Accelerator Update

Timur Shaftan, Director of Accelerator Division

NSLS-II Science Advisory Committee Meeting

September 19-20, 2017

U.S. DEPARTMENT OF ENERGY | Office of Science

BROOKHAVEN NATIONAL LABORATORY | National Synchrotron Light Source II

Outline

- Status of accelerator operations
  - **Reliability**
- Accelerator Division programs
  - Increasing operating current
  - Beam stability
  - Beam study program
  - Future facility upgrades
- Outlook for FY18 and Conclusions

Reliability

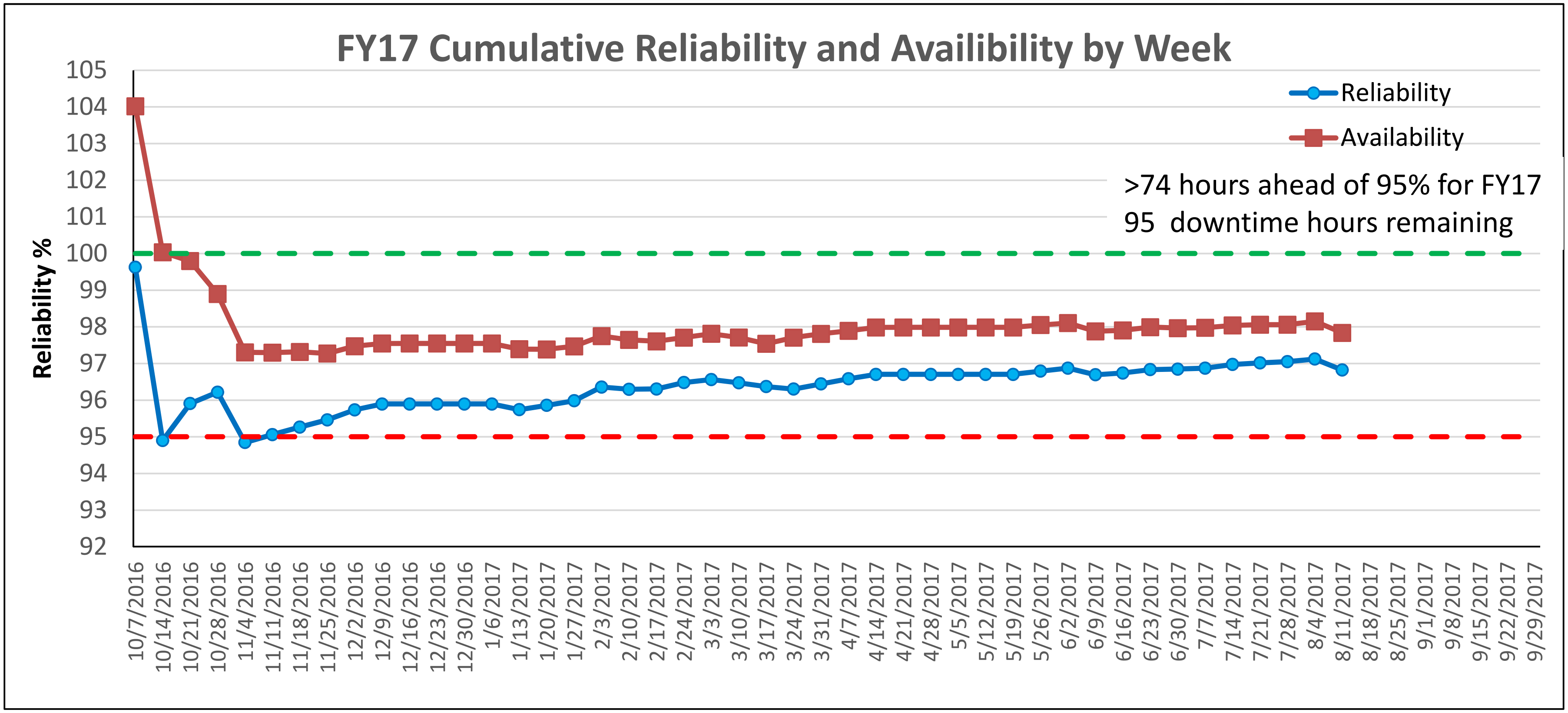
- We entered FY17 with two major increments in operations requirements
  - Reliability 90% → 95%
  - Total operations hours increased by 20%

