Experience of the first six years operations and plan in NSLS-II

Guimei Wang for the NSLS-II team
National Synchrotron Light Source II
Brookhaven National Lab
IPAC21, May 24-28, 2021, Campinas, Brazil

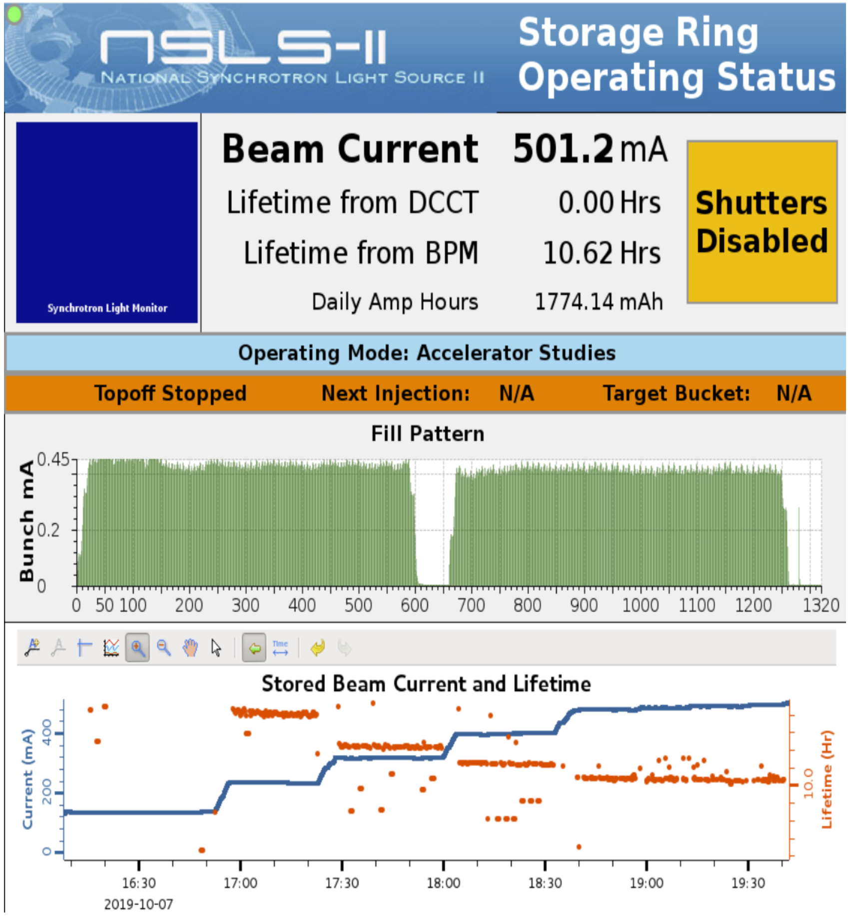
U.S. DEPARTMENT OF ENERGY | Office of Science

