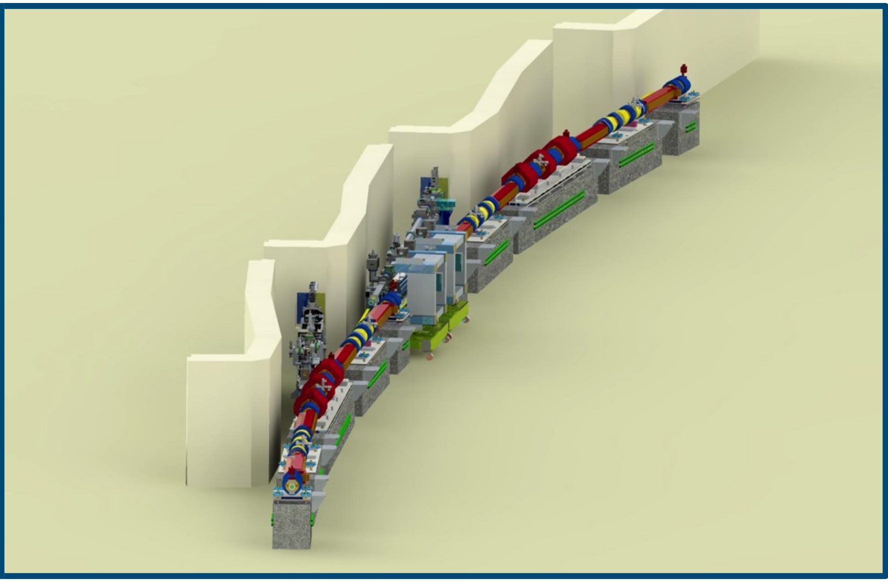
Status of APS operations and recent developments in IDs



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Accelerator Operations and Physics Group
Argonne National Laboratory

High-Brightness Synchrotron Light Source Workshop
April 26-27, 2017

Outline

- Operating modes, availability and MTBF
- Lattice, sextupole optimization
- Superconducting undulators
- Abort kicker
- Helical SCU
- User steering
- ID feedforward

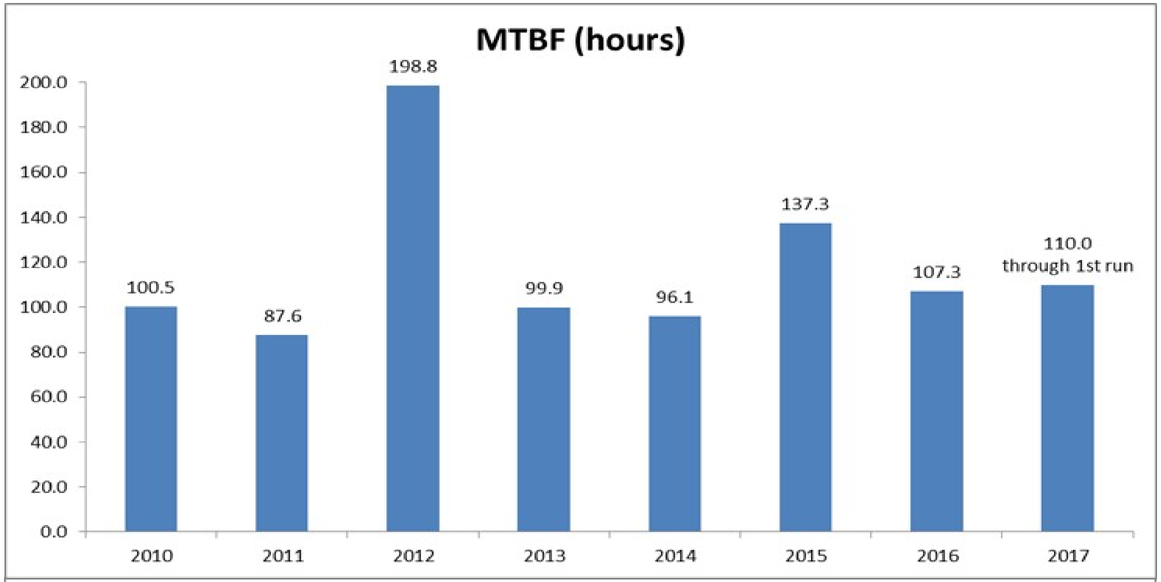
Operating modes

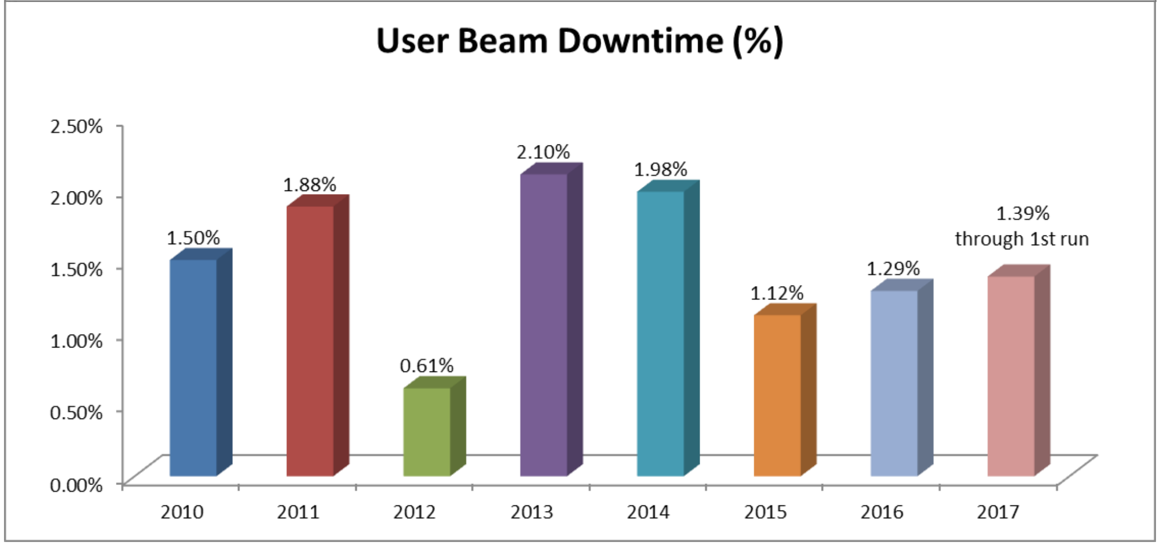
- There are 3 operating modes (fill patterns): uniform fill patterns with 24 and 324 bunches and hybrid pattern where main bunch is separated by a long gap from 500-ns long bunch consisting of 8 septuplets
- APS always operates at 102 mA with effective emittance ratio for all modes of 1.3%

	Uniform 24 bunches	Uniform 324 bunches	Hybrid fill
Charge per bunch	16 nC	1.1 nC	60 nC – main bunch, 5.7 nC – multiplets
Bunch separation	153 ns	11.4 ns	1.6 μs between main bunch and train
Injection	2-min topup	12-hour injections	1-min topup
Beam current variation	< 1%	102 mA to 85 mA	< 1%
Chromaticity	+3	+3	+10
Transverse beedback	ON	OFF	ON
Fraction of operationing time	68%	16%	16%

