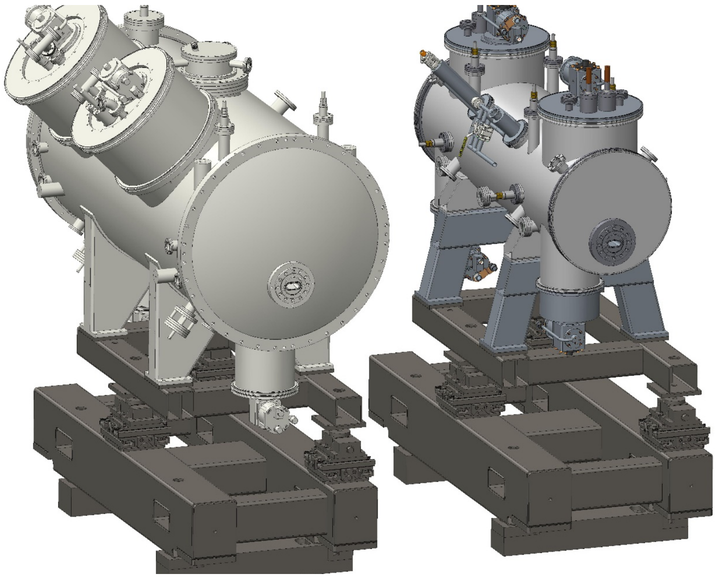
THERMAL MODELING AND CRYOGENIC DESIGN OF A HELICAL SUPERCONDUCTING UNDULATOR CRYOSTAT



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OUTLINE

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2) Cooling schematic of a Planar SCU and a Helical SCU (HSCU) cryostat
3) Overall design
4) FEA model
   - Boundary conditions
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   - Results
5) Discussion and conclusion

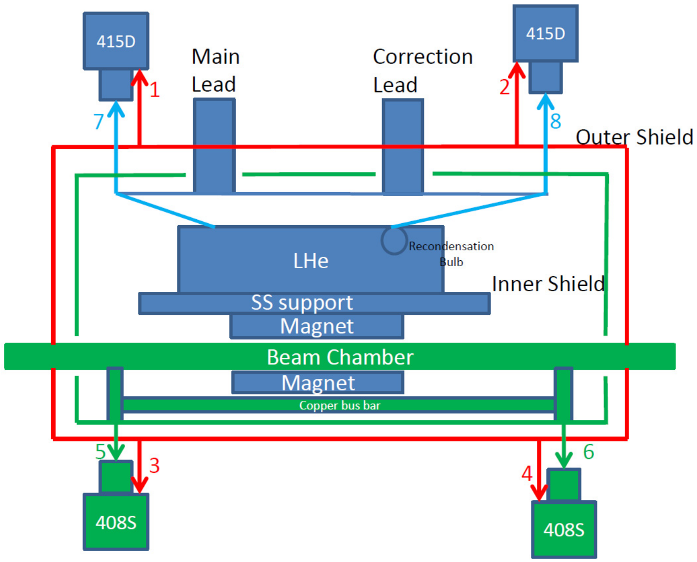
BACKGROUND

- Two planar superconducting undulators (SCU) are currently in operation at APS. The cryogenic system was designed in collaboration with the Budker Institute of Nuclear Physics in Novosibirsk, Russia, based upon design concepts used on their superconducting wigglers [1, 2].
- A conceptual design for a helical superconducting undulator (HSCU) for the Advanced Photon Source (APS) at Argonne National Laboratory (ANL) has been completed.
- In the past, ANSYS thermal analysis for a planar SCU was conducted based on the cryocooler load lines and estimated heat loads. Calculated excess cooling capacity was matched to the measurement for the operating planar SCU [3]. In this talk, we examine ANSYS based thermal analysis of the HSCU cryostat and compare the new design with the existing planar SCU cryostat.