- Operations downtime budget per day is greatly reduced

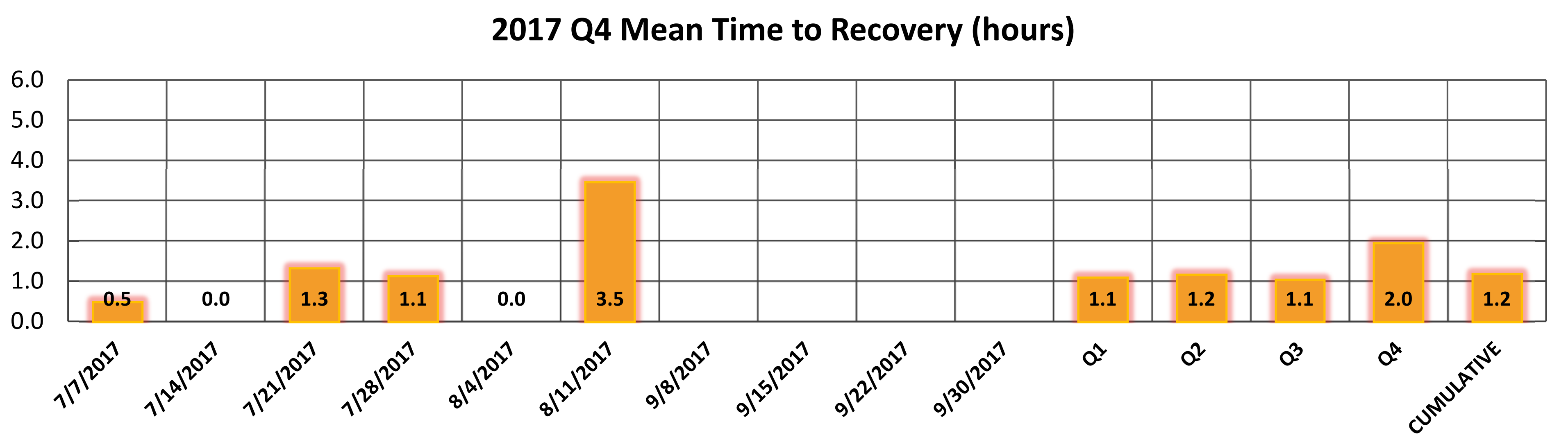
- 4 main challenges in securing high reliability of operations:
  - Insufficient maturity of machine subsystems
    - *Development program targets least reliable systems (~0.6M$ in FY17)*
  - Insufficient staffing in certain areas
    - *Cross-training is in progress*
  - Incomplete set of spares
    - *Procured 4 M$ of spares in FY17*
  - Low component redundancy
    - *Developing 3rd RF system*

