Superconducting wigglers and undulators

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Superconducting shifters and multipole wigglers at the BINP

Types of superconducting magnet systems used as generators of synchrotron radiation:

Superconducting 3 (5) pole shifters with 7-10 Tesla field:
manufactured 5, 3 of them are working for about 20 years.

Superconducting high field 7-7.5 Tesla multipole wigglers:
fabricated- 4, 3 of them are working and 1 is ready to put in operation this year.

Superconducting multipole wiggler with a medium period of 48 to 60 mm and field of 3-4.3 Tesla:
fabricated- 10, 8 of them are working and 2 are ready to put in operation this year.

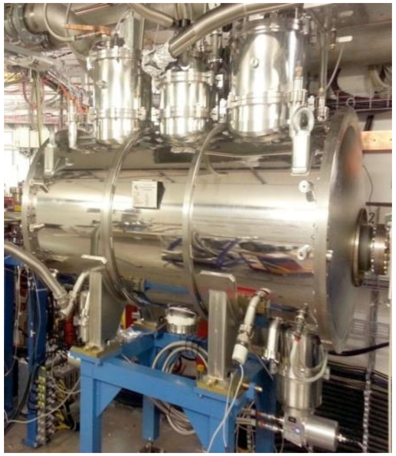
Superconducting multipole wiggler with a short period of 30-34 mm and field of 2-2.2 Tesla:
fabricated 2, both are working.

Superconducting undulator with period 15.6 mm and field 1.2 Tesla is under fabrication now.
Should be ready this year.

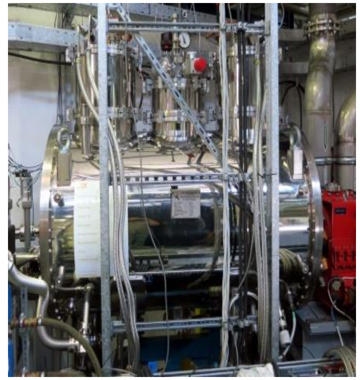
International collaboration on SR generators

Germany:

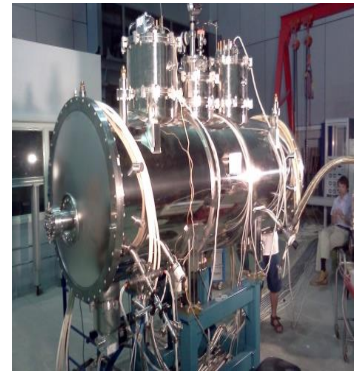
Two superconducting 7 Tesla shifters for BESSY-2 light source (Berlin). 2000,2001



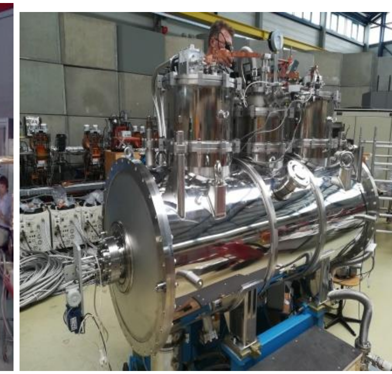
17 poles 7 Tesla, λ=148 mm superconducting wiggler for BESSY-2 light source (Berlin) 2002



44-pole 2.5 Tesla, λ=48 mm superconducting wiggler for ANKA light source (Karlsruhe) 2014

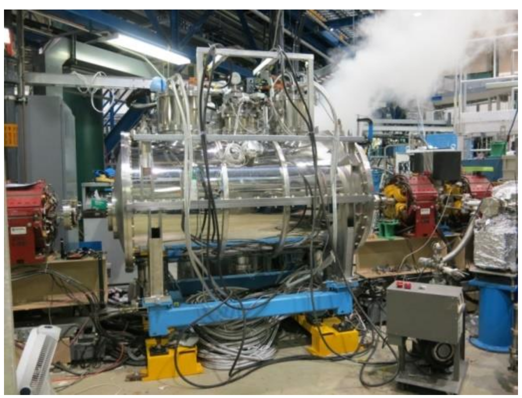


72-pole 3Ttsla, λ=51 mm superconducting wiggler for ANKA-CLIC (Karlsruhe)
Indirect cooling system.
2016

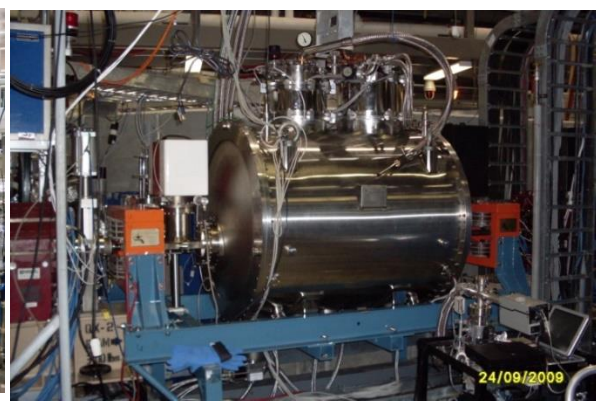


22-pole 7Ttsla, λ=125 mm superconducting wiggler for DELTA (Dortmund)
2019

USA

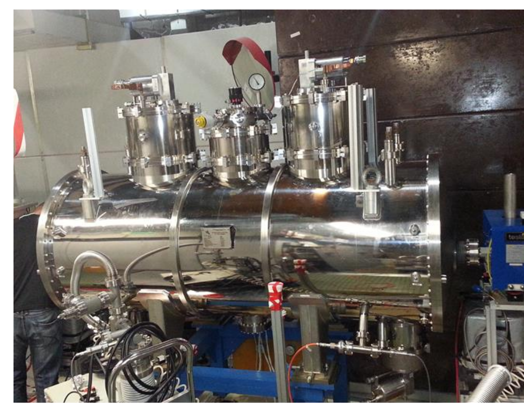


15-pole 7.5 Tesla, λ=198 mm superconducting wiggler for LSU CAMD light source (Baton Rouge) 2013



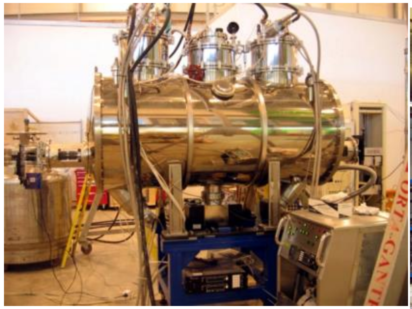
7 Tesla superconducting shifter for LSU CAMD light source (Baton Rouge) 1997

Italy



49-pole 3.5 Tesla, λ=60 mm superconducting wiggler for ELETTRA light source (Trieste) 2002

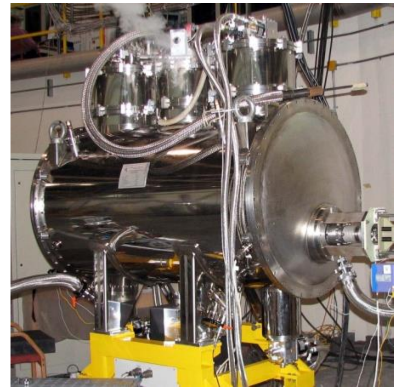
England



49-pole 3.5 Tesla, λ=60 mm superconducting wiggler for Diamond Light source. 2006

49-pole 4.2 Tesla, λ=48 mm superconducting wiggler for Diamond Light source. 2009

Canada



27-pole 4.2 Tesla, λ=48 mm superconducting wiggler for Canadian Light source. 2007

63-pole 2.2 Tesla, λ=32 mm superconducting wiggler for Canadian Light source. 2005

Brasil

35-pole 4.2 Tesla,λ=60mm superconducting wiggler for LNLS light source. 2009

Australia

49-pole 4.2 Tesla, λ=52mm superconducting wiggler for AS light source. 2012

Spain

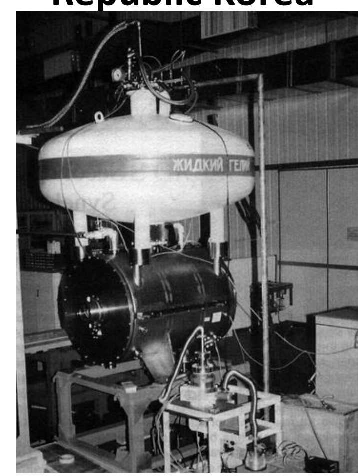
119-pole 2.1 Tesla, λ=30 mm superconducting wiggler for ALBA light source. 2010

