STATUS OF THE DEVELOPMENT OF SUPERCONDUCTING UNDULATORS FOR STORAGE RINGS AND FREE ELECTRON LASERS AT THE ADVANCED PHOTON SOURCE

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ADVANCED PHOTON SOURCE

ARGONNE NATIONAL LABORATORY

On behalf of:

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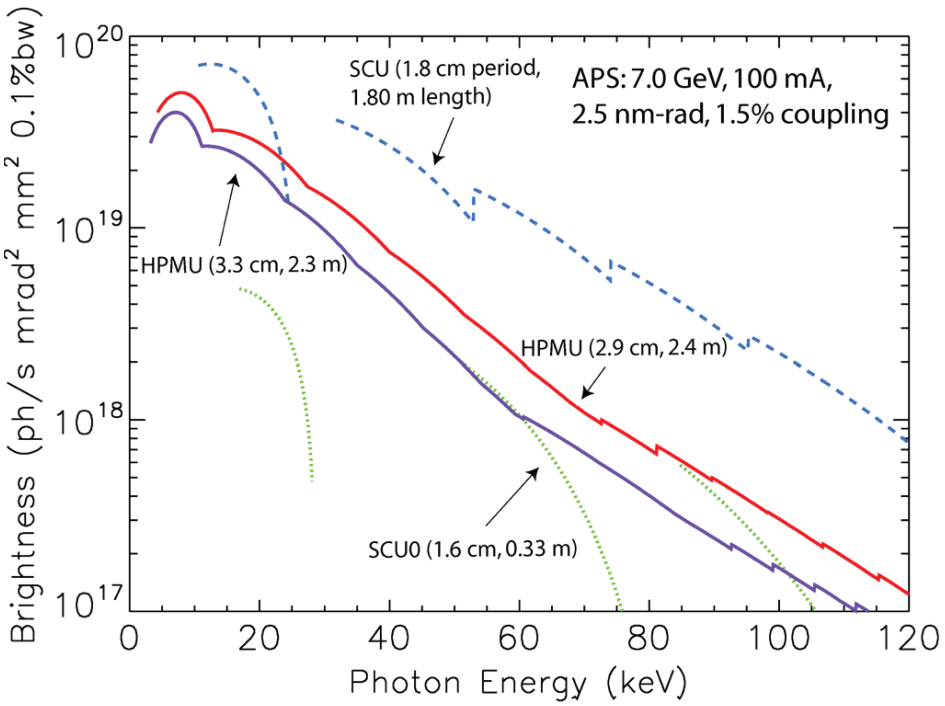
SCOPE

- Why superconducting undulators (SCUs)?
- Development of planar devices:
  - SCU18-1 and SCU18-2
  - LCLS R&D undulator
  - Achieving low phase errors
- Development of circular polarizing devices:
  - Helical SCU for APS
  - New SCU cryostat
  - New universal SCU – SCAPE
- Summary

WHY SUPERCONDUCTING UNDULATORS?

- A superconducting undulator (SCU) is an electromagnetic undulator that utilizes superconducting coils for generating magnetic field.
- For a given period length and magnetic gap, SCU technology outperforms all other technologies in terms of the undulator peak field [1].
- The higher undulator field leads to higher photon fluxes, especially at higher photon energies. This has been demonstrated at the APS with the operating experience of the first test SCU – SCU0 [2].
- The SCU0 was in continuous operation for 3.5 years and was replaced this September by SCU18-2.



Calculated tuning curves for SCUs and for hybrid undulators.

[1] P. Elleaume et al., *Nucl. Instr. Meth.* A 455, pp.503-523, 2000.
[2] Y. Ivanyushenkov et al., *Phys.Rev.ST Accel. Beams,* vol.18, 040703, 2015.

