Refrigeration Systems for SCUs

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For the SLAC/ANL FEL SCU collaboration

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SLAC NATIONAL ACCELERATOR LABORATORY

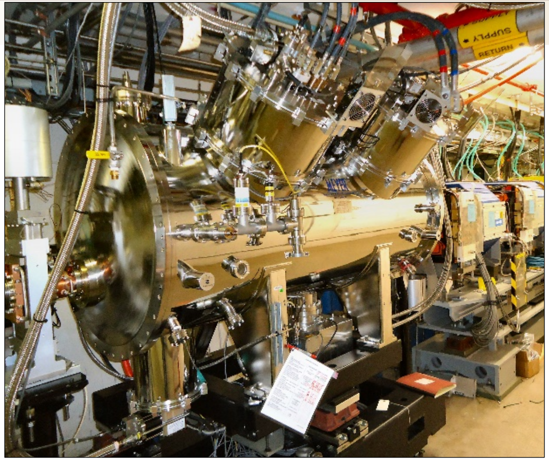
Cryocooled SCUs at the APS Storage Ring (SR)

SCU0 (Sector 6):
- 16 mm period
- 0.33 m magnet
- Jan 2013-Sep 2016

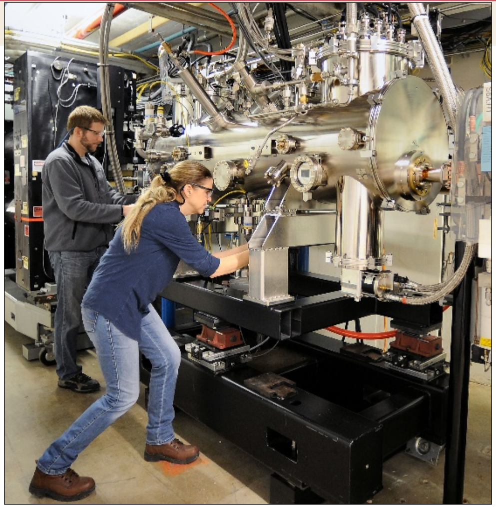
SCU18-1 (Sector 1):
- 18 mm period
- 1.1 m magnet
- since May 2015

SCU18-2 (Sector 6):
- 18mm period length
- 1.1 m magnet
- since Sep 2016.

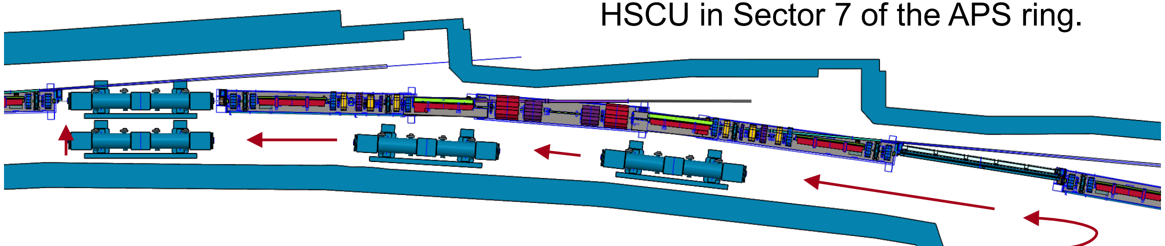
Helical SCU (Sector 7):
- 31.5 mm period
- 1.2 m magnet
- Since Jan 2018



SCU18-1 in Sector 1 of the APS ring.