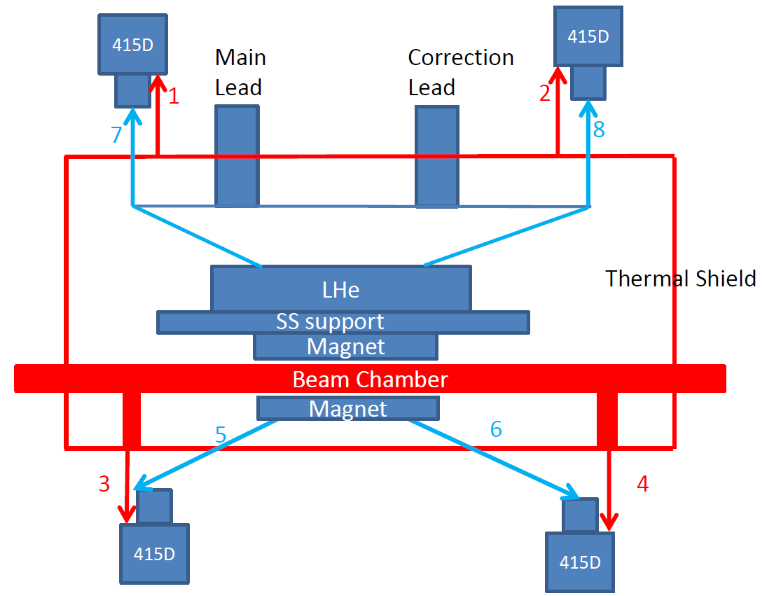
[1] Y. Ivanyushenkov et al., "Development of a planar superconducting undulator for the Advanced Photon Source," *IEEE Trans. Appl. Supercond.* **22** (2012) (3) 4100804.
[2] Hasse Q, et al., "2014 Fabrication and assembly of a superconducting undulator for the APS," *AIP Conf. Proc.* **1573**, (2014) 392.
[3] Y Shiroyanagi et al., "Thermal analysis of superconducting undulator cryomodules," *Advances in Cryogenic Engineering: Proceedings of the Cryogenic Engineering Conference* **101** (2015) 012146.

COOLING SCHEMATIC OF A PLANAR SCU AND A HELICAL SCU CRYOSTAT

Planar SCU



Helical SCU



Three thermal circuits

- Outer shield circuit: Magnet leads and thermal shield are cooled by the four Sumitomo cryocooler 1st stages
- Inner shield circuit: Beam chamber and inner shield are cooled by two 408S 2nd stages
- Magnet cooling circuit: Magnet and LHe tank are cooled by **two 415D 2nd stages**