BROOKHAVEN NATIONAL LABORATORY

Poster: MOPAB079

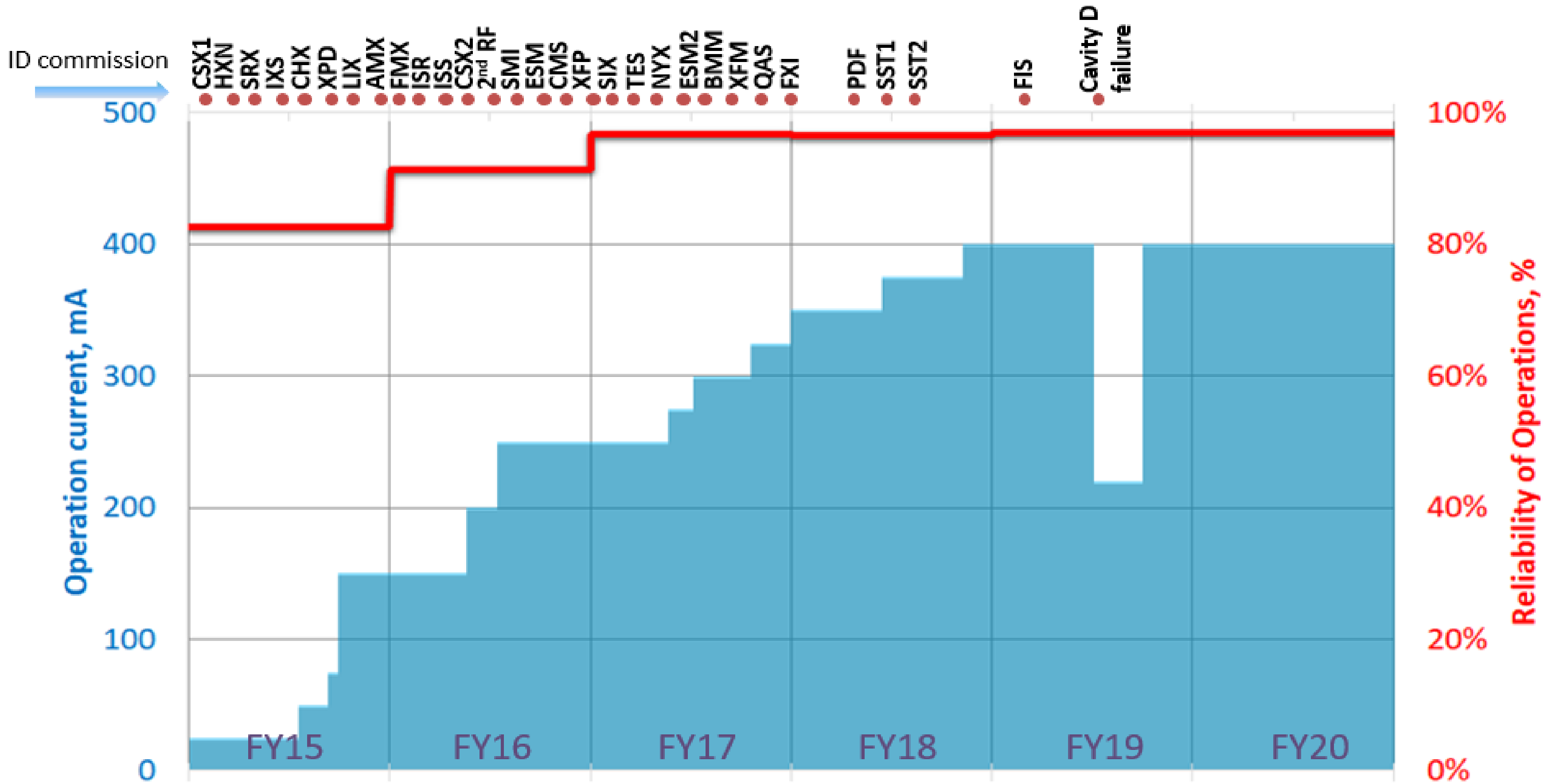
National Synchrotron Light Source II

- NSLS-II is a 3 GeV, 500 mA, high-brightness light source, funded by U.S. Department of Energy (DOE), at the Brookhaven National Laboratory
- One of the newest and most advanced synchrotron facilities in the world.
  - wide spectral range: IR to hard x-ray
  - high average spectral brightness
  - high flux density
  - >60 beamlines



- CD-0 was approved in 2005
- CD-3 was approved in 2009
- SR commissioning started in Mar. 2014
- In Feb. 2015, CD-4, the final milestone of the project, completed
- Total cost is $912 Million
- 28 beamlines in top off operation at 400 mA
- Oct. 2019, demonstrated 500 mA beam current
- May. 2021, 3rd RF cavity in operation