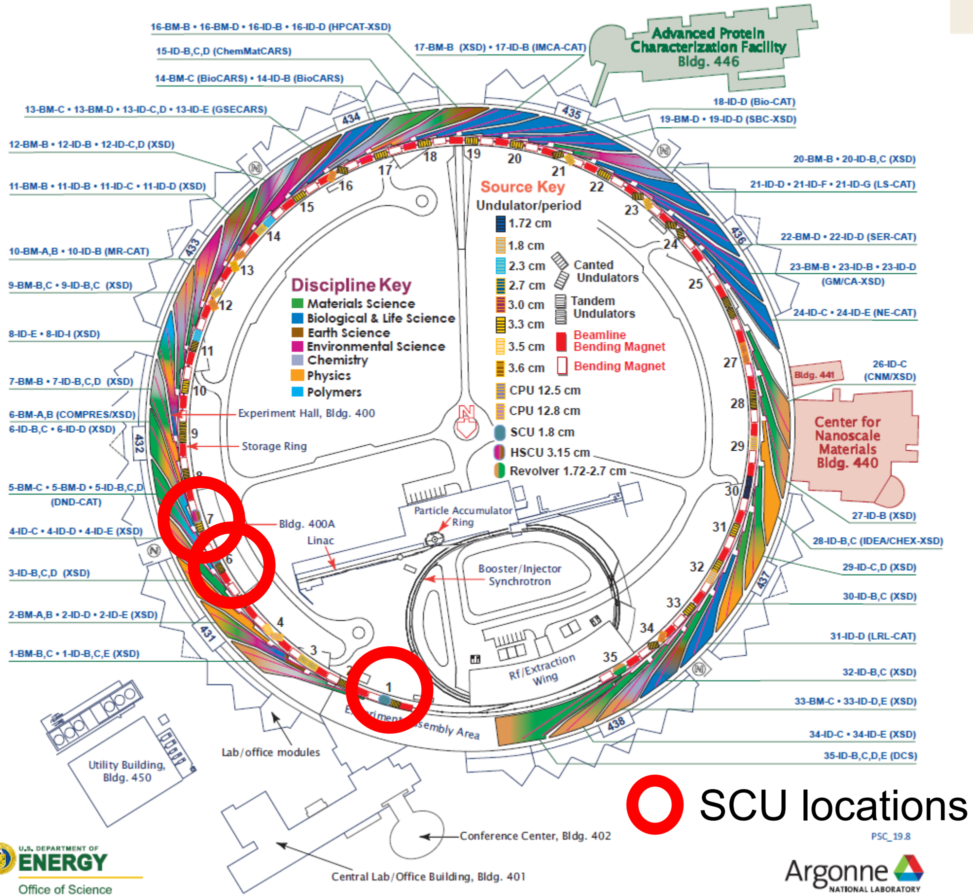


HSCU in Sector 7 of the APS ring.



APS Upgrade will include 5-meter SCUs with two sources (either in-line or canted)