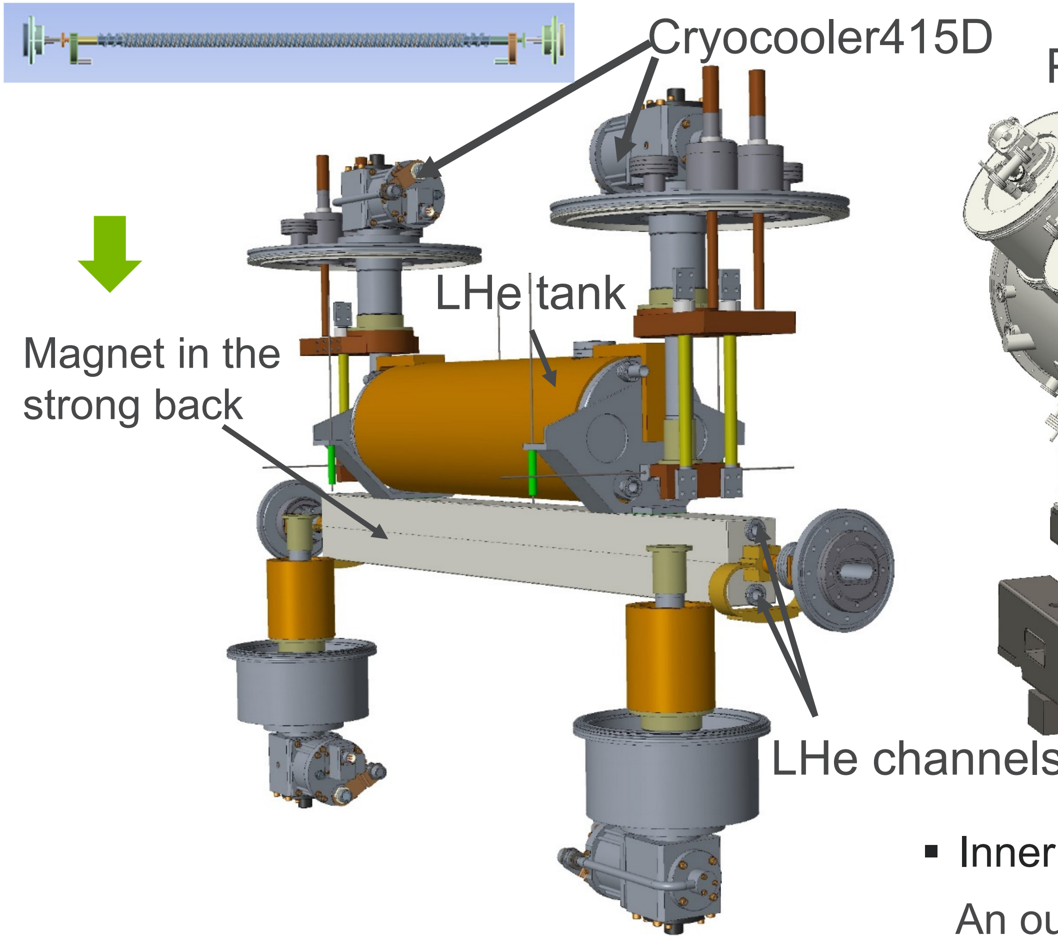
Two thermal circuits

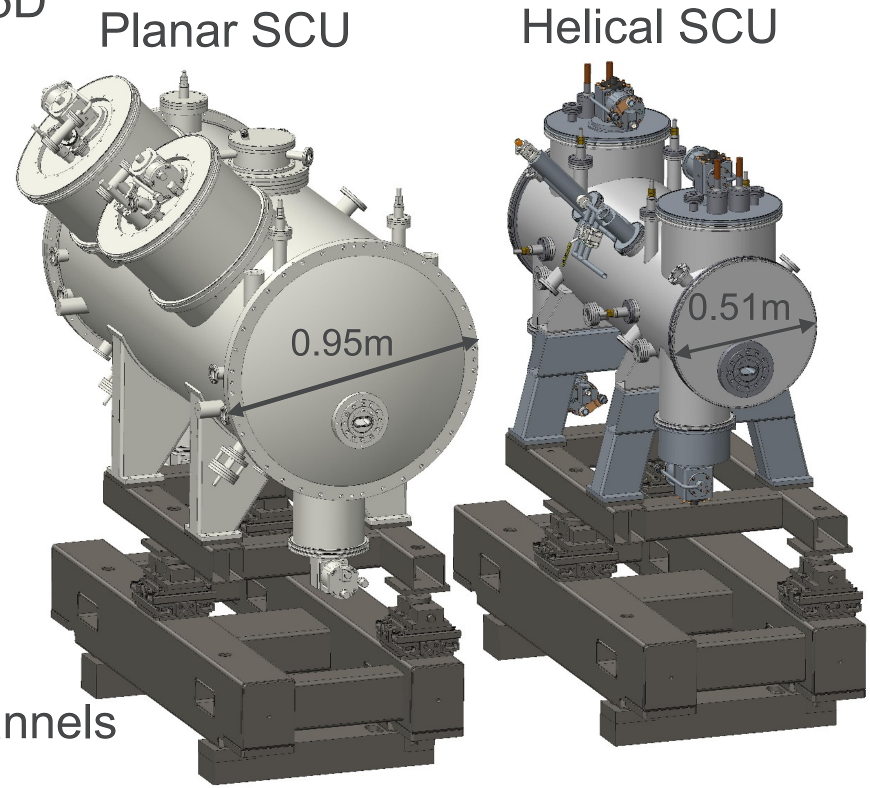
- Thermal shield circuit: Beam chamber, magnet leads and thermal shield are cooled by the four 415D 1st stages
- Magnet cooling circuit: Magnet & mold, LHe tank are cooled by the **four 415D 2nd stages**

Inner shield circuit is eliminated

Magnet is cooled independently from the beam chamber.