DEVELOPING PLANAR SUPERCONDUCTING UNDULATORS

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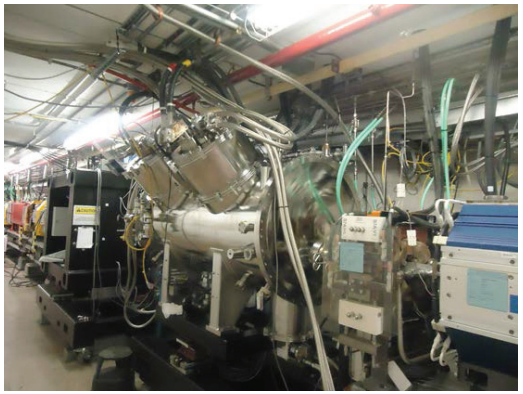
SCU18-1 (SCU1) AND SCU18-2

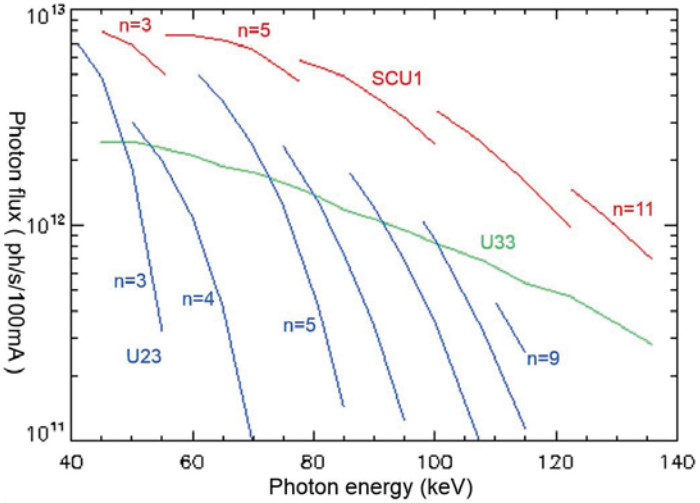
- Two similar undulators, SCU18-1 and SCU18-2, were completed and installed on APS storage ring over the last two years.
- The SCU18-1 has been in operation since May 2015 and SCU18-2 started operation in September 2016.

SCU18-1 in Sector 1 of the APS ring.



SCU18-2 in Sector 6 of the APS ring.

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

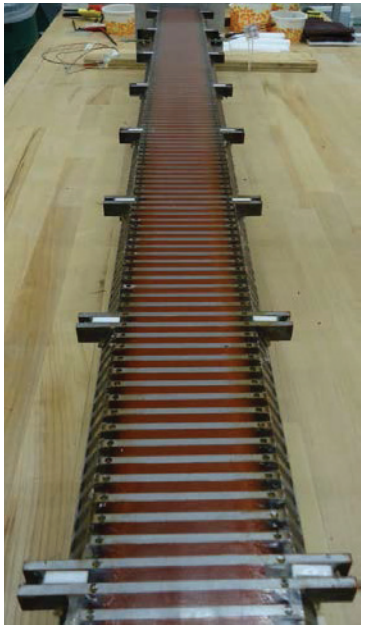


Measured SCU18-1 tuning curves in comparison with those of hybrid undulator U33 (Undulator A).

LCLS R&D UNDULATOR

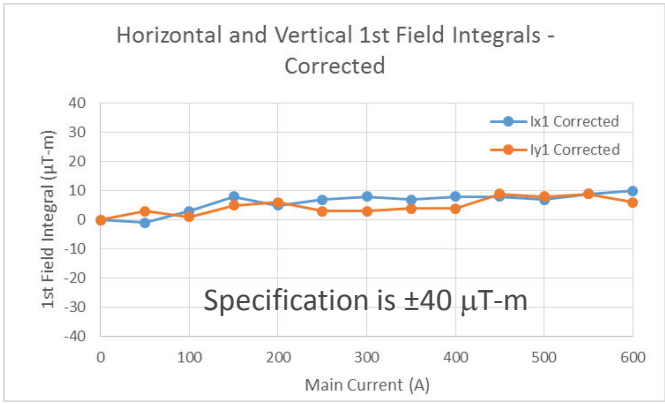
- This NbTi undulator was built as a part of the LCLS SCU R&D project aimed at demonstrating that SCU technology can achieve challenging specifications of FEL undulators [1].
- The undulator did achieve all the specifications including the most challenging requirement of 5º rms phase errors.

