Operational Experience with the Test Superconducting Undulator (SCU0) at APS

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for the APS SU0 Team

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U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Brief history
- X-ray performance
- User experience/experiments
- Cryogenic performance
- Operations
- Summary

SCU0 Team

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Technical Lead and Commissioning Co-Lead

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Commissioning Team
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M. Jaski (ASD-MD)
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Core Team

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	J. Kaluzny (ASD-RF)
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Budker Institute Collaboration
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V. Syrovatin
V. Tsukanov
V. Lev

FNAL Collaboration
(Resin Impregnation)
A. Makarov

UW-Madison Collaboration
(Cooling System)
J. Pfotenhauer
D. Potratz
D. Schick

Technical Support

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D. Capatina (AES-MED)
P. Den Hartog* (AES-MED)
G. Goeppner* (AES-MOM)
W. Jansma (AES-SA)
S. Wesling (AES -SA)

Former management: E. Moog† (ASD-MD)
Associate Project Manager: M. White (APS-U)

*Group Leader †Former group leader

Brief history

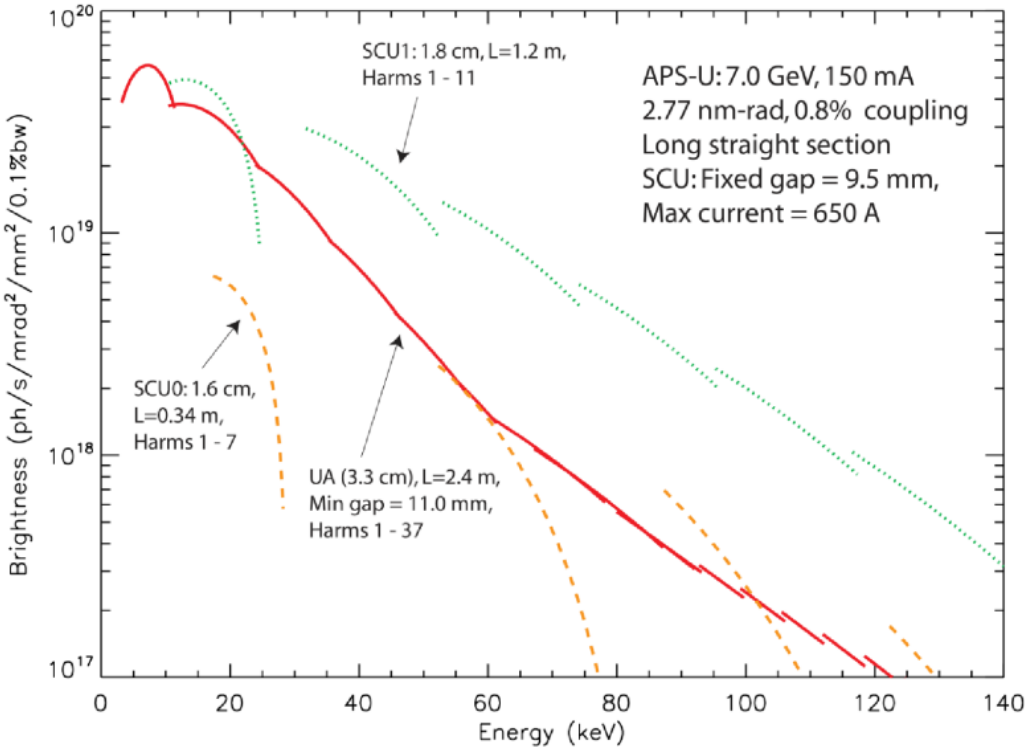
- Superconducting technology R&D: 2002-2009
- SCU0 design, fabrication, magnetic measurements, testing: 2010-2012.
- Pre-installation and commissioning of two test chambers: May & Sep 2012.
- SCU0 installed: Dec 2012.
- Completed detailed commissioning plan during extended machine startup: Jan 2013 (~130 hr).
- SCU0 released for User operation: Jan 29.

First superconducting undulators at APS

APS superconducting undulator specifications

	Test Undulator SCU0	Prototype Undulator SCU1
Photon energy at 1st harmonic	20-25 keV	12-25 keV
Undulator period	16 mm	18 mm
Magnetic gap	9.5 mm	9.5 mm
Magnetic length	0.330 m	1.140 m
Cryostat length	2.063 m	2.063 m
Beam stay-clear dimensions	7.0 mm vertical × 36 mm horizontal	7.0 mm vertical × 36 mm horizontal
Superconductor	NbTi	NbTi

