WE START WITH YES.

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SUPERCONDUCTING UNDULATOR UPDATE PART 1:

CURRENT STATUS, FUTURE PLANS

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Magnetic Devices Group

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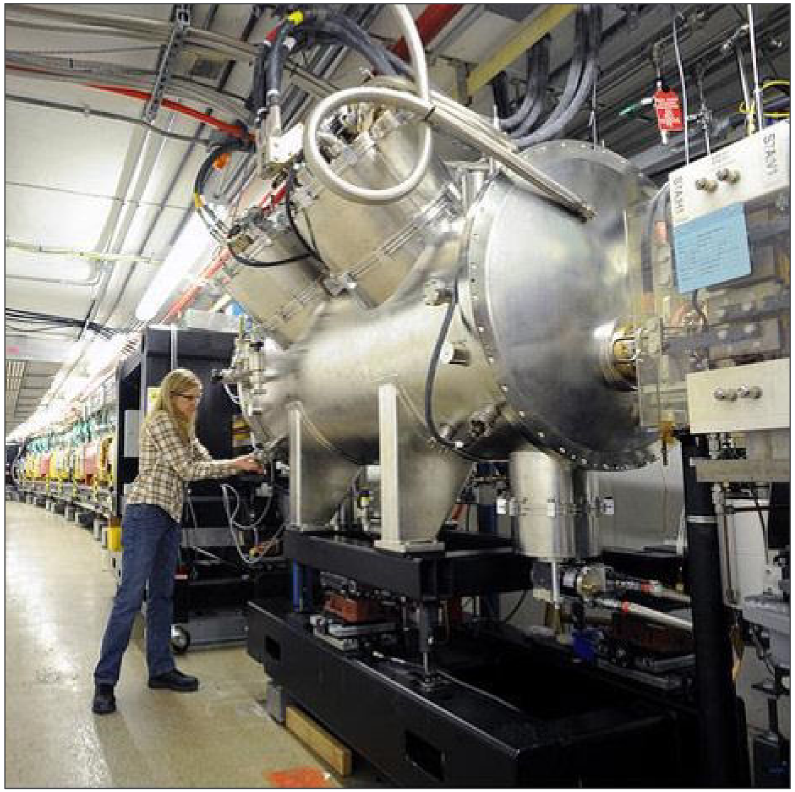
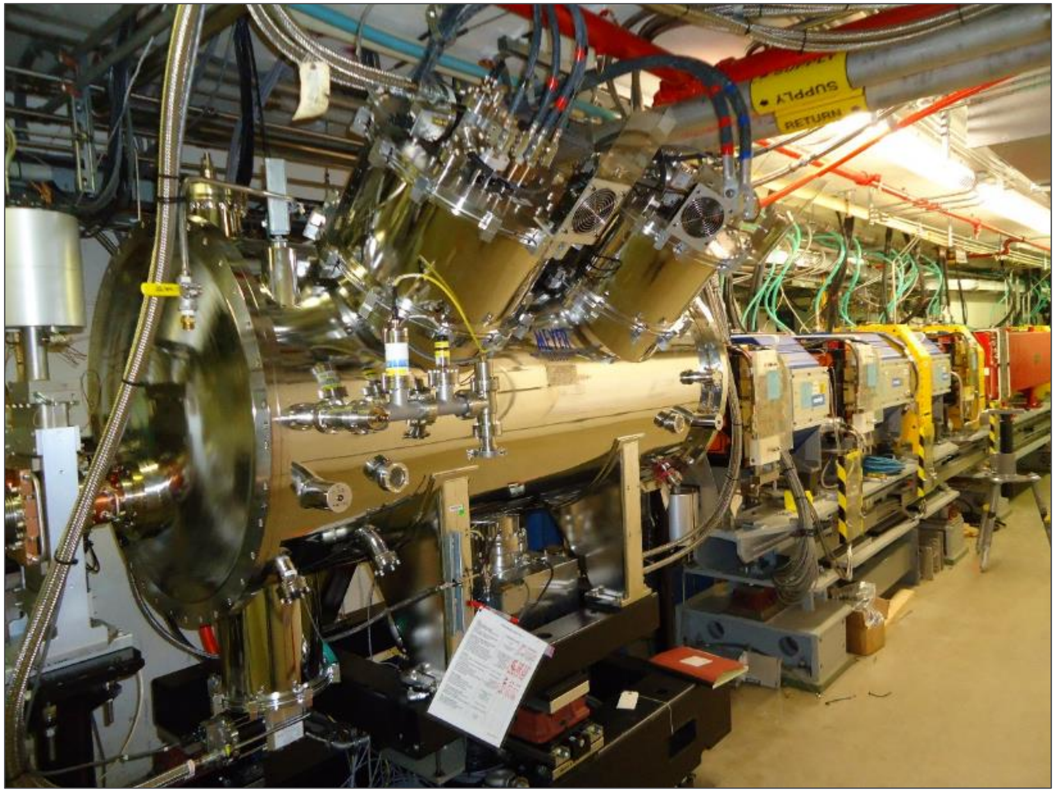
[1]ASD [2]AES [3]MSD

ASD Seminar
23 March 2016

APS SCU HISTORY & NEAR-TERM PLANS



SCU0 installed in APS Sector 6
DEC 2012 (0.3-m magnetic length)



SCU1 installed in APS Sector 1
APR 2015 (1.1-m magnetic length)

- Two SCUs presently installed in the APS SR
- SCU0 to be upgraded with a copy of SCU1 (aka “SCU18-2”) Fall 2016
- 1.2-meter Helical SCU to be installed in Sector 7 Fall 2018

SCU DEVELOPMENT TIMELINE

Activity	Years
A proposal of the helical SCU for the LCLS	1999
Development of the APS SCU concept	2000-2002
R&D on SCU in collaborations with LBNL and NHFML	2002-2008
R&D on SCU0 in collaborations with FNAL and UW-Madison	2008-2009
Design (in the collaboration with the BINP) and manufacture of SCU0	2009-2012
SCU0 installed into the APS storage ring	December 2012
SCU0 is in routine user operation	Since February 2013
SCU1 installed into the APS storage ring and is in user operation	April 2015
FEL/LCLS 1.5-m long prototype designed, built and successfully tested	October 2015

SCU OPERATIONAL STATISTICS (courtesy K. Harkay)

Calendar year	APS delivered	SCU0 operating	SCU0 down	SCU1 operating	SCU1 down
2013	4872 h	4169 h	20 h		
2014	4927 h	4410 h	193 h [1]		
2015	4941 h	4759 h	0 h	2984 h [2]	1 h
Total	14740 h	13338 h	213 h	2984 h	1 h

Total number of SCU0 self-quenches is 5.

E-beam has never been lost due to quenches.

[1] November: Partial loss of one cryocooler capacity

[2] Installed in May; operated May – December 2015

3 YEARS AGO (03MAR2013) A SEMINAR ON SCU0 CRYO PERFORMANCE CONCLUDED THUS:

ROOM TO IMPROVE

- Add visible cold mass fiducials for external alignment check while cold
- Consider abandoning the recondenser bulb in favor of direct attachment to the LHe reservoir exterior for both 4 K coolers to improve 4 K capacity
- Explore optimization of refrigeration levels – consider abandoning “20 K” thermal shield to save cost and improve overall capacity
- Consider reducing LHe reservoir volume (but maintain interior surface area for efficient recondensation…) to reduce cryostat size
- Optimize current lead design to reduce heat load
- Improve subsystem designs to enable highest possible magnet current (since this seems to be what users want)
- 1+ meter magnets
- Cryogen-free (“dry”) magnets?