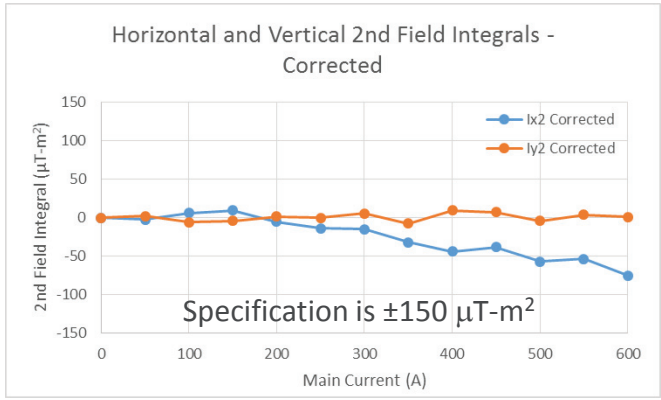
Parameter	LCLS R&D SCU
Cryostat length (m)	2.06
Magnetic length (m)	1.5
Undulator period (mm)	21
Magnetic gap (mm)	8.0
Beam vacuum chamber vertical aperture (mm)	5.7
Undulator peak field (T)	1.67
Undulator parameter K	3.26



Beam side of magnet core.

Measured first and second field integrals of LCLS R&S SCU.

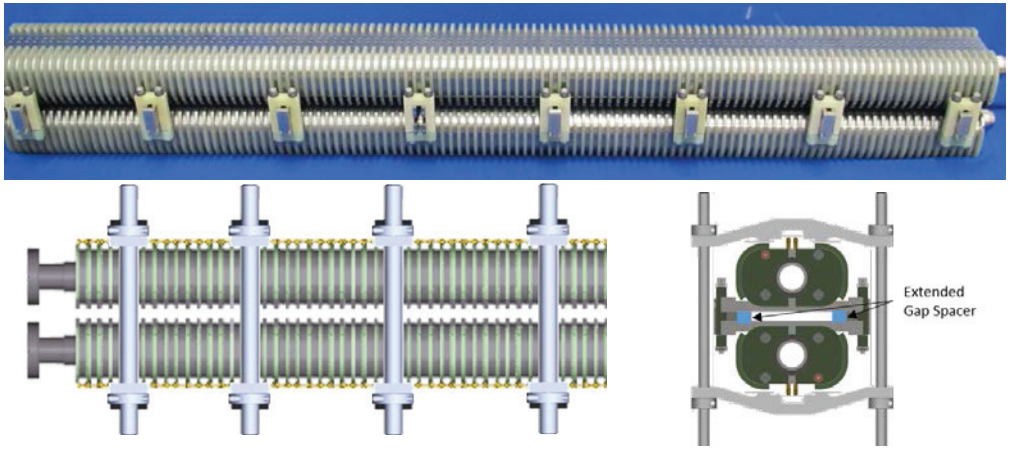




[1] P. Emma et al., in *Proc. of FEL2014*, Switzerland, 2014, paper THA03, pp.649-653.

ACHIEVING LOW PHASE ERRORS

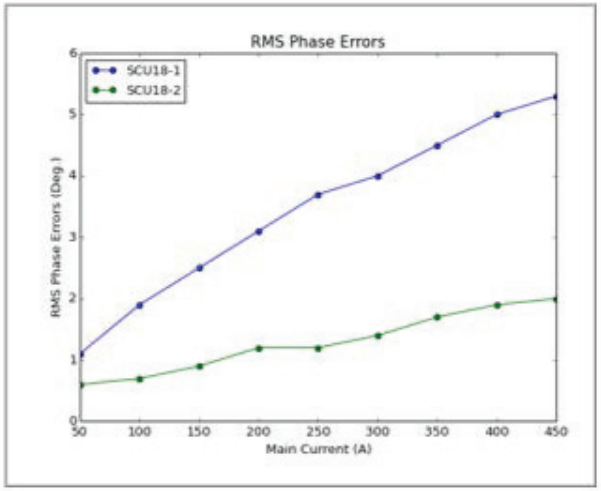
- The SCU field quality depends on:
  - Precise machining of a magnet former [1]
  - Quality of conductor winding [2]
  - Uniformity of the magnetic gap
- A dedicated R&D program was targeted at achieving a very uniform gap [3].
  - A gap correction scheme was developed and implemented using a set of mechanical clamps



Planar SCU magnetic assembly with a concept of gap correction.

Undulator	Measured phase errors (º rms)
SCU18-1	5*
SCU18-2	2
LCLS R&D SCU	3.8

* without gap correction



Measured phase errors in SCU18-1 and SCU18-2.

[1] E. Trakhtenberg et al., "Evolution of the Design of the Magnet Structure for the APS Planar Superconducting Undulators," this conference.
[2] E. Gluskin, "Development and Performance of Superconducting Undulators at the Advanced Photon Source," *Synchrotron Radiation News*, Vol. 28, Issue 3, 2015.
[3] M. Kasa et al., "Progress on the Magnetic Performance of Planar Superconducting Undulators," this conference.

