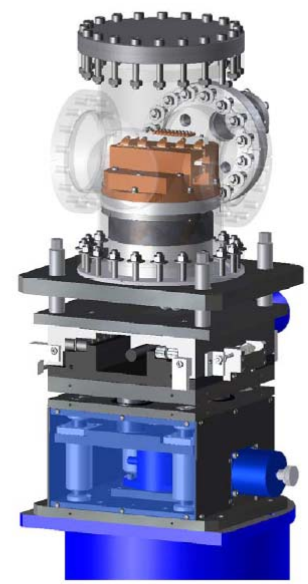


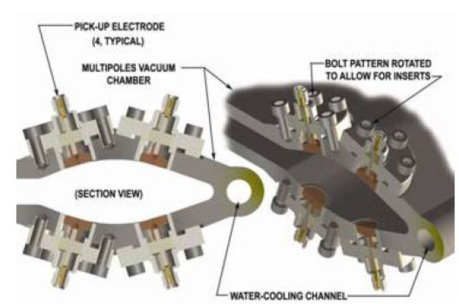
Issues requiring further study:

- Mix of ferrite in HOM for damping at higher frequencies
- Beam feedback may be required to stabilize beam in presence of harmonic cavity
- Choice of power coupling constant, maximum transmitter power

Instrumentation

Monitor	Quantity	Function
4-button pick-ups	226	Beam position, dispersion, response matrix, turn-by-turn dynamics, coupling
Additional PUEs	3	Longitudinal and transverse frequency components, tune monitor, transverse feedback
Tune monitor	1	Betatron tunes measurement, impedance
Loss monitors	16	Beam losses monitoring
Fluorescent flags	4	Position and profile of injected beam
Transverse feedback system	2	Suppress beam instabilities in both planes
Streak-camera	1	Bunch length measurement
DCCT	2	Beam current measurement
FCT	2	Fill pattern monitoring
Beam scrapers	4	Machine studies (beam size, energy aperture), halo
FireWire camera	1	Transverse beam characteristics
Emittance monitor	1	Transverse vertical beam size
Undulator radiation	1	Energy spread, beam divergence, momentum compaction factor
Pinhole camera	2	Horizontal emittance (using undulator radiation)
Counter	1	RF frequency monitor





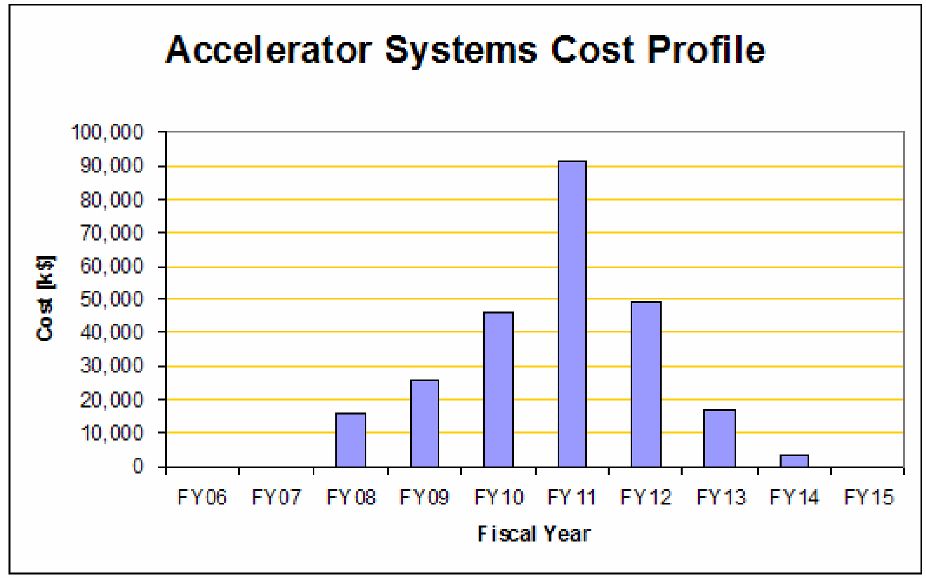
Changes:

Zone plate monitor instead of interferometer, R&D program on BPM started

Cost Estimate

- Status Sept 27 (*moving target*)
- Shown are planned obligations, fully burdened and escalated
- Funding profile is matched
- TPC include 30% contingency