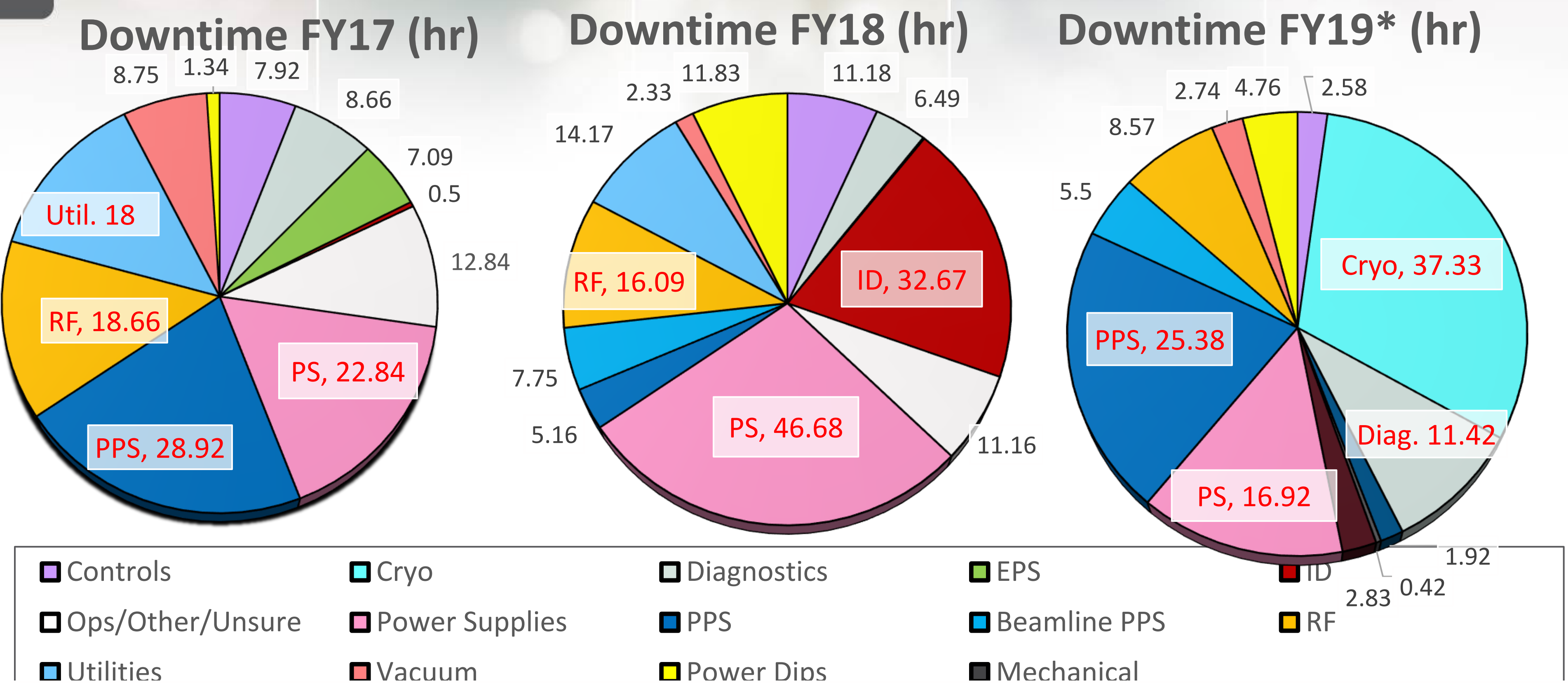
NSLS-II: 6 years operations



	FY15	FY16	FY17	FY18	FY19	FY20
Operation Hrs per FY:	2100 hrs	3740 hrs	4500 hrs	4750 hrs	5000 hrs	5500 hrs
Facility uses per FY:	110	447	1037	1364	1700	~1200

- Commissioned 29 IDs sources (10 IVUs, 6 EPUs, 6 DWs, 5 3PWs, 1 BM and 1 PU)
- High reliability has been maintained while we steadily increased beam current & IDs
- Normal operation with 2 cavities limits our performance (max 400 mA)
- Forced to decrease ops current to 220 mA due to the failure of one cavity in Apr. 2019

Yearly Statistics by subsystems



Main contributors of machine downtime are from utility, PS, cryo plant, RF, PPS and ID

- RF: in 2018 ran at a lower voltage to avoid frequent trips due to vacuum leak
    - Lost RF cavity C in 2019 → 3.5 months of operations at 220 mA
- Cryo Plant: cold box warm up ~monthly after burst disc event in June 2017
- Power Supplies: majority of FY18 downtime due to single booster PS event, frequent kicker failures

✓ Utilities: cooling water quality caused an increase in ground current faults and trips due to magnet overheating, required ~5 hrs to flush

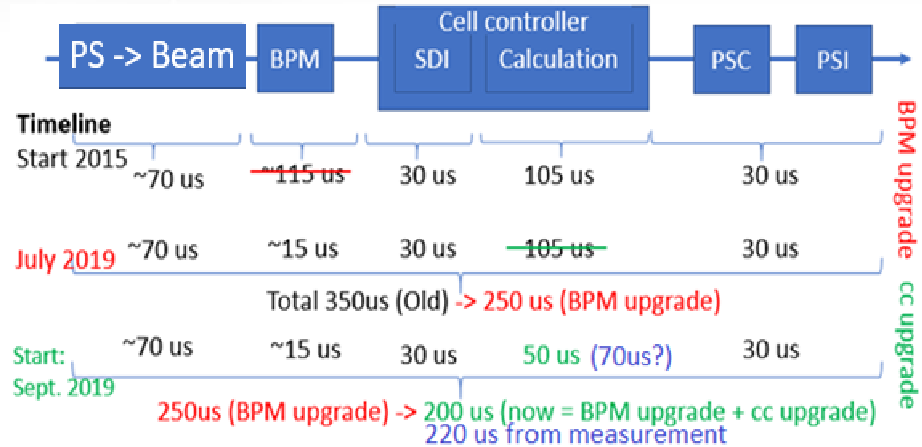
✓ PPS: developing control system diagnostics to record and identify root causes, door switches replaced

✓ ID: sheared cooling water line in the C3 IVU when a drive shaft connecting 2 halves broke

