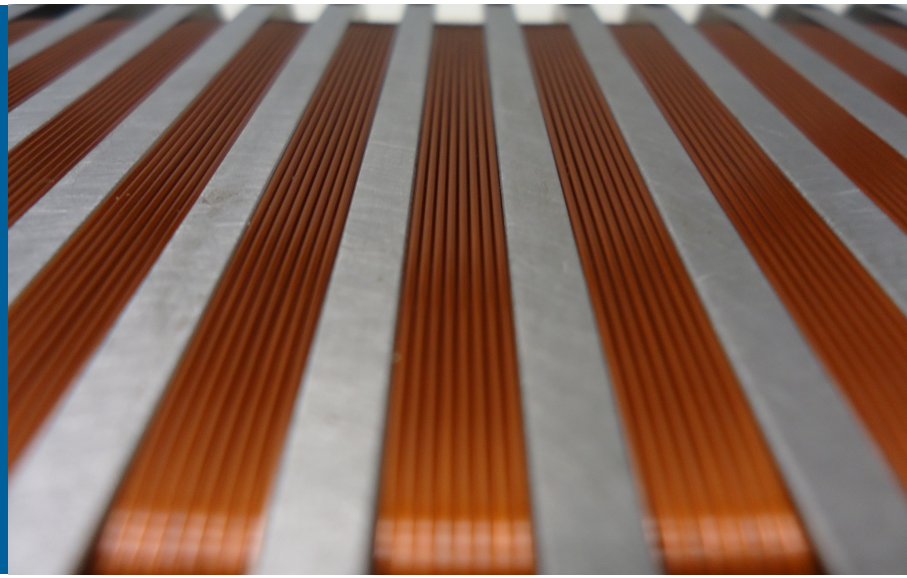
PROGRESS ON THE MAGNETIC PERFORMANCE OF PLANAR SUPERCONDUCTING UNDULATORS



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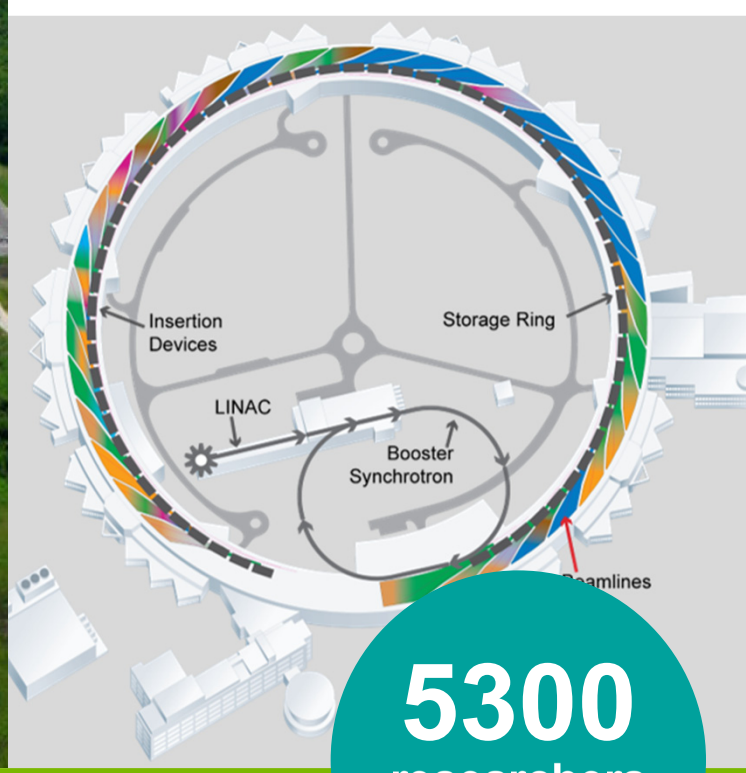
October 11, 2016
North American Particle Accelerator Conference
Chicago, IL