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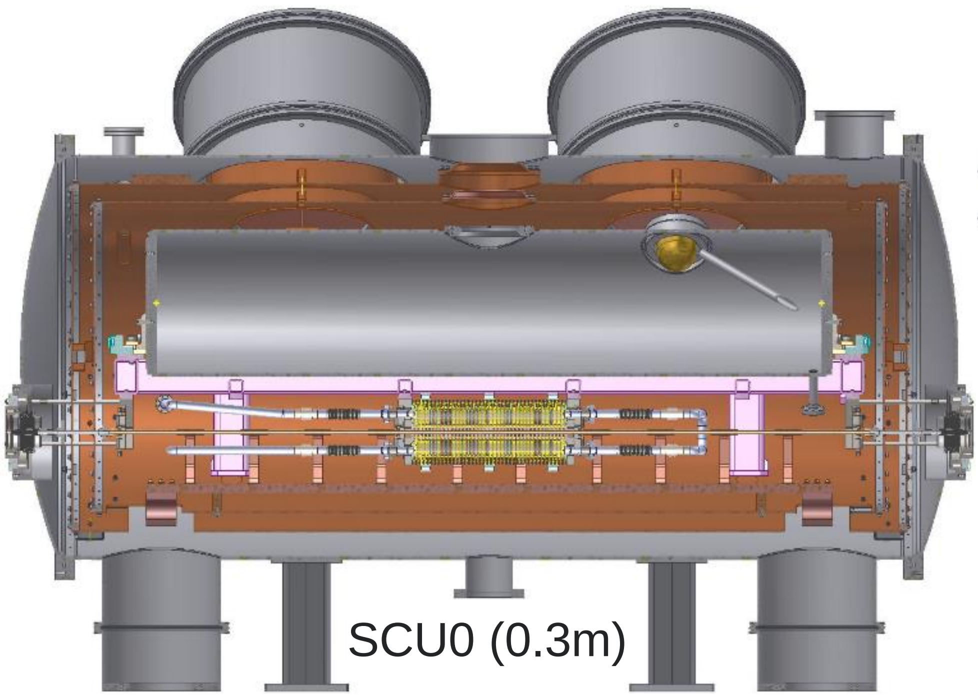
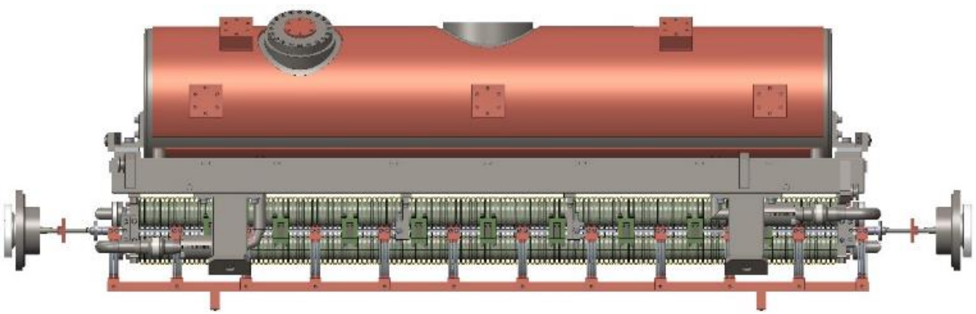
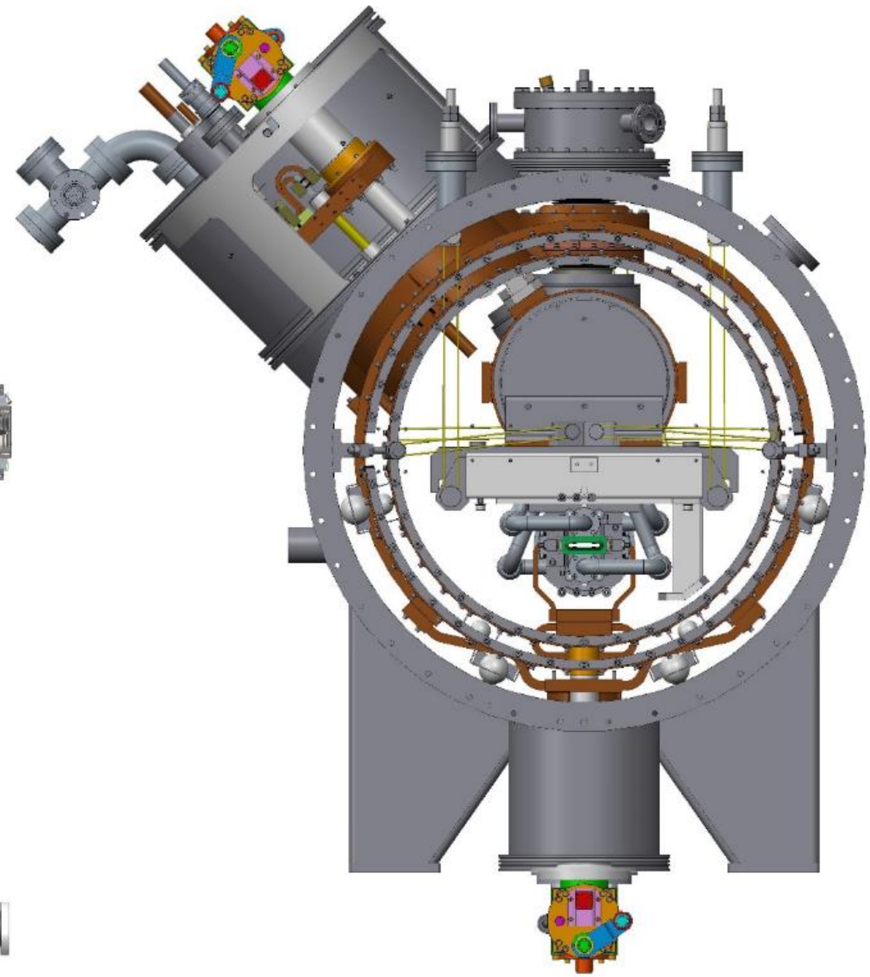
CRYOSTAT DESIGN:
BUDKER INSTITUTE OF NUCLEAR PHYSICS



SCU0 (0.3m)

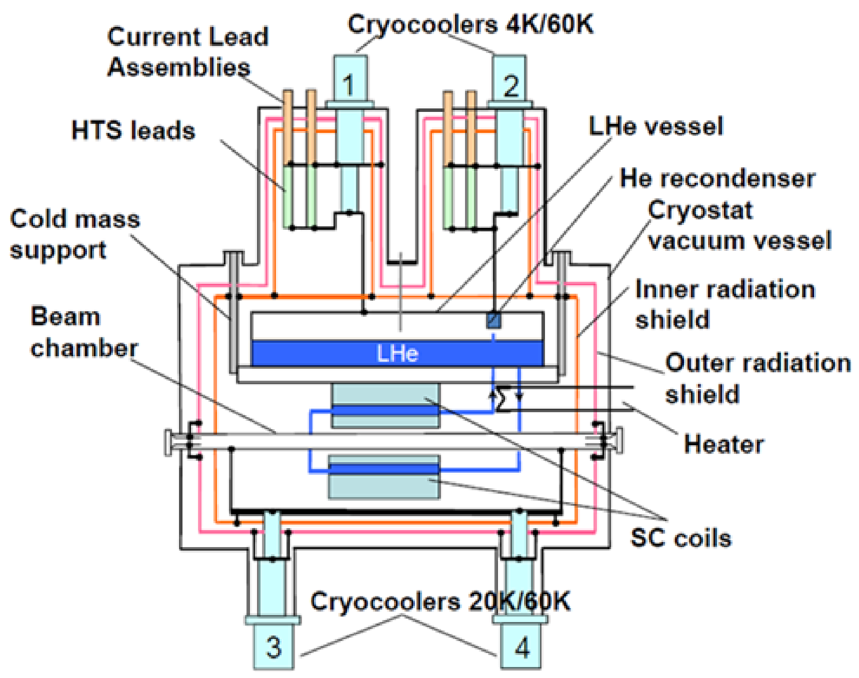


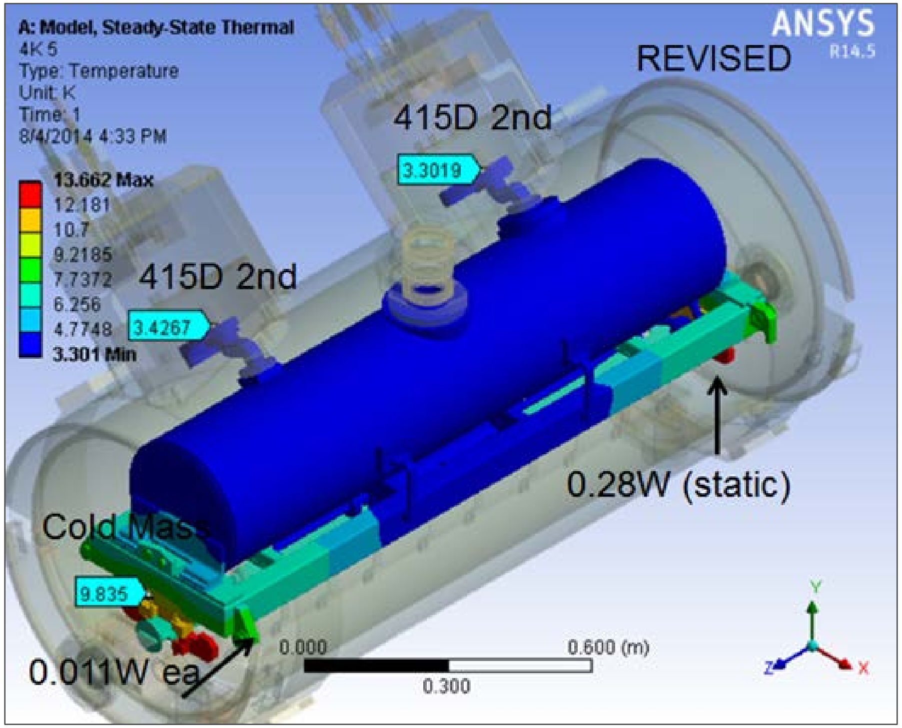
FEL SCU R&D (1.5m)