Japan

10 Tesla WLS for Spring-8 Slow Positron Source

10 Tesla superconducting shifter for SPring-8. 2000

Republic Korea



7.5 Tesla superconducting shifter for PLS light source. 1996.

History of superconducting magnet activity for 40 years

1979 – first in the world 3.5 Tesla superconducting 20 pole wiggler (SCW) for VEPP-3	**NbTi/Cu**
1984 – 5 pole 8 Tesla superconducting wiggler for VEPP-2	**NbTi/Cu**
1985 – 4.5 Tesla Superconducting Wave Length Shifter (WLS) for Siberia-1, Moscow	**NbTi/Cu**
1992 – 6 Tesla superbend (SB) prototype for compact storage rings	**NbTi/Cu**
1996 - 7.5 Tesla superconducting WLS for PLS, South Korea	**NbTi/Cu**
1997 - 7.5 T superconducting WLS with fixed point of radiation for CAMD-LSU (USA)	**NbTi/Cu**
2000 – 10 Tesla WLS for Spring-8, Japan	**Nb3Sn/Cu**
2000 – 7 Tesla WLS with fixed radiation point for BESSY-2, Germany	**NbTi/Cu**
2001 – 7 Tesla WLS with fixed radiation point for BESSY-2, Germany	**NbTi/Cu**
2002 – 3.5 Tesla 49 pole SCW for ELETTRA, Italy	**NbTi/Cu**
2002 – 7 Tesla 17 pole SCW for BESSY-2, Germany	**NbTi/Cu**
2004 – 9 Tesla Superbend for BESSY-2, Germany	**Nb3Sn/Cu**

Red- in operation, black- not in operation

History of superconducting magnet activity for 40 years

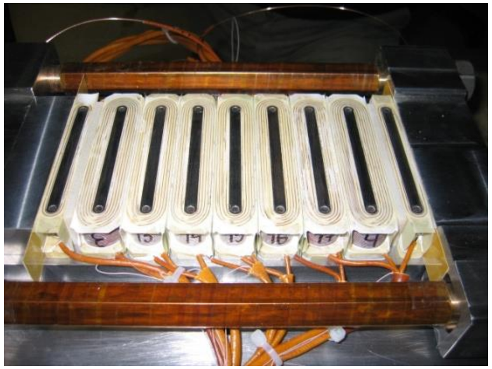
2005 – 13 Tesla superconducting solenoids for VEPP-2000	**Nb_3Sn/Cu**
2005 – 2 Tesla 63 pole SCW for CLS, Canada	**NbTi/Cu**
2006 – 3.5 Tesla 49 pole for DLS, England	**NbTi/Cu**
2006 – 7.5 Tesla 21 pole SCW for Siberia-2, Moscow	**NbTi/Cu**
2007 – 4.2 Tesla 27 pole SCW for CLS, Canada	**NbTi/Cu**
2009 – 4.2 Tesla 49 pole SCW for DLS, England	**NbTi/Cu**
2009 – 4.1 Tesla 35 pole SCW for LNLS, Brasil	**NbTi/Cu**
2010 - 2.1 Tesla 119 pole SCW for ALBA, Spain	**NbTi/Cu**
2012 - 4.2 Tesla 63 pole SCW for AS (Australia)	**NbTi/Cu**
2013 - 7.5 Tesla 15 pole wiggler for LSU CAMD, USA	**NbTi/Cu**
2014 - 2.5 Tesla 44 pole wiggler for ANKA-CATACT, Germany	**NbTi/Cu**
2016 - 3 Tesla 72 pole wiggler for ANKA/CLIC, Germany/CERN	**NbTi/Cu**
2018 – 7 Tesla 22 pole wiggler for DELTA, Dortmund, Germany	**NbTi/Cu**
2018 – 3 Tesla 54 pole 2 wigglers for Siberia -2, Moscow, Russia	**NbTi/Cu**

Red- in operation, green- ready to install

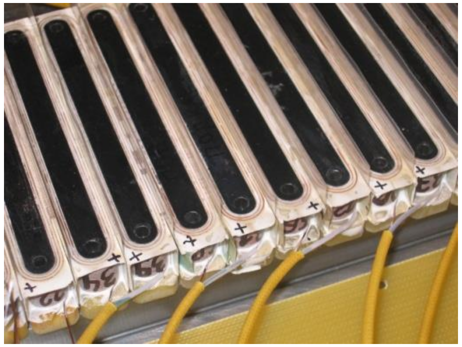
3 groups of SC wiggler

High field SC multipole wigglers
(B=7-7.5 Tesla, λ~125-200 mm)

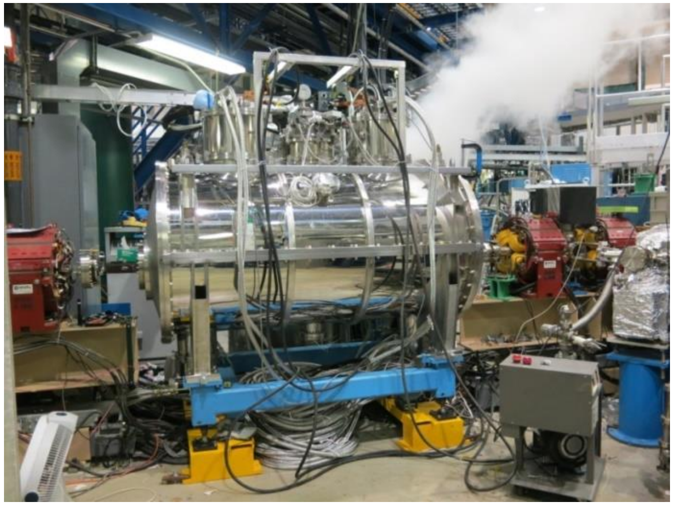
Medium field SC wigglers
(B=3.5-4.2 Tesla, λ~48-60 mm)



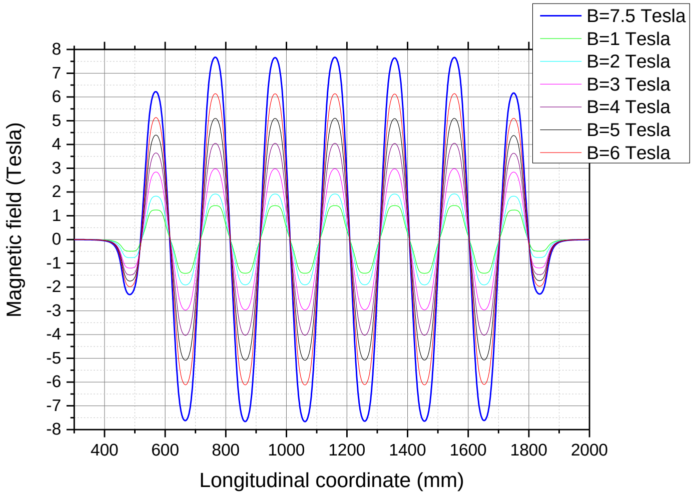
Short period SC wigglers
(B=2-2.2 Tesla, λ~30-34 mm



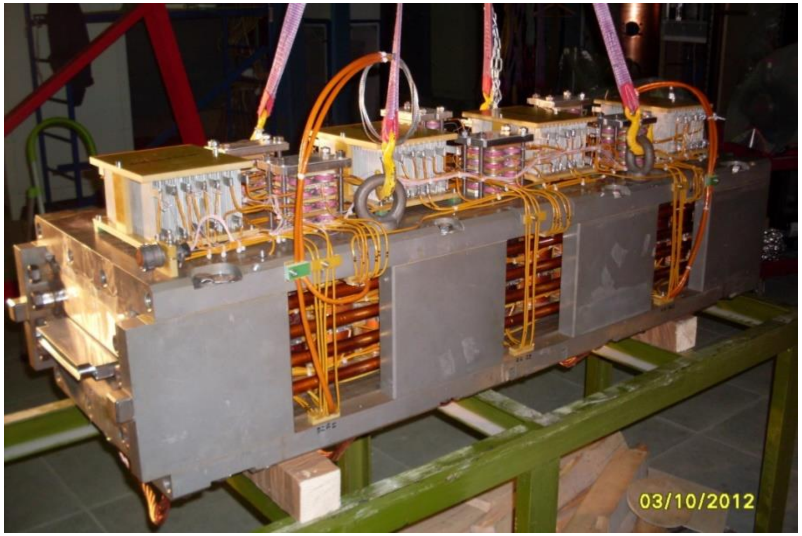
High field long period superconducting multipole wigglers are used for production of hard X-rays on storage rings with low electron energy (BESSY 1.7 GeV, CAMD LSU 1.35 GeV, Siberia-2 2.5 GeV, Dortmund university 1.5GeV)