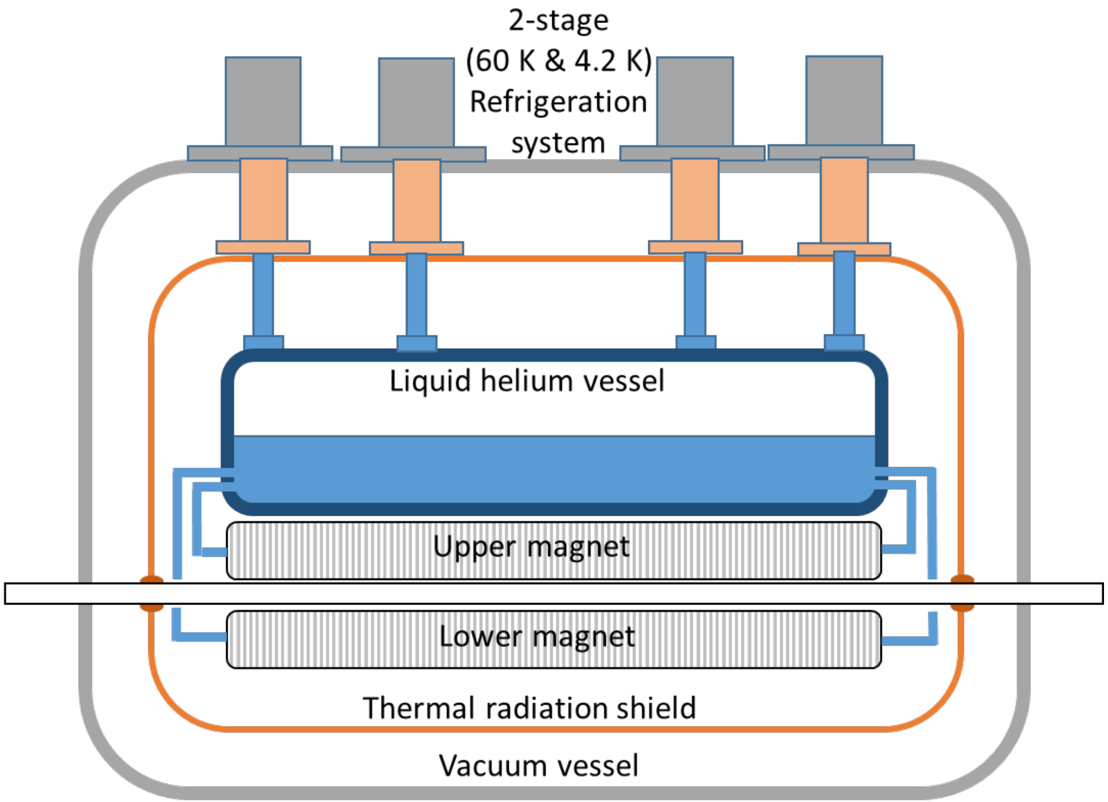
SCU implementation at a SR



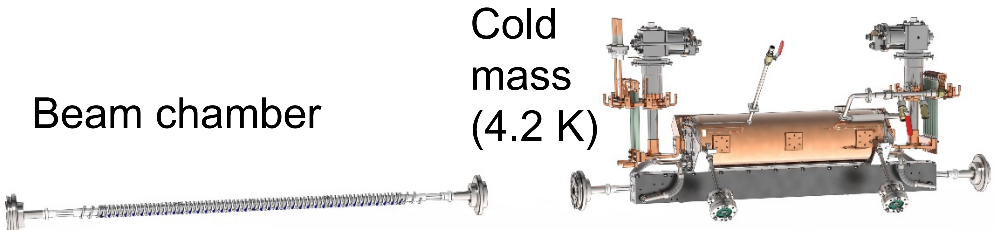
- 35 sources at the APS
- How many SCUs are planned?
- Cryocooled SCUs are easily relocated among Insertion Device locations
- A central cryoplant and ring-wide distribution system would cost about $10M