Fast Orbit Feedback improvement

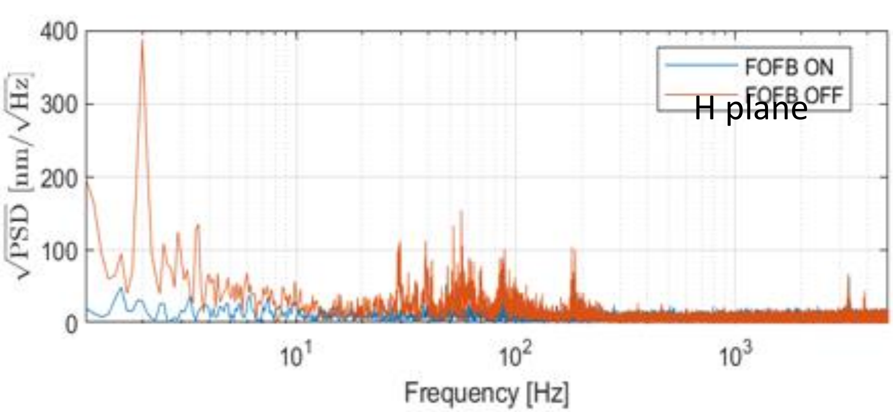
- Stage-to-stage latency characterization
- Improved corrector PS bandwidth from3/1 kHz to 6.3 /4.1kHz (H/V)
- Removed BPMs extra 100us delay in firmware
- FOFB loop total latency: 250 µs
- Bandwidth of the FOFB system increase from 250 Hz to 400 Hz/300 Hz (H/V)
- The orbit beam instability improved by 30%/10% (H/V)
- Typical ID source position/angle integrated motion [1-500 Hz]: 0.6% (H) and 7% (V)
- Long term stability: local bump feedback on ID BPM/xBPM interact with FOFB to reach µm

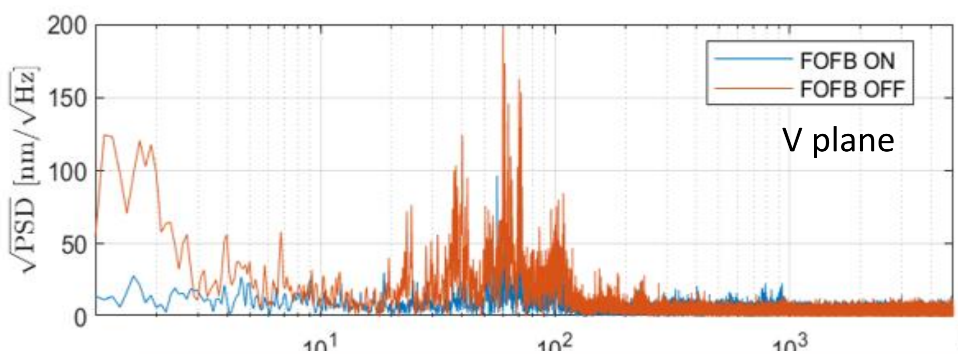
FOFB stage-to-stage latency and improvements