- Proven cryostat design, suitable for magnets up to 1.5 meters long

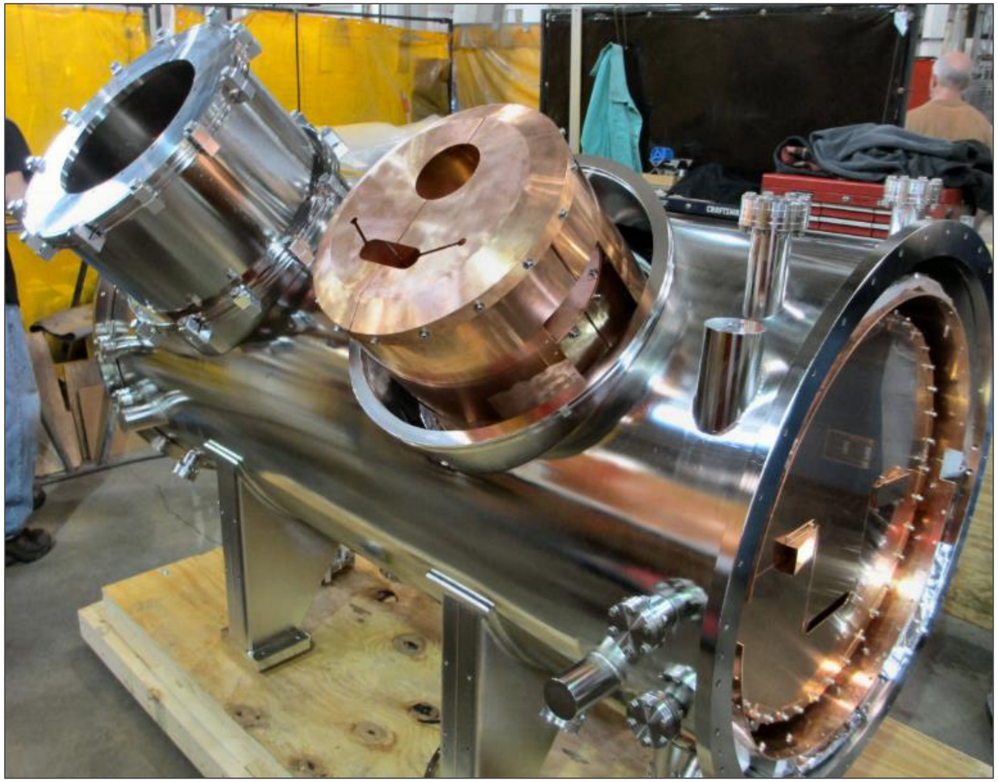
CRYOGENIC SYSTEM DESIGN





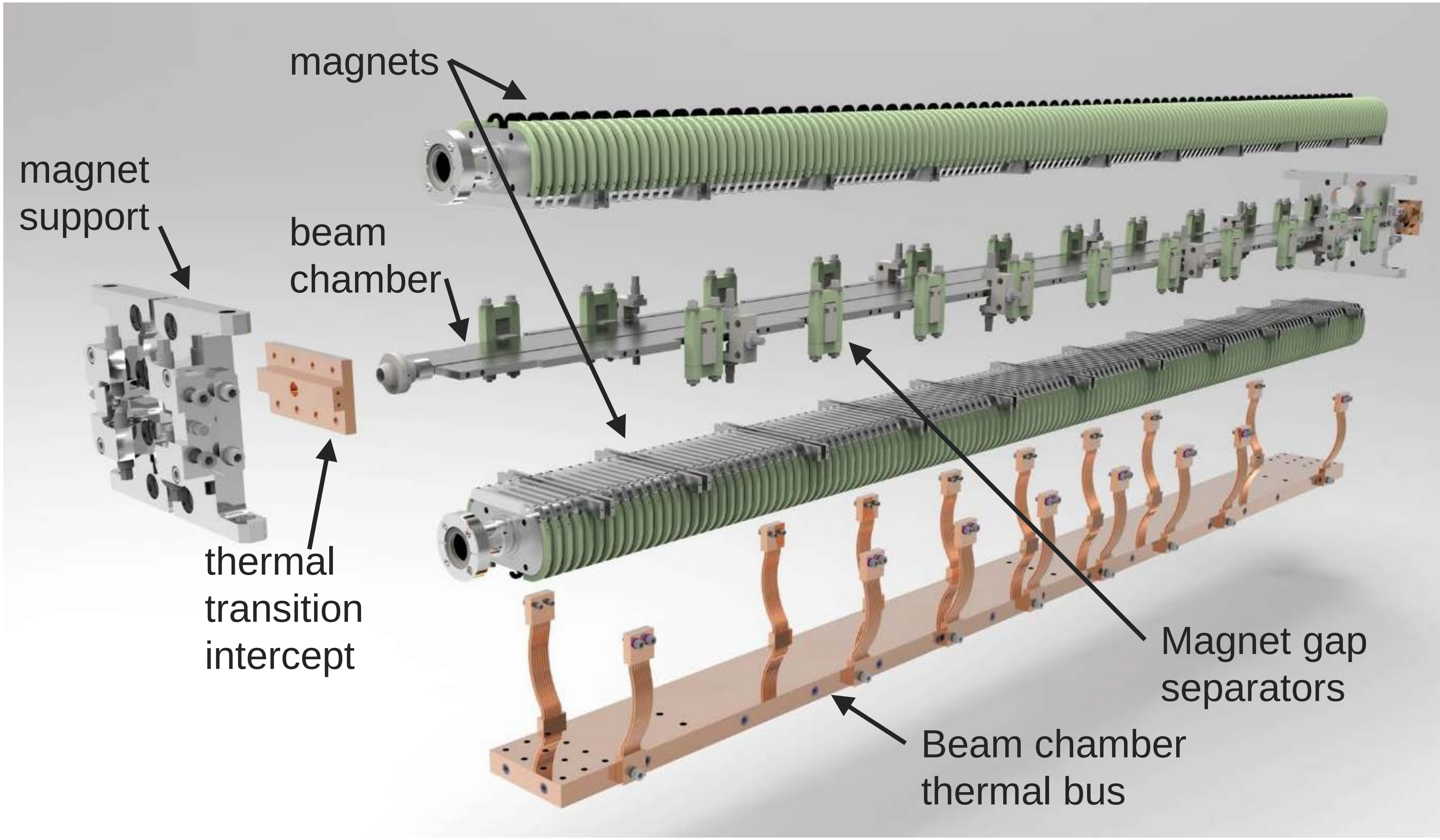
- Closed cycle (zero boil-off) liquid helium bath-cooled magnets with cryocooler-based recondensation. Excess 4 K capacity is about 0.5 W for FEL-SCU R&D.
- Helium bath pressure/temperature is regulated using a heater.
- Beam chamber is cooled at a higher temperature level due to high beam-induced heat loads (up to 20 W) in storage ring applications.
- Numerical simulations verify existing design and guide recent effort.

VENDOR-SUPPLIED HARDWARE



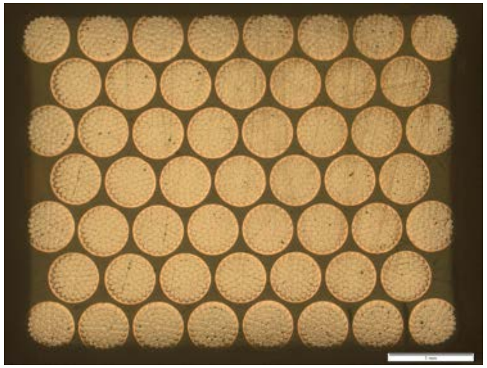
- Vacuum vessel, thermal radiation shields, and liquid helium tank are built-to-print following a detailed SOW.
- To date, three units have been ordered from two separate vendors.
- Cold mass components (magnets, piping, beam chamber, support frame, etc.) are separately sourced or fabricated in-house.
- Final design/detailing can be outsourced to the fabricator