APS reliability recent history

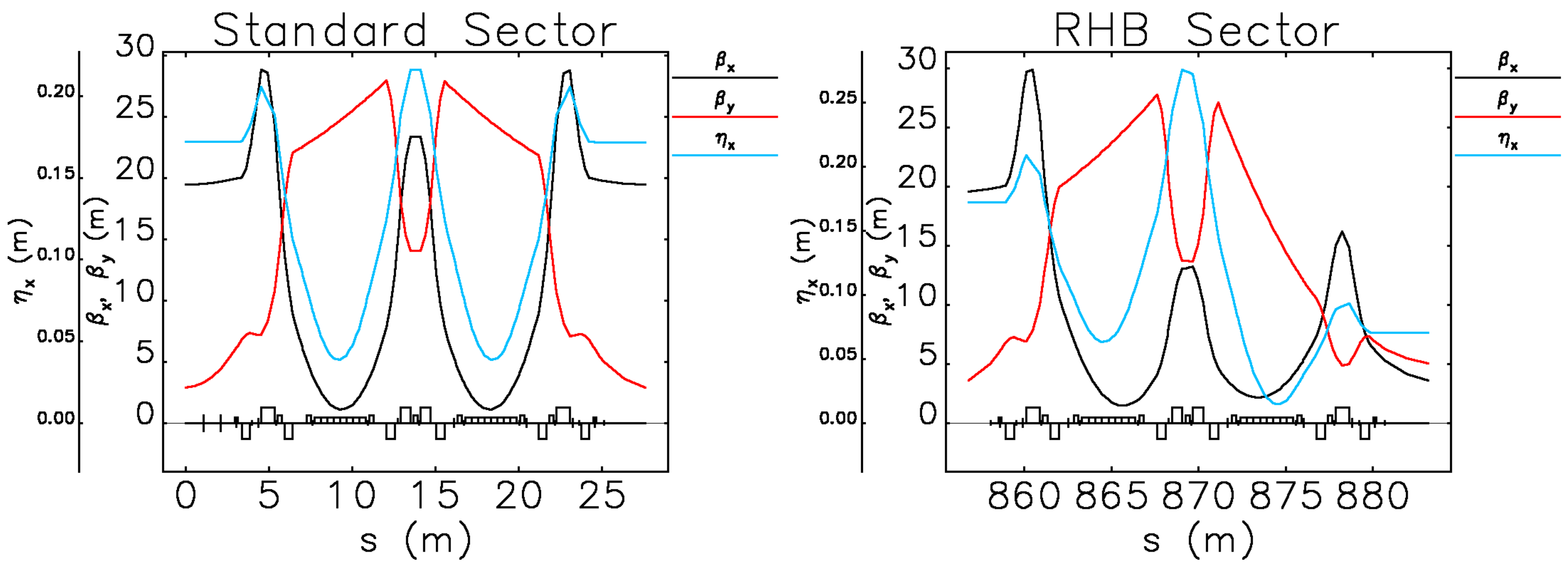
- APS schedule provides for 5000 hours a year of user operation
- There are three 1-month long maintenance shutdowns per year
- Each shutdown is followed by a week-long start-up period
- There is 24-hour long maintenance and beam study period every week



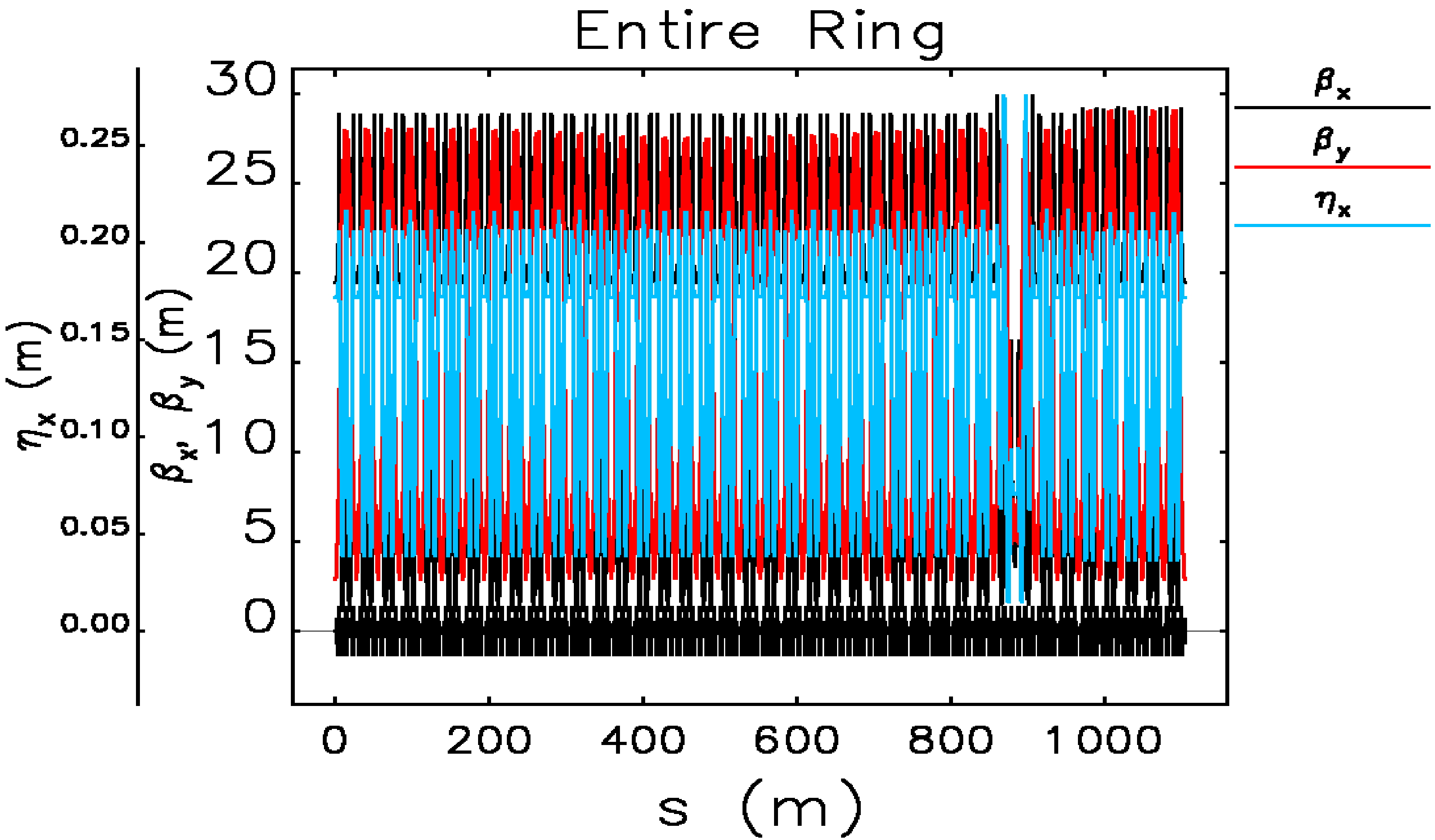


APS Lattice

- APS consists of 40 double-bend sectors, every sector has 10 quadrupoles, 7 sextupoles, 8 dipole correctors per plane, 1.5 skew quad correctors, 11 BPMs
  - All magnets except main dipoles are individually powered
- Every sector is identical except two sectors around ID32, where we provide small horizontal beam size (120 µm vs 270 µm in other straight section)