898M$



Activity ID	Burdened Cost [k$]	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
NSLS-II National Synchrotron Light Source II	715,654	5,800	25,000	54,307	64,588	136,796	208,448	133,199	54,175	23,839	9,501
1.01 Project Management	65,662	0	0	11,575	11,994	11,780	12,837	11,444	4,640	1,392	0
1.02 R&D and Conceptual Design	51,782	5,800	22,979	9,790	5,743	3,909	3,561	0	0	0	0
1.03 Accelerator Systems	249,437	0	0	16,031	25,943	45,772	91,487	49,304	17,405	3,495	0
1.04 Experimental Facilities	79,993	0	0	3,836	5,584	7,867	13,806	36,889	11,072	940	0
1.05 Conventional Facilities	213,223	0	2,021	13,075	15,325	67,468	86,023	27,709	1,358	244	0
1.06 Pre-Operations	55,557	0	0	0	0	0	734	7,853	19,700	17,769	9,501

Detailed Time Phased Cost (WBS level 4)

Activity ID	Burdened Cost	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
NSLS-II National Synchrotron Light Source II	715,654	5,800	25,000	54,307	64,588	136,796	208,448	133,199	54,175	23,839	9,501
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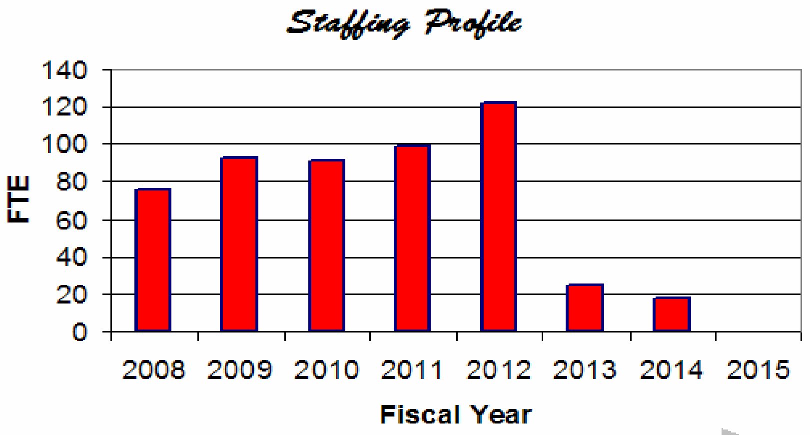
1.03 Accelerator Systems	249,437	0	0	16,031	25,943	45,772	91,487	49,304	17,405	3,495	0
1.03.01 Accelerator Systems Management	4,784	0	0	957	948	972	791	407	353	356	0
1.03.02 Accelerator Physics	13,678	0	0	2,521	2,751	2,810	2,568	1,011	872	1,145	0
1.03.03 Injection System	38,501	0	0	712	2,594	3,819	19,865	11,421	90	0	0
1.03.04 Storage Ring	137,444	0	0	6,524	12,587	31,923	59,206	24,089	3,116	0	0
1.03.04.01 Injection Straight	2,608	0	0	0	9	241	944	1,409	4	0	0
1.03.04.02 Storage Ring Magnet Subsystems	27,433	0	0	1,439	3,119	8,720	12,160	1,996	0	0	0
1.03.04.03 Storage Ring Vacuum System	33,814	0	0	1,265	3,236	10,579	16,013	2,607	113	0	0
1.03.04.04 Storage Ring Power Supplies	15,448	0	0	1,037	1,457	538	7,723	4,694	0	0	0
1.03.04.05 Storage Ring Beam Instrumentatior	6,611	0	0	119	471	172	3,661	2,189	0	0	0
1.03.04.06 Storage Ring RF Systems	18,545	0	0	1,675	2,118	5,314	6,330	2,366	742	0	0
1.03.04.07 Beamline Front Ends	5,736	0	0	281	1,360	2,931	1,145	20	0	0	0
1.03.04.08 Storage Ring Utility Distribution	12,761	0	0	709	817	595	8,893	1,747	0	0	0
1.03.04.09 Storage Ring Installation	14,489	0	0	0	0	2,834	2,337	7,060	2,258	0	0
1.03.05 Controls Systems	19,773	0	0	2,352	2,854	4,411	4,931	3,484	1,501	242	0
1.03.06 Accelerator Safety Systems	4,352	0	0	188	60	37	2,389	1,665	12	0	0
1.03.07 Insertion Devices	22,059	0	0	342	343	343	588	7,229	11,461	1,752	0
1.03.08 Accelerator Fabrication Facilities	8,845	0	0	2,435	3,805	1,457	1,149	0	0	0	0
1.04 Experimental Facilities	79,993	0	0	3,836	5,584	7,867	13,806	36,889	11,072	940	0
1.05 Conventional Facilities	213,223	0	2,021	13,075	15,325	67,468	86,023	27,709	1,358	244	0
1.06 Pre-Operations	55,557	0	0	0	0	0	734	7,853	19,700	17,769	9,501