7.5 Tesla 15 pole superconducting wiggler (CAMD LSU, USA)



Magnetic field distribution at different field levels

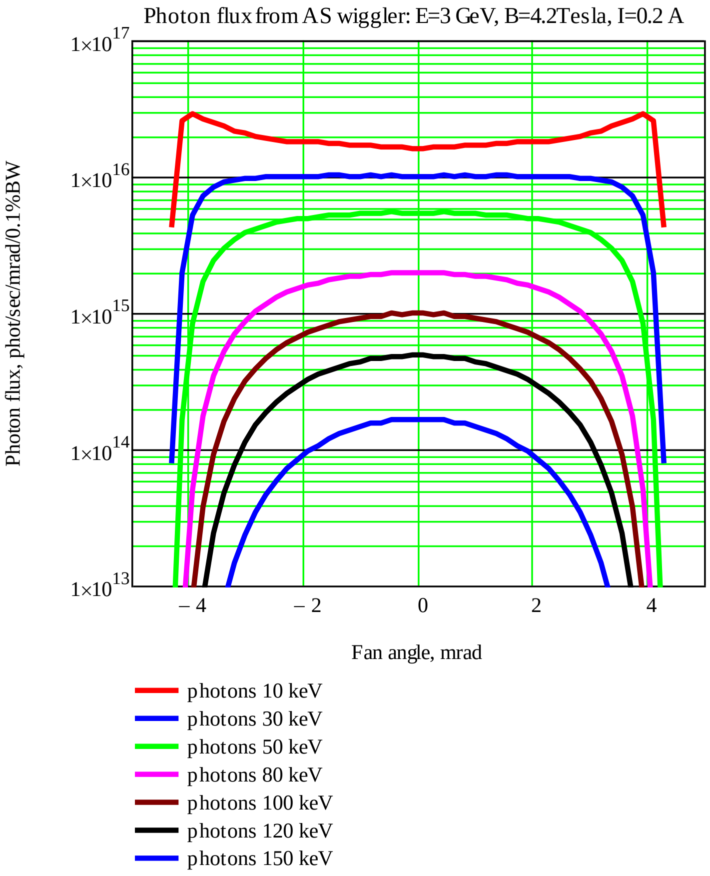


The installation of an insertion device with so high field at an accelerator working energy of 1.35 GeV is quite a complex accelerating challenge, as considerable effort was required for compensation of the influence of the magnetic field on the magnetic structure of the storage ring. All problems connected with the influence of the wiggler field on the beam dynamics were successfully solved during the wiggler commissioning with electron beam.

A PRELIMINARY REPORT FROM LOUISIANA STATE UNIVERSITY CAMD STORAGE RING OPERATING WITH AN 11 POLE 7.5 TESLA WIGGLER R. S. Amin et al, Proceedings of IPAC2015, Richmond, VA, USA

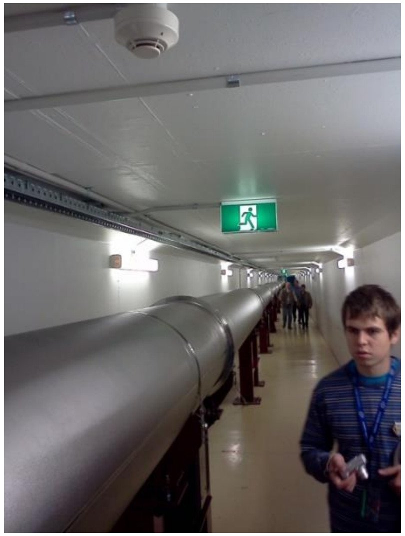
Superconducting multipole wigglers with medium period

Angular-spectral photon distribution from the wiggler (63 poles): B_0=4.2T, E=3 GeV, I=0.2 A,



Australian Light Source

Assembled magnet

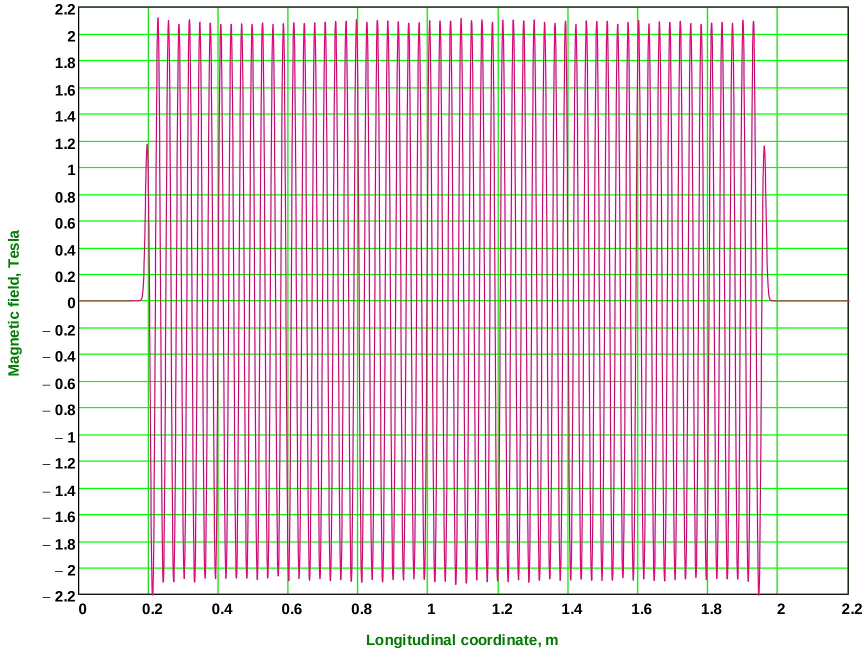


140 m long Imaging and medical beamline

End of beamline- extraction window

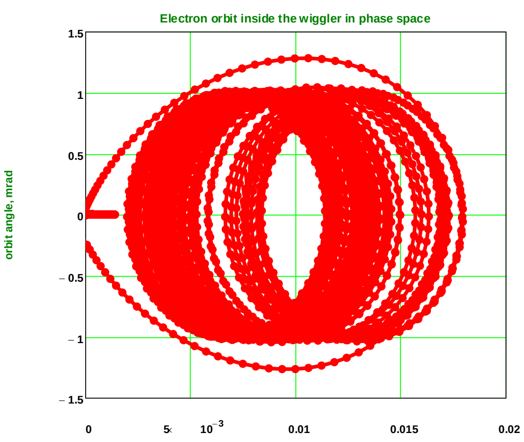
Short period superconducting multipole wigglers

Longitudinal magnetic field distribution

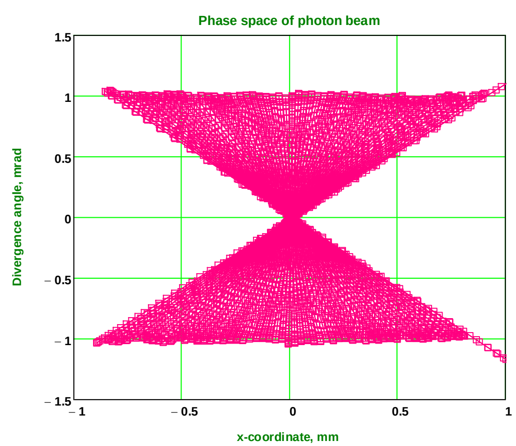


119-pole 2.1 Tesla SC wiggler for ALBA CELLS

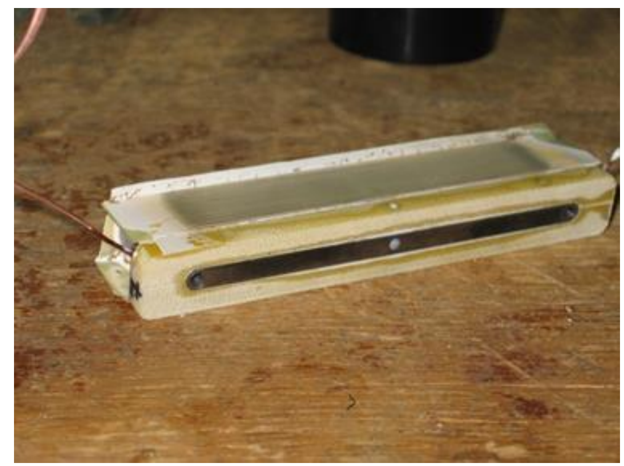
½ of the wiggler magnet



Electron beam orbit in x-x` coordinate



Phase space of the photon beam



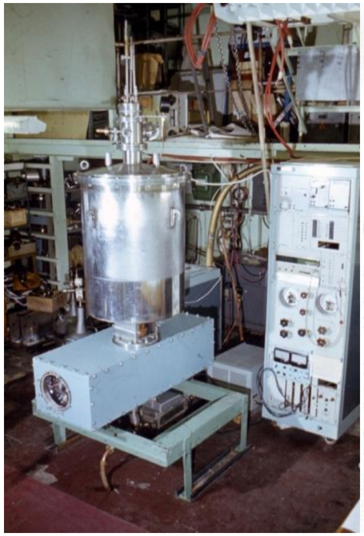
Magnet pole – main element of the magnet