SCU0 and SCU1 spectral tuning curves

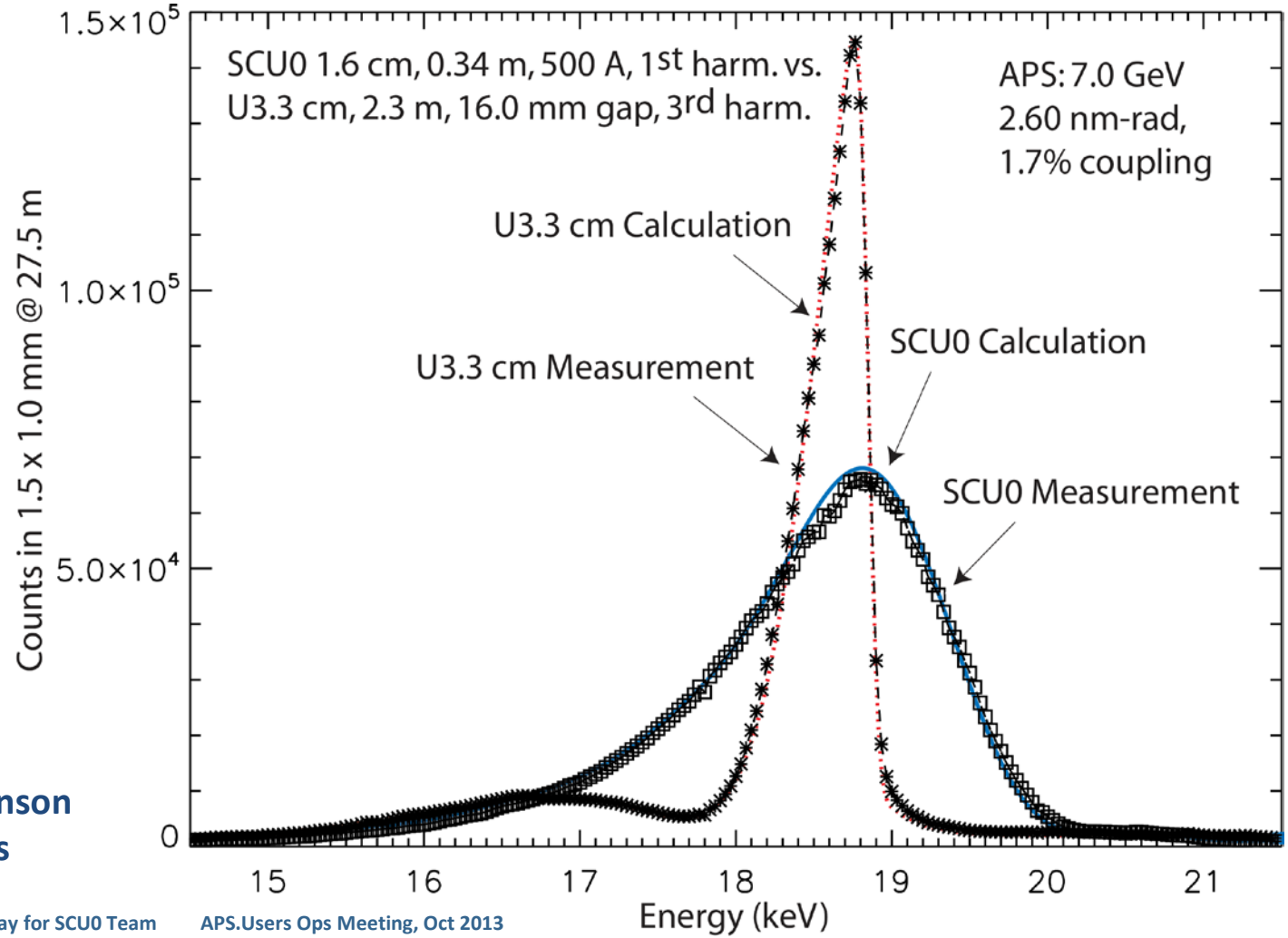


This plot shows the large increases in high-energy flux provided by superconducting devices.

Y. Ivanyushenkov
R. Dejus

SCU0 X-ray performance (1)

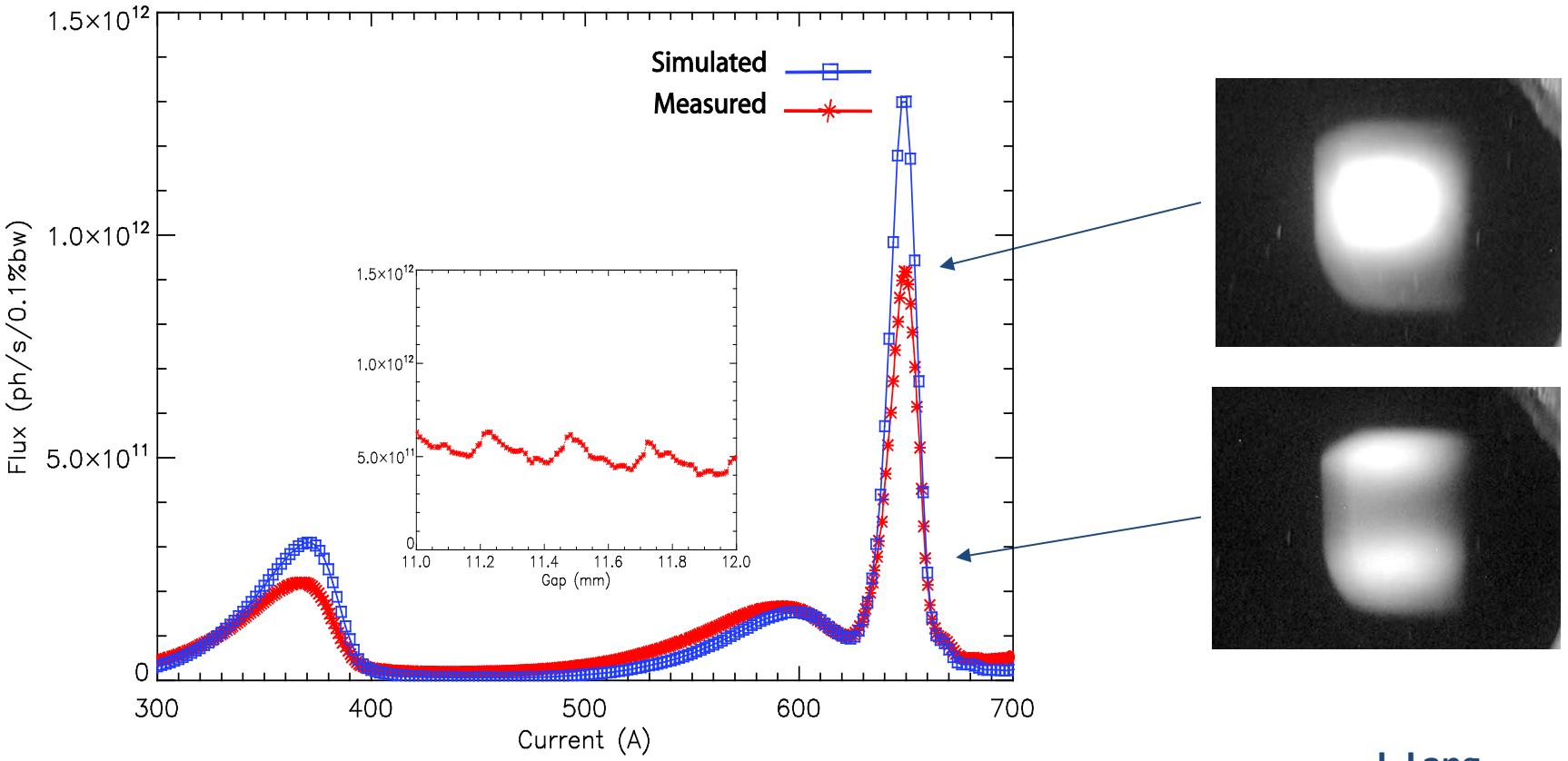
Photon flux of SCU0 was compared with an in-line 3.3-cm-period length permanent magnet hybrid undulator (U33), using a bent-Laue monochromator.