DEVELOPING CIRCULAR AND ARBITRARY POLARIZING SUPERCONDUCTING UNDULATORS

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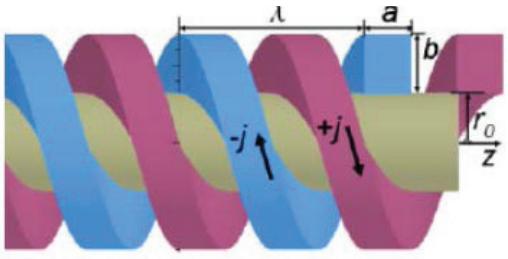
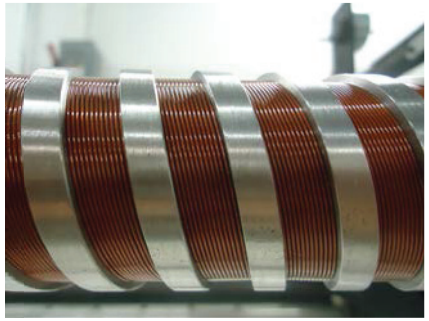
HELICAL SCU FOR APS

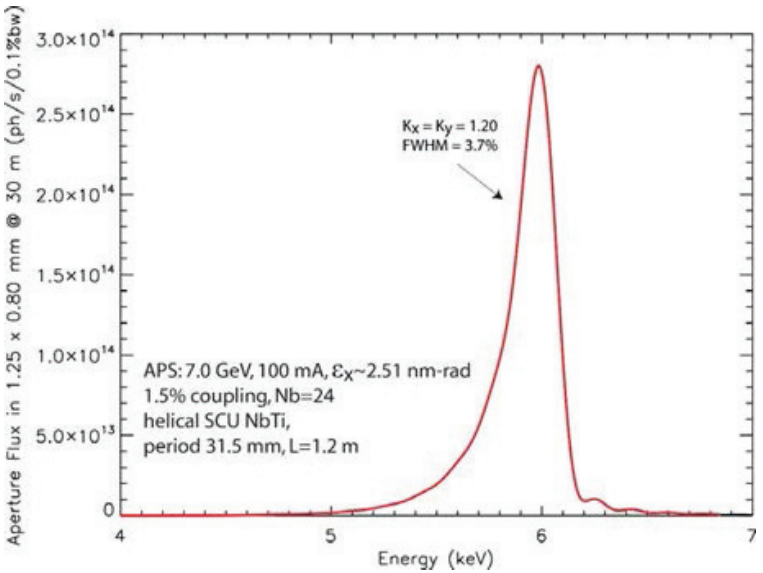
- SCU technology offers the possibility of building circular polarizing helical undulators.
- We are currently working on a helical SCU (HSCU) for the APS.
- X-ray photon correlation spectroscopy program at the APS will benefit from the increased brilliance provided by an HSCU.

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



Magnetic model of HSCU.