NSLS-II: Sukho Kongtawong

ID source position stability feedback ON/OFF

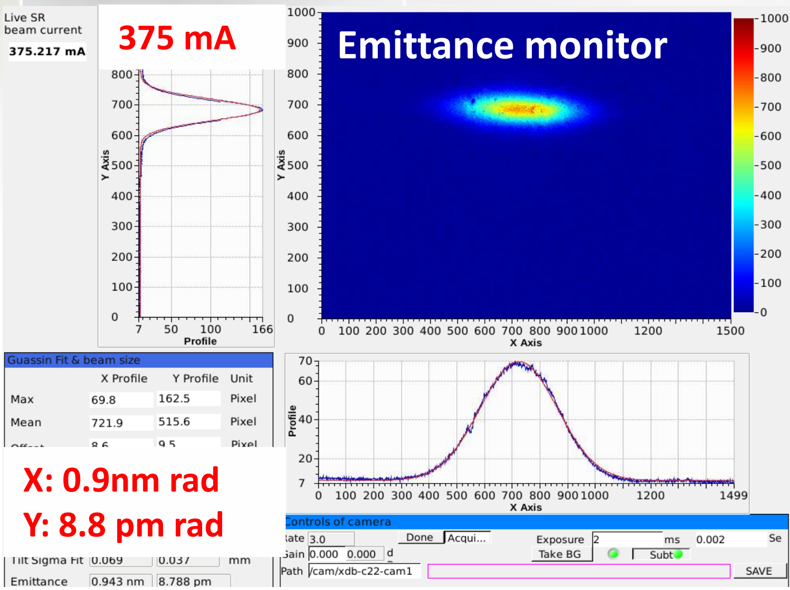




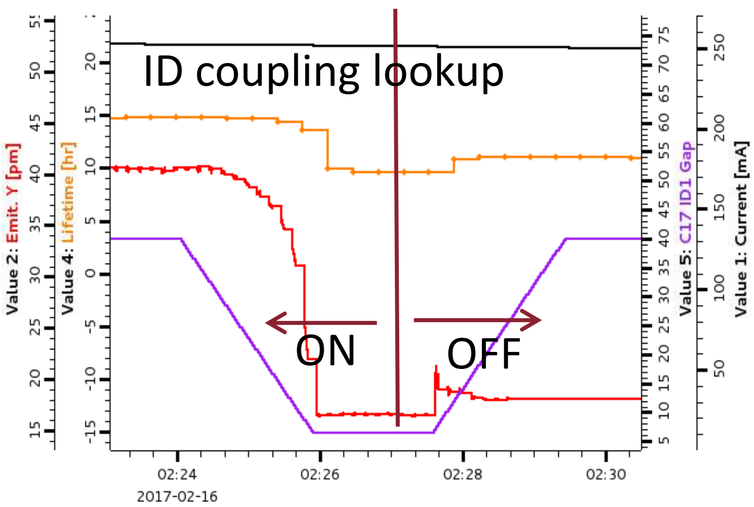
Sukho Kongtawong, Recent improvements in beam orbit feedback at NSLS-II, NIMA 976 (2020) 164250

Low vertical beam emittance

- 8 pm diffraction vertical emittance: using skew quads to control coupling (Yongjun)
- Low emittance study and operation
  - Dedicated low emittance study (Mar. 2017)
  - 8 pm operation at 275 mA and 375 mA (Mar. 2017, July 2018).
  - Survey among beamlines of low emittance operation.
  - HXN: observed 25% increase (VS model 45%) in peak intensity
  - CHX: Interference patterns show a significant increase in the visibility/contrast with the reduced emittance



- ID coupling correction
  - Some ID Gap change affects V emittance dramatically and beam lifetime
  - Developed coupling lookup function with 15 skew quads (Yoshi)
  - Maintain beam emittance at the pin-hole camera very well (w/o: 7.0-7.2 pm/7.1-11.4 pm)
  - Installed dedicated SQ at C17 AMX in May 2017



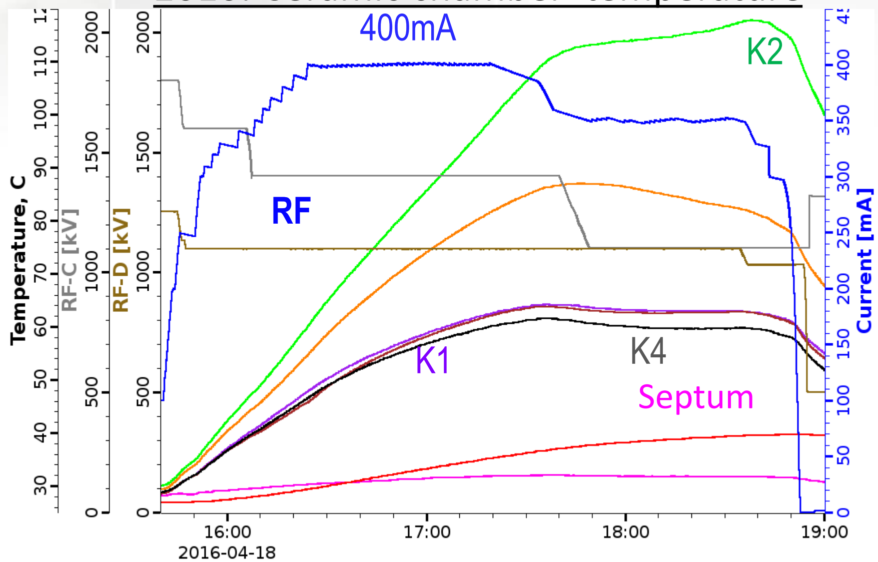
Path to high current: Ceramic chambers

- SR ceramic chambers: 4 fast kickers for beam injection (critical) and 1 pinger for beam dynamics studies
- Require Titanium coating 2 µm thickness over the entire inner surface with ± 10% uniformity

Issues

- Observed heating and vacuum activity during first high current studies in Feb. 2016
- Kicker chamber 2 reached > 100°C @ 400mA. Discovered Titanium coating flaked off and chamber discolored
- Due to limited space, RTDs were installed at the end of chambers to monitor temperature
- High uneven localized heating or abrupt temperature changes
- Chamber failure can cause two days downtime

2016: Ceramic chamber temperature



Damaged Kicker 2 chamber

Path to high current: Ceramic chambers (CONT.)