OVERALL DESIGN



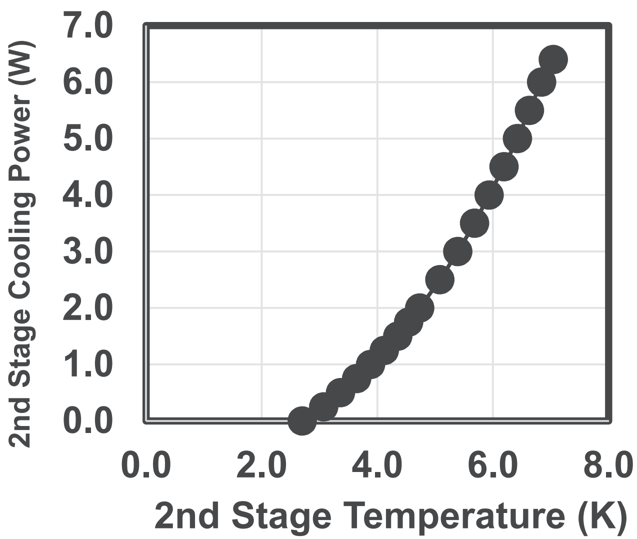


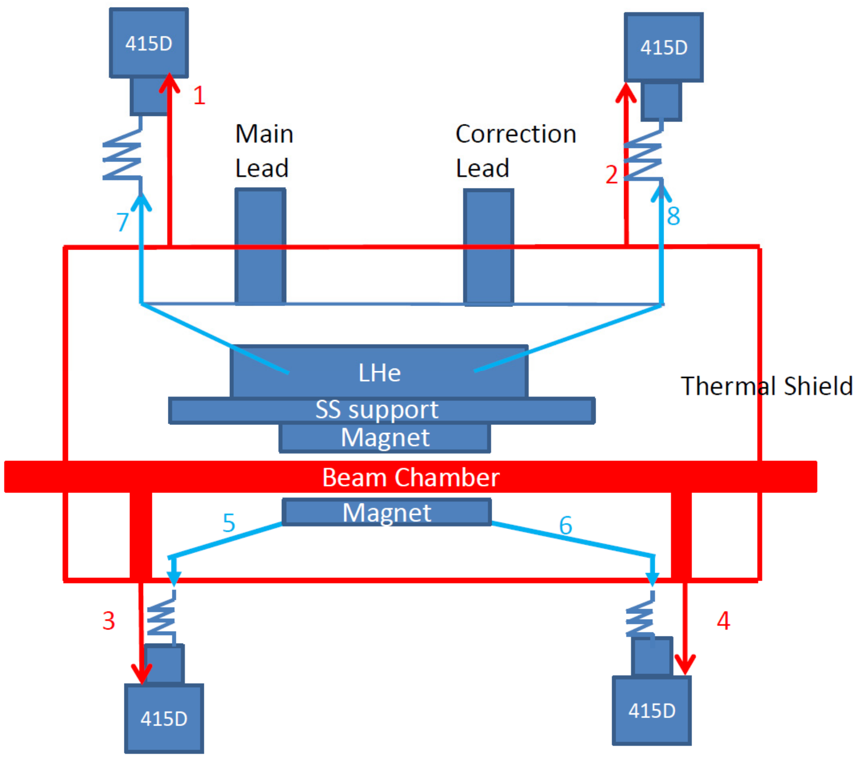
- All four cryocoolers are Sumitomo RDK-415D
- Impregnation mold retained as a strong back
- LHe flow through the mold to cool magnet
- Magnet is cooled independently from the beam chamber.

- Inner shield circuit is eliminated ⟶
  An outside diameter becomes 0.95m → 0.51m
- Upper cryocoolers angle: 45 deg ⟶ vertical
- As a result, installation into the APS ring and its maintenance becomes easier.