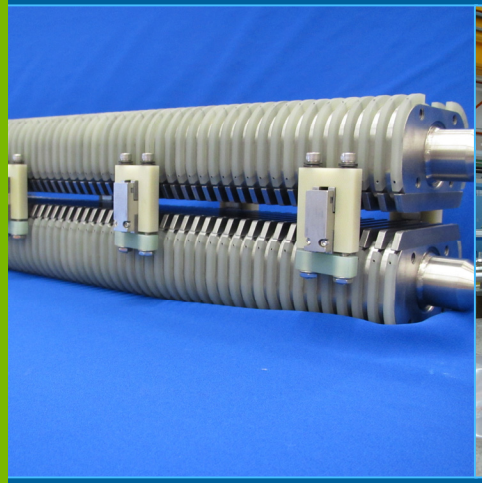


5300
researchers
each year

ADVANCED PHOTON SOURCE

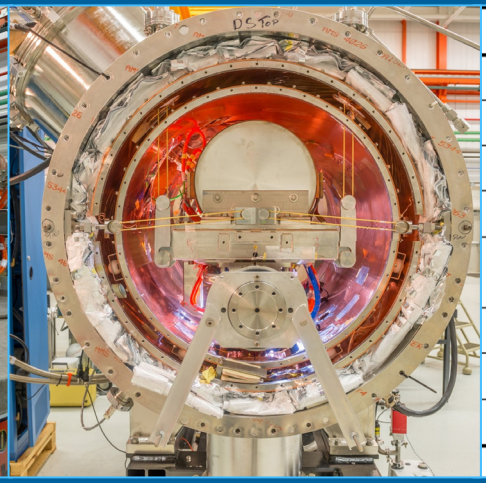
- 7 GeV Synchrotron Radiation Facility
- Researchers come to the APS from:
- 50 states plus Puerto Rico and the District of Columbia
- 33 countries
- 150 companies
- 250 universities

TALE OF TWO UNDULATORS



Assembled cores before winding and epoxy impregnation

Cold mass assembly ready for installation



End view of the cold mass assembly installed into the cryostat

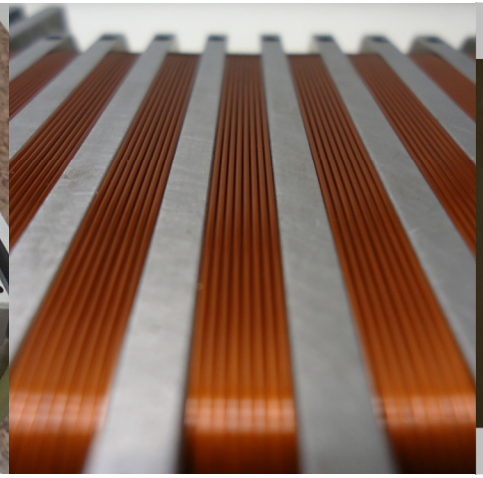
Parameter	Value
Cryostat length, m	2.06
Magnetic length, m	1.1
Undulator period, mm	18
Magnetic gap, mm	9.5
Beam vacuum chamber vertical aperture, mm	7.2
Undulator peak field, T	0.97
Undulator parameter, K	1.63
Operating Current, A	450

SCU Specifications

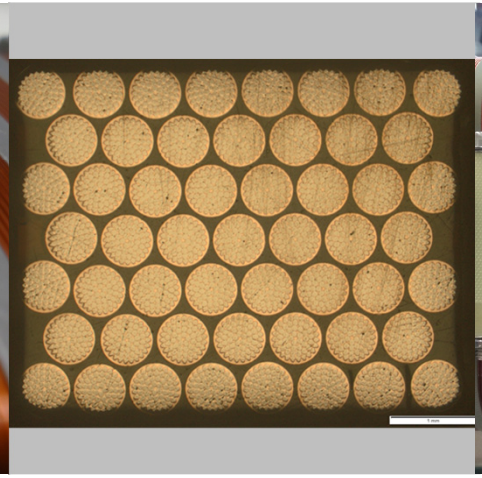
- Two undulators with identical parameters were constructed. Both were wound with 0.6 mm NbTi
  - SCU18-1
  - SCU18-2
- Lessons learned from the SCU18-1 assembly were used to improve the quality of the magnetic performance of SCU18-2