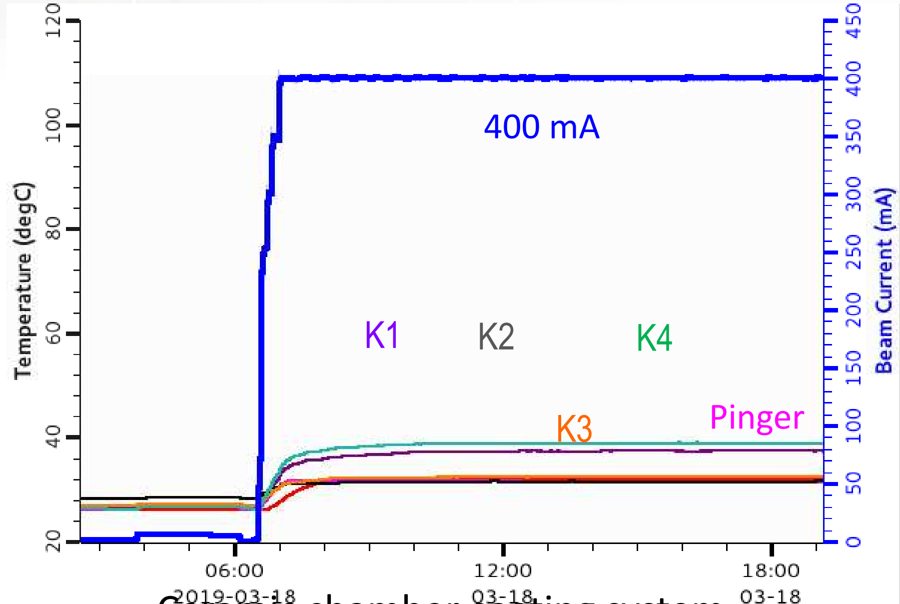
Improvements

- Replaced damaged kicker chamber
- Installed cooling system
- Replaced RF springs between flanges and bellows
- Installed IR camera to monitor heat distribution
- Procured 5 new ceramic chambers and applied Titanium coating in-house. Installed three chambers in May. 2017-Sep. 2018
- Ceramic Temperature reduced to ~40 ^{o}C @400 mA

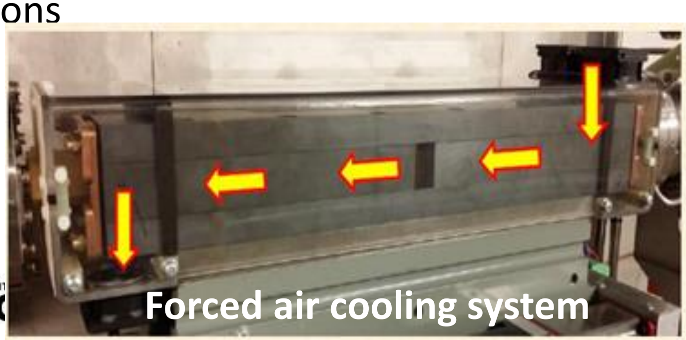
In-house coating development

- DC magnetron sputtering
- Central anode to initiate discharge
- Integrated thickness monitor
- New coating method successfully improved ceramic chamber thermal performance in operations

2019: Ceramic chamber temp.



Ceramic chamber coating system



Forced air cooling system

Path to high current: RF springs

- 770 RF Springs installed in Storage Ring

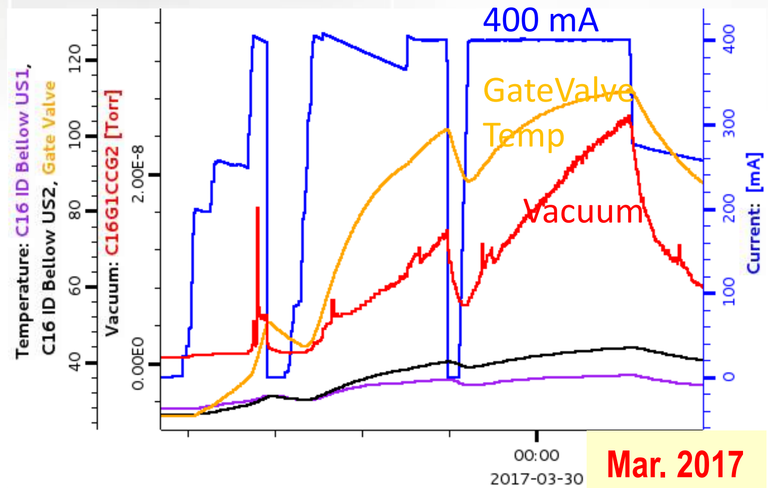
Issues

- Certain temp. sensors indicated temperature > 80°C
- Improper RF spring installation caused trapped mode heating
- Temp. sensors installed at discrete locations do not show all hot spots