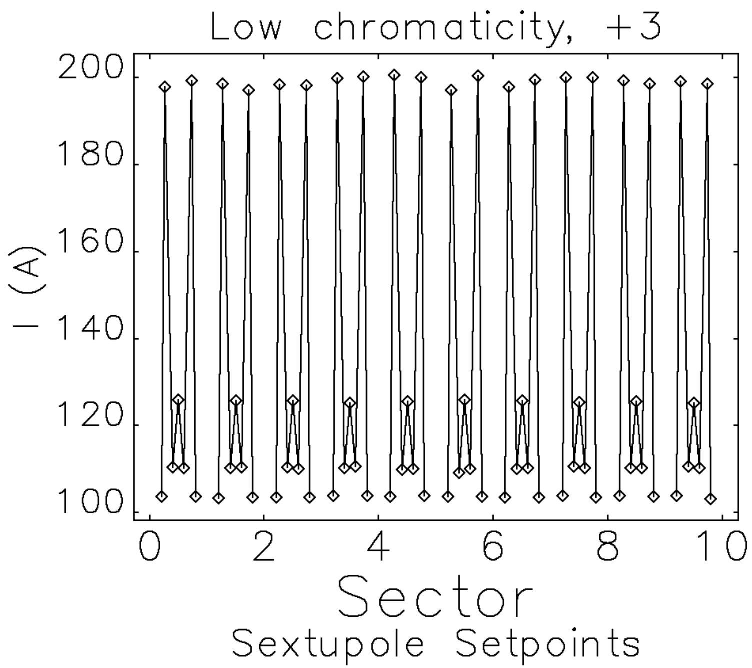


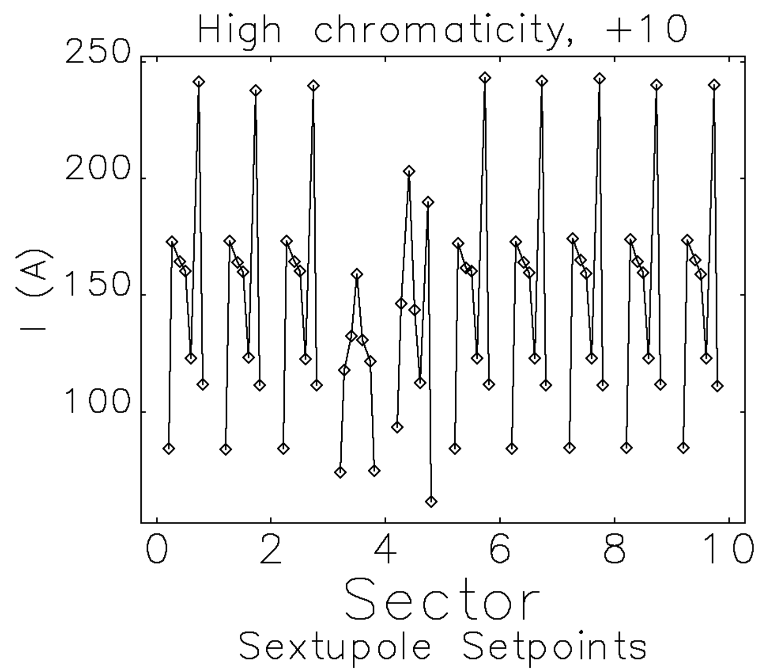
APS Lattice


Entire Ring
η_x (m)
0.25
0.20
0.15
0.10
0.05
0.00
β_x, β_y (m)
30
25
20
15
10
5
0
0
200
400
600
800
1000
s (m)
β_x
β_y
η_x

Sextupole optimization

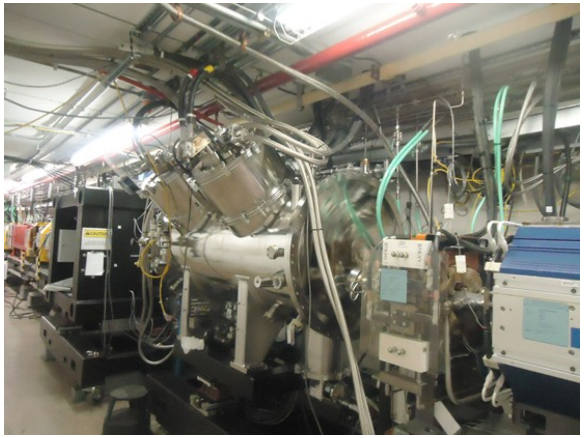
- APS was one of the early adopters of the Multi-Objective Genetic Optimization (MOGA) which we used to improve injection efficiency and lifetime in the hybrid mode
- Low chromaticity sextupoles were optimized pre-MOGA keeping mirror symmetry
- High chromaticity sextupoles were optimized without mirror symmetry plus sextupoles around smallest physics aperture (4.8 mm full gap in ID4) were varied separately
- High chromaticity has actually larger dynamic aperture



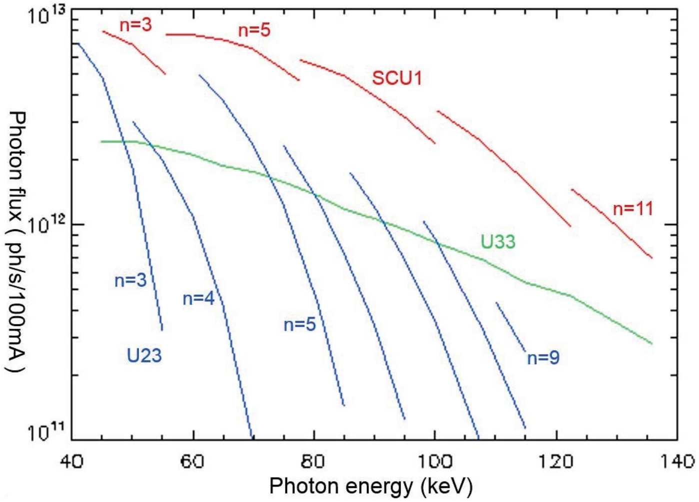


Superconducting undulators (SCU)[1]

- First test SCU device was installed in 2013; currently two SCUs are installed; SCU18-1 is in operation since May 2015 and SCU18-2 since September 2016
- SCUs provide higher flux at high photon energies
- SCUs operate at 80% of critical current
- Trouble-free operation for 7 years (between 3 devices)