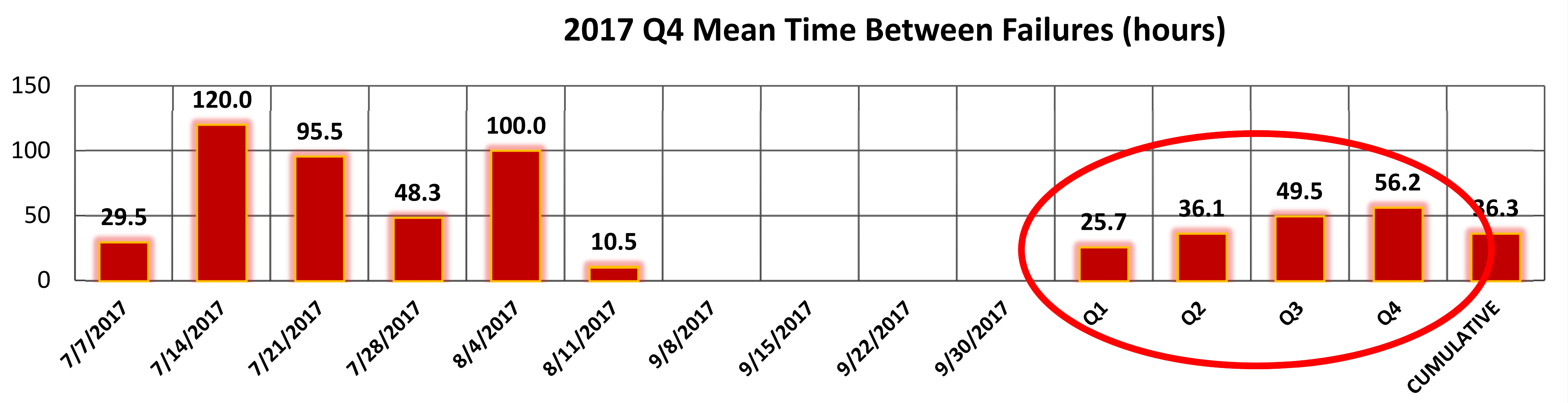
- FY17 operations: Reliability is at 97% from Oct 2016 to date

Reliability of operations in FY17



MTTR and MTBF in FY17





Machine Subsystems of Concern

Cryo-systems

- Full RF cavity warm-up (Sept 2016), Burst disk in RF cavity (May 2017), Warm-up of cryoplant (Aug 2017)
- Number of improvements identified: He liquefier, valves in cryolines, robust PRVs, He purifier, redundant controls

Pulsed magnets

- Booster PMs are based on CC thyrotron technology, difficult to service, frequent faults
- 2 booster injection kickers, installed and operating today; 2 extraction units will be installed in Dec shutdown

Linac klystrons

- Found Thales klystrons unreliable
- Switching to Toshiba klystrons: 1 arrived, 1 on order

DI water

- High leakage currents, oxidation in manifolds, frequent flushing
- Working on DIW plant diagnostics, communicating with sister facilities

Staffing of Accelerator Division

Challenge is in increasing reliability of performance of NSLS-II accelerators during transition from construction to operations as diversity of skill sets is reduced:

- Staff in support of AD operations: 108.5 FTE in FY17
- Overall staff of AD: 175 FTE in FY17. Reducing to ~150 in FY18

Meet this challenge by slight increase in operations FTEs to 114.1 in FY18 and increased efficiencies:

- RF systems
  - Added 1 RF group member through 3rd RF system project
- Pulsed Power systems
  - Educating other EE engineers, considering succession plans
- Controls Increasing by 2 FTEs

- Working on increasing efficiency of AD in operations
  - ID group experts helping Vacuum group
  - RF and Utilities groups support each other in area of cryo projects
  - Electrical Engineering support safety across whole NSLS-II and BNL