Staffing Plans

Staffing plan well developed, though not fully optimized

Acc. Systems: 524 FTE



core staff funded by preops and operations funding

Category	*Total*	*2008*	*2009*	*2010*	*2011*	*201 2*	*2013*	*2014*	*2015*
Project Management	235	42	45	42	42	40	18	6	0
R&D & Concept Design	73	19	19	18	17	0	0	0	0
Accelerator Systems	524	76	93	91	99	122	25	18	0
Experimental Facilities	129	17	25	25	24	20	14	4	0
Conventional Facilities	49	8	8	9	9	9	4	2	0
Pre-Operations	173	0	0	0	2	28	75	68	0
Total	1,183	162	190	185	193	219	136	98	0

Recent Hires

P. Decker Design Engineer

Yu Li Hua Accelerator Physicist

F. Willeke, Accelerator Systems

Heng Jie Ma RF Engineer

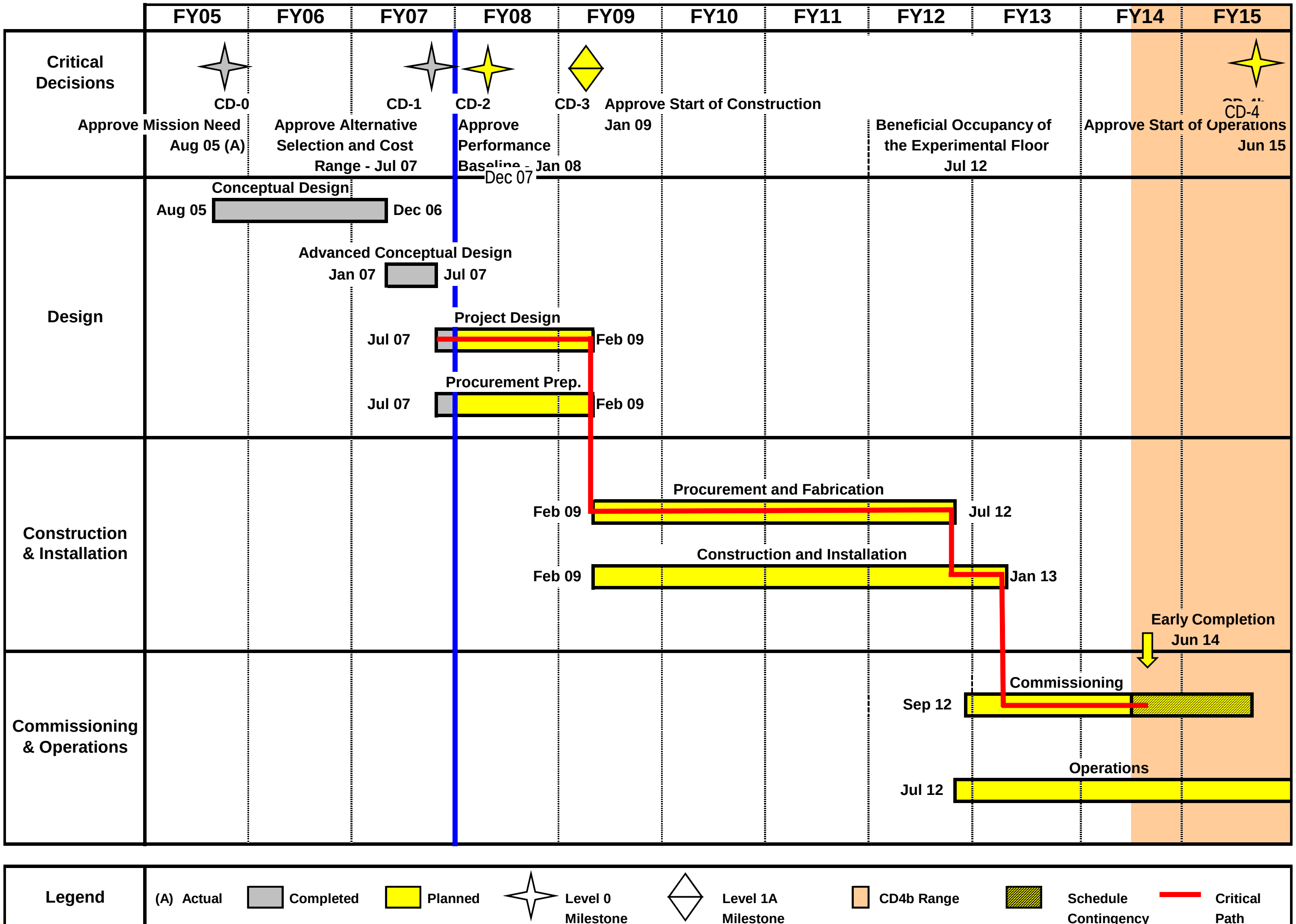
B. Moebes, Adm. Ass.