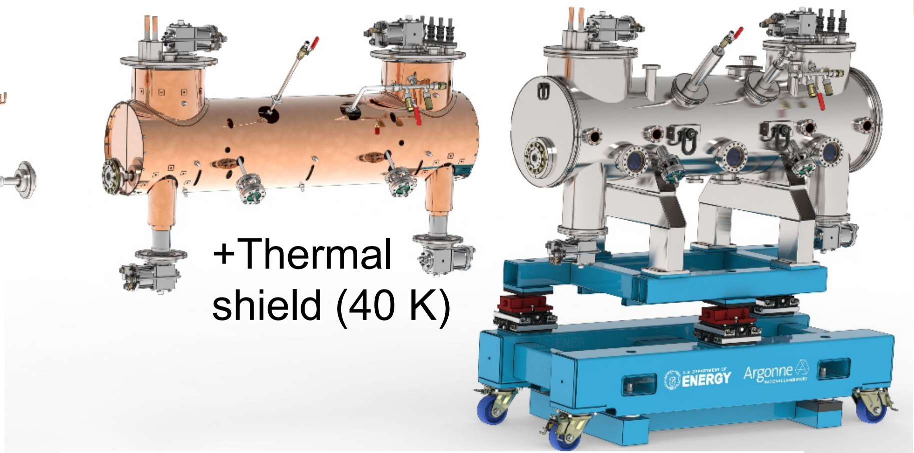
APS SCU refrigeration concept

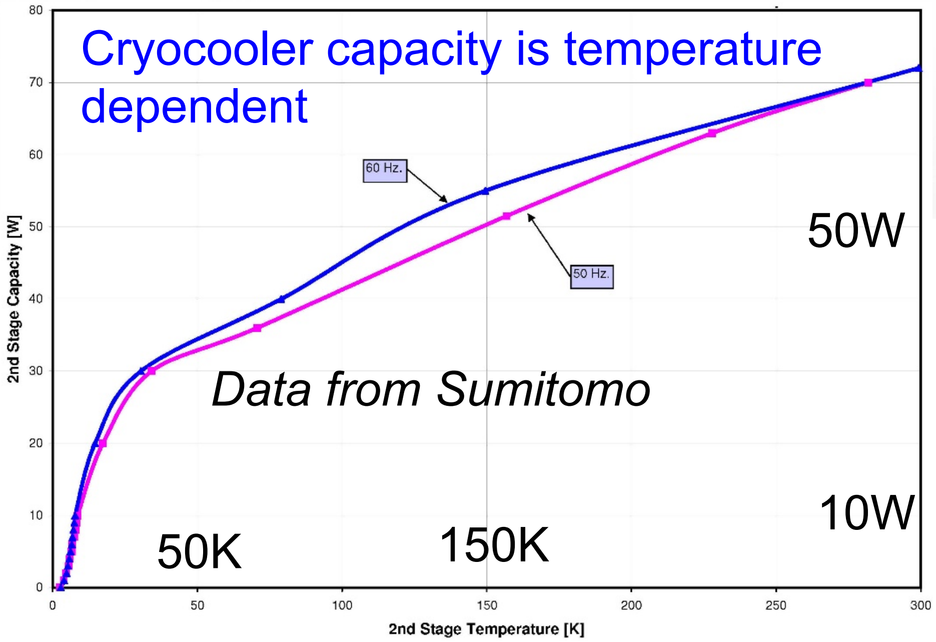
Devices currently in operation at APS are based on a BINP design (**V. Syrovatin, N. Mezentsev)** using liquid helium. They are designed to operate in **zero boil-off mode** (full recondensation - no helium is vented).



Cryocooler-based design layout (HSCU example)





