National Synchrotron Light Source II

Accelerator Update

NSLS-II Science Advisory Committee Meeting

Timur Shaftan

Director of Accelerator Division

September 20, 2018

U.S. DEPARTMENT OF ENERGY | Office of Science

BROOKHAVEN NATIONAL LABORATORY

Outline

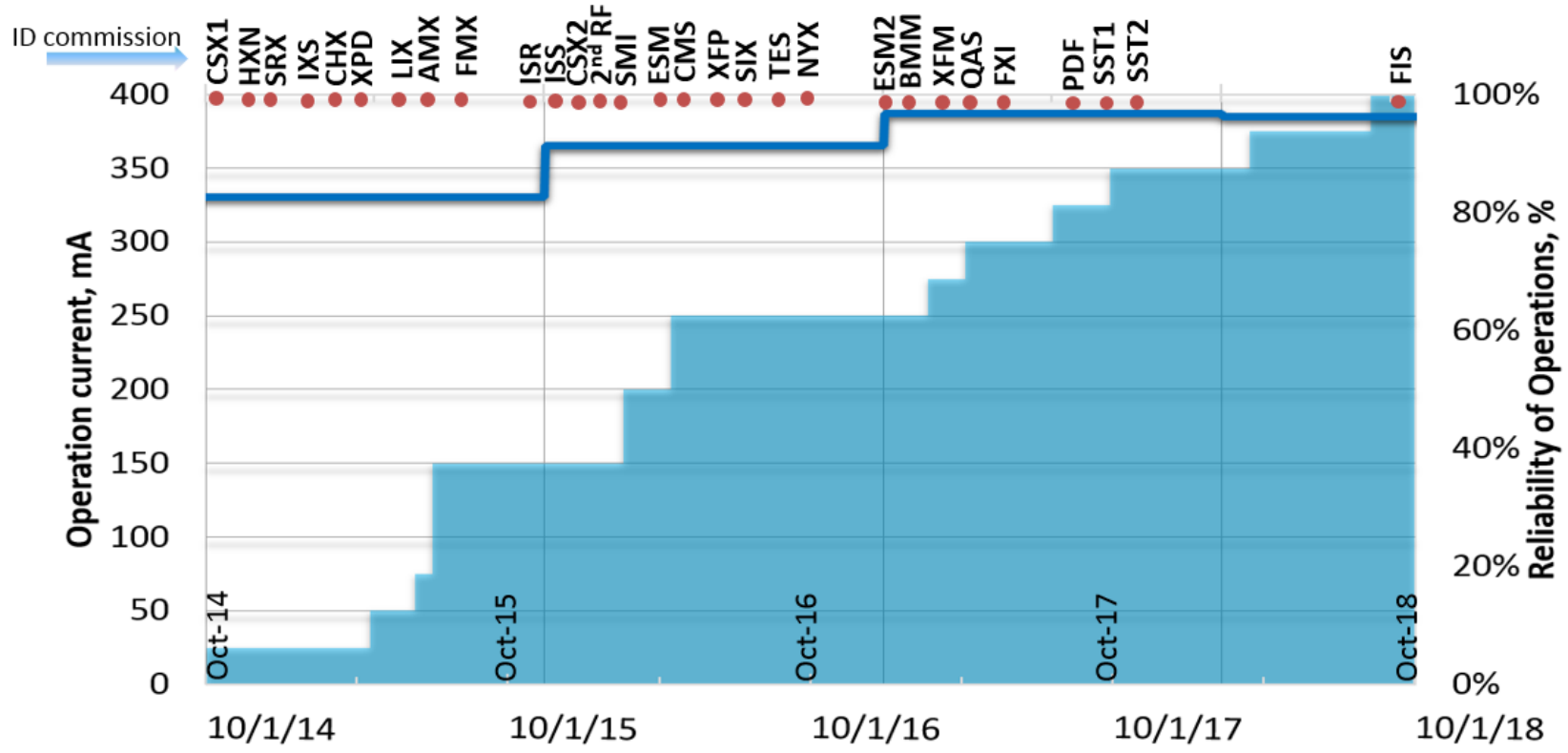
- **Status of accelerator operations**
  - Reliability and recent event in operations
  - Operations staffing
- **Accelerator Division programs**
  - Securing high reliability of operations
  - High current operations and studies
  - 8 pm rad vertical emittance
  - Future facility upgrades
- **Conclusions**

Related Charge Questions

1. Heating issues – are we on the right track there in terms of diagnosing and fixing them ready for 500 mA ops?

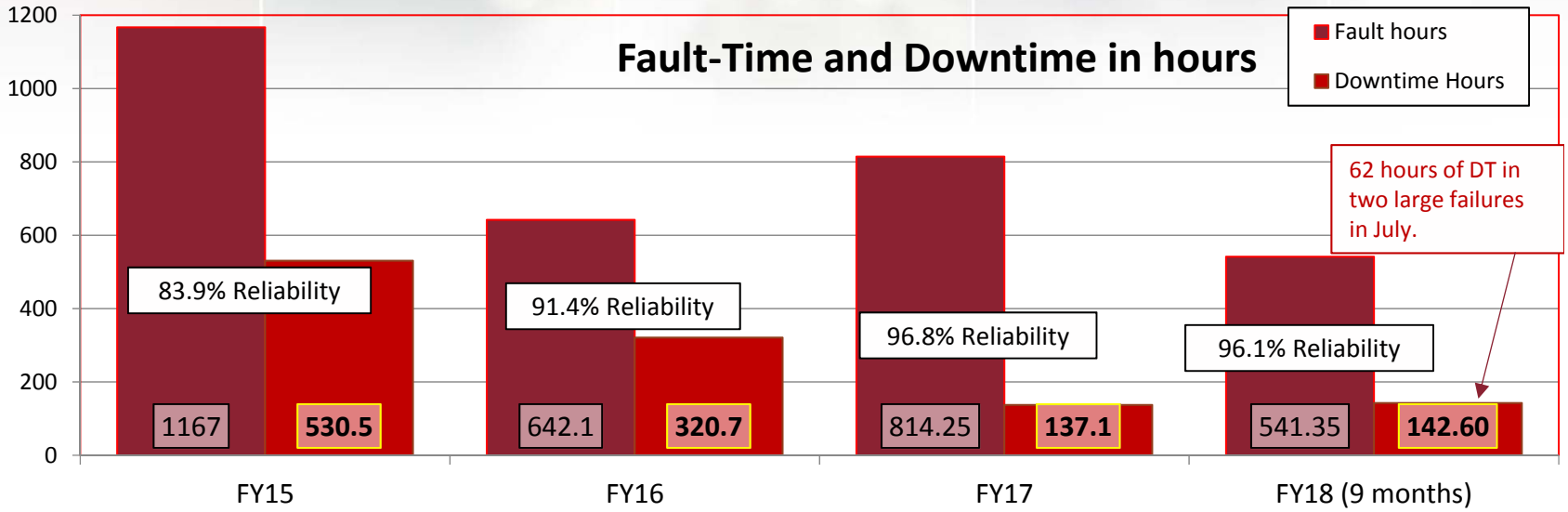
2. Reliability issues - do we have a good handle on the causes of downtime and an appropriate program to address the issues?