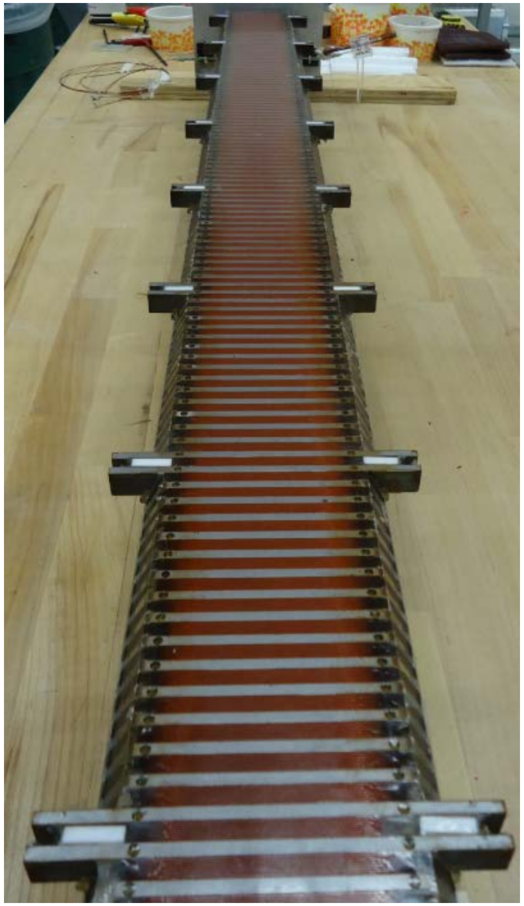
BASIC MAGNET-BEAM CHAMBER LAYOUT

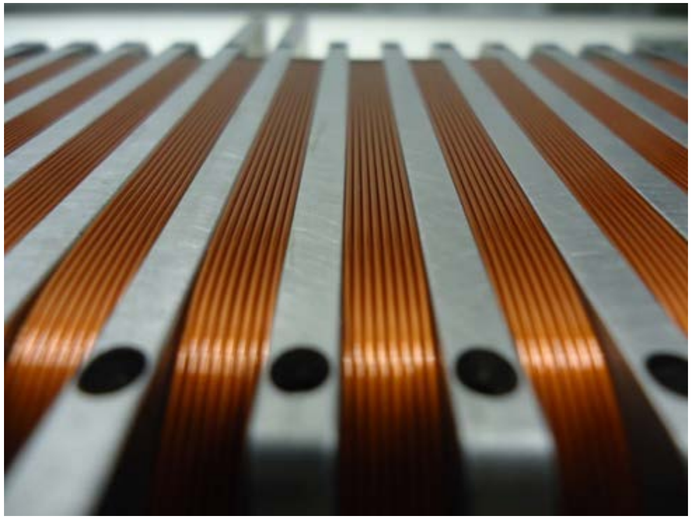


FEL R&D
magnet shown

MAGNET FABRICATION DEVELOPMENT: FROM 300 mm TO 1500 mm







- Techniques and tooling scale to “full-length” magnets
    - Precision core machining
    - Winding/potting

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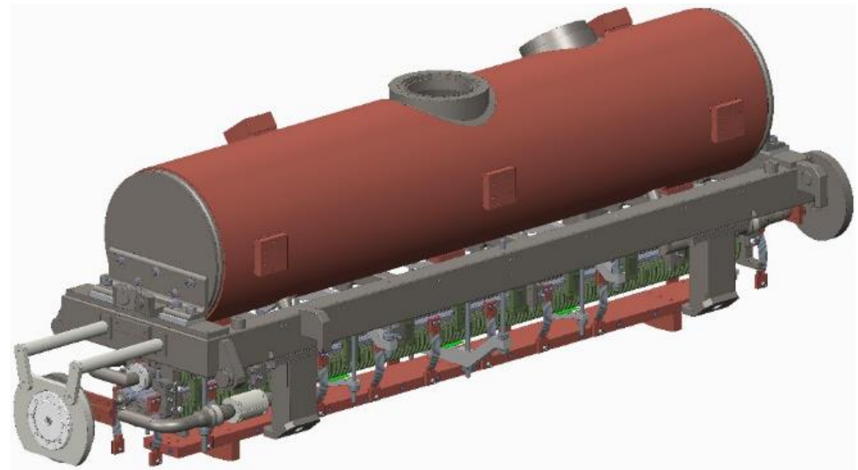
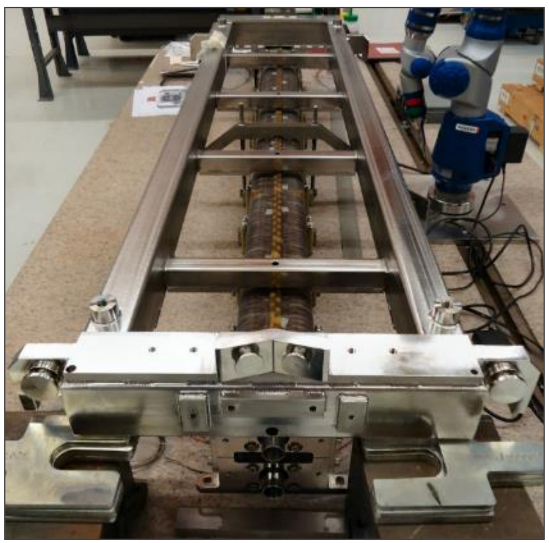
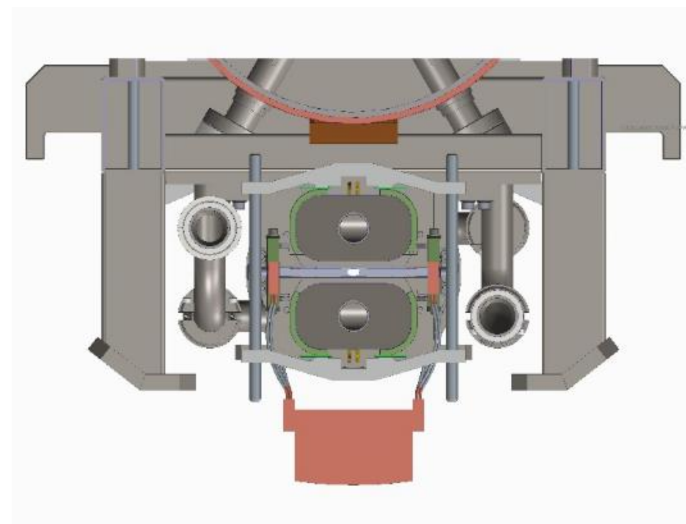
ALIGNMENT IMPROVEMENTS





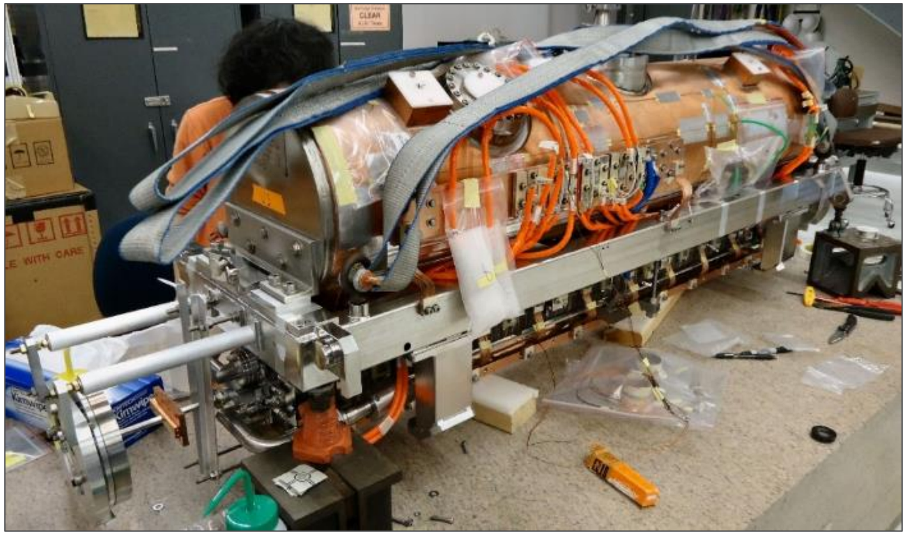
- Improved gap control using revised spacers and outboard clamps
- Inboard support(s) permit adjustment of magnet “sag” to improve centerline trajectory

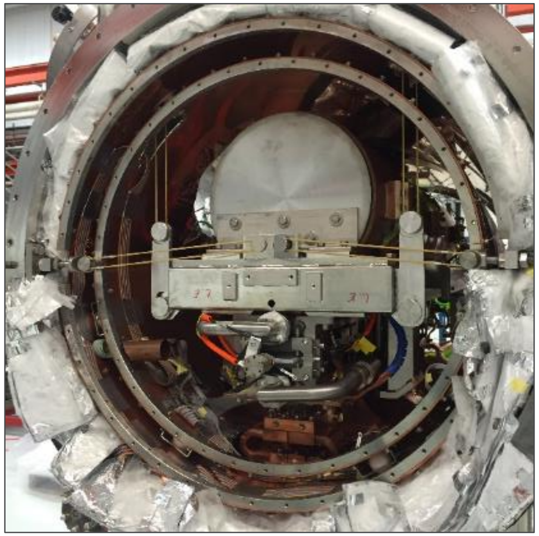


TYPICAL COLD MASS ASSEMBLY

- The liquid helium tank is mounted and connecting pipes between tank & magnets are routed.
- Current leads, voltage taps, temperature sensors etc are added.