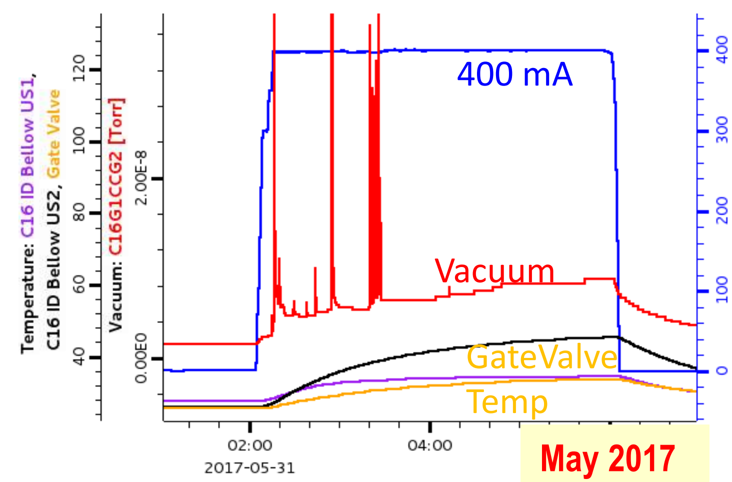
Improvements

- In-situ thermal survey: discovered that majority of heated flanges were located at straight sections
- Installed IR cameras to monitor heat distribution
- Developed new RF spring installation procedure
- Replaced 39 RF springs since 2017 to reduce heating
- Install 770 1-wire sensors at flanges

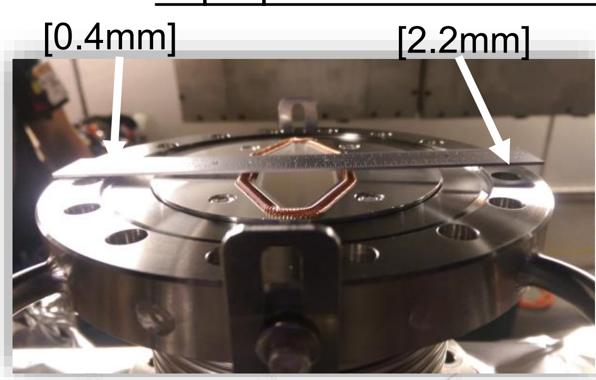
Before: with RF springs improperly installed



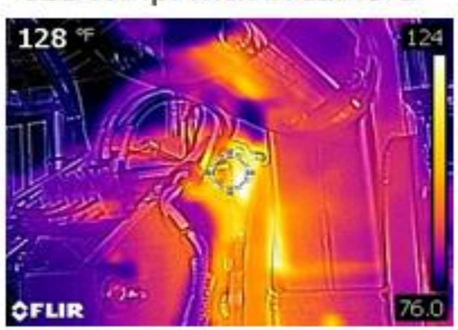
After: RF spring installed properly



Improper installation of RF springs



C16 temp. with IR camera



Systems required to reach 500 mA, 8 pm-rad in operation

- Based on our recent commissioning / operating experience further progress is limited

Limitations	Overheating of chambers	Stress on injector		Redundancy against an RF cavity loss
Operating modes	I_{ave}^2		Q/shot	I limit, mA
	A^2		nC	if 1RFC failed
150 mA, 2RF, 7 beamlines AS IN FY15	4.5		2.0	150
400 mA, 2RF, no THC, 30 pm rad TODAY	12.0		7.5	**220**
500 mA, 3RF, no THC, 8 pm rad TODAY	**19.8**		**9.4**	450
500 mA, 3RF, no THC, 8 pm rad + HEX + MIE	**20.0**		**9.4**	**370**
500 mA, 4RF, THC, 8 pm rad + HEX + MIE	**7.8**		**8.0**	**500**

Conclusions

1. Need Third Harmonic Cavity (THC) for any performance beyond today's
2. For full performance and expected beamline suite need THC + 4th RF system

Systems required to reach 500 mA, 8 pm-rad in operation (CONT.)