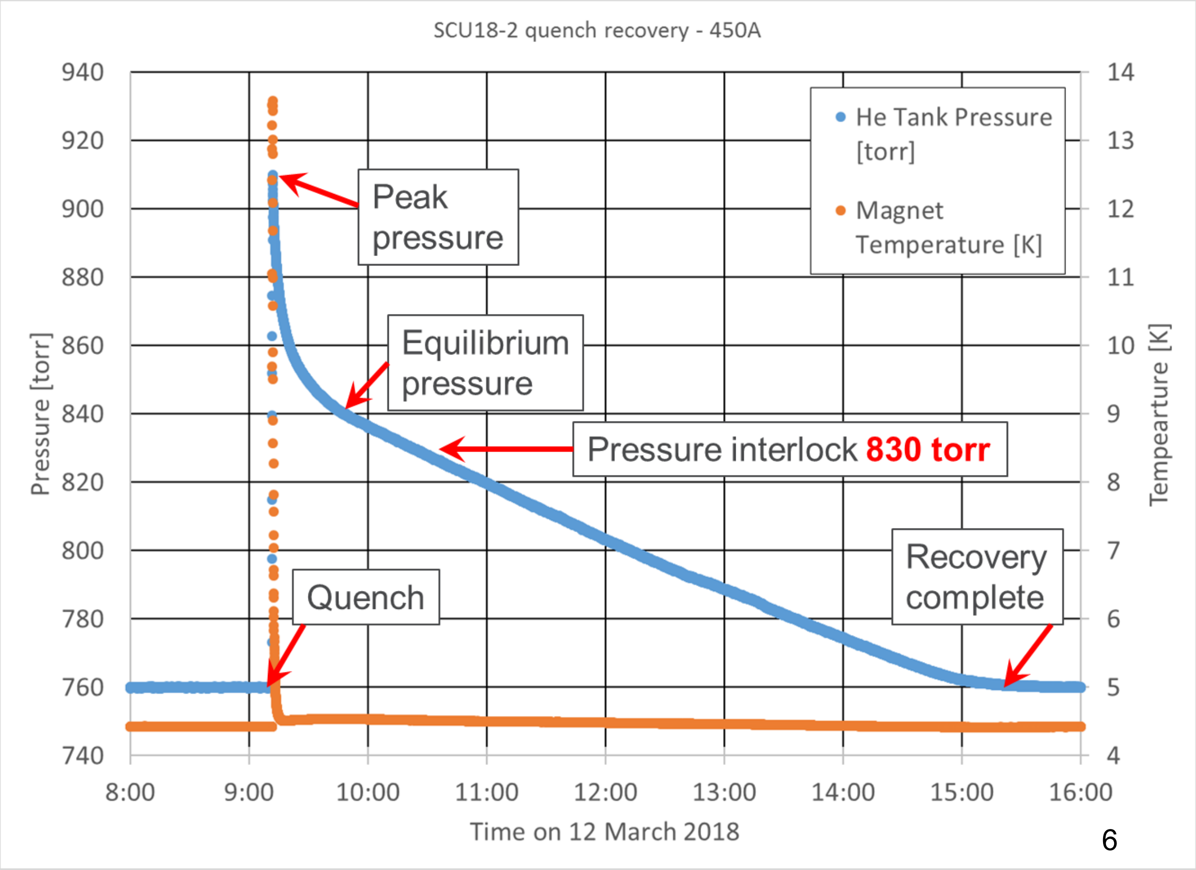


Heat Loads: APS Upgrade SCU	Shield load [W]	4K load [W]
Static (conduction, radiation)	98	1.06
Dynamic (electron beam circulation)	48	0.23
Dynamic (magnets powered)	35	0.41
Total	**181**	**1.70**

Quench response

If zero boil-off operation is to be preserved, quench response requires time to recondense helium and restore operating conditions.

Cryogen-free technology should improve quench response



Refrigeration options

Cryoplant: 10's of W to multi-kW, sub-2 K operation available

LR280 refrigeration performance at ≤ 4.4 K

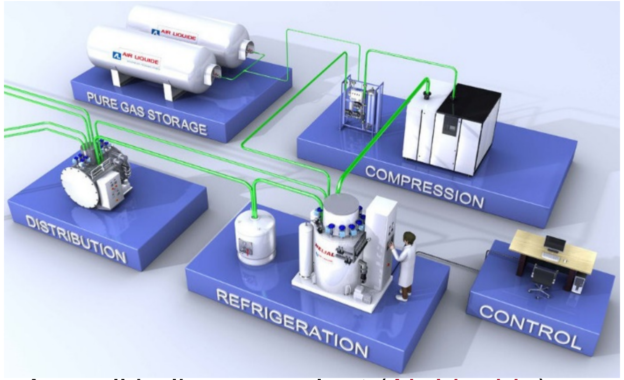
without LN_2 pre-cooling	with LN_2 pre-cooling	compressor/power rating
445 Watt	560 Watt	DSDX305/160 kW
510 Watt	640 Watt	ESD375/200 kW
640 Watt	900 Watt	ESD445/250 kW