BOUNDARY CONDITION OF FEA MODEL

- Fixed temperatures at the outer boundary (300K)
- Sink temperature based on measured cryocooler load line (RDK-415D)





- INPUT: separately calculated heat sources

  (beam heat, current lead heat,

  beam chamber support heat, etc.)

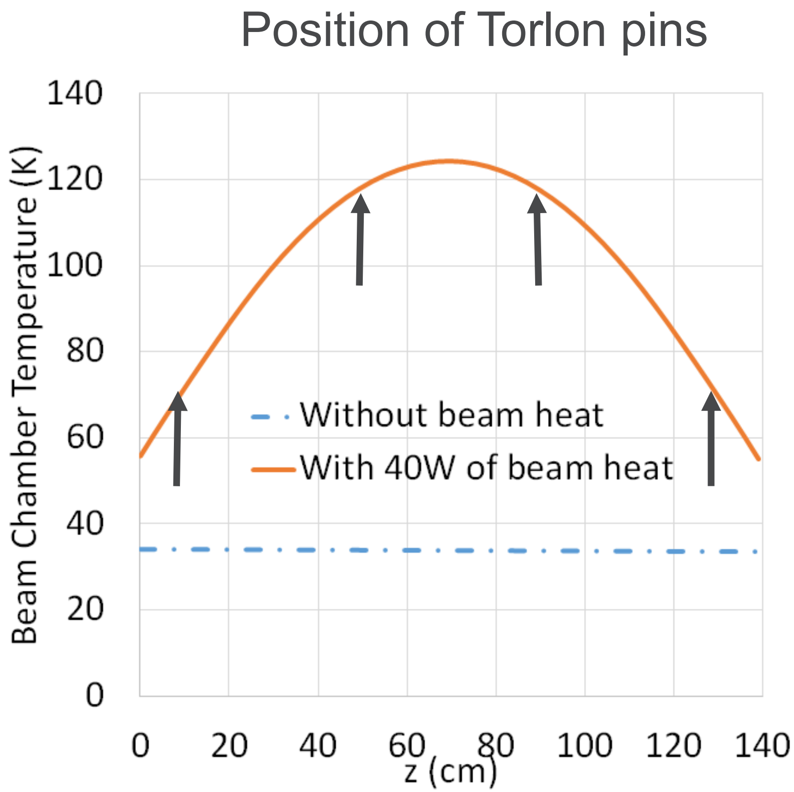
- Thermal contact conductance based on the measured temperatures of the planar SCU

  Cooling power Q(3.3 K) = 0.45 W

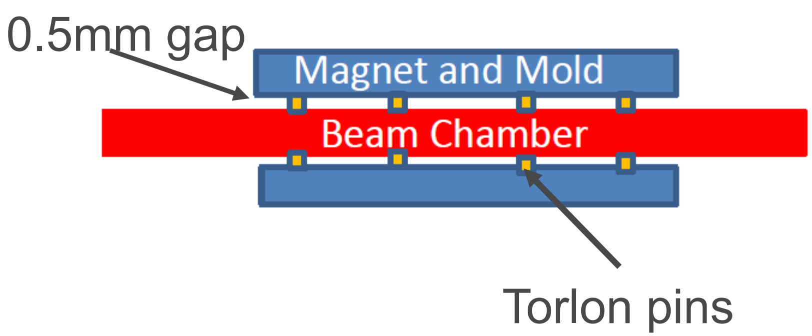
Contact conductance K (W/K) = 0.45 W/(3.97 K-3.27 K)=0.64 W/K

BEAM CHAMBER SUPPORT DESIGN

Since the largest beam heat load is expected to be 40 W and the beam chamber is cooled only at the ends by the 1st stages, the beam chamber temperature is expected to be high. Ideally, the magnet assembly is independently cooled by the 2nd stages.
The beam chamber support therefore needs to be specifically designed to minimize the heat leak.