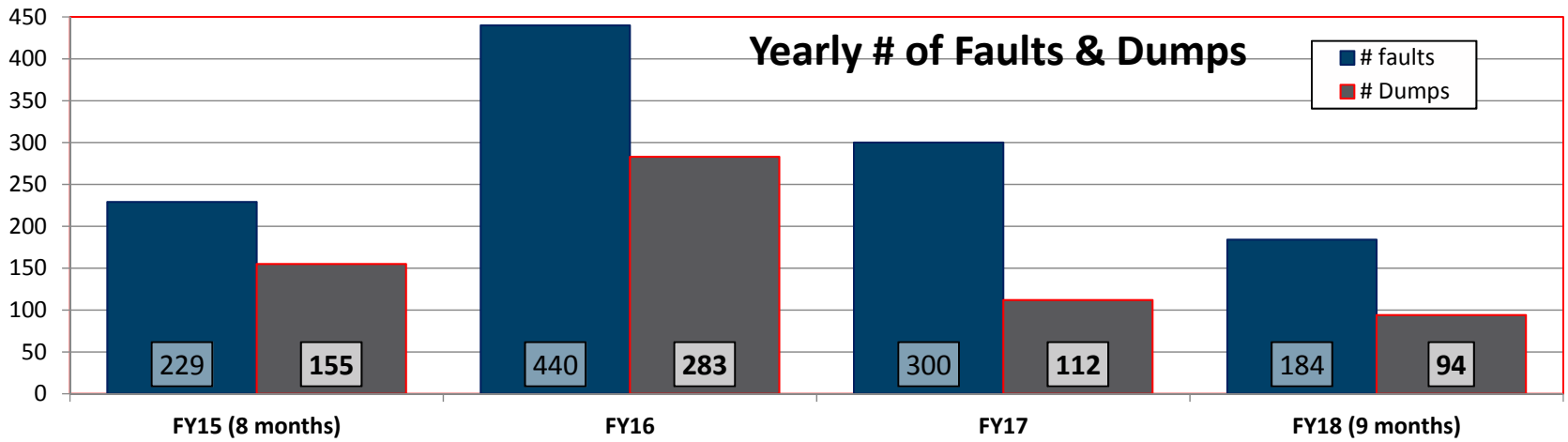
Operation Status



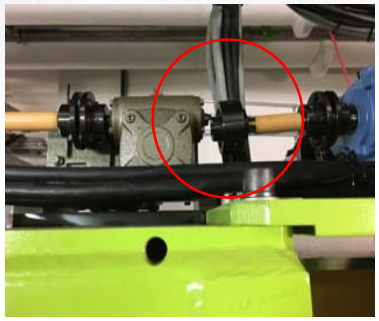
- 3 major shutdowns/year to install new IDs, front end and beamlines
- Commissioned 29 IDs (10 IVUs, 6 EPUs, 6 DWs, 5 3PWs, 1 BM and 1 PU) and supported 27 beamlines commissioning
- Steadily increase beam current and IDs sources while maintain high reliability of operations

Downtime, Faults and Dumps

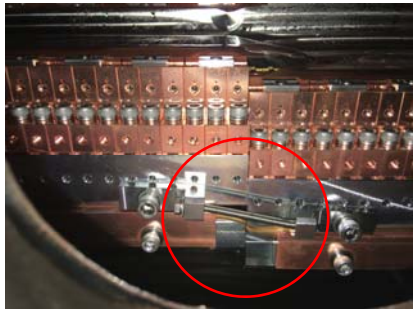




HXN IVU Failure

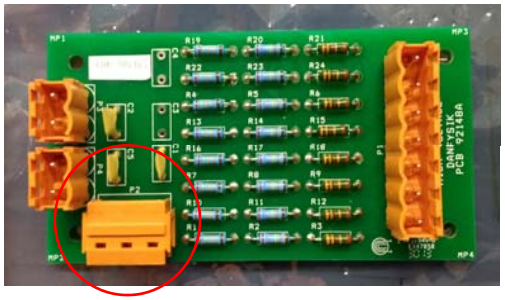


- On July 1st 2018, a gearbox drive shaft on the 3ID IVU failed in torsional shear. Rupture of the water cooling circuit in the IVU's vacuum chamber followed.
  - ~30 hours of loss of operation
  - replacement of vacuum chamber, gate valve, BPMs, NEG pumps /gauges, liner
- The primary root cause was misalignment of the drivetrain.
  - Misalignment caused during transportation from vendor (max 8 G was recorded)
- AD Director called an Investigation Committee
  - Report delivered on 8/14/2018
  - 20 corrective actions are proposed
- The immediate mitigation plans are as follows:
  - Realign drivetrain components on similar IVUs
  - Tighten mounting hardware and pin components
  - Implement control program to shut down the motor when discrepancy between 2 encoders becomes greater than 100 microns
- The long-term mitigation plans:
  - Perform a failure mode effects analysis (FMEA)
  - Resolve G-Force thresholds and evaluate their consistency across all IDs
  - Mechanically couple the two girders.