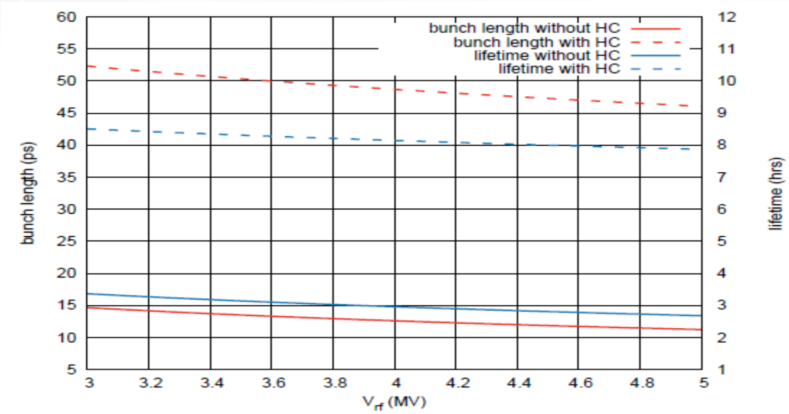
4RF system: supply power loss of all ops IDs + new (HEX, MIE) @500 mA (Refer to Jim's talk)

Third Harmonic Cavity (THC): bunch lengthen

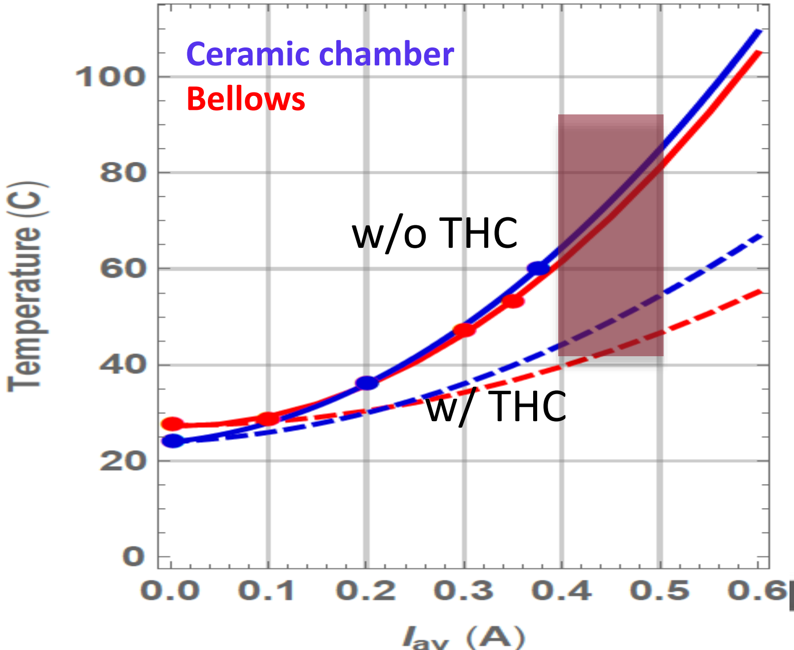
- Increase bunch length by a factor of 2 including gap fill and bunch lengthen effect (3.5 for ideal case)

- Lower heating
  - Power loss lower by a factor of 2.8
  - The ceramic chamber and bellows temp. will reduce with THC
  - Can handle 600 mA heating with predicted temperature upto 70 °C

Bunch length and lifetime w/o HC



Heating w/ and w/o THC



Summary and outlook

- Achieved 400 mA top off routine operation
- Provided 5000 hrs operations with 97% reliability for 28 beamlines
- Achieved designed beam emittance, εx= 0.9 nm-rad and εy = 8 pm-rad
- FOFB system was improved to large bandwidth 400/300 Hz and reach 0.6% (H) and 7% (V) beam size
- Demonstrate beam current 500 mA. Improvements include in-house ceramic coating, RF spring installation correction and 100s new temp. sensors added to monitor vacuum components heating
- 3rd RF cavity was installed in Apr. 2021 and is operating at 400 mA now
- To reach 500 mA, 8 pm reliable operation, 4 RF systems to support all IDs during operation and third harmonic cavity

Acknowledgements

- Accelerator division director: T. Shaftan
- Accelerator Coordination: G.M. Wang, J. Choi, Y. Hidaka, R. Smith, B. Wahl
- Accelerator Physics: V. Smalyuk, G. Bassi, X. Yang, Y. Li, L.H. Yu
- Beam Operations group: E. Zitvogel, R. Fliller, T. Summers, M. Santana, G. Weiner, E. Zeitler, R. Rayner, C. Gardner, P. Marino…
- RF group: J. Rose, F. Gao, J. Cuppolo, J. Culpin, B. Holub, C. Marques…
- ID group: T. Tanabe, J. Rank…
- Vacuum group: C. Hetzel…
- Diagnostics and Instrumentation group: D. Padrazo, B. Bacha, B. Kosciuk, J. Mead
- Electrical Engineering: G. Ganetis, S. Buda, A. Castablanco, D. Oldham, W. Louie
- Controls: Y. Tian, K. Schroff, Y. Hu, K. Ha
- Mechanical Engineering group: L. Doom, S. Sharma, M. Loftus, A. Hussein, C. Spataro, F. Karl…