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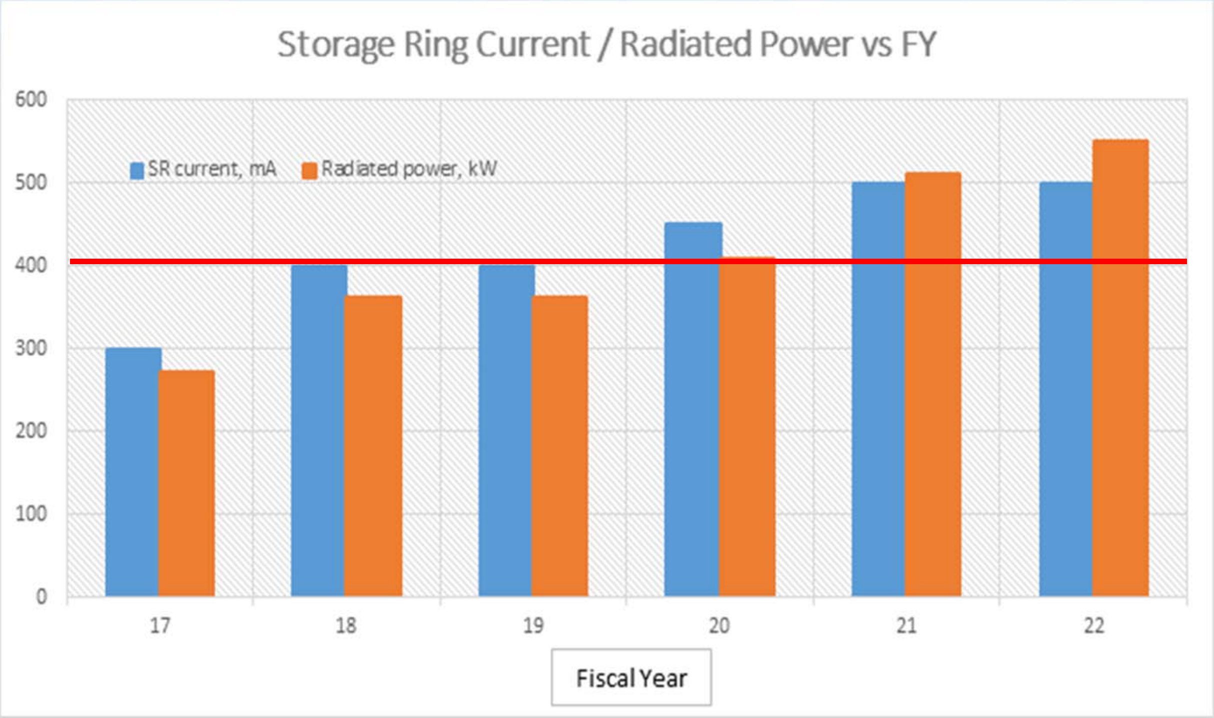
Increase in operating current: RF power

Presently operating at 325 mA



Approximate power limit

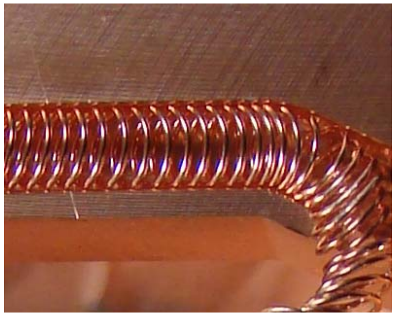
- Limit on RF power is near
  - NSLS-II design is based on 4 RF cavities + 4 transmitters
  - With 2 cavities and present set of beam lines we can reach 400 mA, but not much higher
  - No redundancy: if one transmitter / cavity is down → current is 200 mA

- 3rd RF system is a funded program at NSLS-II
  - Contract for reconditioning, testing and assembly of RF cavity is in progress

- Reached 400 mA in studies, planning on stepping up to 450 mA in FY18 (in studies)

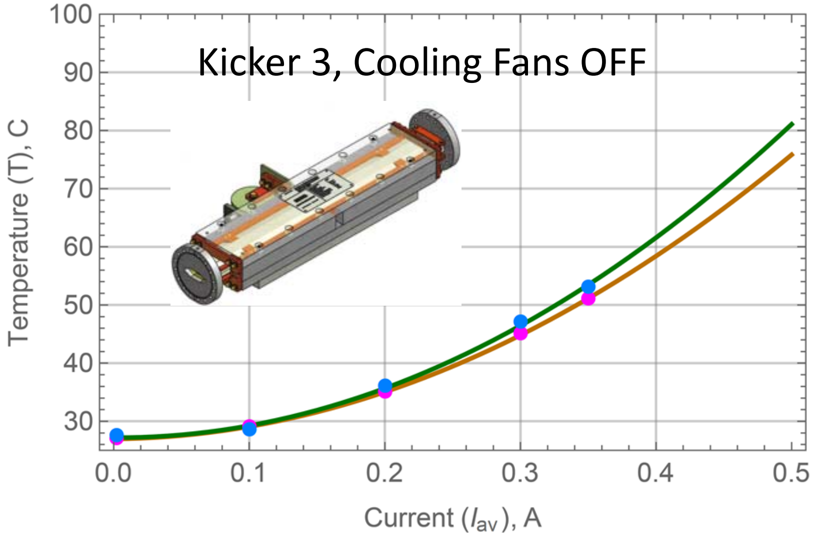
Increase in operating current: Overheating Issues