Issue with Booster Dipole Power Supply

- NSLS-II injector has high-power (900 A / 450 V) dipole PS in the booster (Danfysik)
- The failure in BD1 was discovered when it was being turned on after the 2-day maintenance period on July 11th 2018
  - Manifested itself in audible noise with output voltage oscillating 200 V at 600 Hz
  - Work planning was completed the same evening and investigation / debugging commenced
  - High power system: electrical hazards. Careful planning, barriers, documentation were put in place
  - We contacted Danfysik immediately; some help via teleconferences daily
- On 7/13/2018 we were able to localize the problem to connector on one of the scaling cards: oxidation of contacts
  - Reconditioned the card and restarted operations on Friday evening
- Investigation report is available
  - Will augment maintenance procedures
  - Author of the DPSs from Danfysik is being scheduled for site visit for consultations and preparing needed documentation
  - Project on installing a separate diagnostic monitoring system is pending funding



Operations in FY18

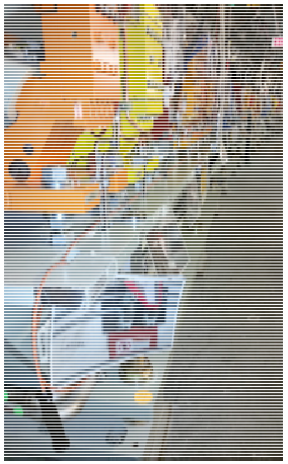
- Operating at 400 mA; studies at 450 mA

- 3 major operations requirements in FY18
  - Internal reliability goal 97% (DOE goal 95%)
  - ✓ Total operations hours 4750
  - ✓ Internal MTBF goal 35 hours

- 4 main challenges in securing high reliability of operations:
  - Insufficient maturity of machine subsystems
    - *Development program targets least reliable systems*
  - Insufficient staffing in certain areas
    - *Labor planning and cross-training*
  - Incomplete set of spares
    - *Continue procuring spares in FY18 and beyond*
  - Low component redundancy
    - *Developing 3rd RF system*

FIS-MET installation

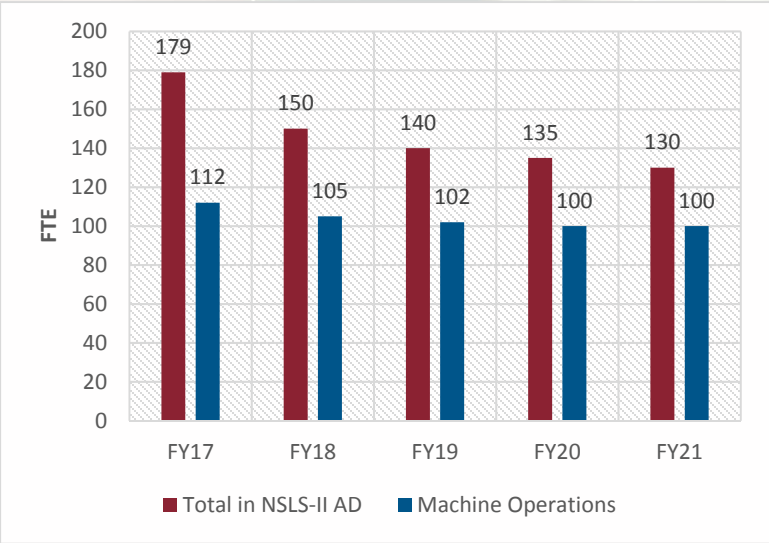
Leak detection system

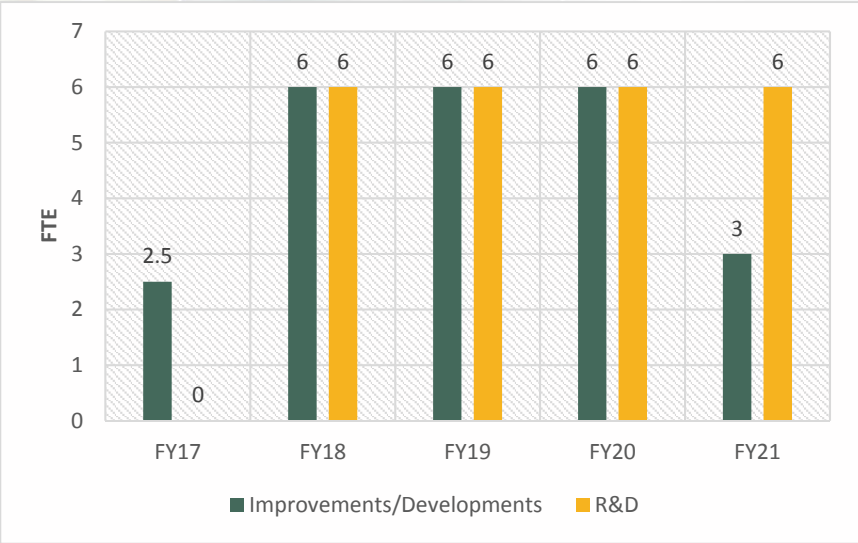


Machine Subsystems of Concern

- RF system
  - Full RF cavity warm-up (Sept 2016, Jan 2018), Burst disk (May 2017)
  - 3rd RF system project is progressing; Valvebox is awarded. **SSA transmitter to be awarded soon**
  - 3rd RF cavity will be available in the beginning of 2019
- Cryoplant
  - Contamination detected → periodic warm-ups of cryoplant
  - Pump & purge of RF D during May shutdown
  - Purifier project funded, new PRVs are on order
- Pulsed magnets and power supplies
  - Booster PMs are based on CC thyrotron, difficult to service, faults
  - 4 booster kickers, installed and operating today
- Linac klystrons
  - Found Thales klystrons in hand unreliable
  - Switching to Toshiba klystrons / modulators: 2 arrived, klystron and modulator are on order
- DI water
  - High leakage currents, oxidation in manifolds, frequent flushing
  - DI Working group. Flushing every girder, removing flow restrictors, beefing up coil T measurement, klixon and leak detection systems

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

- Working on increasing efficiency of AD in operations
  - Cross-training between groups
  - Split Utility group
    - DI Water experts to ME group (searching for a new GL)
    - Cryo experts to RF group
  - Electrical Engineering support safety across whole NSLS-II and BNL
  - Accelerator physicists are planned to work on Controls projects
    - 2 on FOFB, 2 on PS controls, 2 on motion control, 1 on diagnostics controls
  - 1st PhD student is on board! Planning for 2 more in FY19
  - Actively looking for Work For Others!