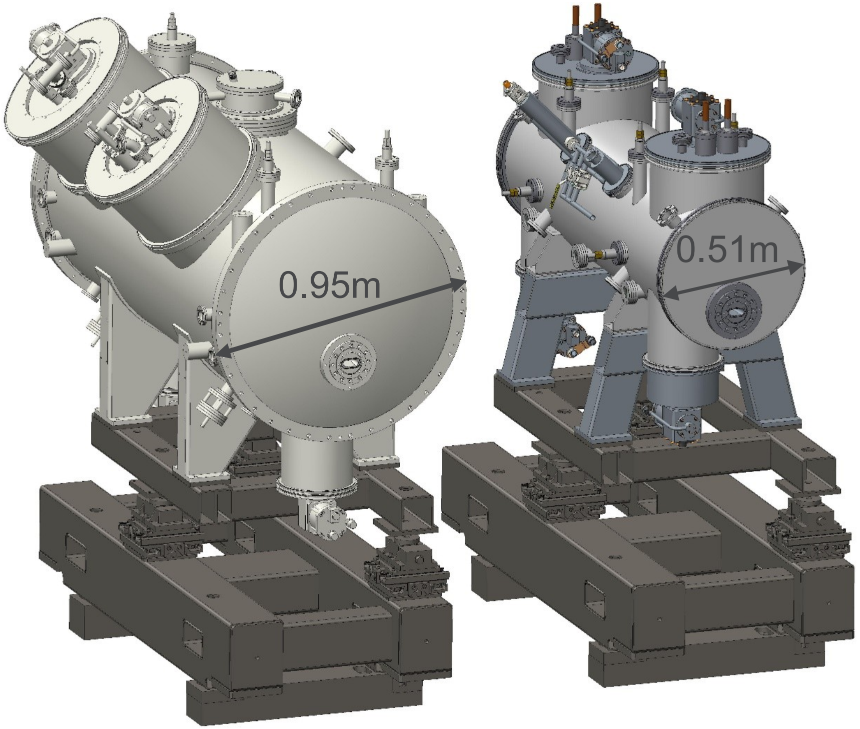
Parameter	SCU18-1 and SCU18-2
Cryostat length (m)	2.06
Magnetic length (m)	1.1
Undulator period (mm)	18
Magnetic gap (mm)	9.5
Beam vacuum chamber vertical aperture (mm)	7.2
Undulator peak field (T)	0.97
Undulator parameter K	1.63



[1]Y. Ivanyushenkov et al., PRST AB 18, 040703 (2015)

New cryostat for SCUs

- All 3 APS planar SCUs used SCU0-type cryostat designed in collaboration with BINP (Novosibirsk, Russia)
- Next device (HSCU) will use a new cryostat
- Design of the new cryostat is based on experience of operating 3 SCU0-type cryostats and a rigorous thermal analysis[1]
- HSCU cryostat will be more compact and cheaper to build
- HSCU cryostat will likely become a standard cryostat for next SCUs

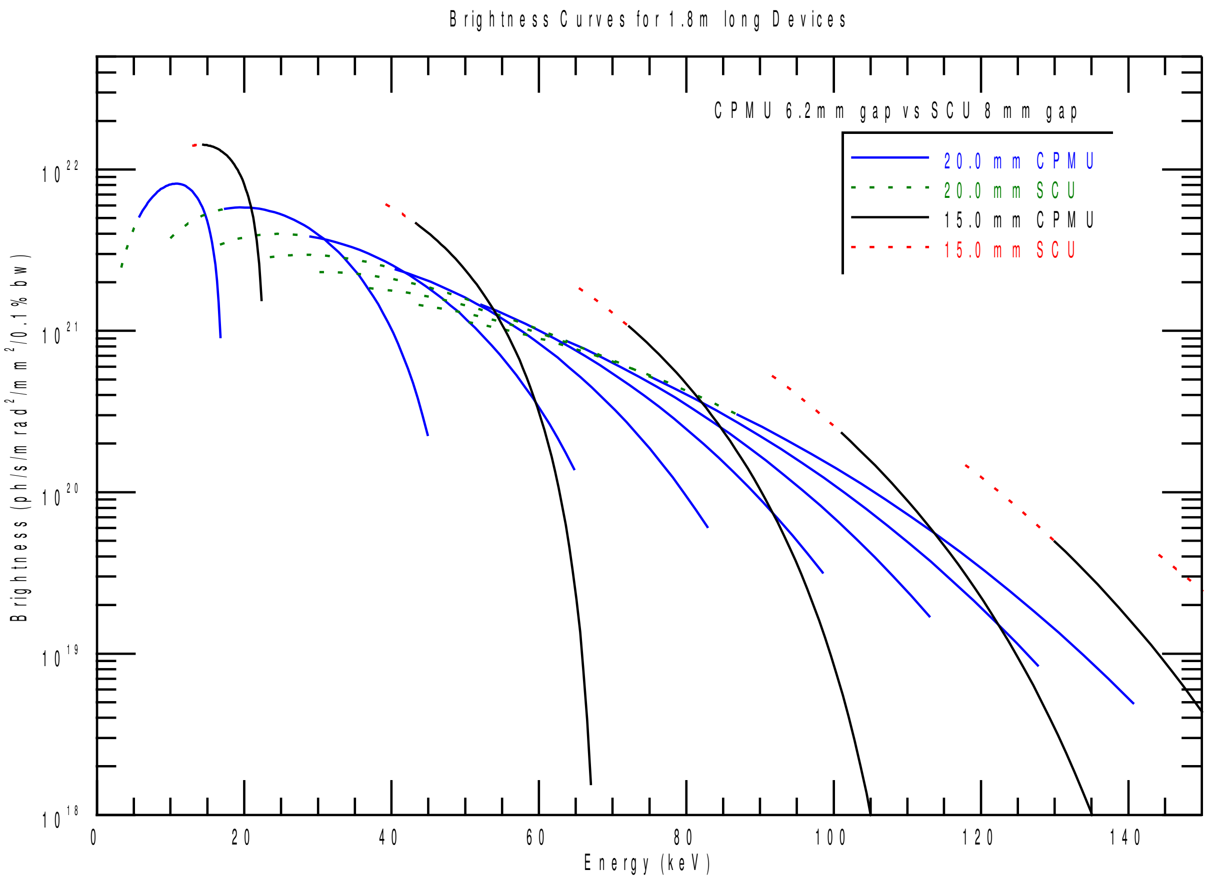


SCU0-type cryostat New cryostat

[1]Y. Shiroyanagi et al., NAPAC 2016

Comparison of SCU and Cryogenic PMU[1]

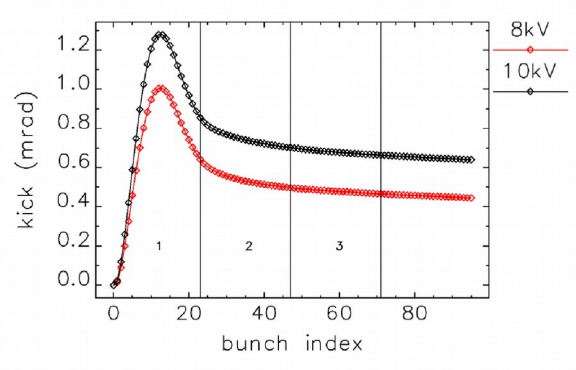
- For APS-U periods and gaps, SCU provides higher magnetic field on axis than CPMU for the same period length (between 15 and 20 mm) and the same vacuum gap (6.2 mm, 8-mm magnetic gap for SCU)