http://accelconf.web.cern.ch/AccelConf/IPAC2011/papers/thpc172.pdf

Cryogenic system

Cryogenic system of SC insertion devices progress (Budker INP)

1979



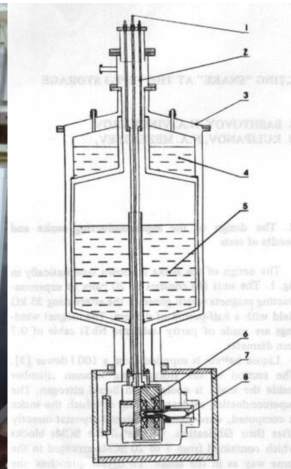
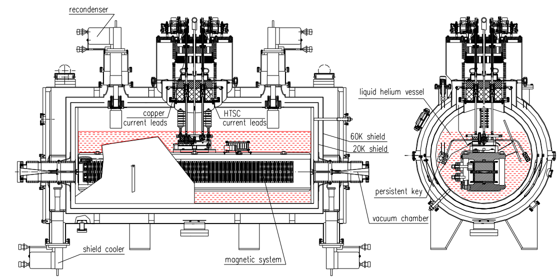


Fig. 1. A general view of the snake for the storage ring VEPP-3; 1 – liquid helium supply pipe, 2 – current leads, 3 – dewar, 4 – liquid nitrogen, 5 – liquid helium, 6 – superconducting magnets, 7 – vacuum container, 8 – storage ring vacuum chamber.

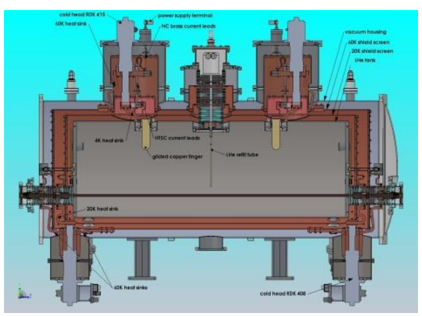
Liquid helium consumption ~ **4 l/hr**

2002



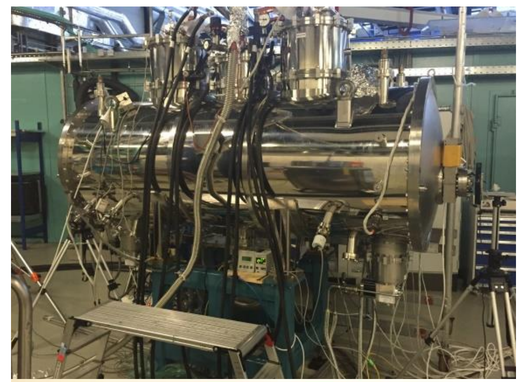
Liquid helium consumption ~ **0.6 l/hr**

2007

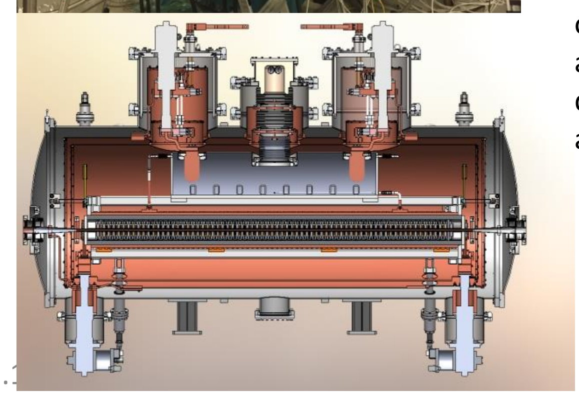


Liquid helium consumption < **0.03 l/hr**

2015



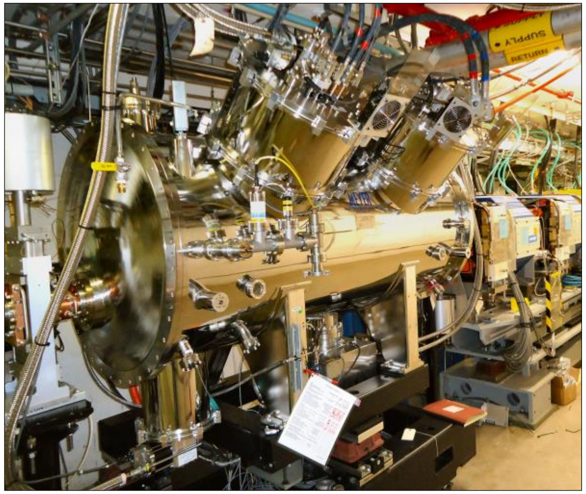
Indirect cooling system. Liquid helium used as cooling agent



For initial cooling of the magnet thermal tubes on the basis of nitrogen and helium are developed, fabricated and tested.

SCUs at the APS (on behalf Efim Gluskin)

- SCU0:
  - 16-mm period length
  - 0.33-m long magnet
  - Operation: Jan2013-Sep2016
- SCU1(SCU18-1):
  - 18-mm period length
  - 1.1-m long magnet
  - Operation: since May2015
- SCU18-2:
  - 18-mm period length
  - 1.1-m long magnet
  - Operation: since Sep2016.



SCU18-1 in Sector 1 of the APS ring.

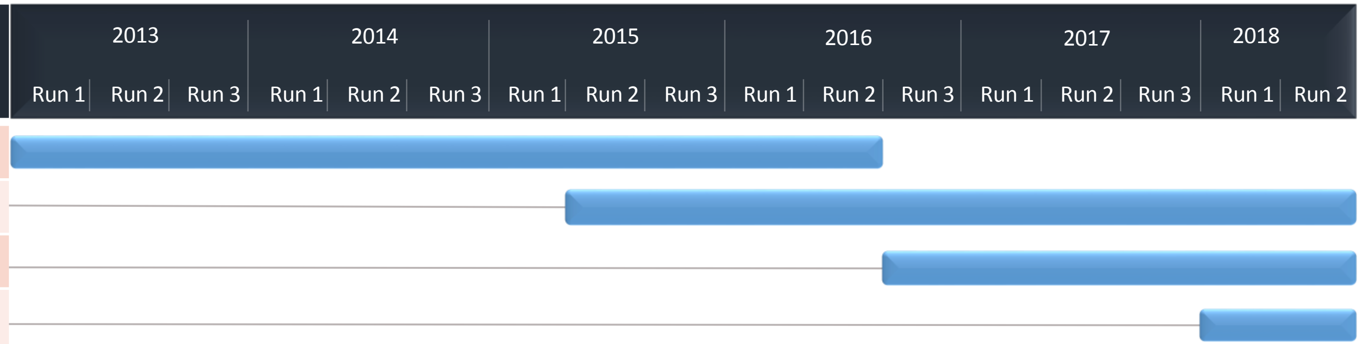
Helical SCU in Sector 7 of the APS ring.