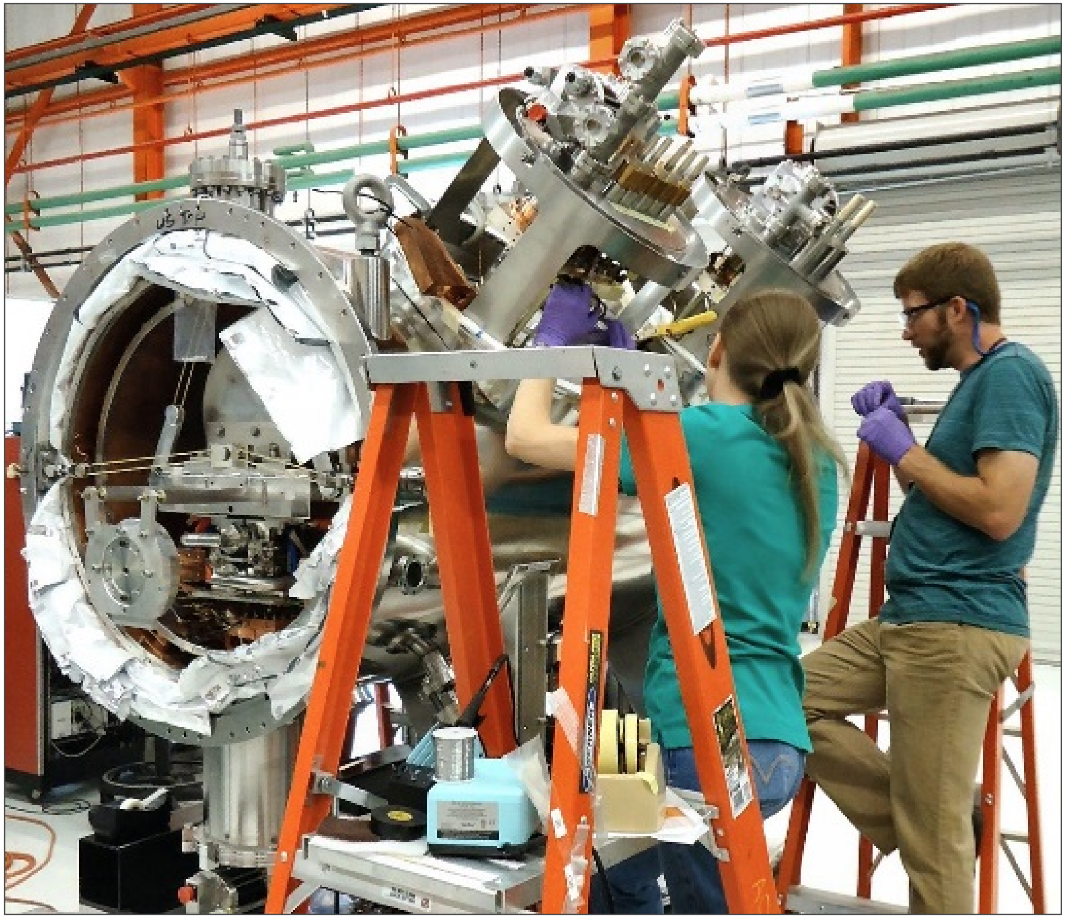
TYPICAL FINAL ASSEMBLY (1)

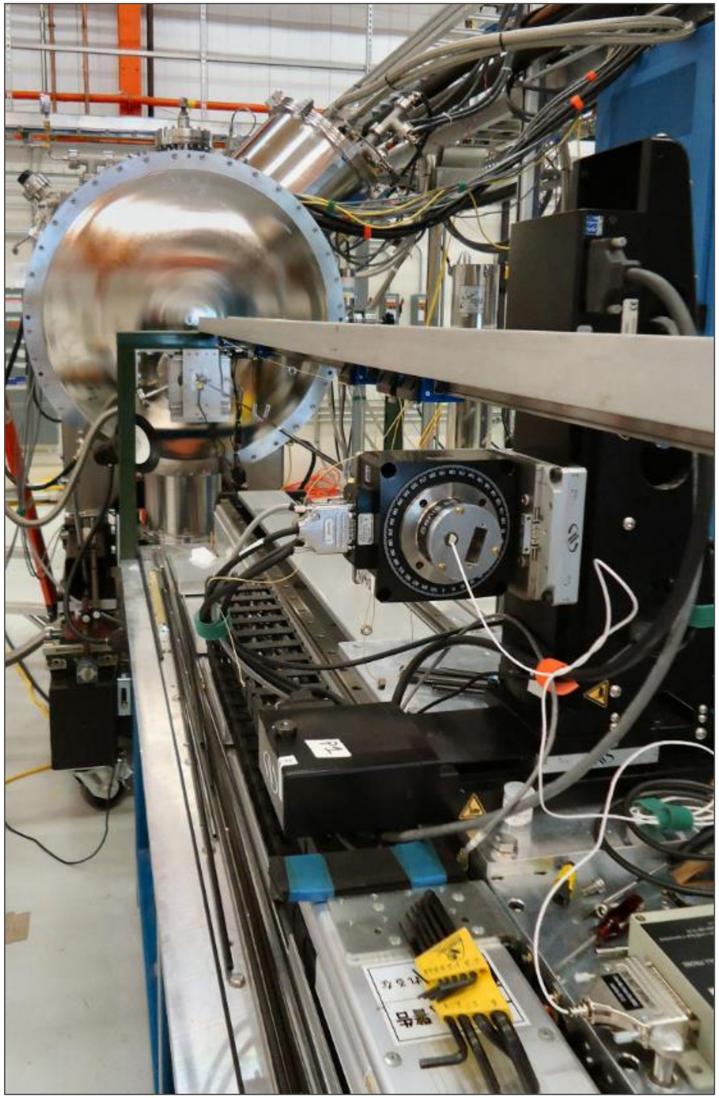




- Wiring checkout & end loading

FINAL ASSEMBLY (2), MAGNETIC MEASUREMENT





- Final electrical connections are made between the cold mass and the current lead/cryocooler turrets.
- Vacuum vessel turret and end covers are installed.
- Cryostat is moved to the measurement bench and aligned.