Cryocooler: 1-2 W, limited temp reach

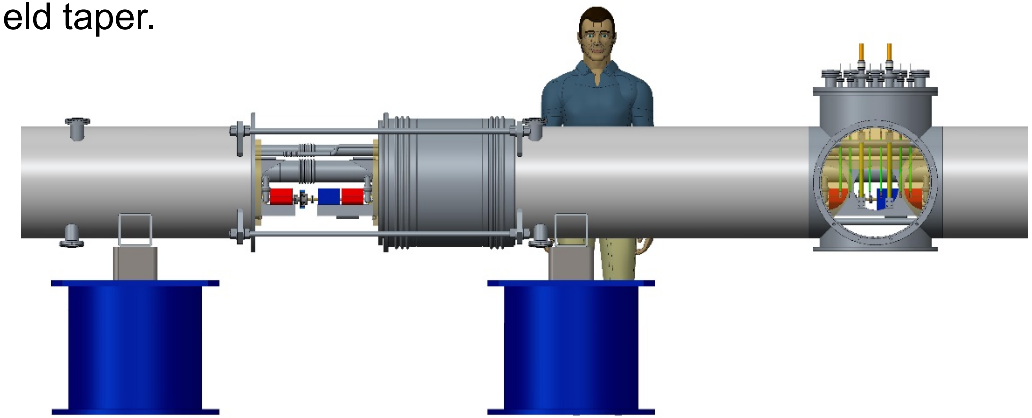
	Cryocooler (each)	Cryoplant
4.2K capacity	Up to 2 W	Variable (445-900W size shown)
Utilities	8.5 kW, 10 lpm water	160-250 kW, ~200 lpm water
maintenance	10,000 hr	Annual
cost	~$50K per unit	Multi-M$ (plus distribution sys)

Refrigeration and array segmentation for an FEL

- The topology of an FEL SCU array makes a centralized helium cryoplant plus distribution system attractive on cost and performance over cryocoolers. The higher available cooling power can impact cryostat design choices - for example, 4.2 K beam chamber operation may simplify design and reduce magnetic gap. 2K refrigeration technology commonly used for SRF is a reasonable option.
- Cryogenic distribution can reside either internal (XFEL, LCLS-II) or external (CEBAF, SNS, FRIB) to the SCU cryostats. This choice affects the degree to which the SCU array is ***segmented*** (how frequently the cryogenic insulating vacuum breaks occur) and impacts system heat load and maintainability.
- Individual SCU cryostat lengths may be set by transportation limits while the active length of individually powered magnets should support optimal field taper.