- LCLS R&D SCU:
  - 21-mm period length
  - 1.5-m long magnet
  - Project completed in 2016.
- Helical SCU:
  - 31.5-mm period length
  - 1.2-m long magnet
  - Installed in Dec2017.
  - Operation: since Jan2018

APS SCUs operational performance

- SCUs have been essentially transparent to the APS SR beam
- Most quenches occur during unplanned beam dumps
- SCU0,18-2 quenches decreased dramatically after beam abort system added in January 2016

	λ (mm)	# of periods	B (T)
SCU0	16	20.5	0.8
SCU18-1	18	59.5	0.97
SCU18-2	18	59.5	0.97
HSCU	31.5	38.5	0.41

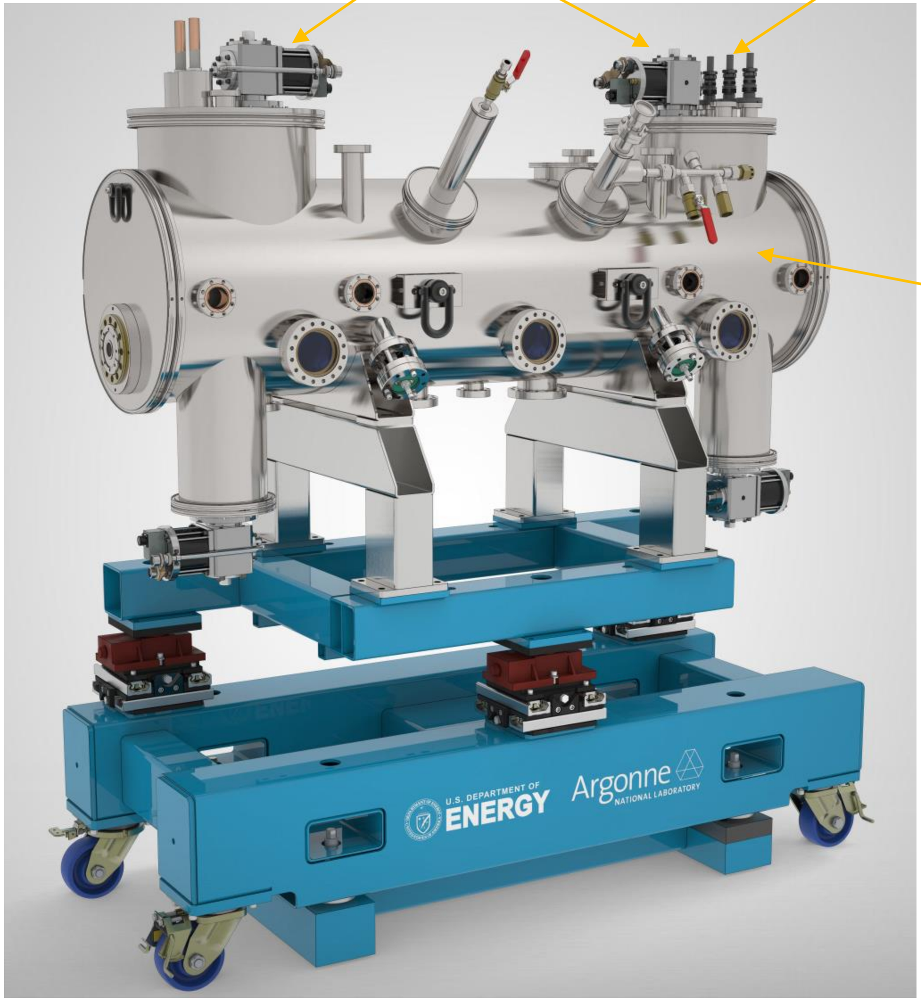


		SCU0 and SCU18-2				SCU18-1				HSCU			
Year	**APS delivered**	**Oper.**	**Down**	**quench**	**avail. %**	**Oper.**	**Down**	**quench**	**avail. %**	**Oper.**	**Down**	**quench**	**avail. %**
2013	4871 h	4189 h	20 h	*34* + 3	99.5	-	-	-	-	-	-	-	-
2014	4926 h	4391 h	174 h [1]	*32* + 2	96.2	-	-	-	-	-	-	-	-
2015	4940 h	4834 h	0 h	*26* + 1	100	3059 h [2]	0.1 h	*5* + 0	99.997	-	-	-	-
2016	4941 h	4647 h [3]	0 h	*9* + 0	100	4585 h	0.3 h	*11* + 1	99.990	-	-	-	-
2017	4840 h	4756 h	0 h	*8* + 1	100	4818 h	0.75 h	*13* + 2	99.984	-	-	-	-
2018 [4]	3327 h	3236 h	5 h	*11* + 1	99.8	3199 h	0.59 h	*9* + 2	99.981	533 h	0 h	*0* + 0	100
Total	27845 h	26053 h	199 h	*120* + 8	**99.24**	15661 h	1.74 h	*29* + 3	**99.99**	533 h	0 h	*0* + 0	**100**

- e-beam has never been lost due to self-quenches
- *Red = beam dump-induced quench*
- Blue = non-beam dump, possible self-induced quench

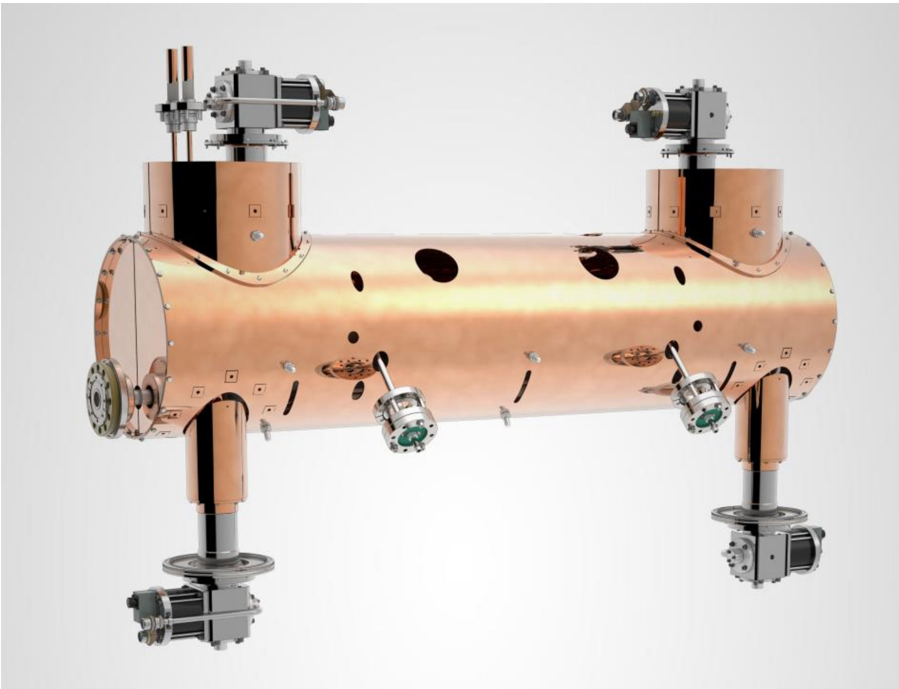
[1] November: Partial loss of one cryocooler capacity
[2] Installed in May; operated May – Dec. 2015
[3] SCU18-2 replaced SCU0 in Sep.
SCU0 3310 h, SCU18-2 1337 h
[4] January 2018 through September 2018

APS SCU cryostat

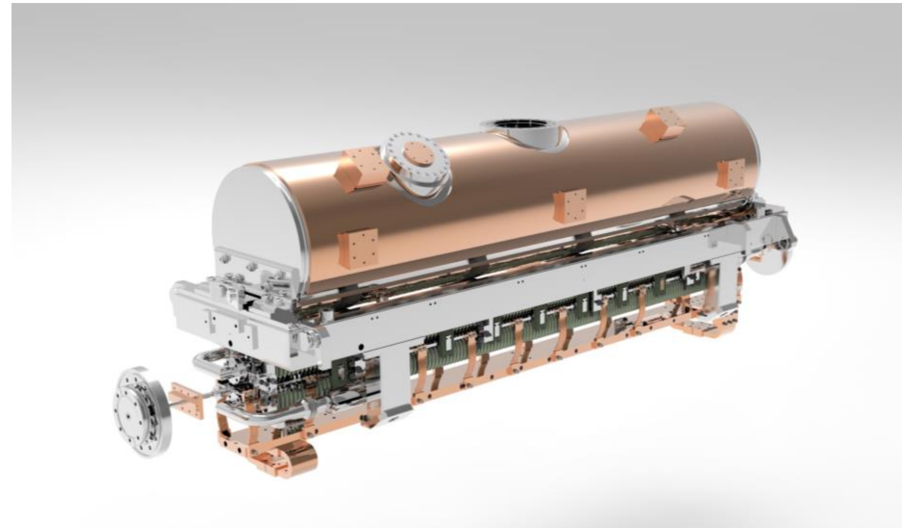


- Vacuum vessel
- Cryogenic circuits
- Undulator magnet
- Mechanical supports& alignment systems