J. Lang
D. Robinson
R. Dejus

SCU0 X-ray performance (2)

At 85 keV, the 0.33-m-long SCU0 produced ~45% higher photon flux than the 2.3-m-long U33.



Photon flux comparisons at 85 keV. Main: Simulated and measured SCU0 photon flux . Inset: Measured photon flux for in-line U33.

J. Lang
D. Robinson
R. Dejus
M. Borland

User experience with SCU0

- Beamline 6-ID-D
  - Before: ran ~50% of the time

    shared ID with 6-ID-B resonant scattering program.
  - Now: Experiments scheduled ~100%

    Provides more high-energy beamtime with little additional power on optics
- Since Feb. 1:
  - Feedback from users/staff on operation and reliability of SCU0

    Reliable/Stable operation; some minor communications/mode issues (prototype) that are being sorted out.
  - 23 unique experiment performed using SCU0

    6 more scheduled 2013-3
  - Represents 20 unique user groups
- Wide range of science (*general purpose high-energy scattering*)
  - Single crystal diffraction using 2D and point detectors (Bragg & Diffuse)
  - In-situ crystallization from levitated liquids (electrostatic & acoustic)
  - High energy fluorescence mapping of thick samples
  - Deformation studies of thin films & solder joints
  - PDF in non-standard environments

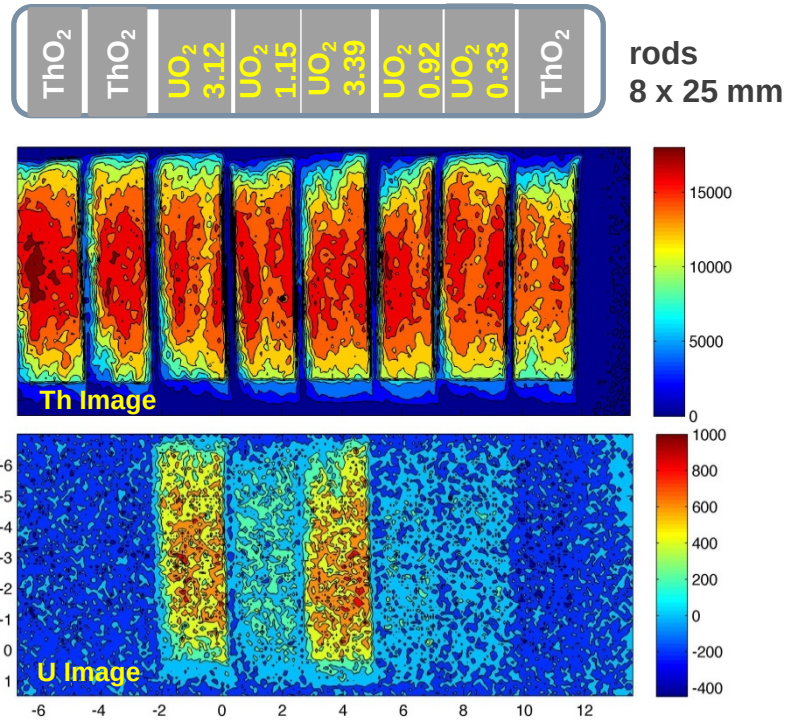
J. Lang
D. Robinson

User experiments with SCU0

Diffraction pattern of 10-fold axis in new GdCd magnetic quasicrystal

Cover image for August 2013 issue of Nature Materials features image taken with SCU0.
A. Goldman *et al., Nature Mat.* **12**, 714 (2013)