- RF contact springs
  - Several flange joints were found with T>80°C at 275mA
  - RF springs were replaced and temperatures dropped to below 40°C



Flanges joint design w/ RF contact spring

- Ceramics Chambers
  - Kicker 3 temperature reduced after RF spring replacement.
  - All other RF springs in the injection straight section has been recently replaced



- Stripline Kickers in cell 16
  - Temperature and Vacuum pressure will be studied further

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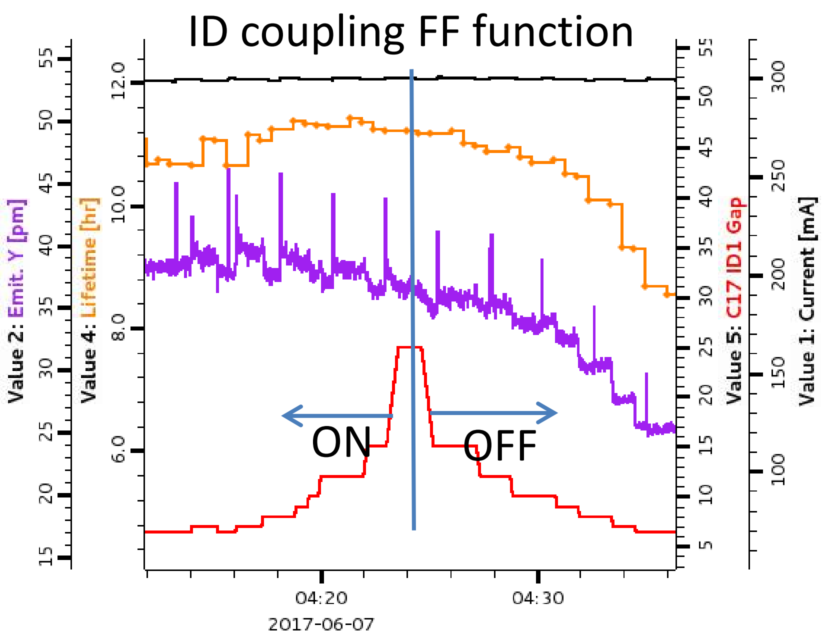
Increasing stability of vertical beam size

- Demonstrated vertical emittance at NSLS-II at 6 pm rad (2015)
- Operating now at ε_y=30pm rad for longer lifetime

- Reducing variations of vertical beam size due to coupling induced by changing ID gaps
- Reduced IVU gaps ‘full open’ limit change to 25 mm to minimize the swing of skew multipole between ‘open’ and ‘closed’ state.

- AMX IVU
  - New skew quadrupole installed for C17 IVU local coupling compensation with feed forward function
  - New local FF function replaced global coupling correction with 15 skew quadrupole magnets

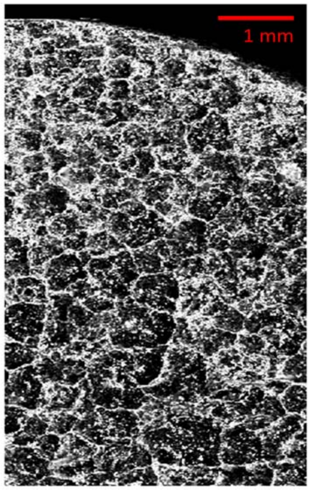


Beam stability improvements

- Instrumentation
  - Developed tools to routinely monitor beam stability
  - Dedicated studies with beamline to establish ID sources stability tolerance, including beamline optics sensitivity (BSTF)
- Local orbit bumps
  - Improved localized local bumps around ID source points with feedforward correction
  - Implemented dedicated BM local bump function
- Implemented RF frequency feedback to improve long term drift in BM beamlines
- FOFB
  - Shift of fast-to-slow corrector strength
  - Golden orbit recovery function with FOFB
  - Included ID BPMs in FOFB loop
  - Local feedback from xBPM is under development