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  - 8 pm rad vertical emittance
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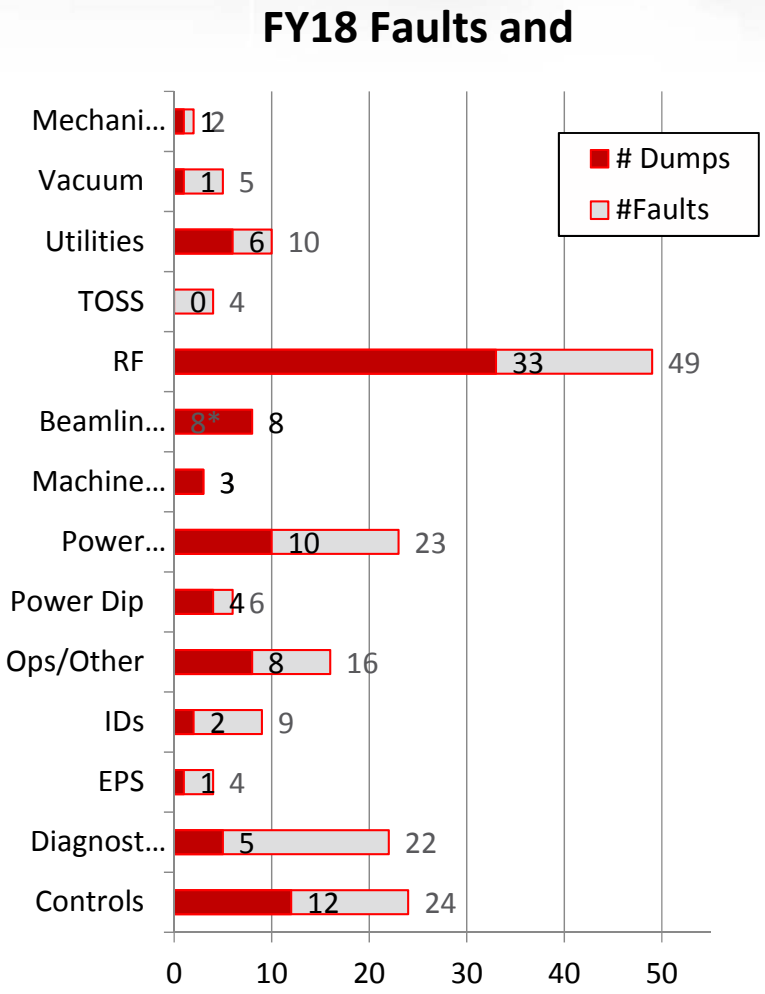
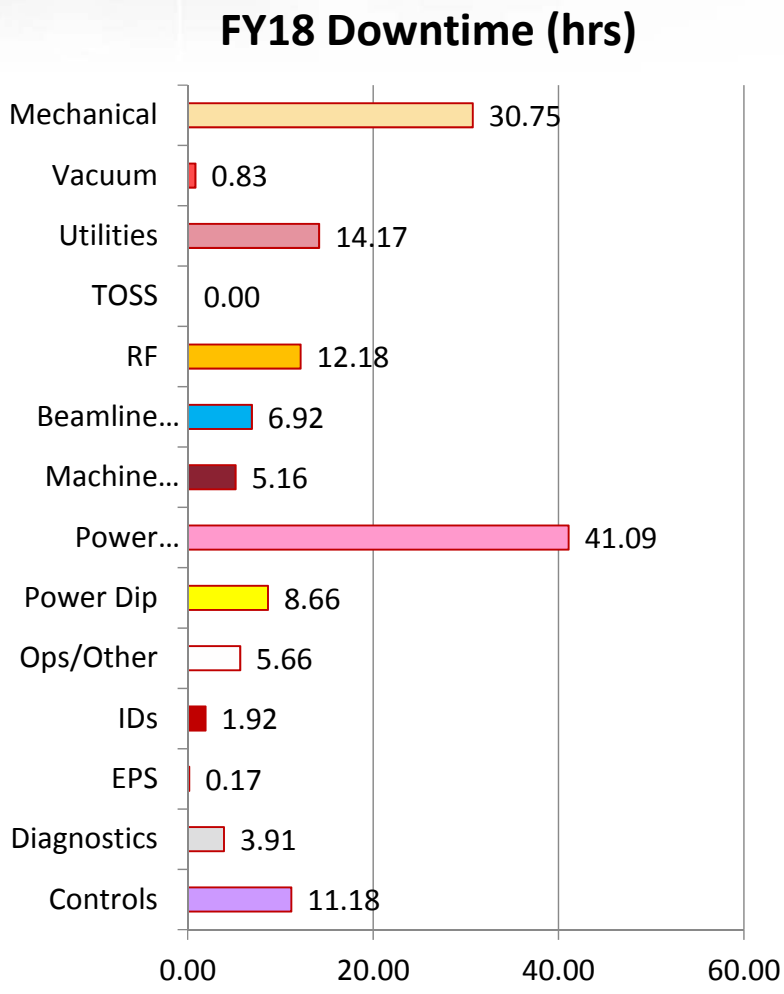
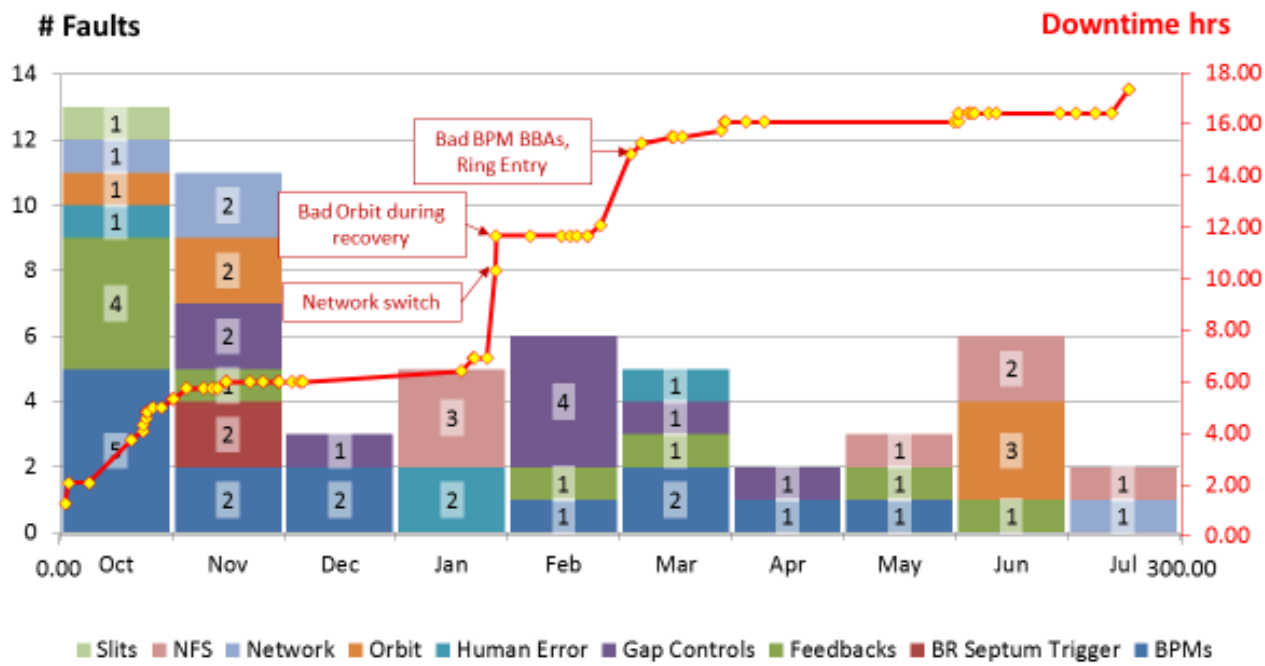
Downtime by Subsystem in FY18