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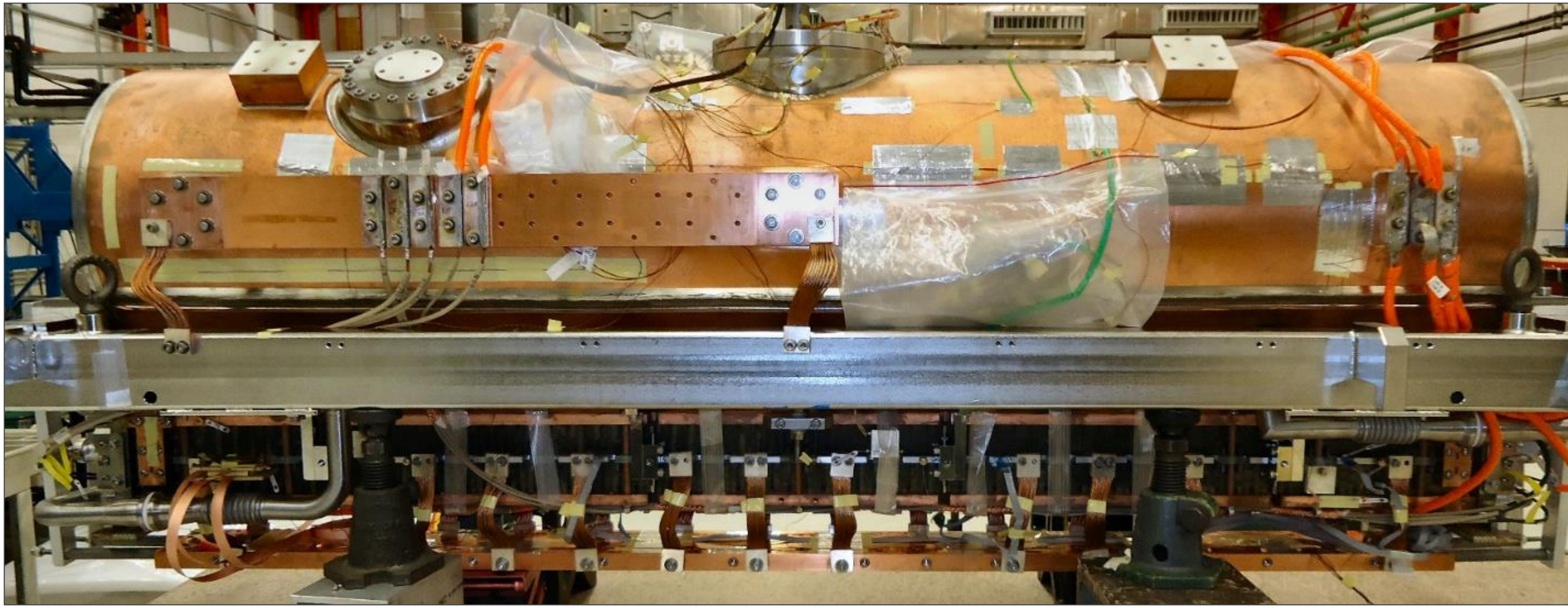
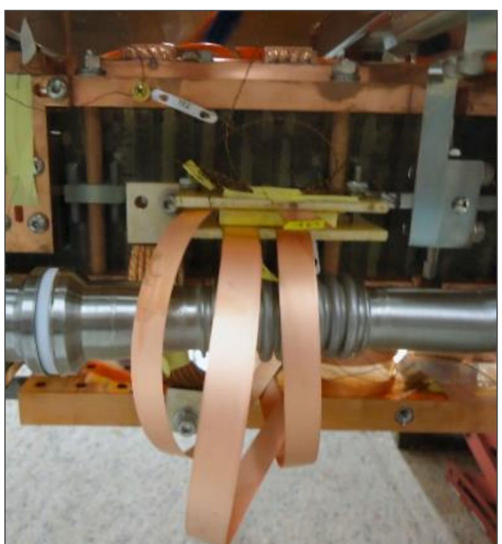
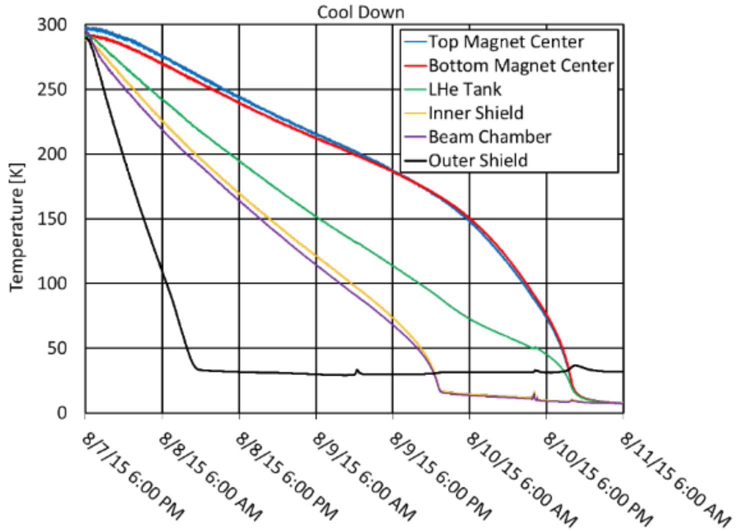
FEL R&D: NB$_3$Sn MAGNET FROM LBNL

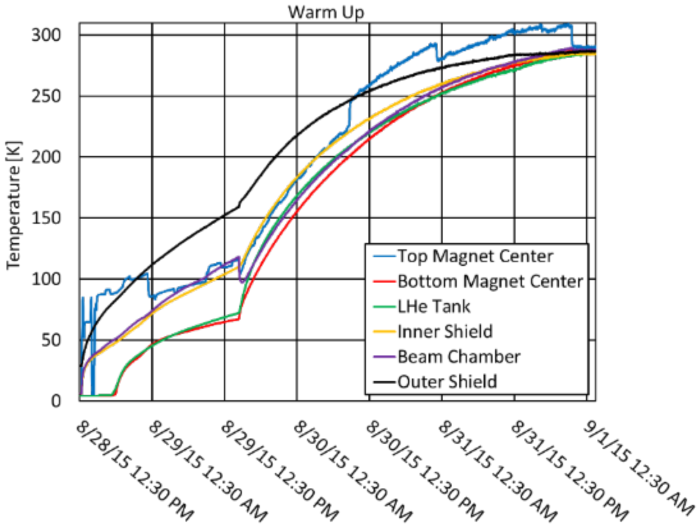


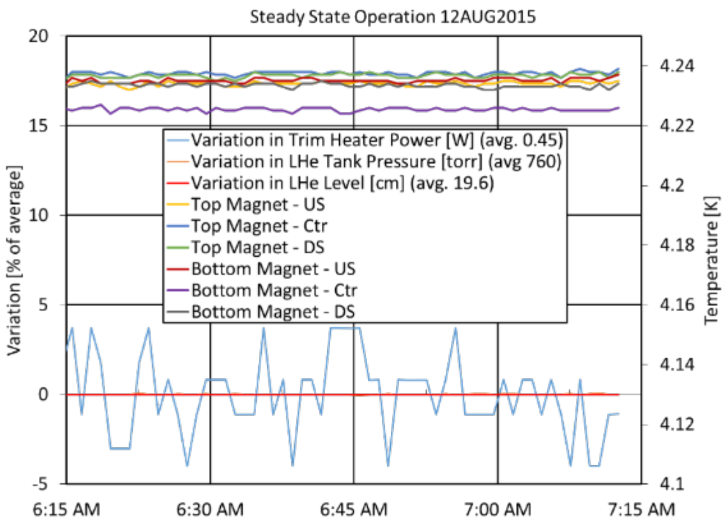


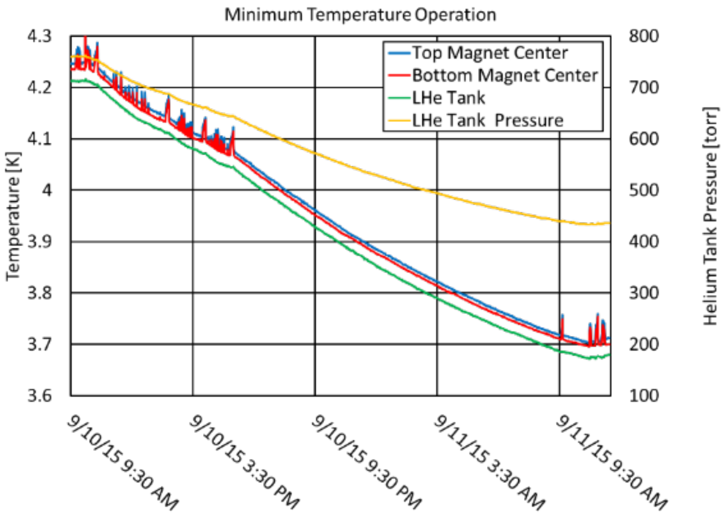
- Magnet envelope is similar to NbTi version.
- Additional tuning and cooling features need to be accommodated.
- Alignment between beam chamber and magnet is critical.

CRYOGENIC PERFORMANCE (1): FEL SCU R&D (NbTi)