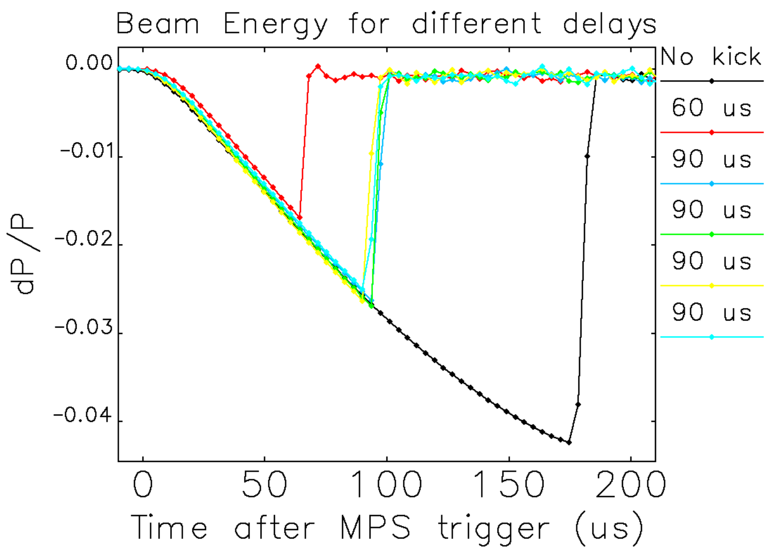


[1]M.Ramanathan, private communication

Abort kicker[1]

- Fast beam dumps were causing SCU quenches
- It was determined that small fraction of stored charge reaches SCU coils and causes local heating
- A pinger magnet was modified to make it a beam abort kicker
- Abort kicker is delayed relative to the RF muting
- Quench rate due to beam dumps:
  - ID6 SCU decreased from 80% to 14%
  - ID1 SCU decreased from 23% to 19%





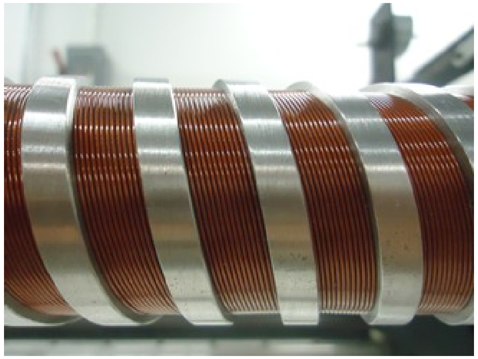
Charge lost at ID1 and ID6 for different kicker conditions

Conditions	ID1 Q (nC)	ID6 Q (nC)
0 kV, 0 delay	11.5	0.29
10 kV, 60 μs	0.33	0.060
10 kV, 90 μs *	0.044	0.0028
8 kV, 90 μs	0.56	0.54

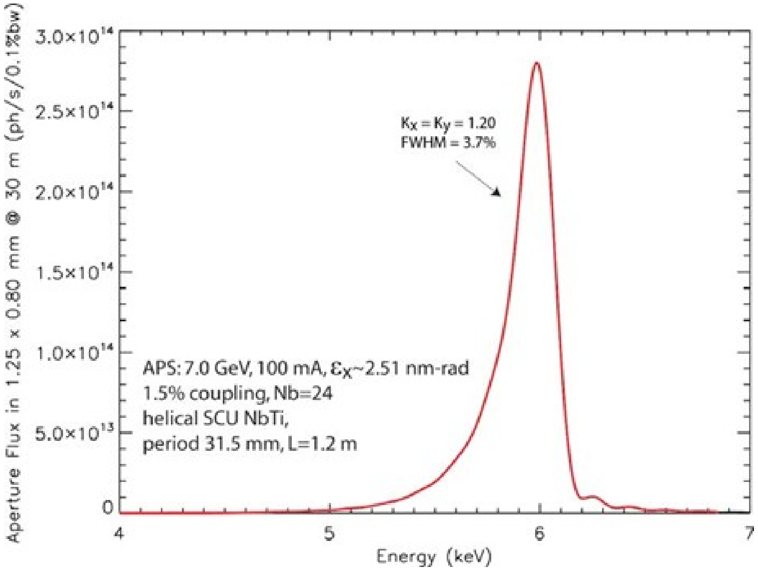
[1]K.Harkay et al, NA-PAC 2016, WEPOB05

Helical SCU

- SCU technology offers the possibility of building circular polarized helical undulators
- APS is currently working on building a HSCU for X-ray photon correlation spectroscopy program (installation December 2017)
- It will be the smallest horizontal aperture in the ring
  - ±13 mm vs present ±15 mm
- Cold vacuum chamber will be directly hit by the synchrotron radiation from the upstream dipole