Tracking Subsystem Performance

An example: Controls Systems



Tactics in Increasing Reliability of Operations

- Weekly review causes of recent beam dump and machine down time. Evaluating fault reports and subsequent corrective actions.

- System and component failures
  - Review lessons learned and formalize standard response (Cryo problem, water leak)
  - After hours faults: Call-in lists
  - FLOCOs trained to replace klixon panels, troubleshoot with system expert support, reset ion pump and ID drive controllers, reset dipole power supply, relieve helium pressure at valve box

- Maintenance activities: two days/~3 weeks
  - Work Requests are generated for all tasks
  - Approve, Track, Confirm "Ready for operations" and close all jobs
  - Spreadsheet based with emails→ *online work request under development*

- Developed EPICS control system for NSLS-II primary water utility system, accelerator and beamline PPS) utility performance trend, water leak monitor

- Tracking subsystem performance trends

Strategic Assessment of Vulnerabilities in NSLS-II Operations

- Identified vulnerabilities of NSLS-II operations to catastrophic failures
  - No redundancy in critical subsystems
  - Lack of spares
  - Required developments

- The following systems required for addressing risks to facility operations:
  - Complete built-out of RF system
    - 4th RF system
    - Spare RF cavity
  - Complete spare inventory
  - Redundant systems
    - Thermionic Gun
    - Storage Ring Dipole Power Supply
    - Booster Dipole Power Supply
  - Development project: 3rd harmonic cavities

- The total direct cost is 25M$. Technically limited schedule of 5 years.

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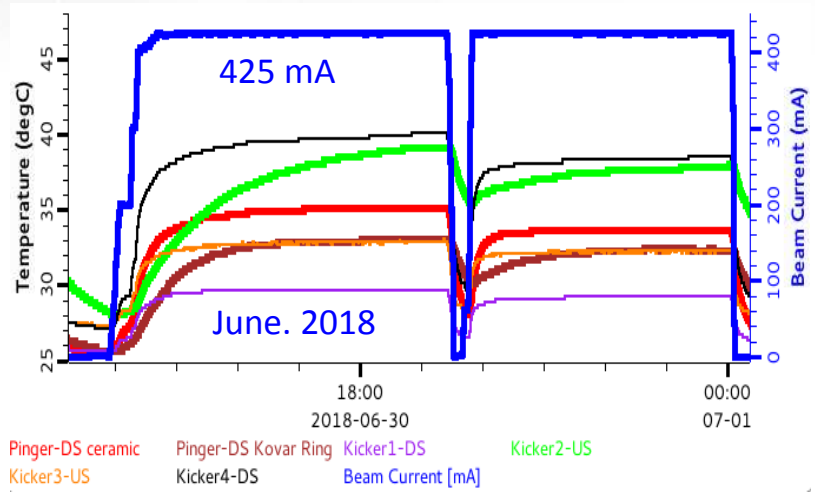
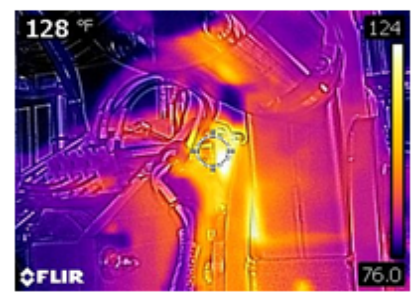
High Current Improvements in Prior Years

- Ceramic chambers
  - Observed heating and vacuum activity during first high current studies in Feb. 2016 with two RF cavities:
  - K2 reached > 100°C @ 400mA. Found Ti flaked off and discolored
    - Replaced kicker chamber and installed cooling fans
    - Replaced RF springs in joint flanges and bellows
    - Installed IR camera to monitor heat distribution
    - Developed in-house two new coating chambers and installed them in May 2017/Jan. 2018
  - Ceramic chambers T reduced to ~40°C @425 mA

- Bellows/BPMs heating
  - A few temperature sensors (RTD, out of hundreds) showed higher temperature up to 80°C
  - On site heating survey all bellows around SR
  - Added cooling water to SR chambers
  - Replaced RF springs/bellows
  - Heating and related vacuum issues were improved by replaced 9 bellow's RF springs (totally ~770)