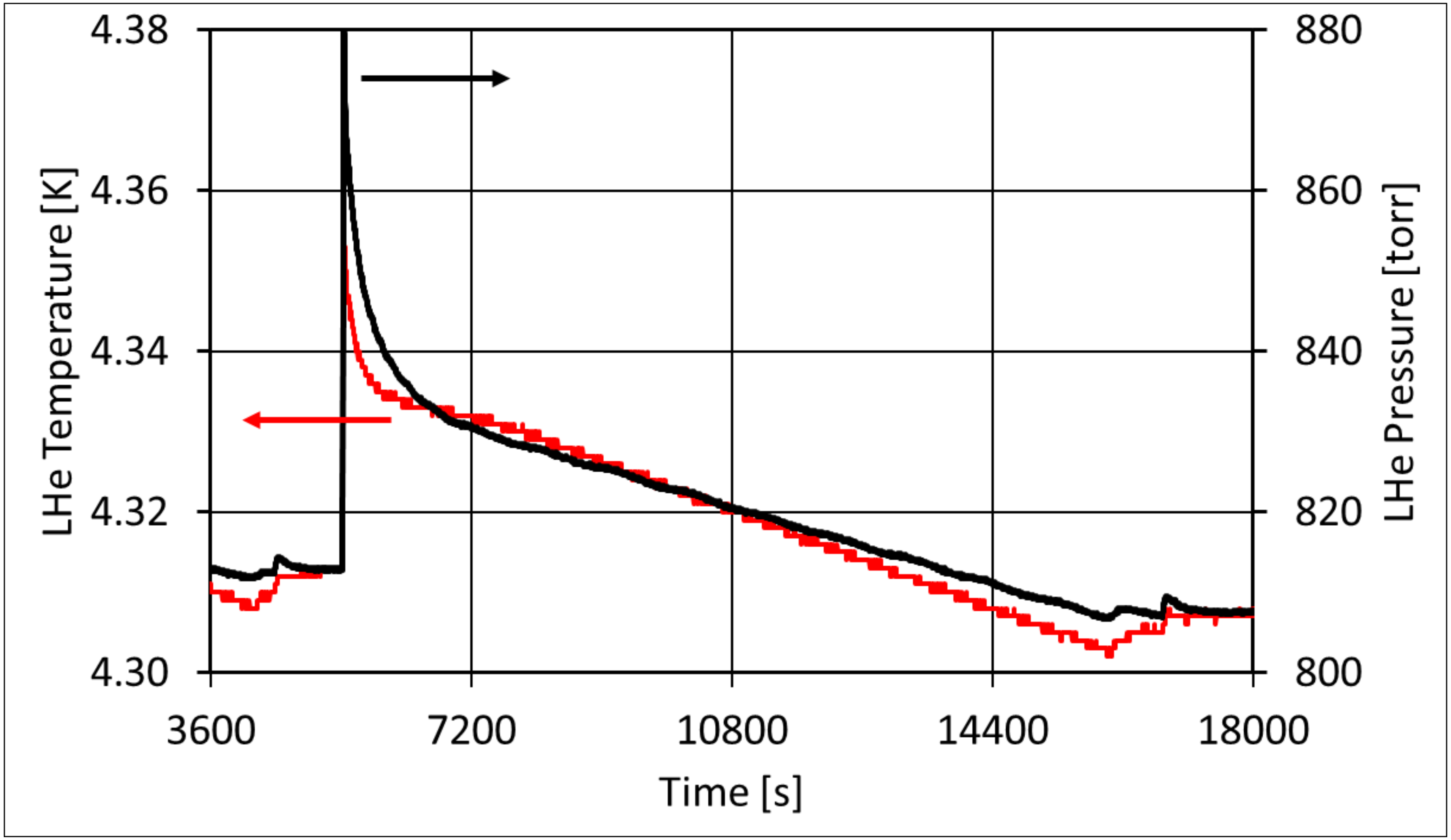






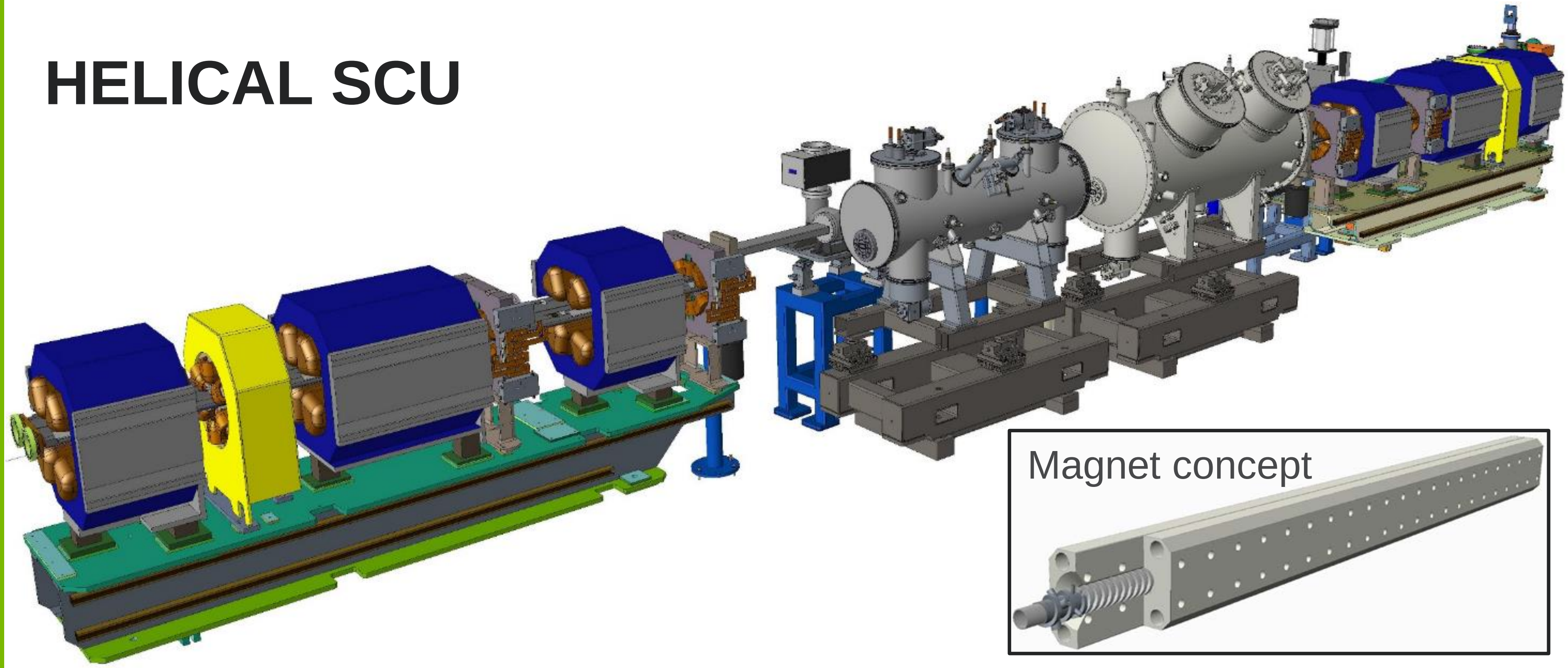


CRYOGENIC PERFORMANCE (2): QUENCH (SCU1)

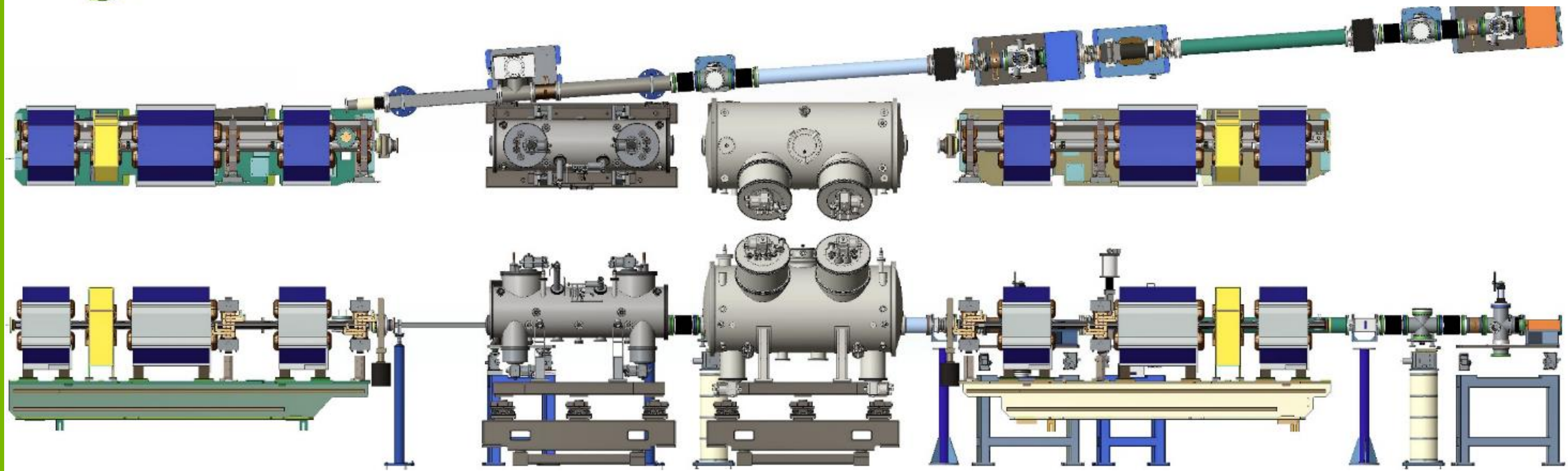


- Initial spike indicates rapid boiling, after which liquid and vapor return to equilibrium. System remains closed throughout, with no helium venting.
- Slow linear reduction in temperature/pressure reflect the available excess cooling capacity of the cryocoolers.