UNDULATOR FIELD QUALITY

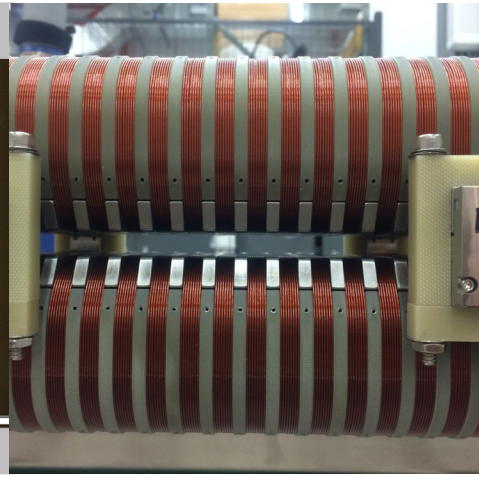
Precision machined core



Precise placement of the superconductor [2]



Cross section of epoxy impregnated winding [2]



Magnetic gap

- Three main factors influence the repeatability of the peak magnetic field from one undulator period to the next
  - Precise machining and repeatability of the winding groove [1]
  - Quality of the winding [2]
  - Uniformity of the magnetic gap
- One figure of merit that is typically used is the RMS phase error from Hall probe field scans
  - Goal was to achieve phase errors <5° RMS over the entire operating range without magnetic shimming

[1] E. Trakhtenberg, M. Kasa, Y. Ivanyushenkov, "Evolution of the Design of the Magnet Structure for the APS Planar Superconducting Undulators," this conference.

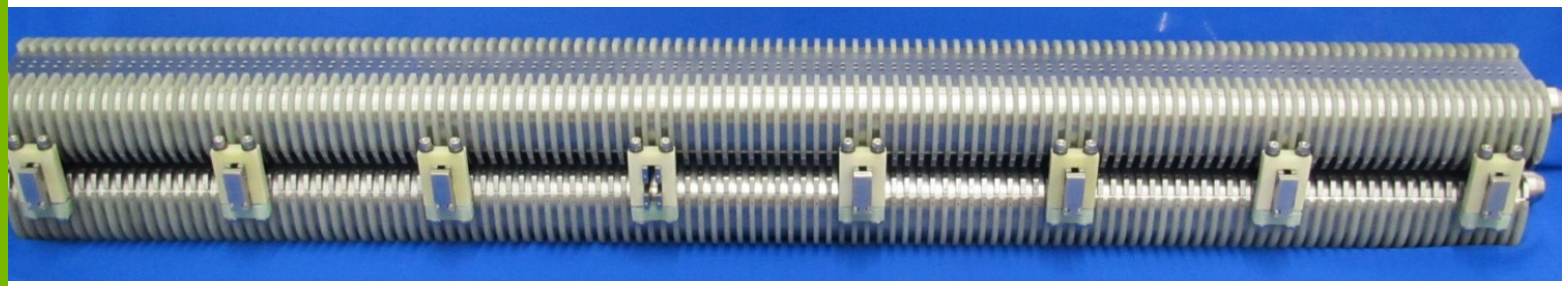
[2] E. Gluskin, "Development and Performance of Superconducting Undulators at the Advanced Photon Source," Synchrotron Radiation News, Vol. 28, Iss. 3,2015.

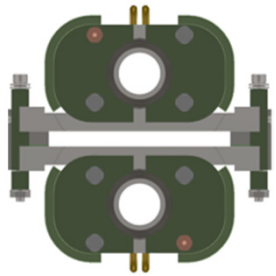
SCU18-1 ASSEMBLY

- Cores were precisely machined and wound
  - Groove width and depth within 50 μm, RMS error of 15 μm
  - Periodicity of the winding grooves within 30 μm, RMS error of 10 μm
  - Flatness of the pole side within 30 μm, RMS error of 10 μm

- After winding and epoxy impregnation each core developed a bow of ~100 μm resulting in an increased gap at the ends of the assembly