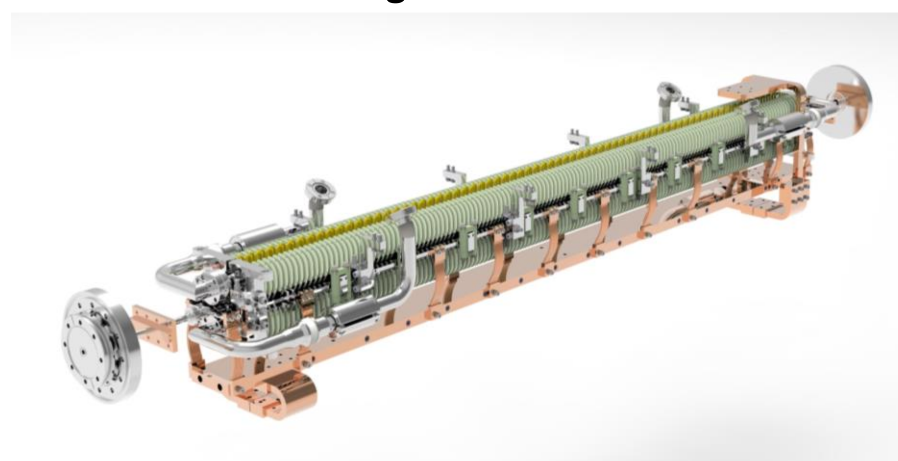
Thermoshield with cryocoolers



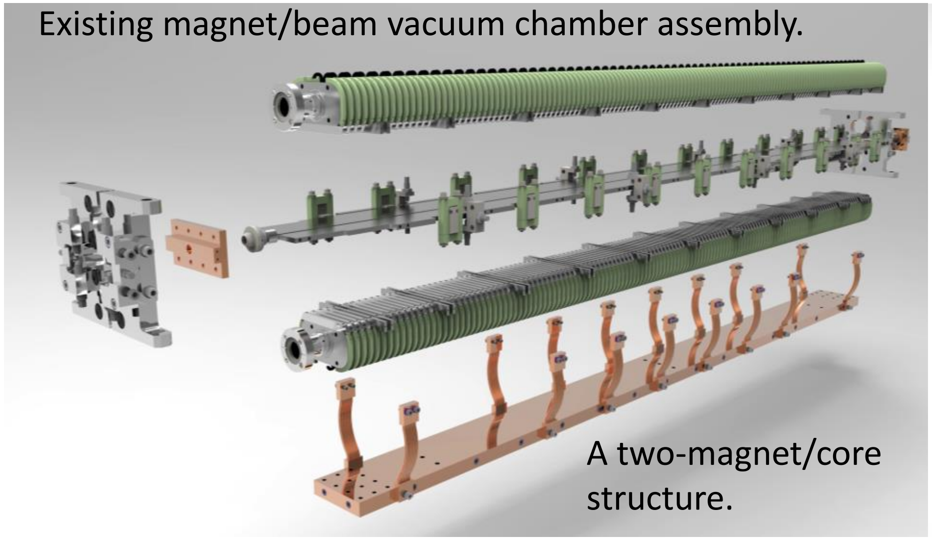
Planar SCU – “cold mass”: LHe tank and undulator magnet



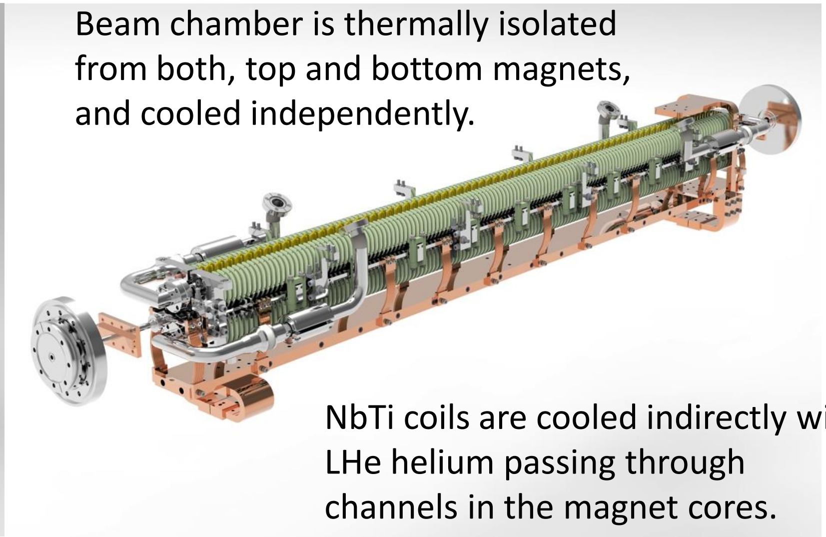
Planar SCU – magnet and vacuum chamber



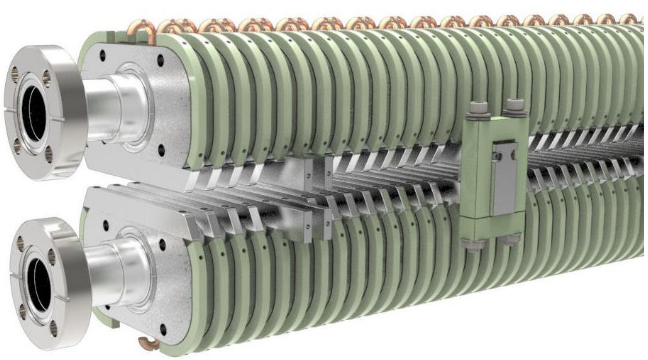
Planar SCU: magnets/cores

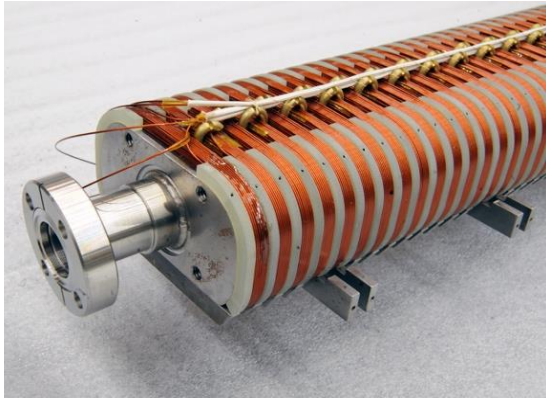

Existing magnet/beam vacuum chamber assembly.

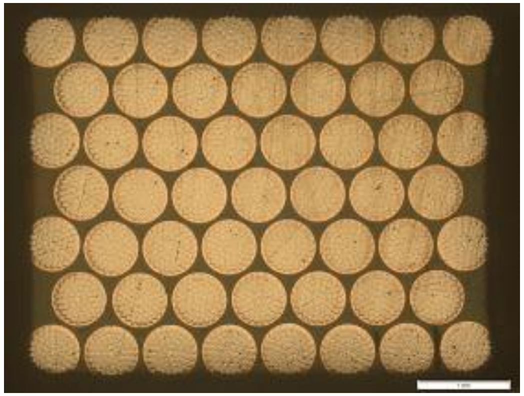
A two-magnet/core structure.


Beam chamber is thermally isolated from both, top and bottom magnets, and cooled independently.

NbTi coils are cooled indirectly with LHe helium passing through channels in the magnet cores.

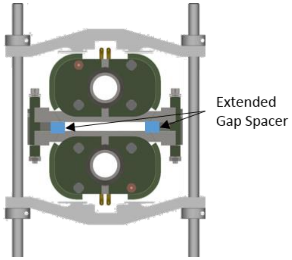






Phase errors control

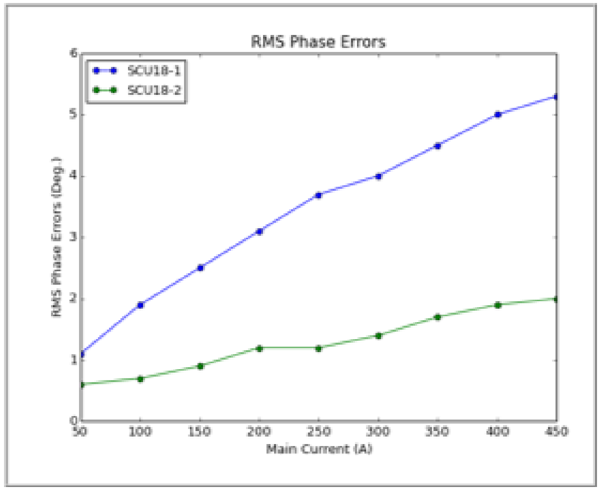
- The SCU field quality depends on:
  - Precise machining of a magnet core
  - Quality of conductor winding
  - Uniformity of the magnetic gap
- A dedicated R&D program was targeted at achieving a very uniform gap.
  - A gap correction scheme was developed and implemented using a set of mechanical clamps



Planar SCU magnetic assembly with a gap correction.