Fluorescence mapping from nuclear fuel pellets

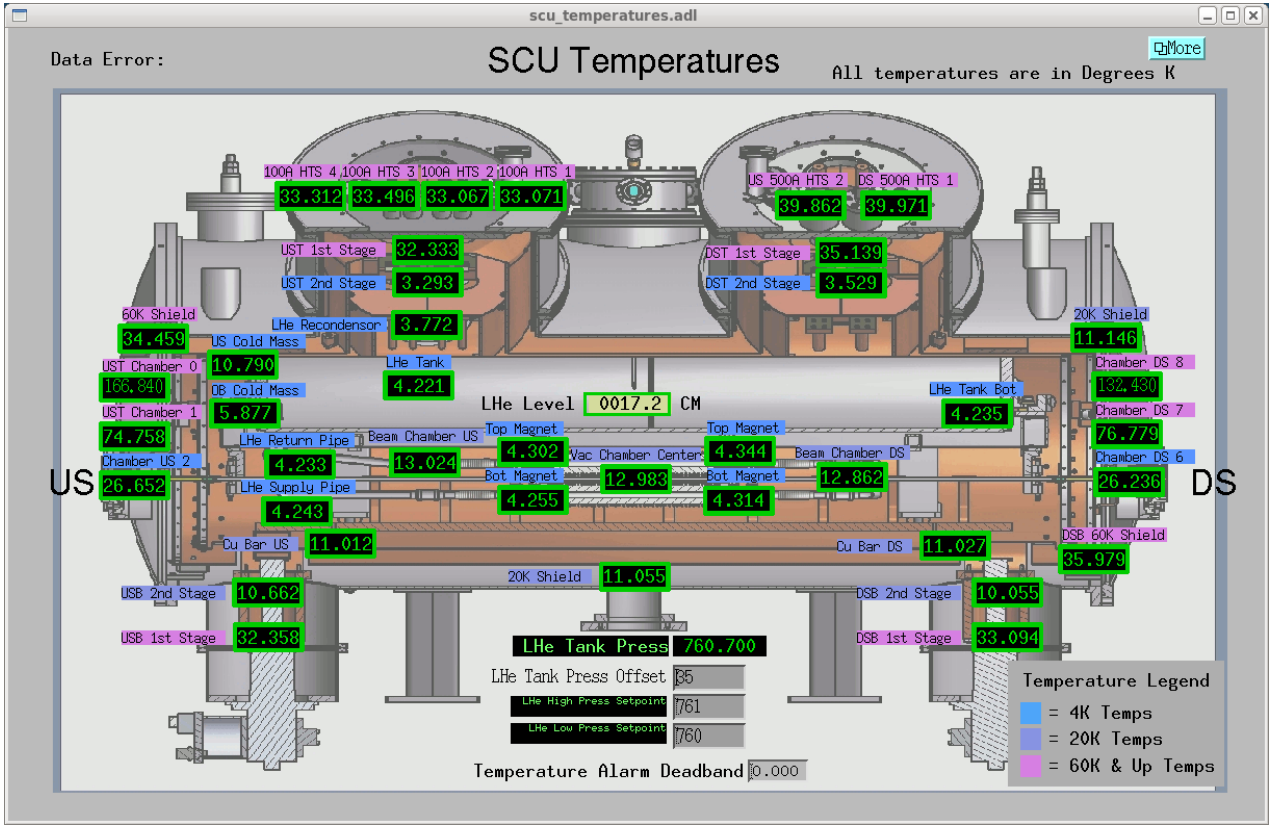


Uranium and Thorium fluorescence maps of mock fuel pellets encased in Zirconium.
G.J. Havrilla et al. to be published

J. Lang
D. Robinson

Cryogenic system performance

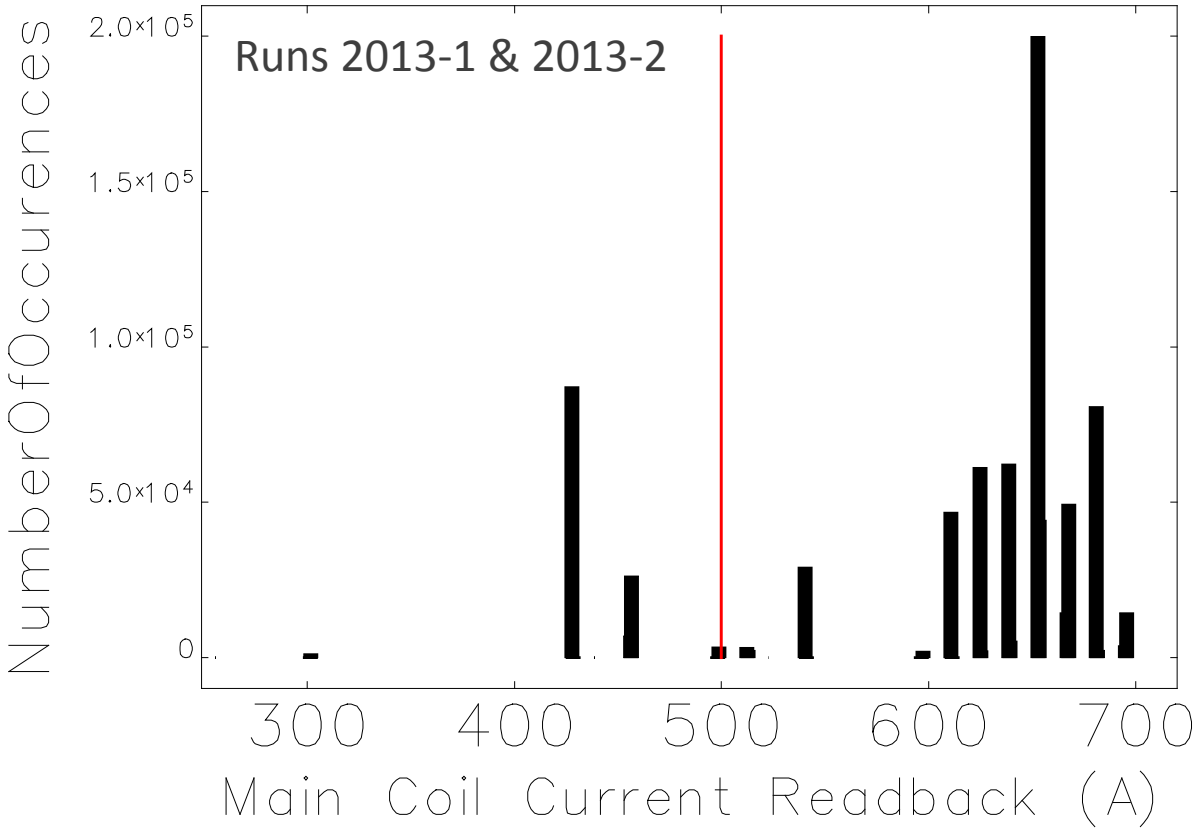
- Unique design features: out-of-vacuum magnetic device, thermally isolated beam chamber, cryocoolers.
- Magnet cores held at ~4 K even with 16 W of beam power on the beam chamber.
- No loss of He observed in an 10-month period.