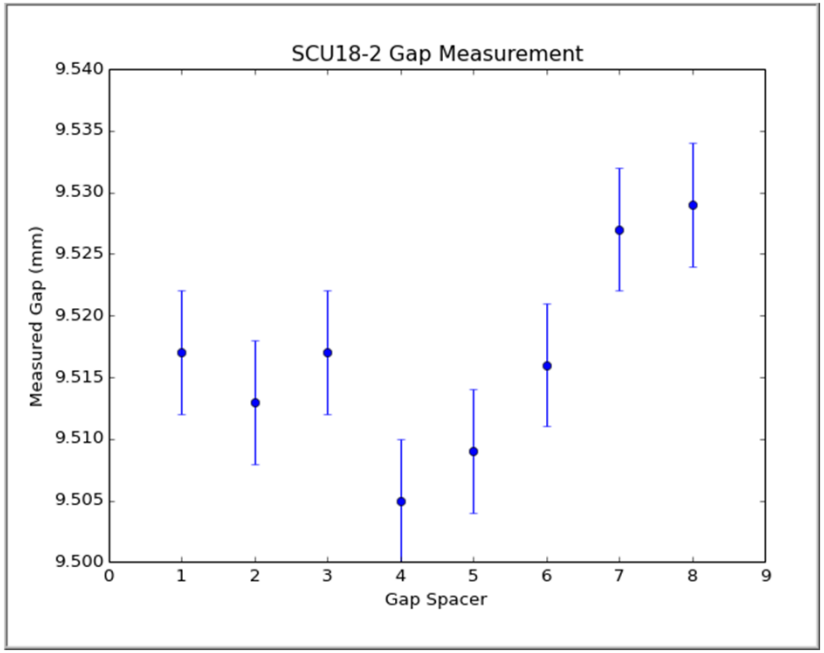
- At the time there was no method of accurately measuring and correcting the magnetic gap