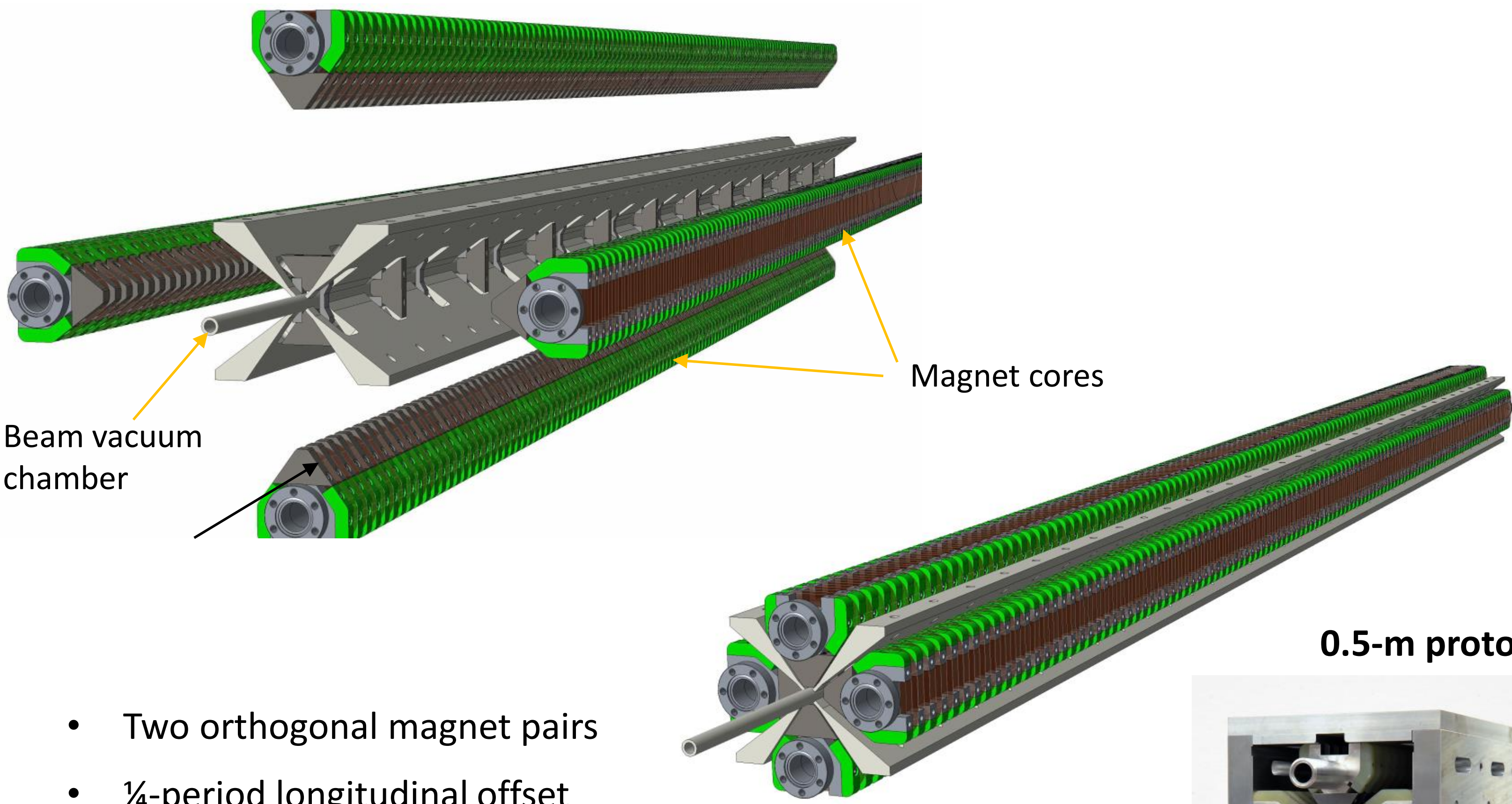
Undulator	Measured phase errors (º rms)
SCU18-1	5*
SCU18-2	2
LCLS R&D SCU	3.8

* without gap correction



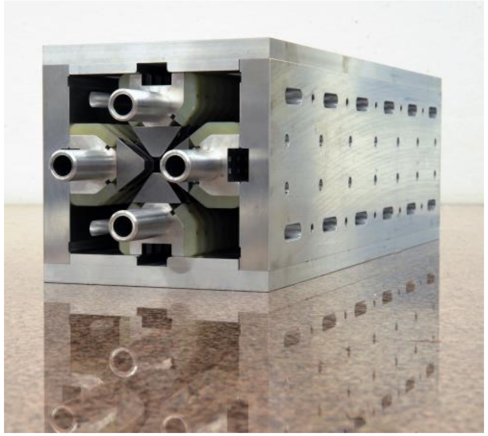
Measured phase errors in SCU18-1 and SCU18-2.

SCAPE magnet and vacuum chamber design

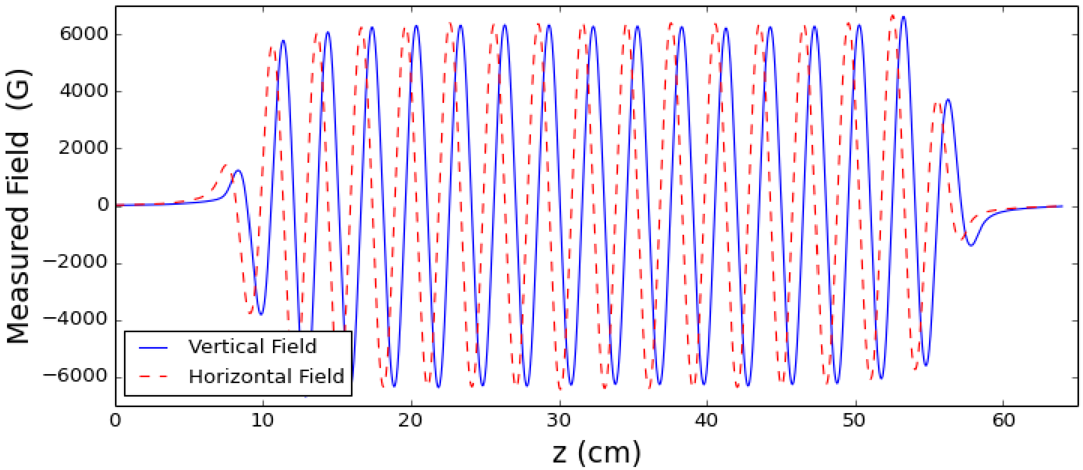


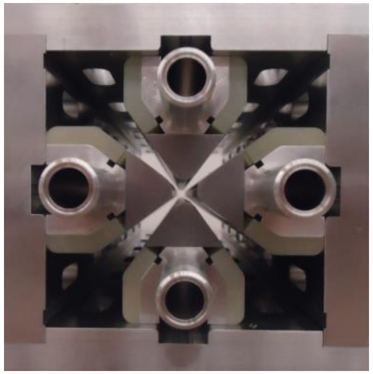
- Two orthogonal magnet pairs
- ¼-period longitudinal offset
- Beam vacuum chamber operates at elevated temperature, screens magnet from beam heating