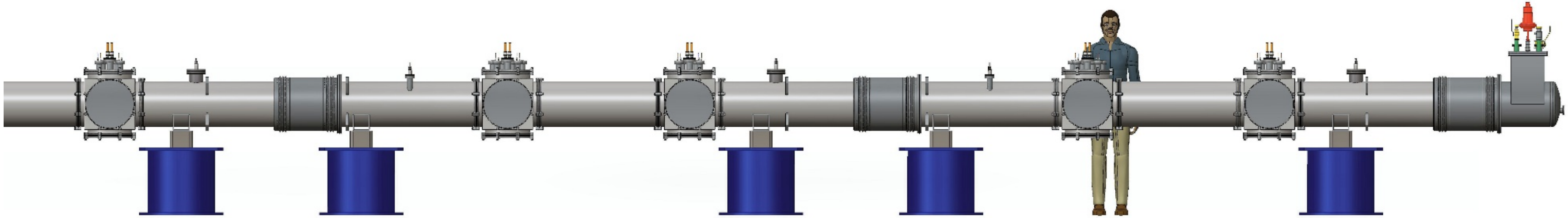


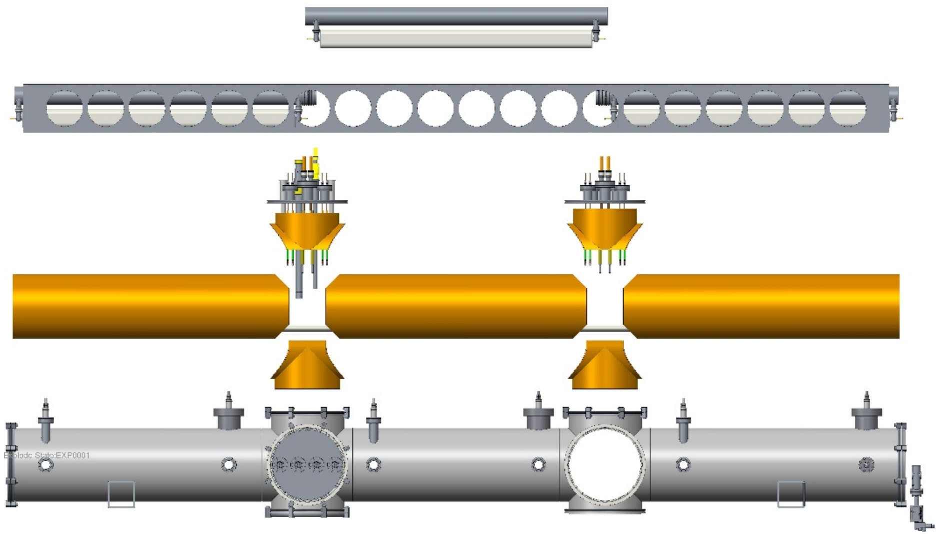
A small helium cryoplant (Air Liquide)

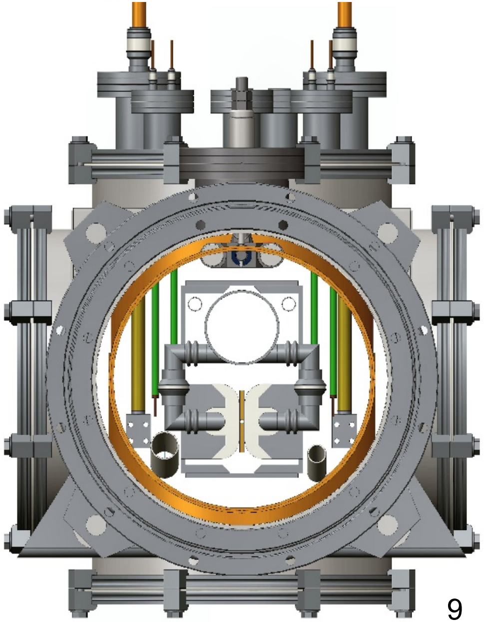


SCU cryostat interconnect showing internal cryogenic distribution

Minimally segmented (internal distribution) concept





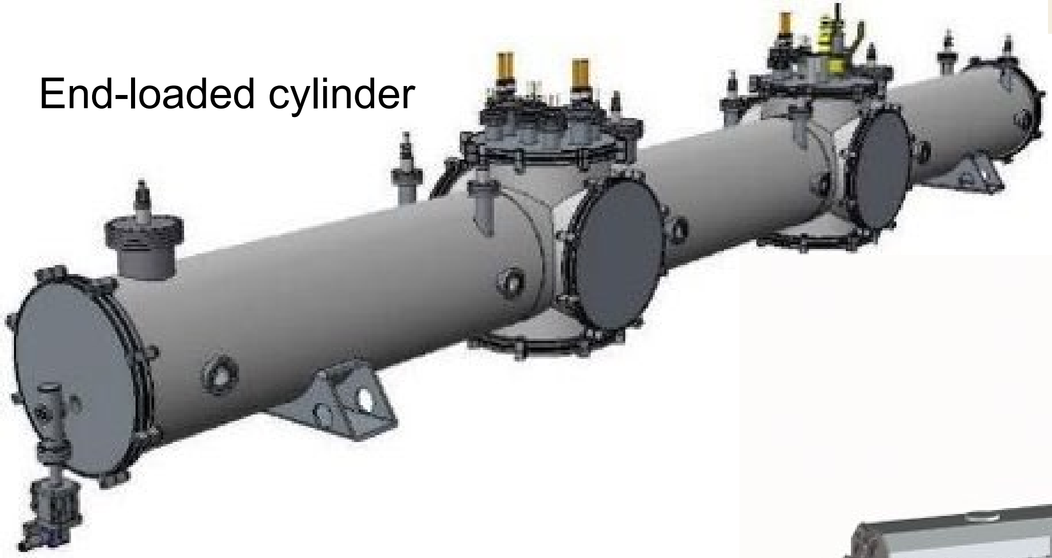


Array Segmentation:

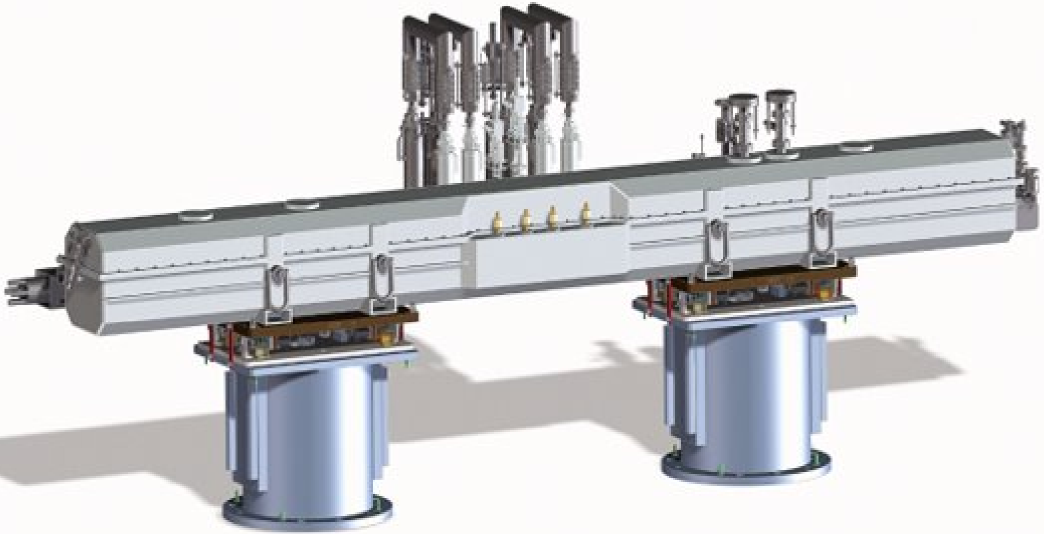
- Minimal (common insulating vacuum)
- Full (independent insulating vacuums)

Highly segmented (external distribution) concept

End-loaded cylinder



External distribution system allows rapid removal of a cryomodule but increases the cryoplant heat load and adds cost.



Cold-to-warm transitions and external beamline vacuum valves reduce packing efficiency

Vertically-loaded box (LBNL)

Comparison of FEL SCU layouts

SLAC

Minimal segmentation with cold cryostat interconnects (EuXFEL, LCLS-II)	Maximal segmentation with separate insulating vacuum for each cryomodule (CEBAF, SNS, FRIB)
➢ Internal cryogenic distribution system • CM replacement requires string warmup • Higher packing factor • Reduced CM and distribution system cost • Reduced heat load • Magnets are a low failure risk • “Installed spares” mitigates risk	➢ External cryogenic distribution system with U-tubes • Enables rapid replacement of individual cryomodules • Lower packing factor • Increased cryomodule and distribution system cost • Increased heat load

Final thoughts

- Cryocoolers are suitable for discreet SCUs in a SR
  - Relocating an SCU to a different sector is straightforward
  - Adding new SCUs does not require major new infrastructure
- Cryocoolers cannot support magnet operation below ~3.5K
- For SRs, a cryoplant makes sense if most sources are SCUs
- For FELs, the clear choice is a central cryoplant + distribution system for a contiguous SCU array
- FEL array segmentation choice is a tradeoff between several factors: cryomodule accessibility, packing efficiency, and cost

Questions?