Imaging at TES beamline
Data accumulated for **14** hours

w/o FB



with FB

Beam stability program

- Improvements delivered by joint efforts from Accelerator Coordination, Accelerator Controls and Accelerator Physics groups of AD together with beamline representatives from Photon Division

- BSTF = Beam Stability Task Force cross-divisional platform for dialog between AD and PD on improvements of orbit / beam size stability
  - Meeting biweekly
  - Reporting two times a year

- Plans for future developments:
  - Short-term:
    - Improvements in stability of BPMs, gap-dependent effects, instrumentation and diagnostics
    - Local feedbacks
  - Long-term:
    - FOFB: control over gain and bandwidth
    - Unified Feedback

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Mid- and Long-term Beam Study projects

	Mid-term	Long-term
Reliability	• Development of common software tools for operations and beam studies • Development and implementation of new Injector operating modes • Development of 3rd RF system	• 2nd gun for generating complex bunch patterns • Slow bump in the Storage Ring injection straight section • Storage Ring injection scheme with a pulsed multipole • Beam stacking in the Booster
Stability	• Flexible bandwidth control of FOFB • Local feedbacks for most sensitive beamlines • Online optimization of nonlinear beam dynamics • Minimization of the injection transients	• Orbit stability within 5% of r.m.s. beam size.
Intensity	• Reaching 500 mA of beam current • Hybrid fill patterns for time-resolved experiments	• 3rd harmonic RF cavity. • Exploring possibilities of further increase of the beam current up to 1 A
Brightness	• Low-emittance lattice with changed damping partitions (LDRD 17-015)	• Conversion of the NSLS-II lattice from two-bend achromat to four-bend achromat

Highlights from the beam studies

- Increase of beam current
  - 400 mA of average beam current has been achieved
- AC LOCO, a fast and precise technique for lattice correction
  - Published in Phys. Rev. Accel. Beams 20, 054001 (2017).
- Lossless crossing of a half-integer resonance
  - Accepted for publication in New Journal of Physics.
- Analysis of nonlinear dynamics by square matrix method
  - Published in Phys. Rev. Accel. Beams 20, 034001 (2017).
- AC orbit bump method of local impedance measurement
  - Published in Nucl. Instrum. Methods Phys. Res., Sect. A 871 (2017), p. 59-62.
- High-brightness lattice upgrade options for NSLS-II
  - Experimental lattice with redistributed damping partitions has been developed and tested with a beam, a emittance reduction (factor of 2) was measured.
- Lower-energy operational modes of the NSLS-II injector
  - 170 MeV operation mode has been implemented for NSLS-II user operations. After implementation of this mode, less frequent klystron failures have been observed.

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Possible future facility upgrades

- Development of 3rd harmonic RF cavity
  - 3rd HC will increase beam lifetime and aid in reducing impact from collective effects
  - Reduce vacuum chamber overheating and beam instabilities
- Low-emittance lattice with changed damping partitions
  - Horizontal emittance is inversely proportional to the x-damping partition number
  - Halve x-partition number by off-center beam orbit in achromats
  - Factor of 2 emittance reduction is expected and observed
- Lattice upgrade: DBA → DDBA
  - Replacement of the existing dipole magnets by MBA cells without major changes outside of the dipole girders
  - X-emittance can be reduced by a factor of 4 and three damping wigglers could give an additional factor of 1.5
  - Taking into account effects of all IDs x-emittance can be reduced to about 200 pm·rad

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Plans for operating in FY 18 and 19

- Further increasing annual hours of operations
- Shorter study and shutdown periods while:
  - Increasing current
  - Commissioning new IDs, FEs and beam lines