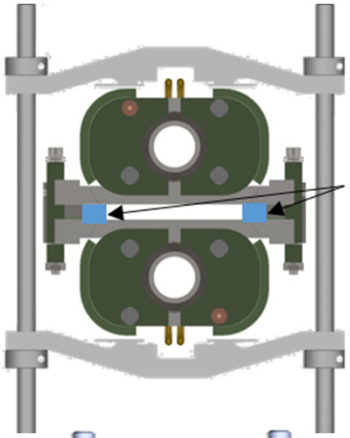


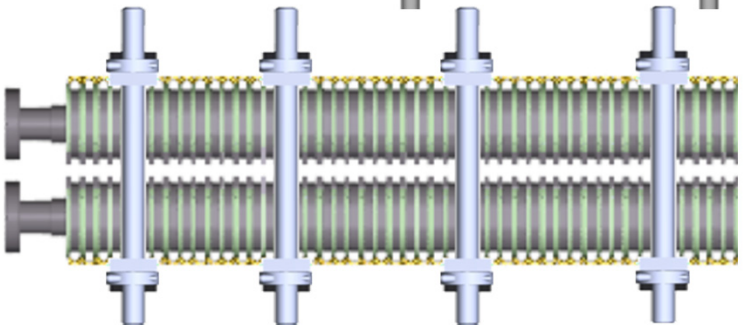


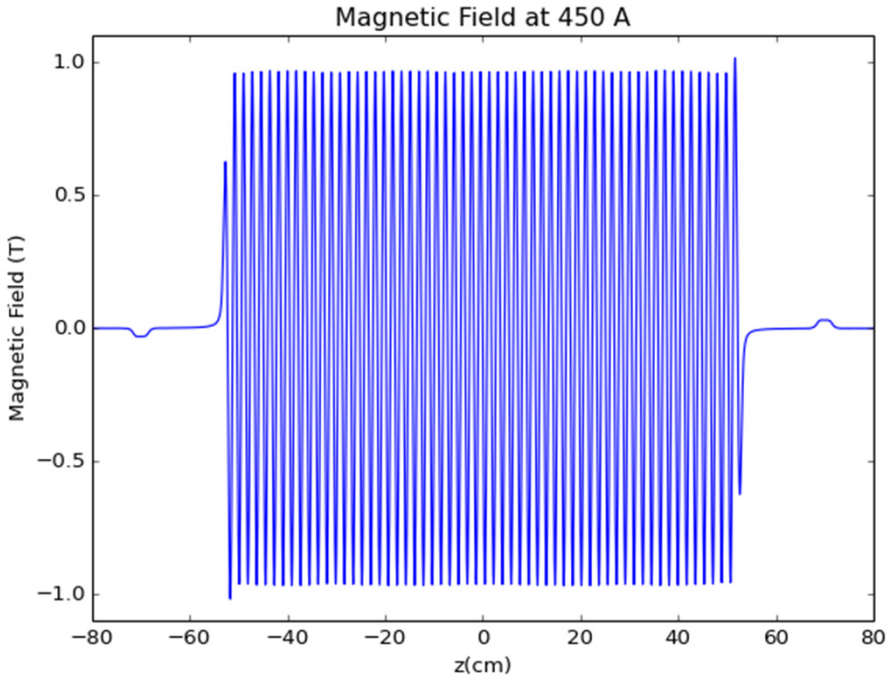
SCU18-2 ASSEMBLY

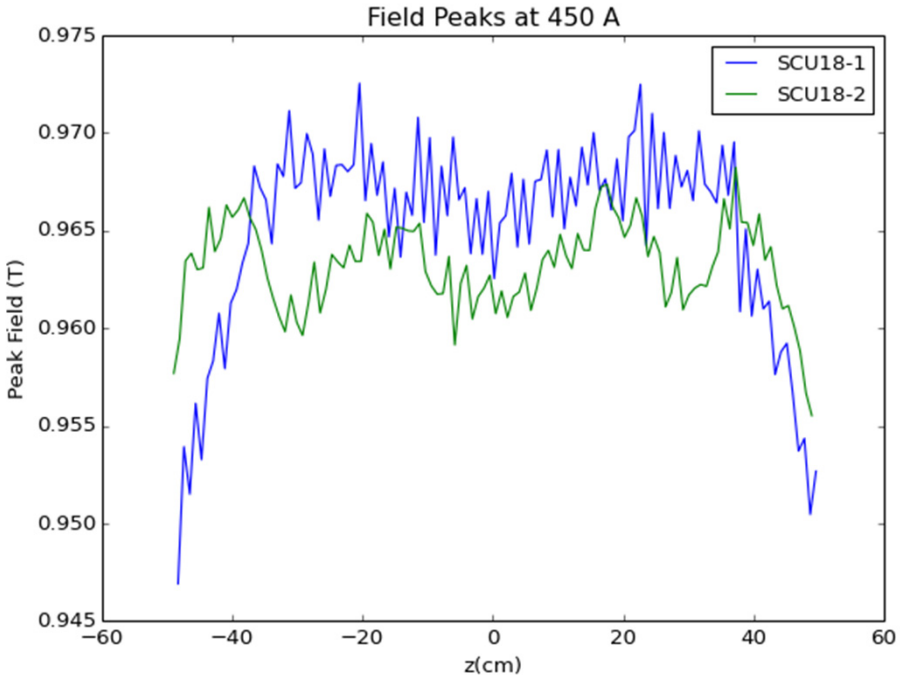
- Similar machining and winding precision was achieved
- Similar bowing of the cores after winding and epoxy impregnation
- This time we had the ability to accurately measure and correct the magnetic gap before installation into the cryostat
  - Capacitec Gapman Gen3 portable electronic feeler gage, 0.254 µm resolution, ±5 µm accuracy
  - External clamps and extended gap spacers