Measured temperatures in the SCU0 cryostat at beam current of 100 mA (24 bunches), SCU0 magnet coil off.

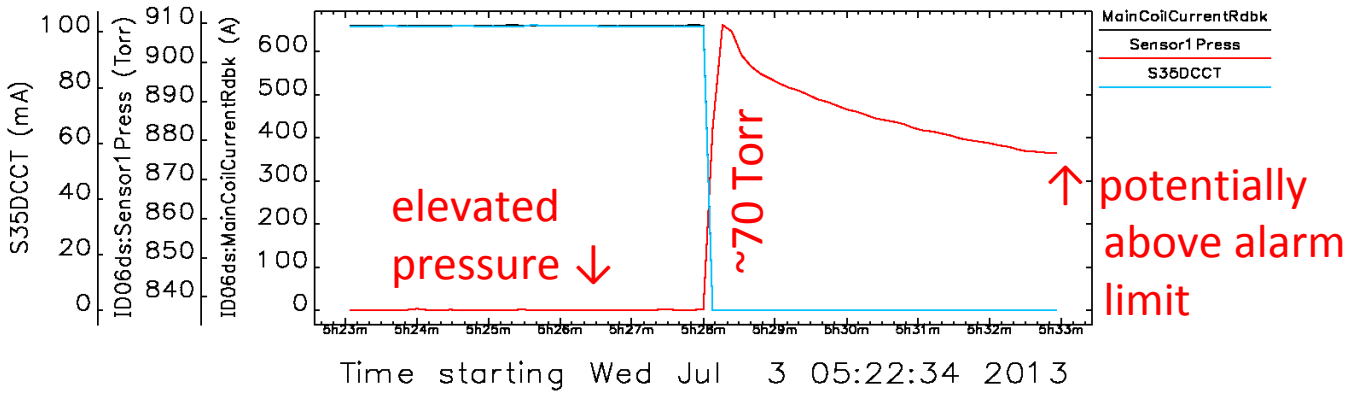
Operations

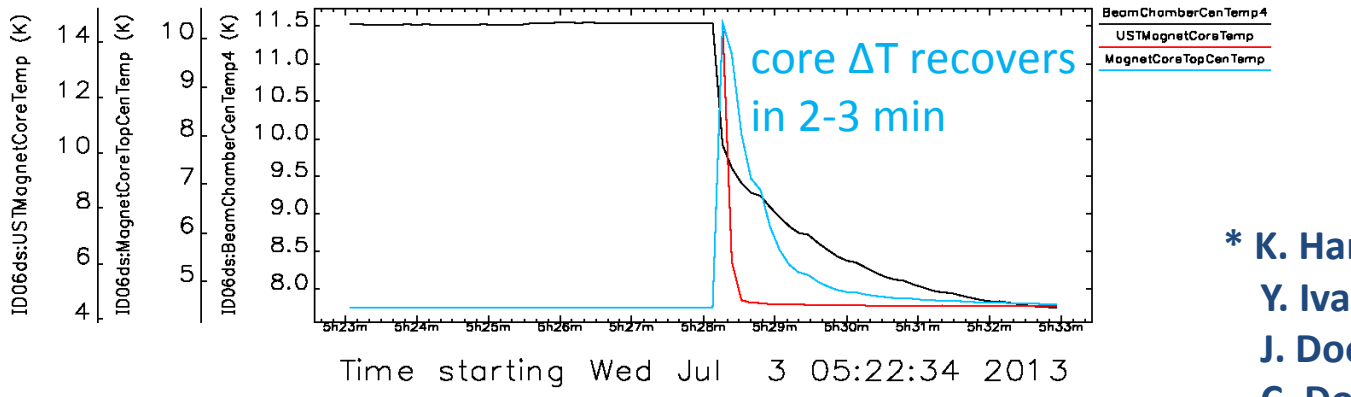
- SCU0 operates reliably well above its design main coil current of 500 A.
- User coil current setpoint & control returned automatically after interruptions, such as beam dumps, but not working perfectly yet.
- Operated with 150 mA (324 bunches) and no significant issues were identified.



Beam dumps and quenches

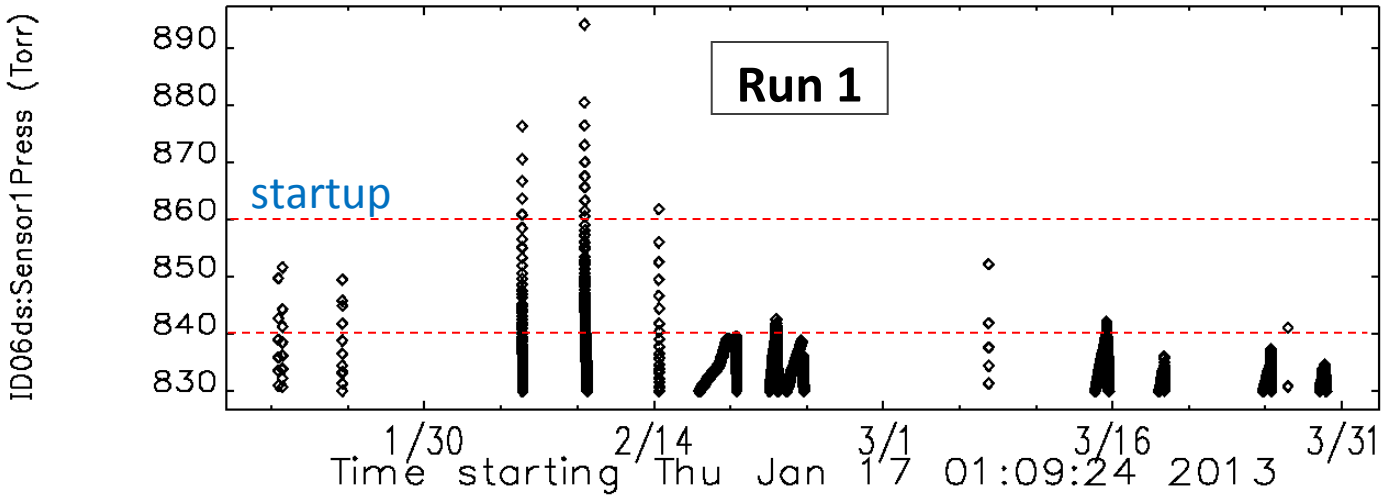
- SCU0 quenched only twice with stored beam during operations, and it did not cause orbit perturbation or beam loss.
- SCU0 typically quenches with beam dumps. Recovery is fast and impact on SCU0 User has been minor. Mitigation is under study.*