Conduction heat through the beam chamber support:
Without beam heat: Q = 33 mW
With 40 W of beam heat: Q = 140 mW.

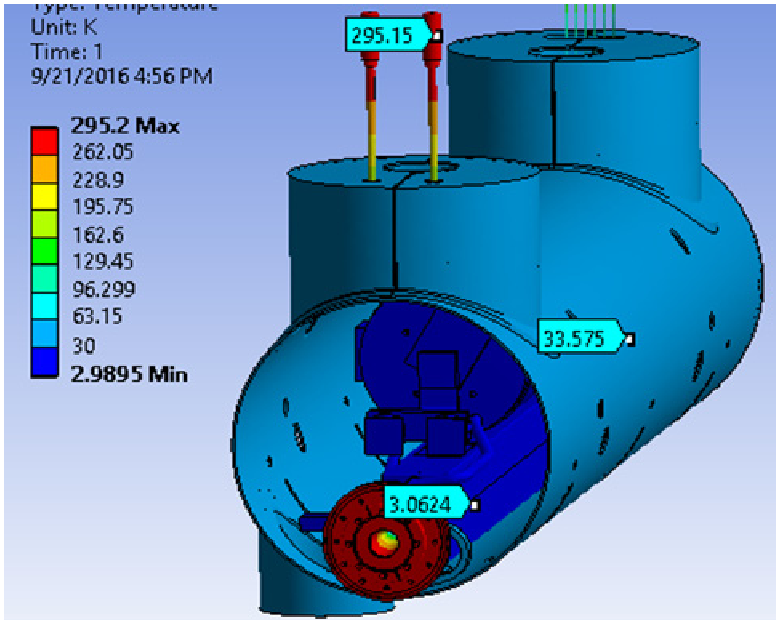


ANALYSIS RESULTS

CASE 1 (0 W in beam chamber, 0 A magnet current):

Shield temperature 34 K

LHe tank temperature ~3.06 K (LHe pressure is 208 Torr)



CASE 2: 37 K
CASE 3: 40 K

CASE 1: 0 W, 0 A magnet current (static)

CASE 2: 40 W, 0 A magnet current

CASE 3: 40 W, 500 A magnet current

Heat load at magnet cooling circuit

CASE	Heat Source	Heat Flux [W]
CASE 1	HTS main conduction heat (one pair)	0.212
	HTS correction conduction heat (4 pairs)	0.128
	Thermal radiation from shield	0.025
	Cold mass support (Invar rods)	0.055
	Beam chamber support	0.033
	Instrumentation (300 K to 4 K)	0.034
	LHe & relief piping	0.02
	Total static heat load	**0.50**
CASE 2	Beam chamber support conduction	0.14
	Thermal radiation from beam chamber	0.042
	Total heat load for CASE 2	**0.68**
CASE 3	Total Joule heat due to resistive joints	0.13
	Total heat load for CASE 3	**0.81**

Ultimate temperature of LHe for static case is 3.06 K. However, in real operation, heat is applied to keep LHe at 4.2 K (LHe pressure is 760 Torr). This heater power is “excess cooling capacity”

DISCUSSION AND CONCLUSION

When LHe and magnet are at 4.2 K, the 2nd stage cold head temperature is at ~3.3 K. Excess cooling capacity is a total available cooling power of cryocoolers minus total heat load. From the load line, cooling power of each cryocooler at 3.3 K is 0.45 W. Therefore, an excess cooling capacity becomes 0.45 W×4 - 0.5 W = 1.3 W for static case (CASE 1).

1) Based on the current planar SCU design and operation experiences, a more compact HSCU cryostat has been designed.
2) FEA model indicates that HSCU cryostat has larger excess cooling capacity than the planar SCU in all operational cases.

	CASE	Total Heat Load [W]	Excess Cooling Capacity [W]
Planar SCU observed	CASE 1	0.5	0.44
	CASE 2	0.6	0.36
	CASE 3	0.67	0.34
HSCU calculated	CASE 1	0.5	1.3
	CASE 2	0.68	1.1
	CASE 3	0.81	1.0

END