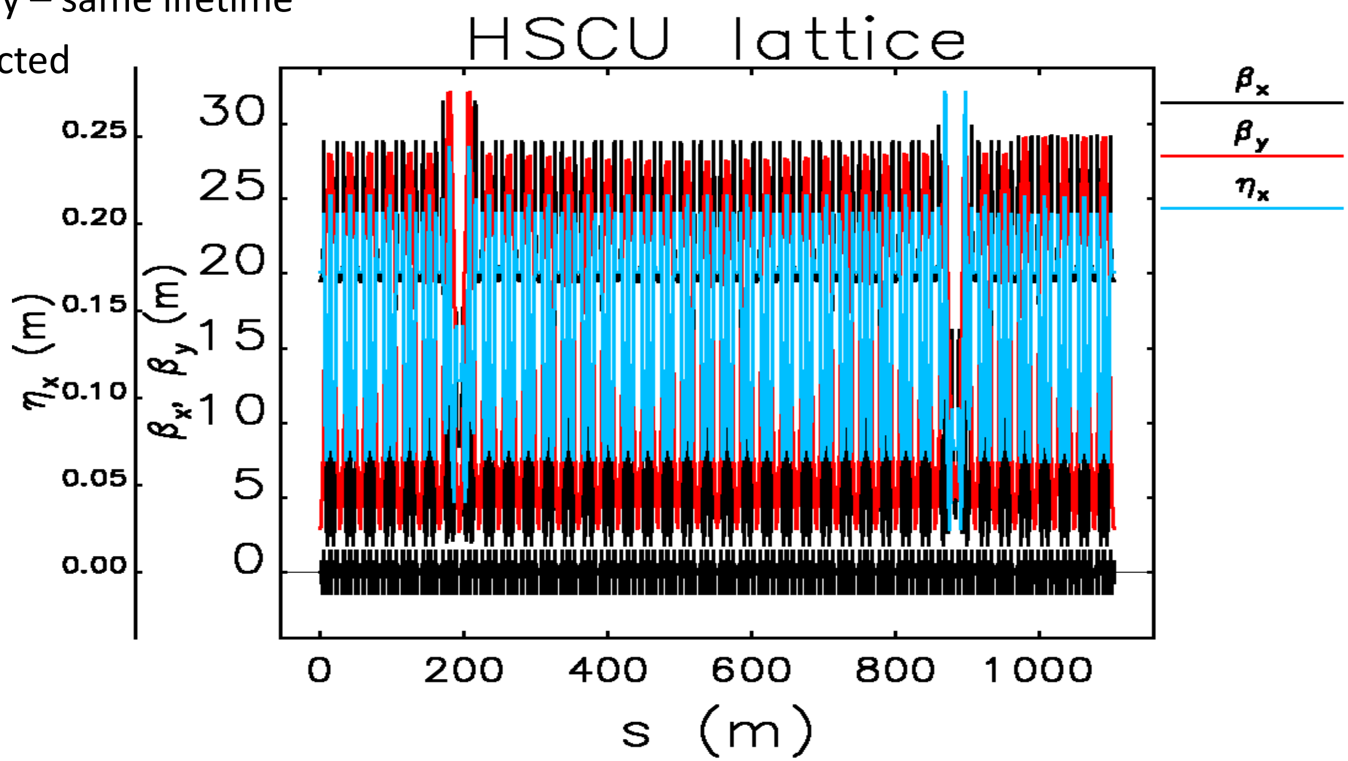


Parameter	HSCU
Cryostat length (m)	1.85
Magnetic length (m)	1.2
Undulator period (mm)	31.5
Magnetic bore diameter (mm)	31.0
Beam vacuum chamber vertical aperture (mm)	8
Beam vacuum chamber horizontal aperture (mm)	26
Undulator peak field Bx=By (T)	0.4
Undulator parameter Kx=Ky	1.2



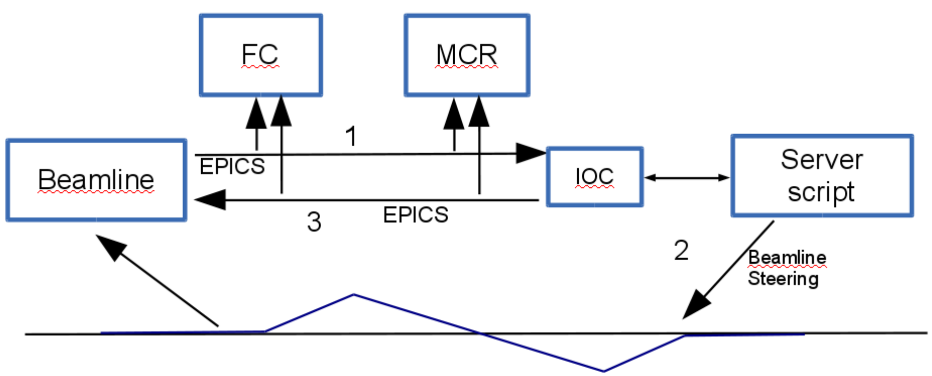
HSCU lattice

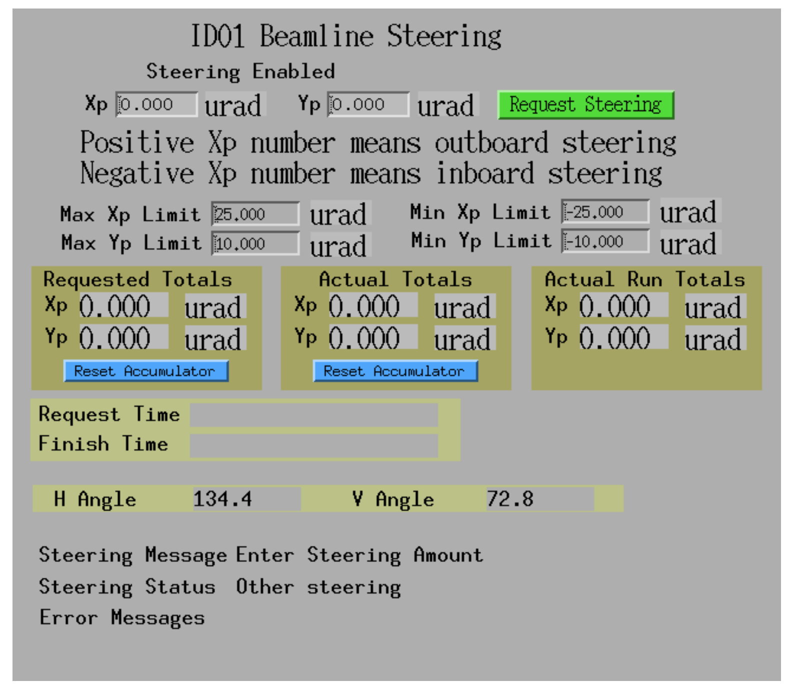
- To protect the device from lost particles, beta functions were changed to make HSCU chamber acceptance larger than 2 smallest acceptances (~20% of ID chambers)
- Sextupoles were optimized for low and high chromaticity
- Lattice test were conducted
  - High chromaticity – 10% lifetime reduction
  - Low chromaticity – same lifetime
  - Injection unaffected



Automated user steering[1]

- In May 2016, APS implemented user steering that bypasses the MCR
- Steering is performed by applying feedforward adjustment to correctors and BPM setpoints between orbit correction steps
- Corrector bump coefficients are calculated from an accurate optics model, steering is split into several small steps, so the resulting orbit distortion does not exceed 1μm, which is corrected by the orbit correction on the next step
- MCR and Floor Coordinator are notified of the steering by the server
- Only angle steering is allowed
- Beamline steering optimization is still run by MCR