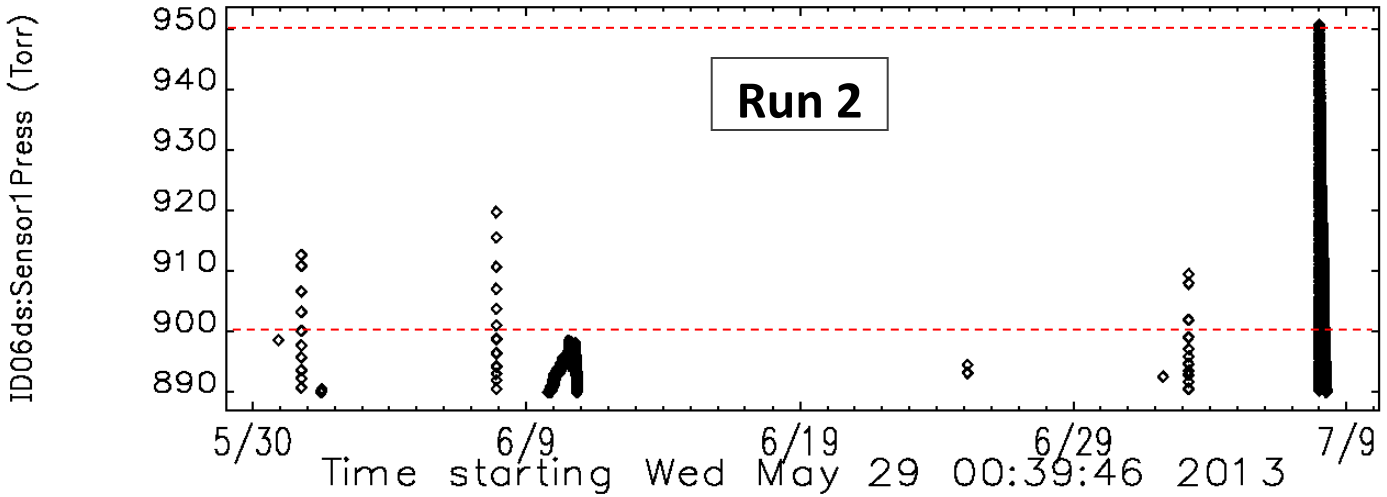
* K. Harkay, Y. Ivanyushenkov, J. Dooling, A. Vella, C. Doose, M. Kasa

LHe pressure and SCU0 downtime



Estimated SCU0 downtime: 13 h

Main cause: LHe pressure above alarm limit during operations. Limits raised in Run 2.



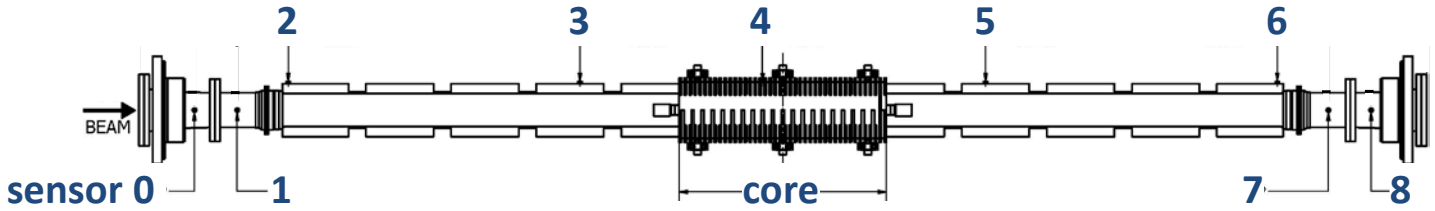
Estimated SCU0 downtime: 6.5 h

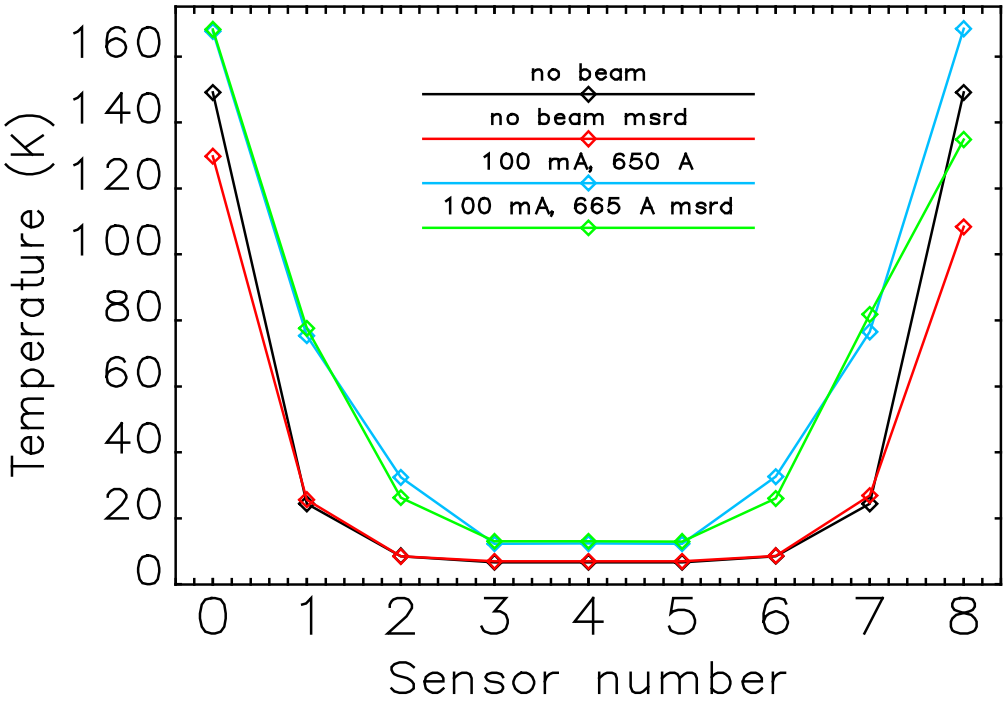
Main cause: chilled water pressure dip caused cryo pump trip.