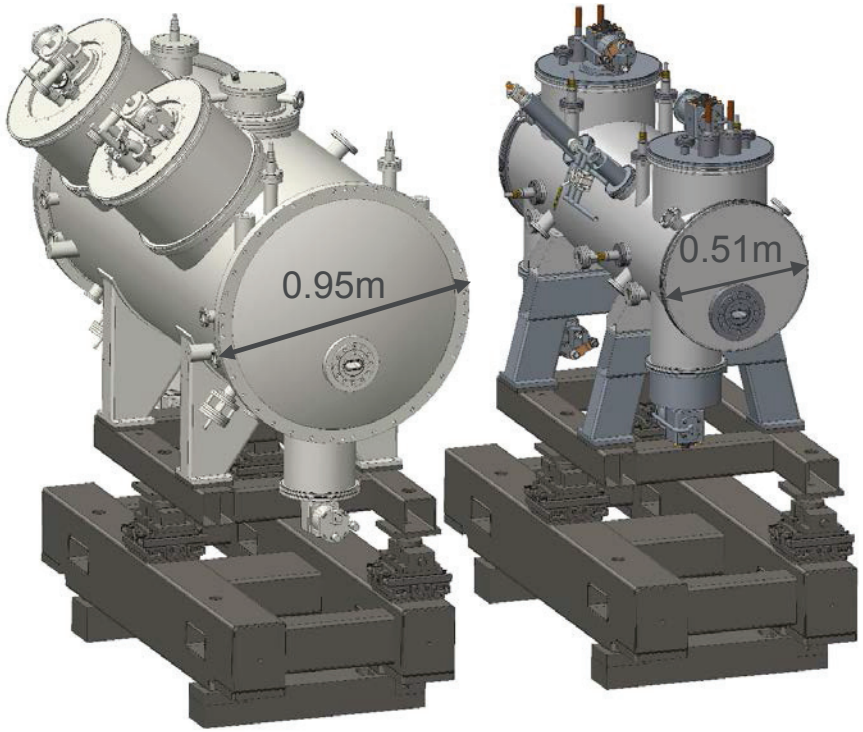

HSCU prototype coil winding.



Calculated photon spectrum of helical SCU.

NEW CRYOSTAT FOR SCUs

- All three APS planar SCUs used the SCU0-type cryostat that was designed in collaboration with the Budker Institute, Novosibirsk, Russia.
- Helical SCU will use a new cryostat.
- Design of the HSCU cryostat is based on the experience of operating three SCU0-type cryostats and a rigorous thermal analysis [1].
- HSCU cryostat is more compact and cheaper than the SCU0-type cryostat.
- HSCU-type cryostat will likely become a standard cryostat for the next SCUs.

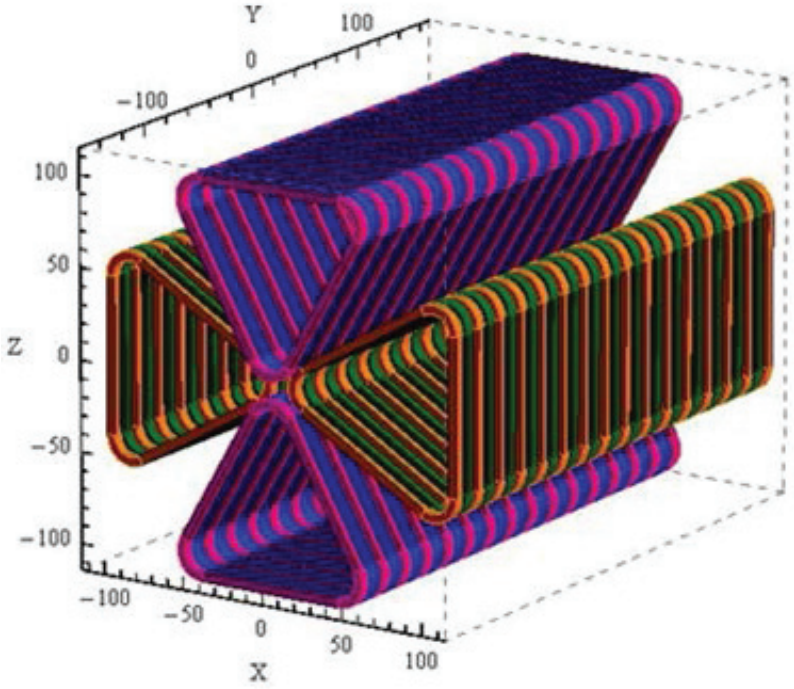


SCU0-type cryostat. New HSCU cryostat.

[1] Y. Shiroyanagi et al., “Thermal Modeling and Cryogenic Design of a Helical Superconducting Undulator Cryostat,” this conference.

ARBITRARY POLARIZING SCU— SCAPE

- Some of the APS users would like to have an undulator that can generate both circular and planar polarized photons.
- To answer this challenging request, we have developed the concept of a Super Conducting Arbitrary Polarizing Emitter, or SCAPE.
- This electromagnetic superconducting undulator employs four planar magnetic cores assembled around a cylindrical beam vacuum chamber.
- The APS Upgrade multi bend achromat lattice enables round beam chambers for insertion devices.
- The SCAPE concept will be tested in a prototype.



Concept of SCAPE: a universal SCU with four planar superconducting coil structures. A beam chamber is not shown.

SUMMARY

- The first APS superconducting undulator, SCU0, was removed from the APS storage ring after 3.5 years of successful operation.
- Two SCUs – SCU18-1 and SCU18-2 – are currently in operation at the APS.
- Work on a helical SCU is in progress.
- A concept of an arbitrary polarizing undulator, SCAPE, has been developed and will be tested in a prototype.