C16 temp. with IR camera

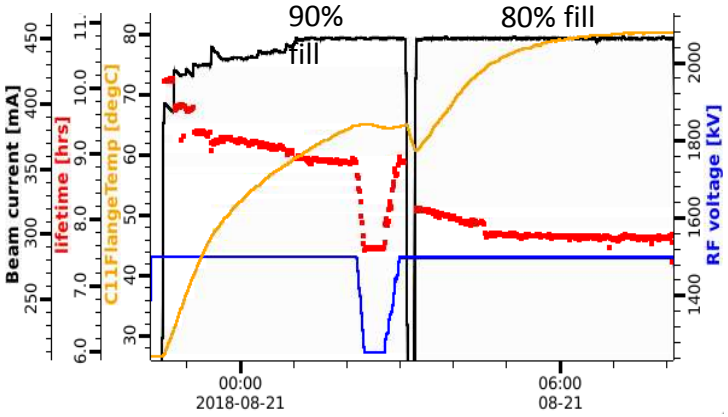


Recent Studies at 450 mA

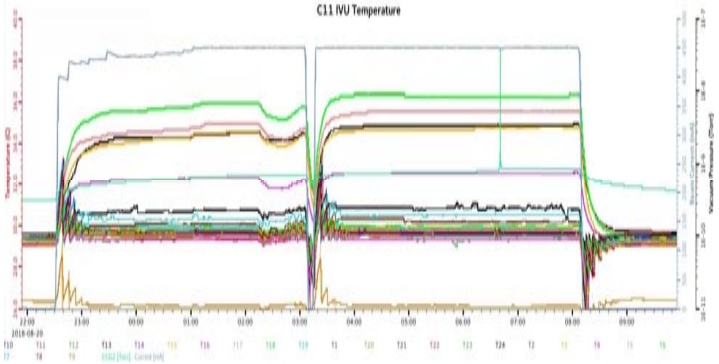
- Increased current to 400 mA in regular operations on Aug 9th
  - 8 hrs beam lifetime at 30 pm emittance
  - Noticed gradual decrease of lifetime and found a vacuum leak at C11 G4 downstream flange
  - Stopped ops next day, leak checked, found a leak, tightened bolts

- Studies of 450 mA on Aug 20th
  - Successfully stored beam at 450 mA for 7 hrs with 3 DWs closed only.
  - RF klystrons' power is about 200kW.
  - Studied two fill patterns (change peak current and bunch length):
    - For 80% fill induced flange heating is substantially higher than for the 90% fill
  - Run ring at two RF voltage levels 2.4 MV and 3 MV (change in the bunch length)
  - Vacuum leak opened in C28
  - Temperature of two flanges reached 80°C and raised above 60°C at some others
  - Gauges in IVUs indicated vacuum activity and spikes

Below overheating



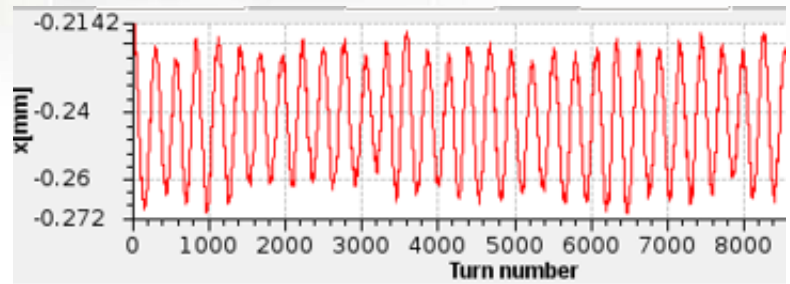
Vacuum activity in IVUs

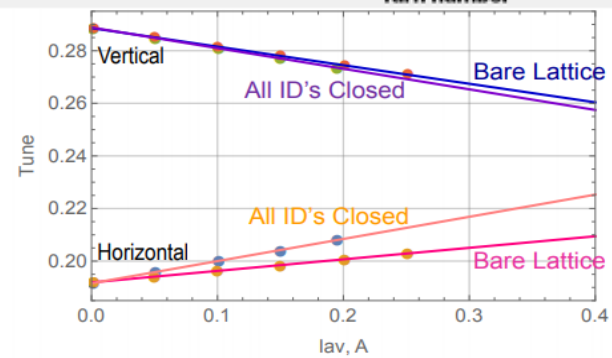


Recent Studies at 450 mA

- Changing RF voltage
  - 3 MV induced chamber heating is substantially higher than for 2.4 MV due to bunch length change
  - Beam is longitudinally unstable at 2.4 MV with 1.35 kHz motion

Beam longitudinal motion at 2.4 MV

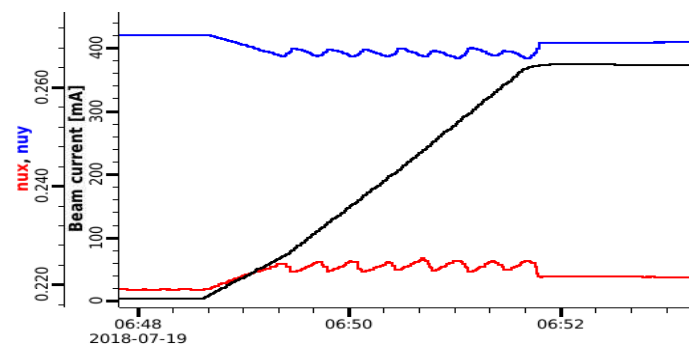




Horizontal and vertical betatron tune shifts vs. average current

- Tune shift dependence on Average current
  - Measurement results agree with analytic result
  - The observed IDs effect on tune slope change in x plane is bigger than y plane, due to high beta function→ Tune feedback