Commissioning activities

- Thermal sensor and vacuum monitoring
- Vacuum chamber layout and chamber transition heating
- *Cryogenic system performance*
- Orbit stability with given limits on field integral rate-of-change and absolute error requirements
- *Quench response*
- Field correction coil response
- → Validity of estimates of beam-induced heat load
- → Alignment procedures
- → Vibration effects of the cryocoolers on beam motion
- *X-ray performance*
- *Storage ring operation procedures*

Thermal analysis of beam-induced heat load

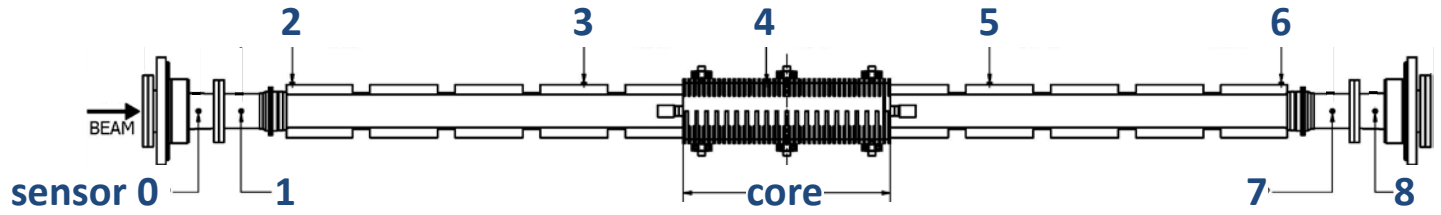




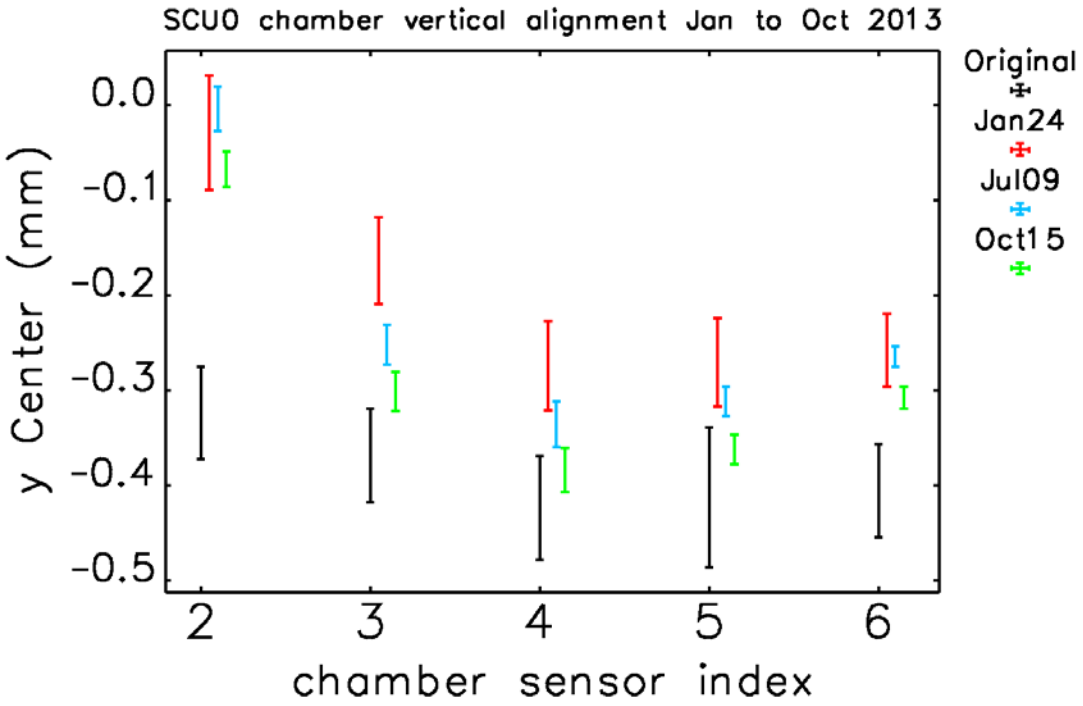
- Analytical image-current heat load modeled using ANSYS.
- Modeled chamber temperatures are within 10% of the measured temperatures.
- Results are very satisfying, in light of 2-to-10-fold underestimated heat loads at ESRF, MAX (in-vac).

Y. Shiroyanagi, K. Harkay, R.L. Kustom, S. Kim
C. Doose, J. Fuerst, J. Kaluzny, M. Kasa

Chamber alignment



- Chamber alignment critical to protect SCU0 from excessive beam-induced heat loads.
- Alignment corrected for cool-down, novel methods developed.*
- Novel beam-based alignment using ID steering and ΔT, giving 100-µm accuracy.**
- Initial vertical chamber offset of ~0.3 mm was detected; partially realigned *in situ*.
- Alignment is stable over time.