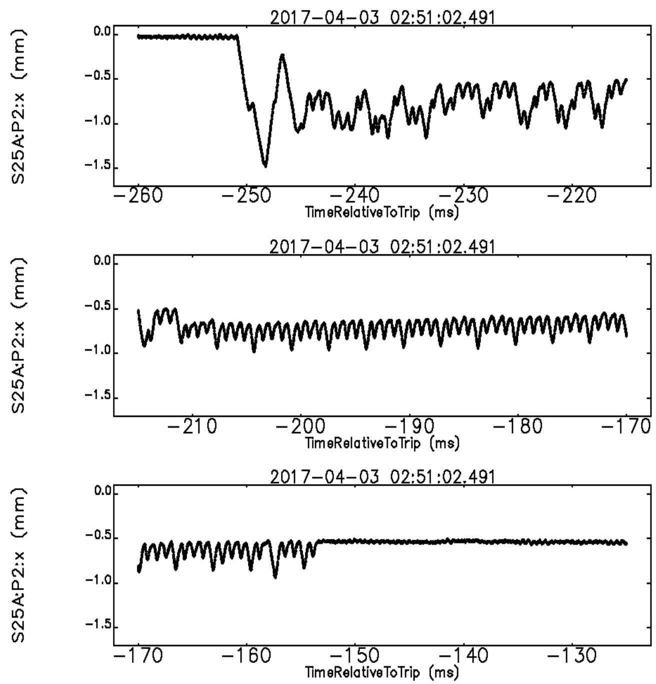


[1]L.Emery et al, NA-PAC 2016, WEPOB04

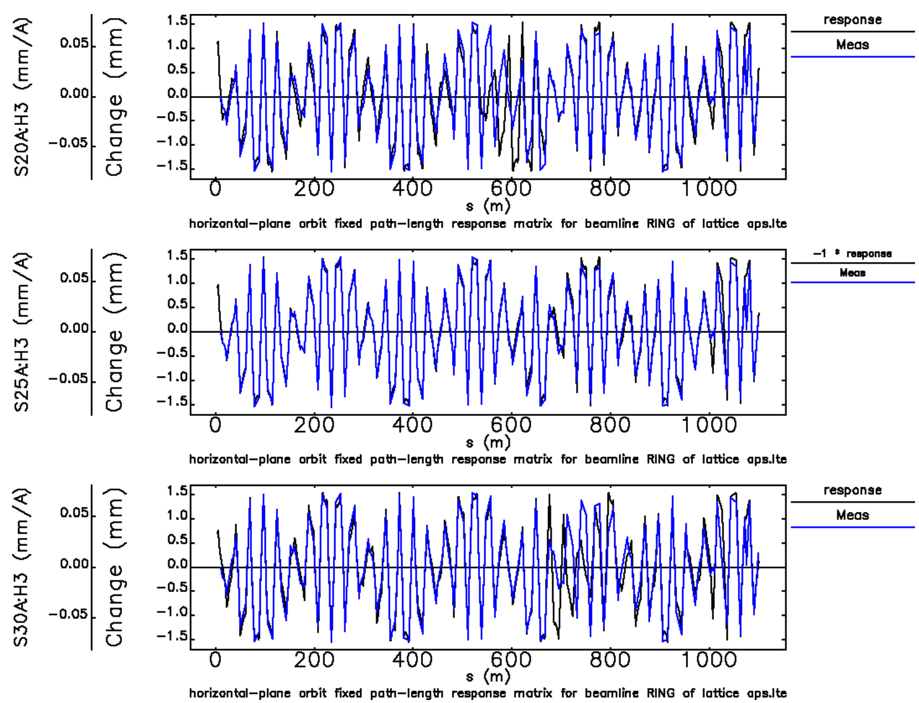
BPMs in post-mortem analysis of beam losses

- Beam orbit behavior is used to analyze reasons for beam losses
- Orbit change before beam dump is compared to pre-calculated responses to corrector or quadrupole changes
- Good for detecting malfunctioning power supplies that were not caught by alarm and glitch loggers

Orbit motion before beam dump

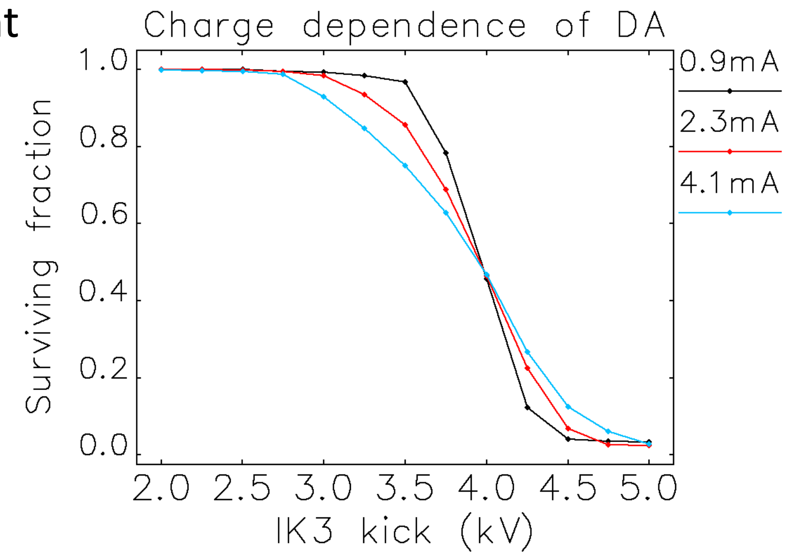


Comparison with precalculated responses

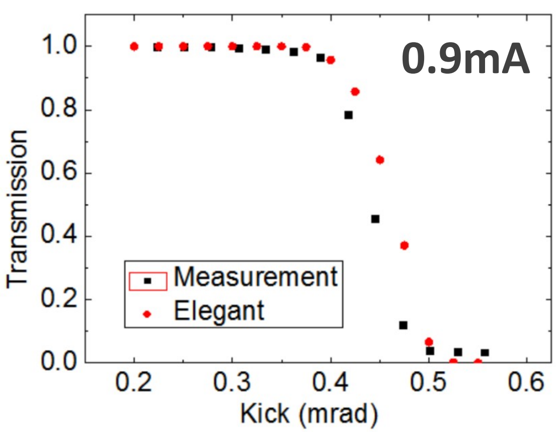


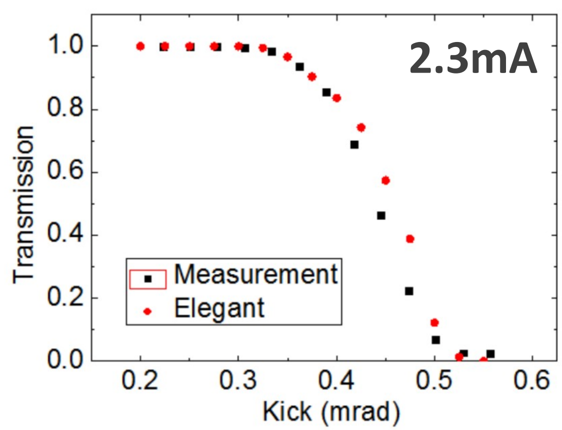
Using APS for code benchmarking – DA

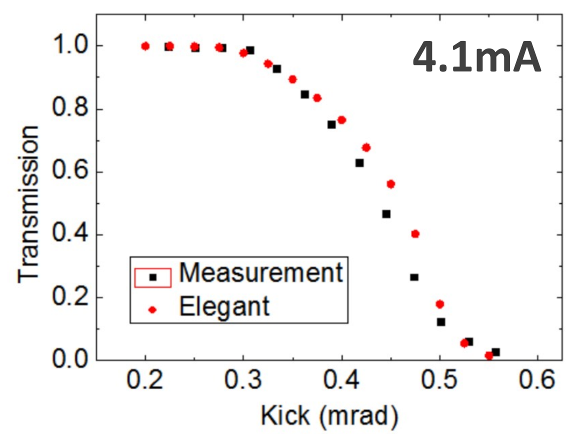
- APS Upgrade project is underway, relies heavily on simulations
- We work on benchmarking codes vs experiment
- Charge dependence of dynamic aperture – combination of nonlinear dynamics and collective effects[1]
  - Fast kick measurement is simulated
  - Disagreement with experiment is below 5%
  - Calibrated model and latest results from the Impedance Database are used