	NSLS-II				NSLS X-Ray	APS
	FY16	**FY17**	**FY18**	**FY19**	**FY12**	**FY16**
Operations (hours)	3718	4500	4750	5000	5150	5000
Studies (hours)	1713	872	850	850	721	632
Maintenance and certification (hours)	594	440	440	440	376	872
Shutdown (hours)	2825	2224	2200	2200	2513	2256
ID, FE, BL Commissioning (hours)		724	520	270		
Reliability Goal	90	95	95	95	95	
Operating Current: Start/End (mA)	200/250	250/300	300/400	400/500	300	100

Comments from the last SAC (March 2017)

- The intention of accelerator studies and development should be included in the strategic plan, and, each development be connected to scientific goals (for example, why is a segmented undulator useful?) and that these connections be clearly articulated in plans, reports, etc

- SAC would like NSLS-II management to give an account of its definition and valuation of in-house research, in particular addressing some frustration from staff of not having enough room to develop more risky, cutting-edge capabilities

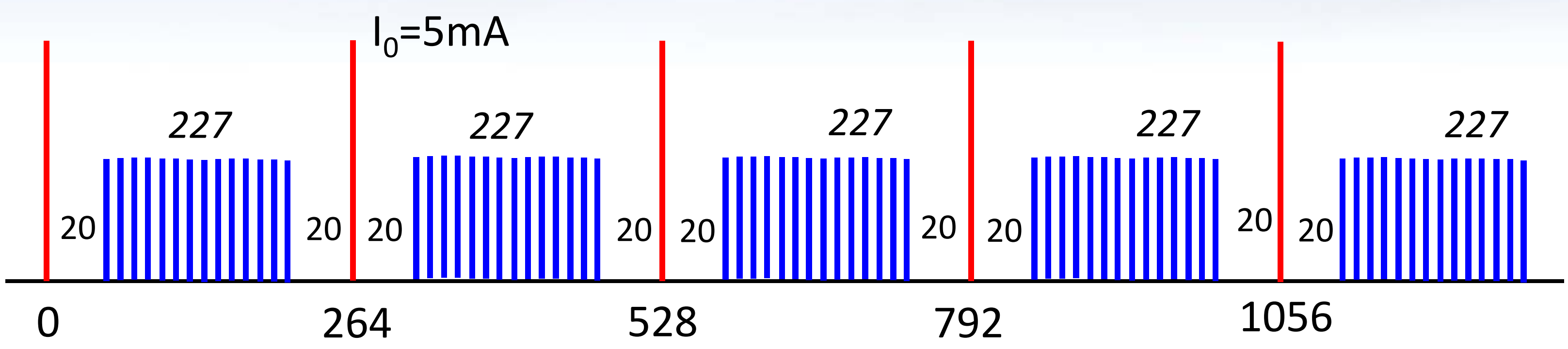
- SAC would welcome a more specific account of accelerator performance issues observed at beamlines (such as stability, beam size) and mitigation strategies

- In the near future, with fewer new beamlines to construct, a larger share of accelerator study time will and should become available for accelerator improvements. SAC encourages the accelerator division and the NSLS-II management to outline mid- and long-term goals for accelerator upgrades, in order to maintain a high standard of accelerator development and to satisfy existing intellectual resources, but also in order to make sure that future beamline developments are prepared for a possible significant improvement in the accelerator performance.

Conclusions

- NSLS-II accelerators are delivering reliability at the ~97% level in FY17
- Challenges ahead of us:
  - Increasing stored current
  - Understanding and solving problems with overheating of chambers
  - Increasing annual operations time
  - Including more IDs, FEs and beam lines
  - Delivering 3rd RF cavity and 3rd Harmonic RF cavity
  - Increasing staff in the areas of concern
  - Procuring sufficient inventory of spares
  - Building necessary subsystem redundancy
- Evolution of facility since commissioning in 2014 has been very exciting!
- Progress due to breath and depth of expertise, talent and diligence of NSLS-II staff

High Single-Bunch Current Operation



- Beamlines expressed moderate interest in High Single-Bunch Current operations
- Collective effects beam studies are planned to understand limiting effect on intensity
- I_0 ~ 12 mA has been achieved in combination of the positive chromaticity +8/+8 & TFB system
- SB current was limited due to the vacuum pressure growth around the ring