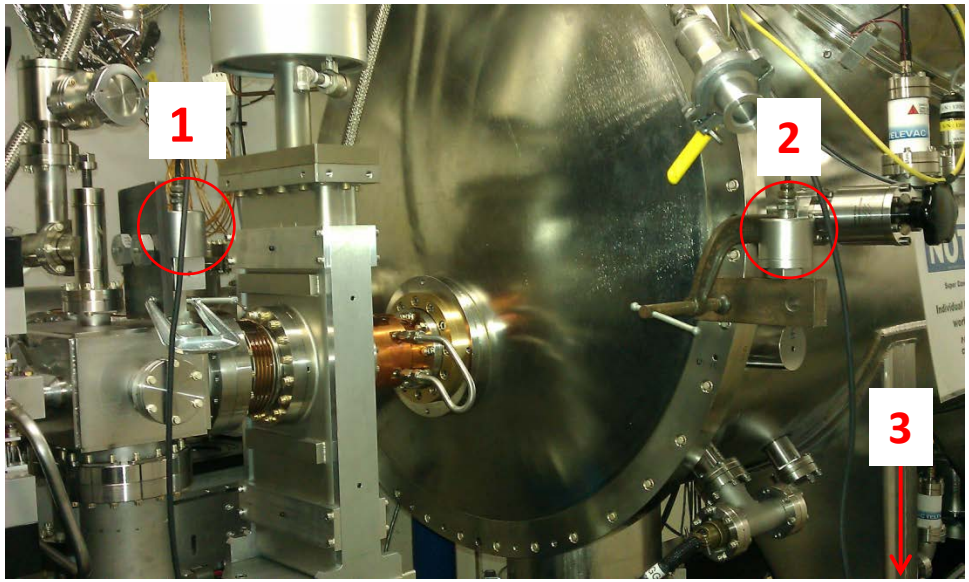


* E. Trakhtenberg, W. Jansma, S. Wesling, J. Penicka, M. Kasa, C. Doose, Q. Hasse. Y. Shiroyanagi

** K. Harkay, L. Boon, M. Borland, L. Emery, R. Kustom, V. Sajaev, A. Xiao

Mechanical vibration

- Cryocooler vibration was not observed to adversely affect the beam motion.
- Vibration measured at three locations:
  1. Beam chamber, 40 cm upstream of SCU0
  2. Vacuum vessel, beam height
  3. Support girder base (not shown)
- Results for beam chamber shown at right.

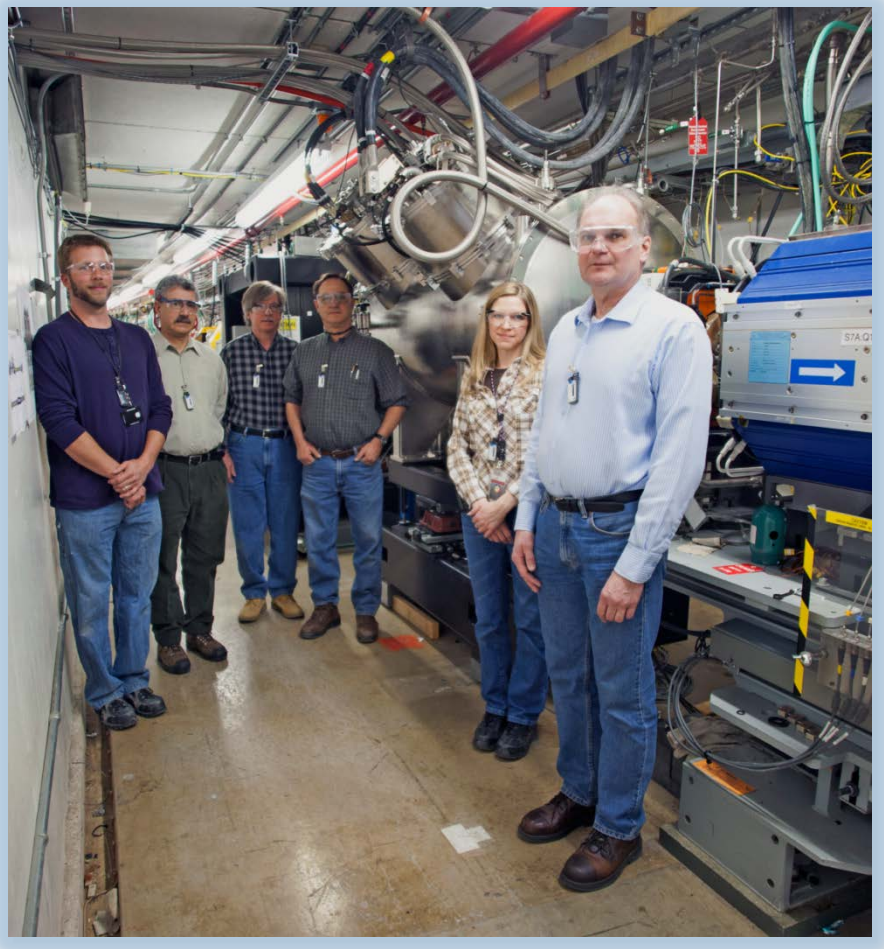


Integrated power density (μm rms), from 2 Hz to 100 Hz	
Cryocoolers off	0.38
Cryocoolers on	0.68

Amplitude at 8.375 Hz (μm rms)	
Cryocoolers off	0.06
Cryocoolers on	0.57

C. Doose
M. Kasa

Summary



- An almost decade-long R&D program on development of superconducting undulators at APS was successfully completed in Dec. 2012 with the installation of the SCU0.
- Beam commissioning was highly successful; all the operational requirements were satisfied.
- Device is in user operation since Jan. 2013, operating reliably above its design current, delivering enhanced photon flux at energies above 50 keV.
- Future SCUs are under design.*

* see Y. Ivanyushenkov, Proc. NA-PAC 2013 (jacow.org)