Dynamic aperture measurement



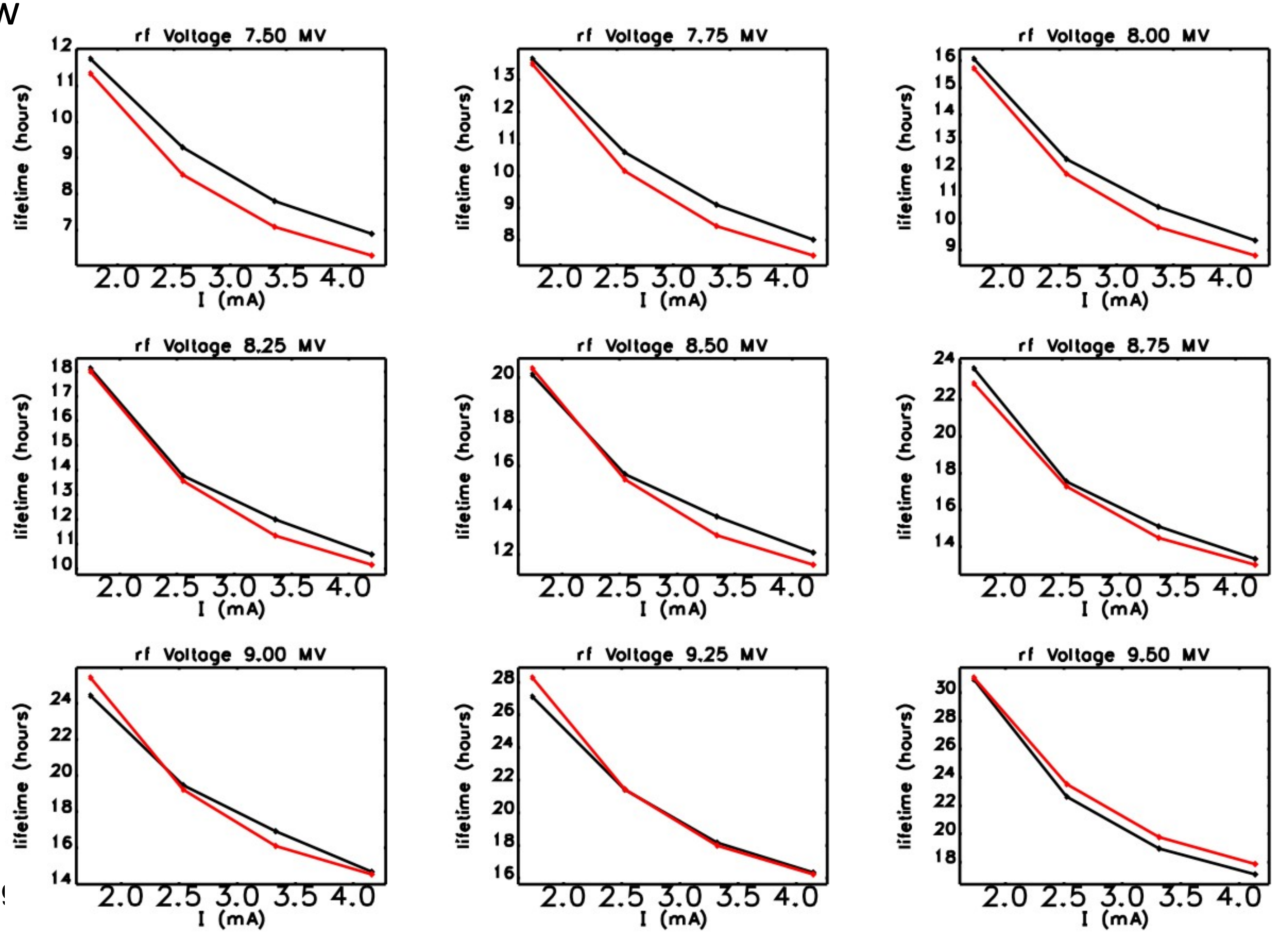




[1] Seunghwan Shin, private communication

Using APS for code benchmarking - lifetime

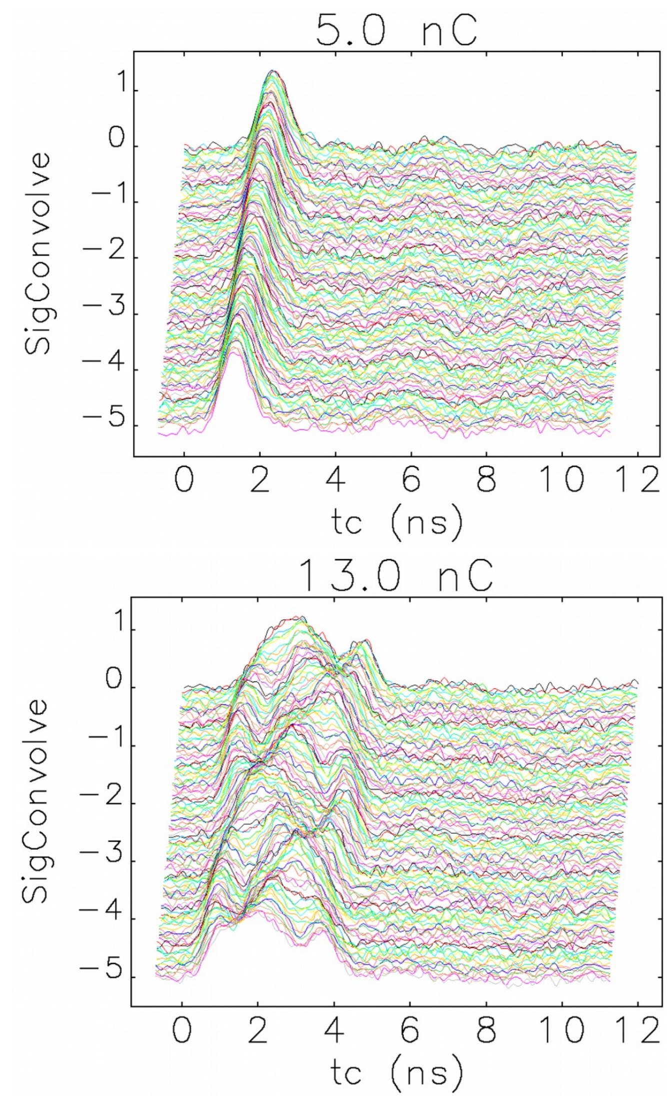
- Lifetime comparison is done for different RF voltage (bunch length) and different bunch charge
- Piwinski's formula is used; momentum aperture is calculated using calibrated model; bunch length is measured
- Discrepancy is below 10% for worst case of low RF voltage



[1]A. Xiao, AOP-TN-2016-018

Increasing injector charge for APS-U

- APS-U will operate in swap-out regime, will require about 20 mA bunch from the injector (presently, we use 1-3 nC for operations)
- Study and upgrade program for injectors is underway
  - Many beam study hours is spent on injectors now
- PAR can accumulate more than 20 nC from linac at 375 MeV
  - Transverse beam size blow-up due to ions does not seem to affect the injection into booster
  - We think that bunch length increase (presumably due to RF cavity beam loading) limits injection to booster at ~10 nC[1]
- Booster work involve:
  - BPM upgrade to allow orbit correction along the ramp
  - Sextupole power supply upgrade to keep chromaticity positive during ramp
  - Tune correction during ramp



[1] J. Calvey, J. Dooling, private communication

Conclusion

- APS operates with high reliability and long MTBF
- APS has two SCUs presently operating and is working on constructing helical SCU
- Individually powered quadrupoles and sextupoles allow for local beta function customization while MOGA optimized sextupoles reduce its impact on beam dynamics
- Automated user steering is implemented which does not require MCR participation
- In preparation for APS Upgrade, injector charge increase effort is underway
- Code benchmarking is ongoing to increase confidence in APS-U design simulations