D. Dohan, DB Expert

Li Yong Jun Accelerator Physicist

…

Schedule Schematic



15 months total schedule contingency

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CD-4

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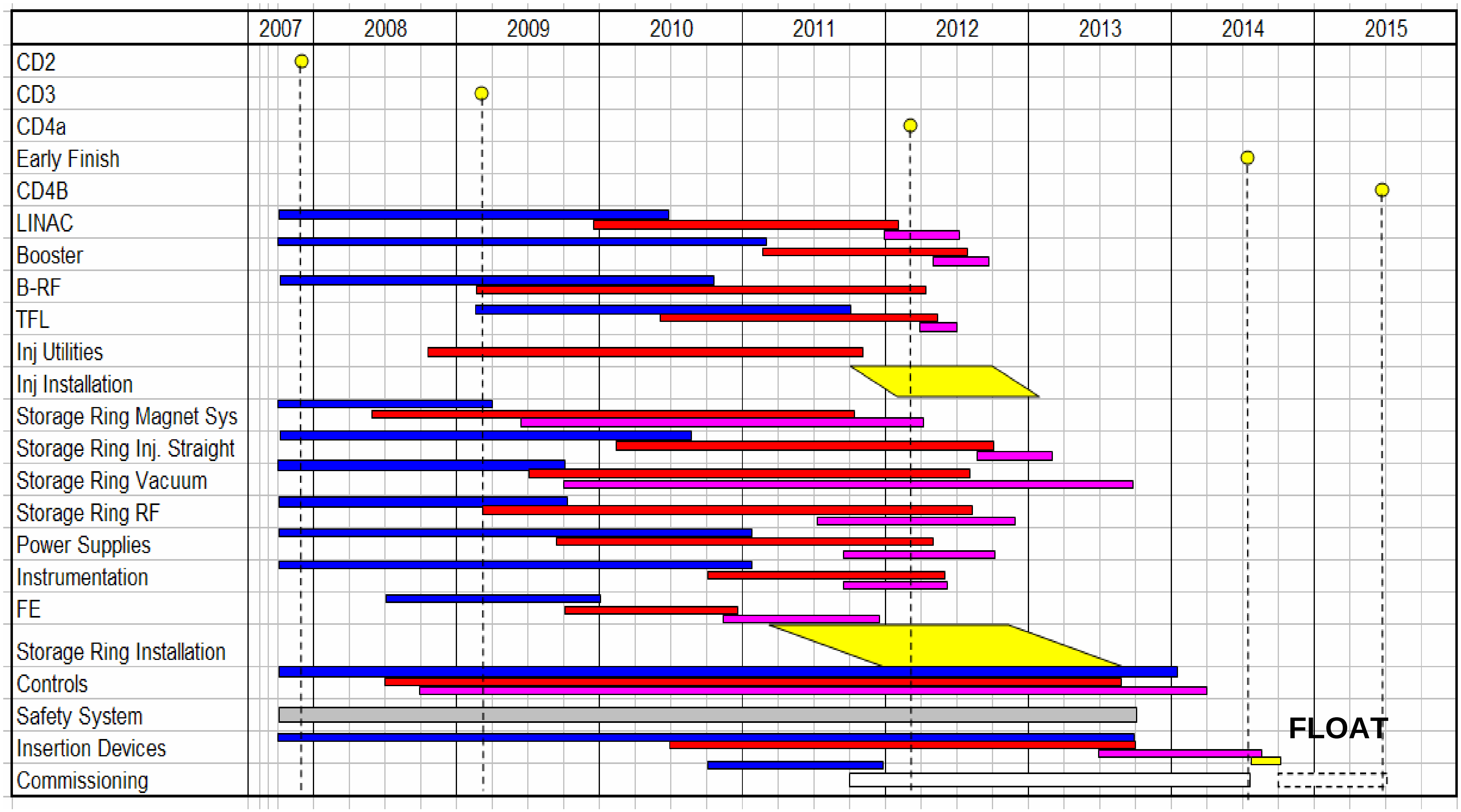
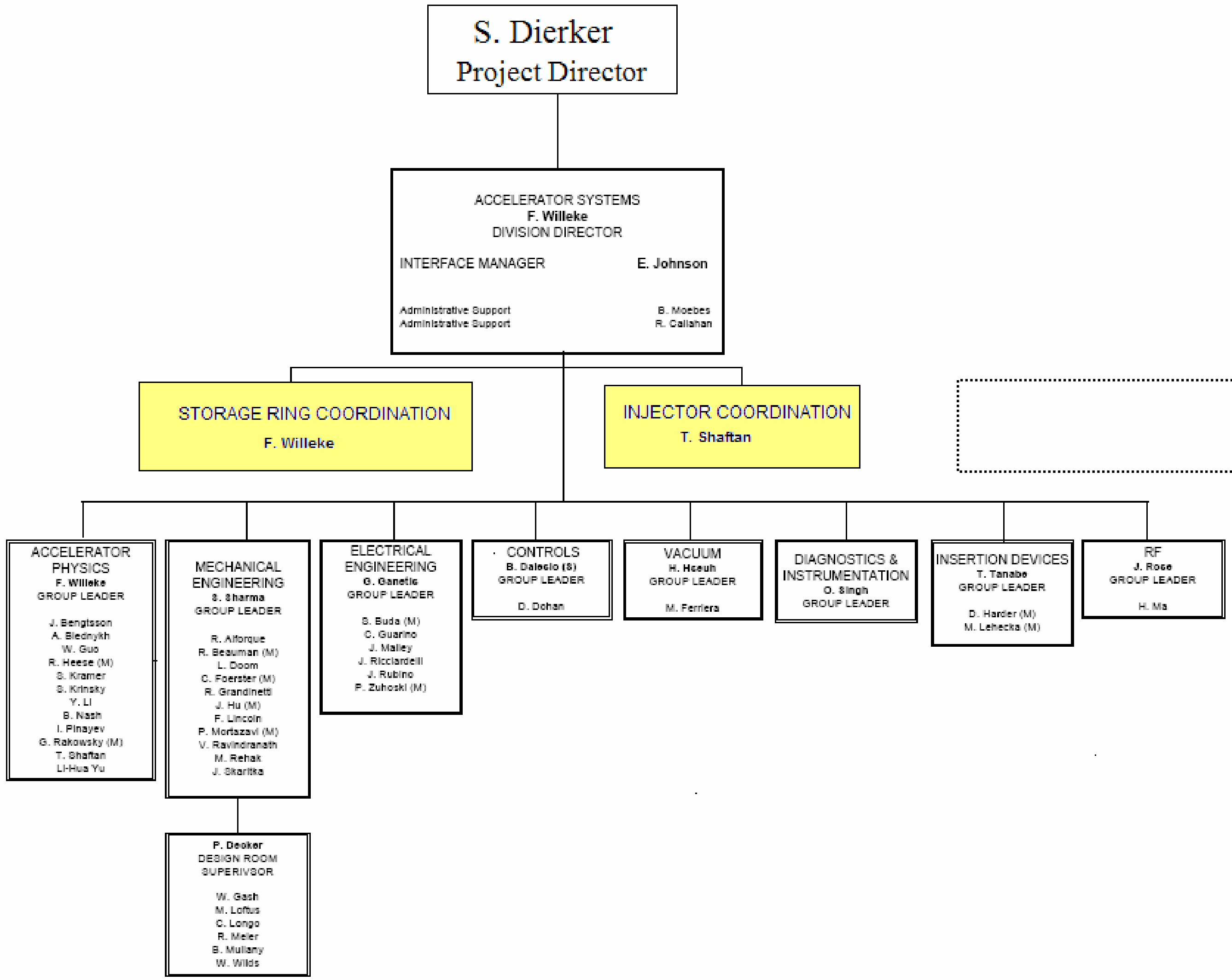
Schedule (Cartoon)



Accelerator Systems Division Organization



Office of Science
U.S. DEPARTMENT OF ENERGY

BROOKHAVEN NATIONAL LABORATORY
BROOKHAVEN SCIENCE ASSOCIATES

Summary

- NSLS-II High Brightness Synchrotron Light Source is a very demanding 3rd Generation Design pushing the performance parameters close to fundamental limits

- Preliminary Design has progressed well
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- Value engineering choices have been made in response to detailed technical review process

- Thorough and defendable cost estimate has been performed

- Detailed Resource loaded Schedule has been worked out

- NSLS-II Accelerator Systems is ready to move into the next project phase