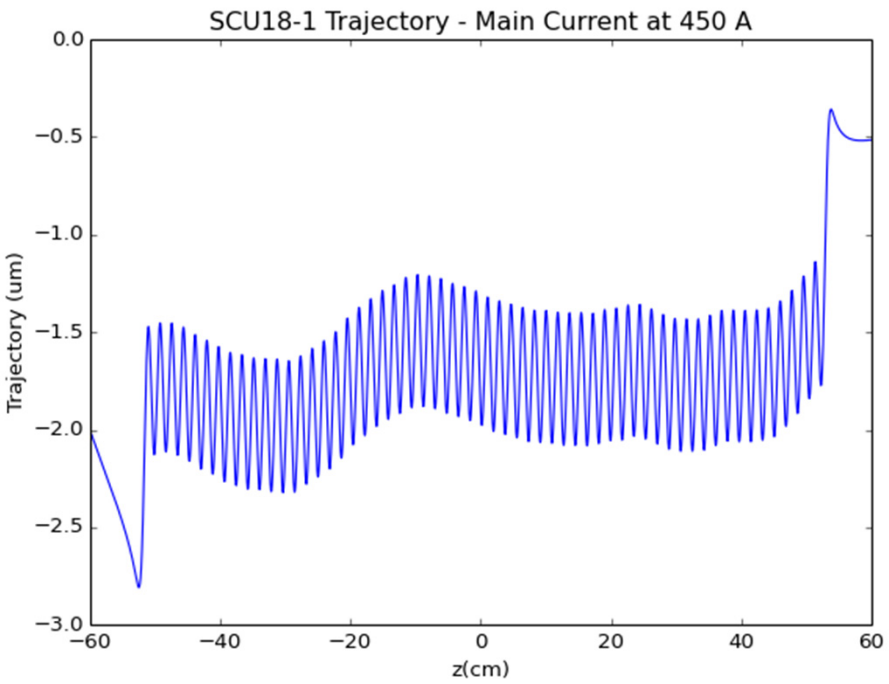


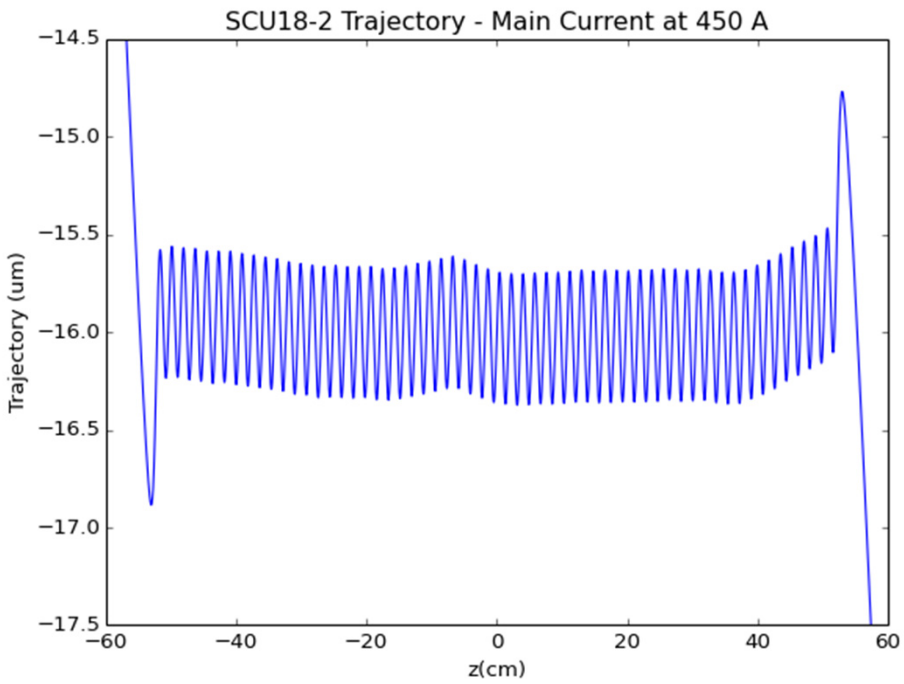


HALL PROBE FIELD SCANS

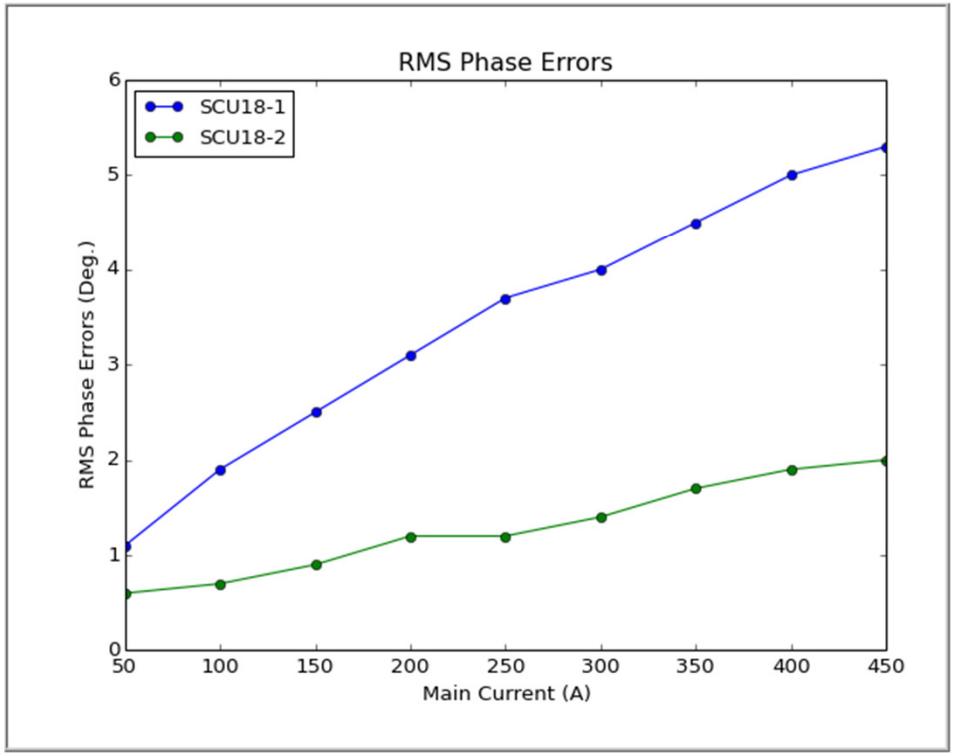
- Noticeable improvement in the uniformity of the peak fields