Tune feedback



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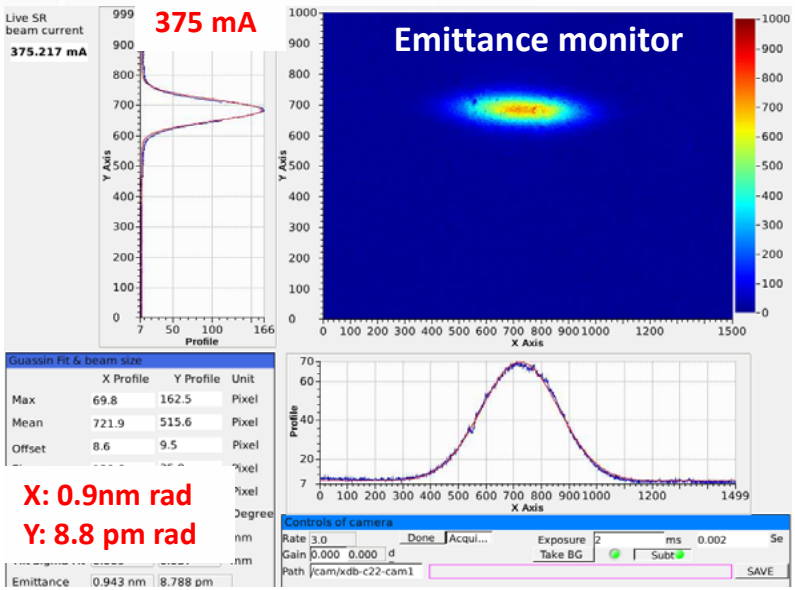
Low Vertical Beam Emittance

- Routine operations at vertical emittance of 30 pm

- Beam studies with vertical emittance of 8 pm rad
  - using skew quads to correct vertical dispersion and betatron coupling
  - Electron beam size and divergence decrease by a factor of 1.7
  - Beam life is shorter; lifetime drops from 8 hrs to 4 hrs at 375 mA
  - More frequent Top-off injections; 140 s → 90 s between shots



- 2 weeks of operations with diffraction-limited emittance
  - Dedicated low emittance study (Mar. 2017)
  - 8 pm V emittance operations at 275 mA and 375 mA (3 days in Mar. 2017, 2 weeks in July 2018)
  - Feedback from beamlines of low emittance operation
    - 19 beamlines joined for studies in 2017
    - 27 beamlines joined for operations in 2018
    - Discussions with beamlines on their feedback are ongoing

Outline

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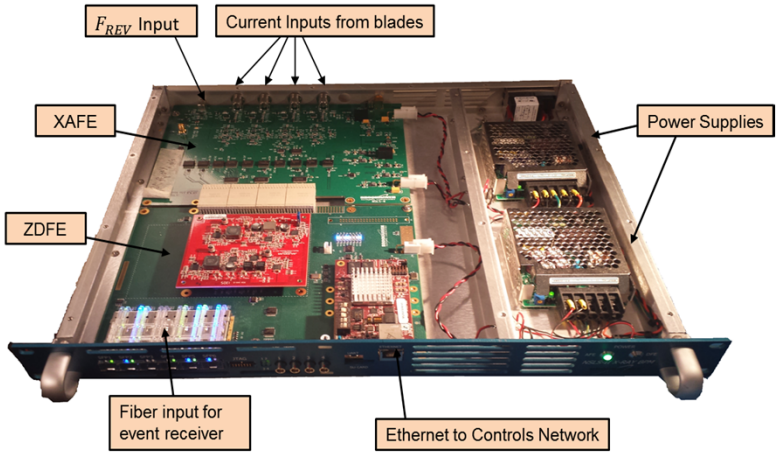
  - 10 pm rad vertical emittance
  - **Future facility upgrades**
- Conclusions

Ongoing and Future Projects

- Construction, installation and commissioning of 3rd RF system
  - Cavity will be available in the beginning of 2019
  - Tenders for RF transmitter and valvebox are awarded
- Development of 3rd harmonic RF cavity
  - 3rd HC will increase beam lifetime and aid in reducing impact from collective effects
  - Reduce vacuum chamber overheating
- BPM R&D
  - Prototyping new DFE and considering AFE upgrade
  - Comparison with Itech BPM receivers
- Testing new undulator concepts at NSLS-II
  - ID test straight section

Cavity string assembly in RF building

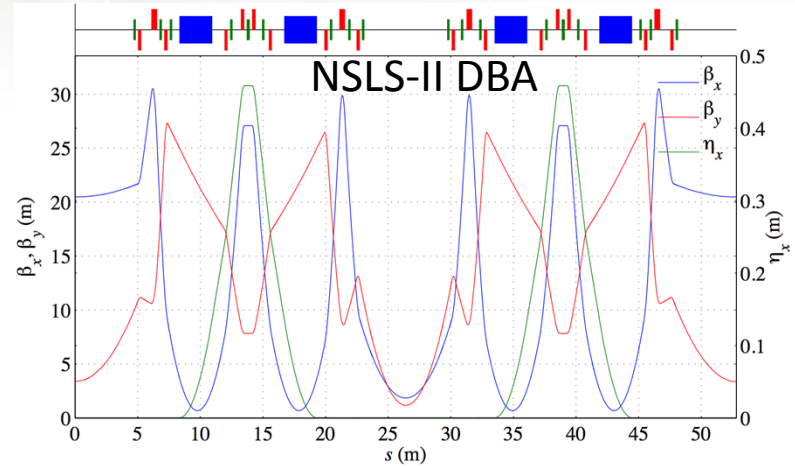


X-Ray BPM Electronics

Low-emittance upgrade of NSLS-II via "Split-Bend" Approach

Funded BNL LDRD

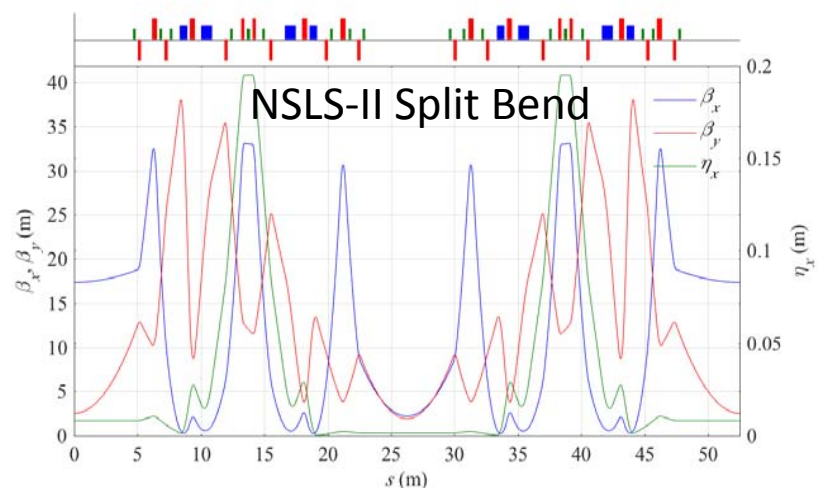
- Factor of 0.25 in ε_x will be of great impact for NSLS-II users
  1. reducing J_x
  2. further optimization of $F(lattice)$
  3. increase of N_d ×2: potential gain of factor 2^3=8 with minimized hardware changes