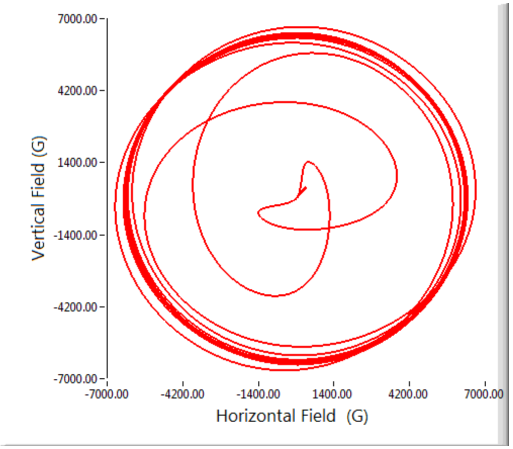
0.5-m prototype

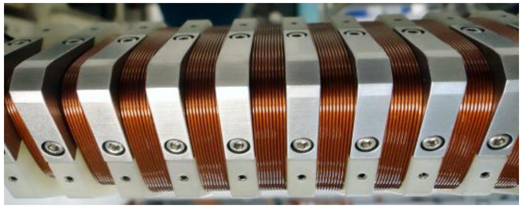


SCAPE: 0.5m prototype tests



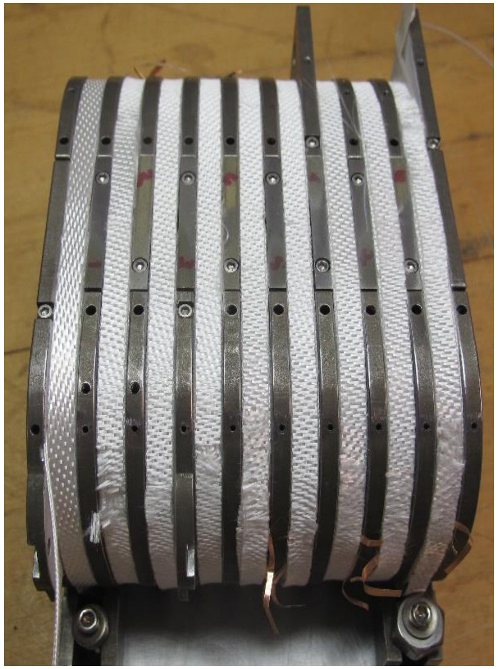


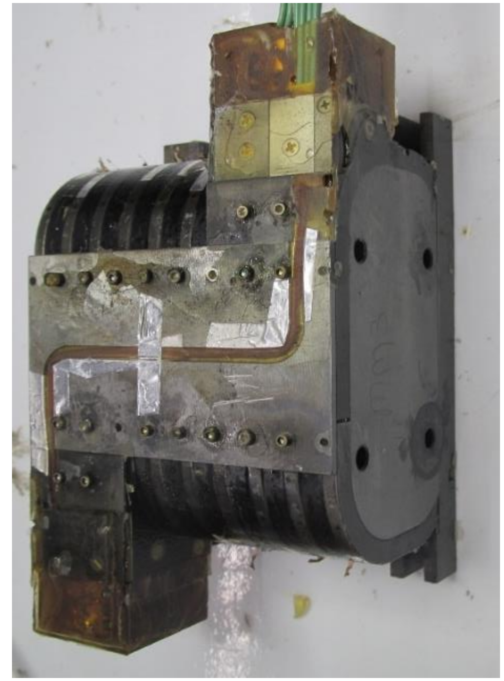




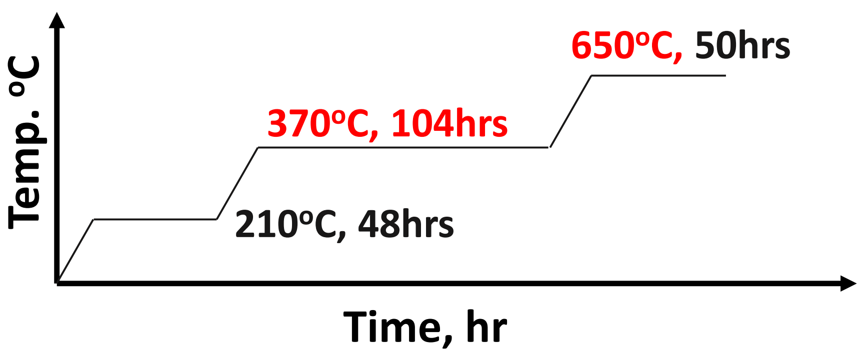
- 30 mm period
- 10 mm pole gap
- Four 0.5 m long magnets
- Planar, circular, and elliptical modes were measured in a vertical LHe bath cryostat

Nb_3Sn short undulator prototype



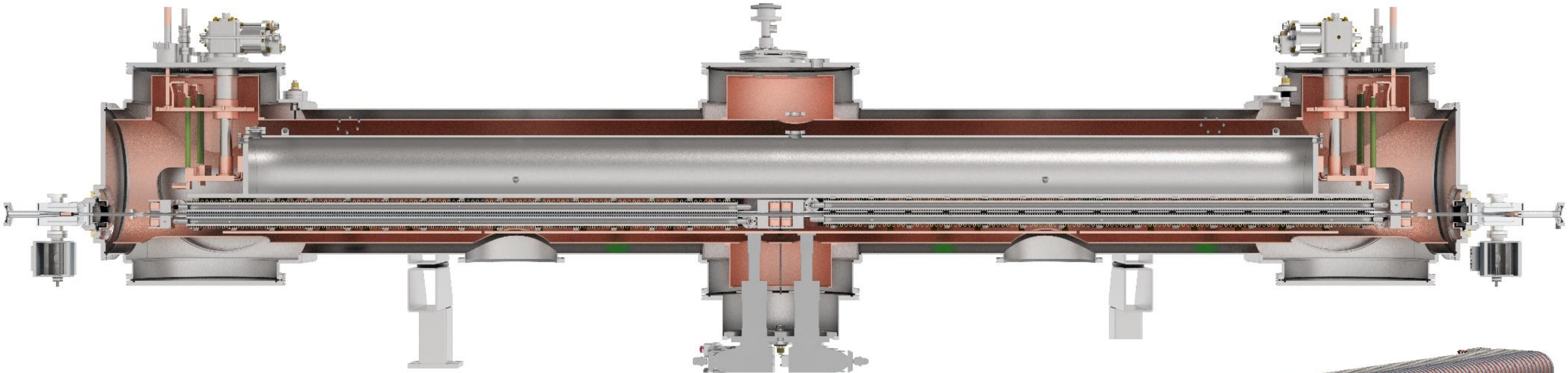


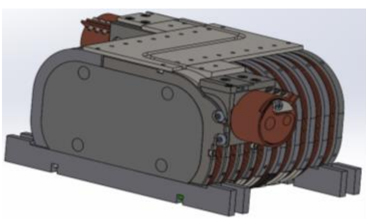
B-OST suggested the HT profile modified by FNAL



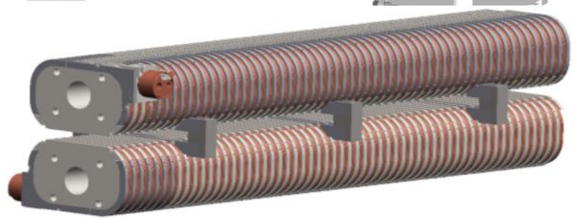
- 0.6 mm diameter conductor with filament diameter of 35 microns
- No thick epoxy build-ups
- HT cycle optimized

In-line double Nb_3Sn unduator for APS

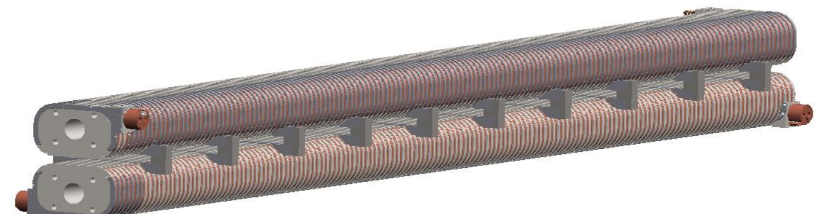




84 mm



0.5 m



1.3 m

Schedule

Short Magnets R&D — **12/18**

*Go, no go decision

12/18 **0.5 m Magnets R&D** **8/19***

8/19 **1.3 m Full Scale SR grade Magnets** **11/20**

9/19 **Cryostat fabrication & Assembly** **4/21**

APS-U SCU Developments

- The APS Upgrade includes **four** full-ID-length SCUs, each with **two** 1.8-m planar SCU magnets in series separated by either a phase shifter or a canting magnet.
- The APS Upgrade also includes one SCAPE SCU and re-uses one existing SCU.
- New long SCU cryostats will be modeled on the HSCU 2nd-generation design.

CAD model of long SCU in the APS-U.

Thanks for attention