	Mean (T)	Std. Dev. (T)
SCU18-1	0.9650	0.0050
SCU18-2	0.9630	0.0022

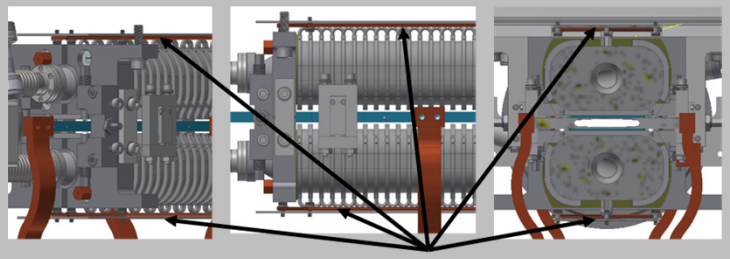




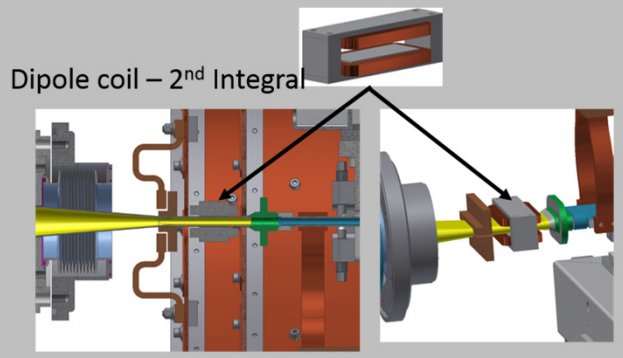
7 GEV ELECTRON TRAJECTORY FROM HALL PROBE MEASUREMENTS



RMS PHASE ERRORS OF SCU18-1 AND SCU18-2



Helmholtz-like coil – 1st Integral



Dipole coil – 2nd Integral

Parameter	Unit	SCU18-1	SCU18-2
I1y	G-cm	20*	25*
I1x	G-cm	35	200
I2y	G-cm^2	25,000*	12,000*
I2x	G-cm^2	5,000	35,000
Normal Quadrupole	G	60	65
Skew Quadrupole	G	20	135
Normal Sextupole	G/cm	100	100
Skew Sextupole	G/cm	150	120
Normal Octupole	G/cm^2	60	40
Skew Octupole	G/cm^2	20	20

*With correction coils energized

1ST AND 2ND FIELD INTEGRALS AND INTEGRATED MULTIPOLES

- Correction coils available for the vertical 1st and 2nd field integrals
- Integrated field measurements will be verified by beam based measurements

AFTER THE SUCCESSFUL IMPLEMENTATION OF GAP CONTROL MEASURES WE WERE ABLE TO CONSTRUCT A 1.1 M LONG SUPERCONDUCTING UNDULATOR WITH PHASE ERRORS OF ~2° OR LESS OVER THE ENTIRE OPERATING RANGE.

SCU18-1 HAS BEEN IN OPERATION ON THE APS STORAGE RING SINCE MAY 2015 AND SCU18-2 WAS RECENTLY INSTALLED IN SEPTEMBER 2016.

DURING THIS TIMEFRAME, A 1.5 M LONG SCU WAS BUILT AND TESTED WITH A LIMITED IMPLEMENTATION OF THE GAP CONTROL MEASURES. THIS DEVICE ACHIEVED PHASE ERRORS OF ~5° OR LESS. THERE ARE FUTURE PLANS TO TEST THIS DEVICE WITH ALL OF THE GAP CONTROL MEASURES IN PLACE.

THANK YOU!