- ε_x=333 pm rad is accomplished
- with Damping Wigglers ε_x=*200* pm rad

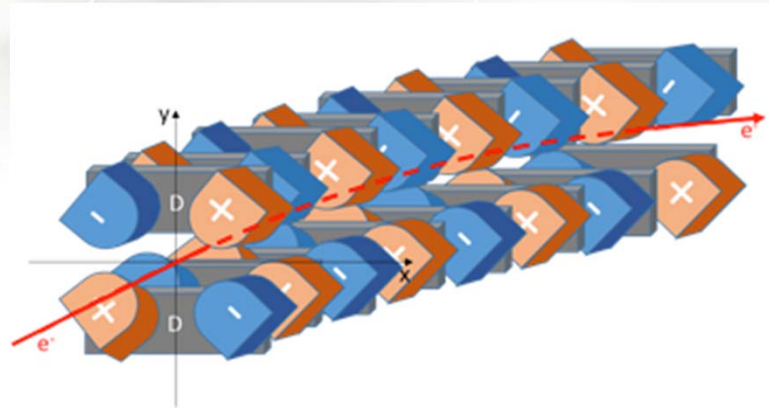
- Studies ahead of us:
  - chromaticity compensation and DA
  - injection options
  - magnet design
  - vacuum analysis
  - collective effects

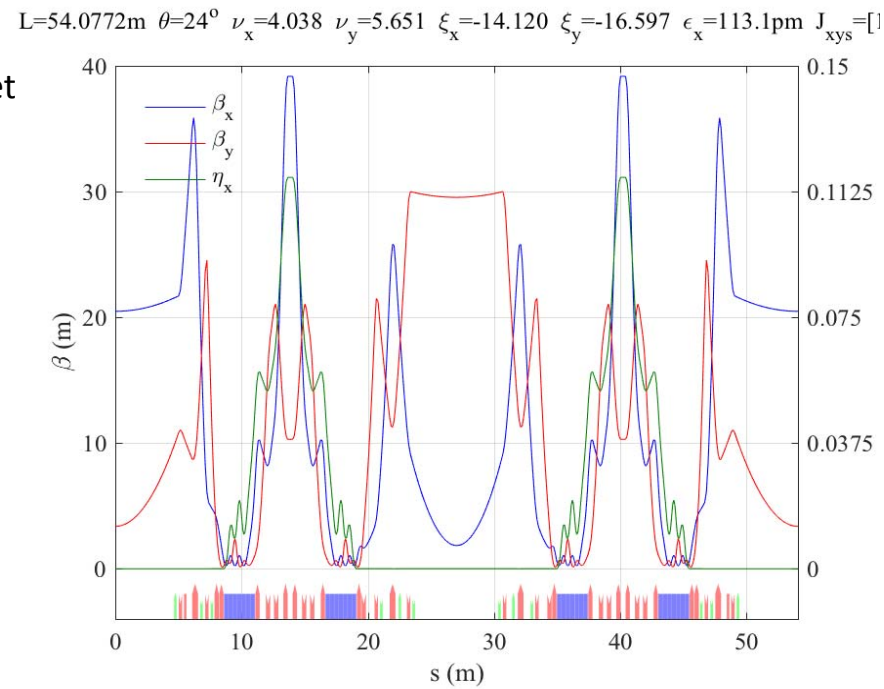
$$\varepsilon_x = \overset{2}{F(\nu_x, lattice)} \frac{E^2}{\underset{1}{J_x} \underset{3}{N_d^3}}$$



Upgrade via Complex Bends

- Alternative solution to MBA optics for low-emittance synchrotrons
- Transition from individual dipoles to multiple dipole poles in a wiggler-type structure
  - APS DBA: 40x2=80 **dipoles**→
  - APS-U MBA: 40x7=280 **dipoles**→
  - NSLS-II upgrade: 30x2**x20**=1200 **poles**
- Challenges
  - Gradients of 200-500 T/m are required
  - Small apertures
  - Cryomagnet (similar to HEX SCW) or Permanent Magnet
  - Heat load from Synchrotron Radiation
- New type of optical elements
  - Complex Bend element
  - Dispersion Suppressor and Dispersion Amplifier
- Pursuing this as a 2nd option for NSLS-II upgrade
  - Every magnet is replaced by Complex Bend
- Two preprints published and a paper in PR-AB is nearing publication
- Prototype at 70 MeV + beam tests at ATF are funded by NSLS-II Facility Improvement budget





Recommendations from the Previous SAC Meeting

- If not done already, the AD should develop plans for restoring accelerator operation as quickly as possible should a critical component, for which there is no spare, fail.
  - *Response: Developed plans for replacement of SR septum, cryomodule, insertion device, DCCT, repairs of booster dipole and storage ring diploe PS*

- Continue to develop an accelerator improvement road-map that can provide focus for more near-term developments.
  - *Response: Following and updating list of near-term accelerator improvements (45 projects in total). Budgeted completion of these projects in 3 upcoming years.*

- Work with the NSLS-II Director to help resolve deficiencies in computing support from CSI.
  - *Response:*
  - *AP group prefer to run codes on the local cluster. Most AP experts need <10 nodes.*
  - *Small users are at low priority at CSI. Support of special codes is lacking.*

Conclusions

- NSLS-II accelerators are delivered reliability at the 96.4% level in FY18

- We are busy with:
  - Increasing annual operations time
  - Balancing staff in the areas of concern
  - Procuring sufficient inventory of spares
  - Building necessary subsystem redundancy

- We are looking ahead for future upgrades of the NSLS-II facility to keep our facility at the cutting edge
  - Critical for maintaining skillset and keeping up morale of NSLS-II accelerator staff

- Actively looking for Work for Other and collaboration with other facilities

- Doing well due to breath and depth of expertise, talent and diligence of NSLS-II staff