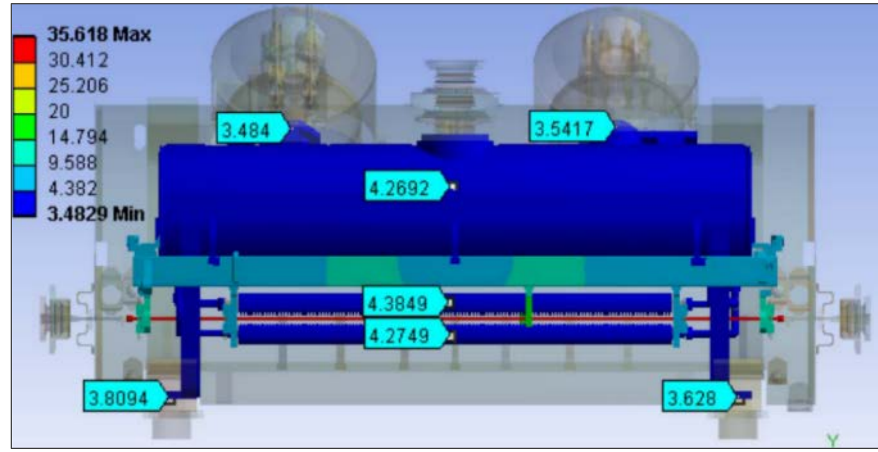
HELICAL SCU



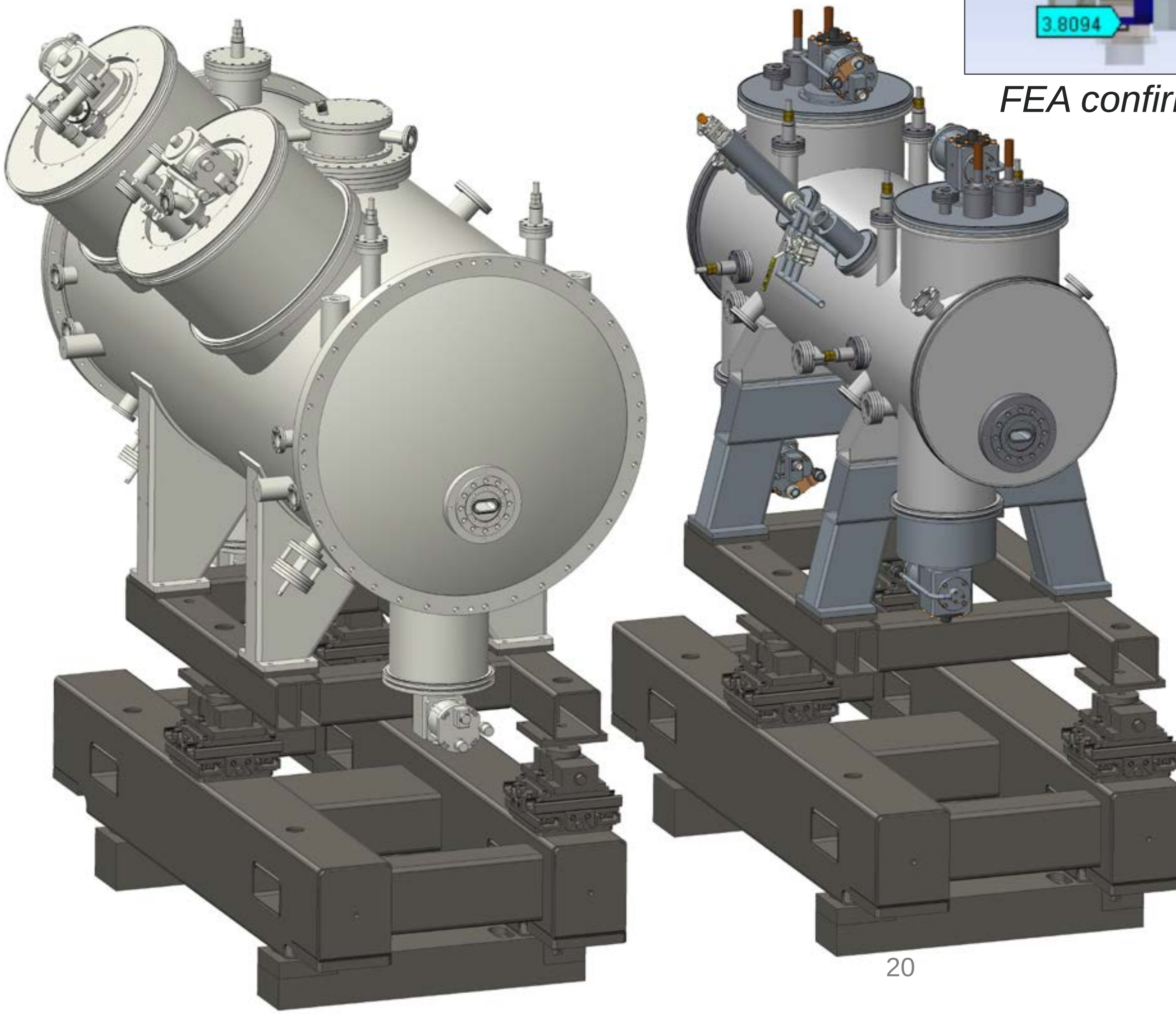
Magnet concept



CRYOSTAT EVOLUTION

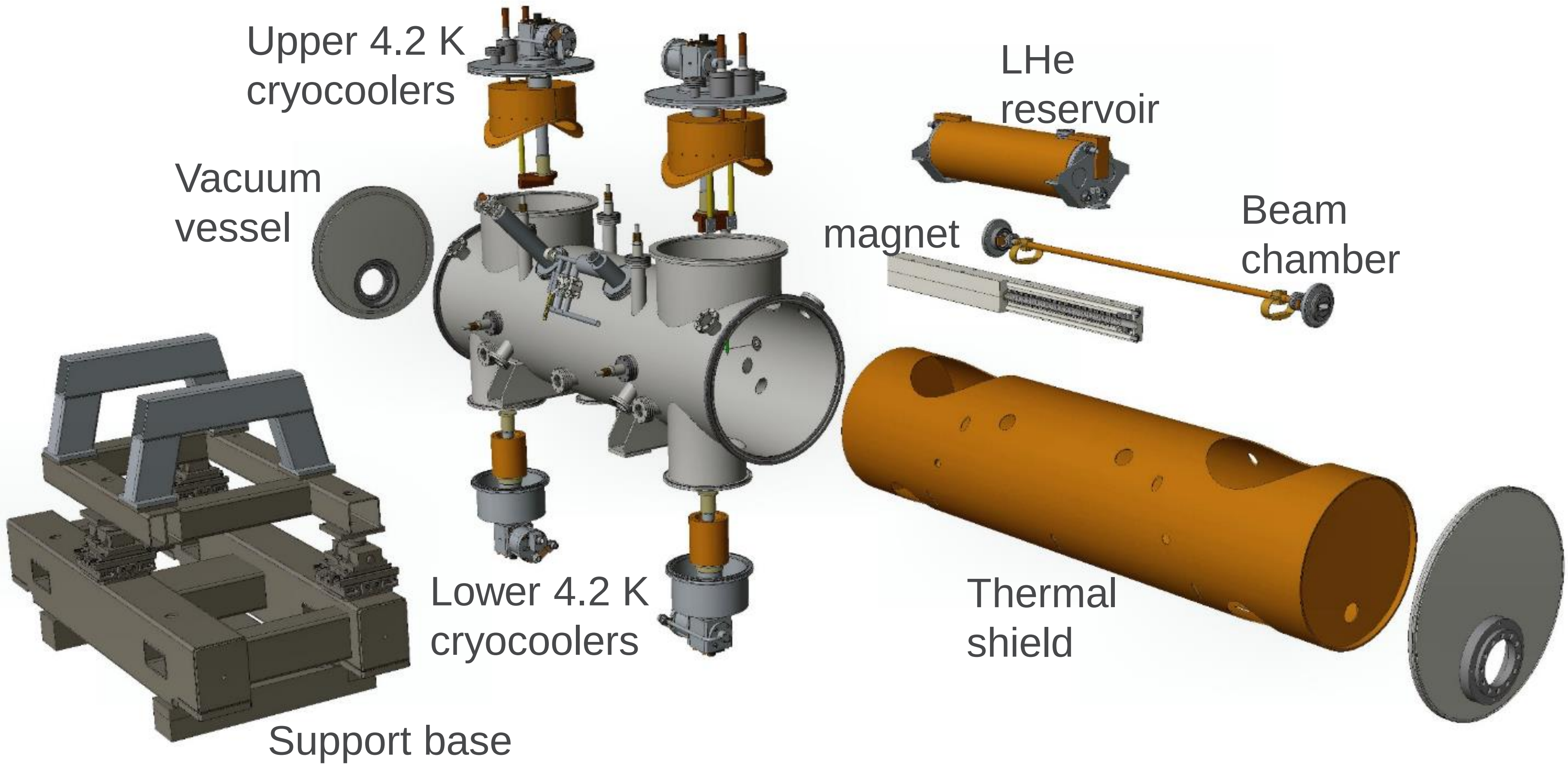


FEA confirms suitability of QTY4 4.2K cryocoolers



- Further (final?) implementation of lessons learned:
  - Alignment/fiducialization
  - Thermal performance (shield, cryocoolers)
  - Smaller, cheaper
  - Able to test LHe-free cooling strategy

CRYOSTAT MAJOR COMPONENTS



Value Engineered design:

- Single thermal shield
- revised helium vent/fill
- Smaller vacuum vessel
- “All 4.2 K” cryocooler refrigeration
- Upright cryocooler installation
- Std. flange components

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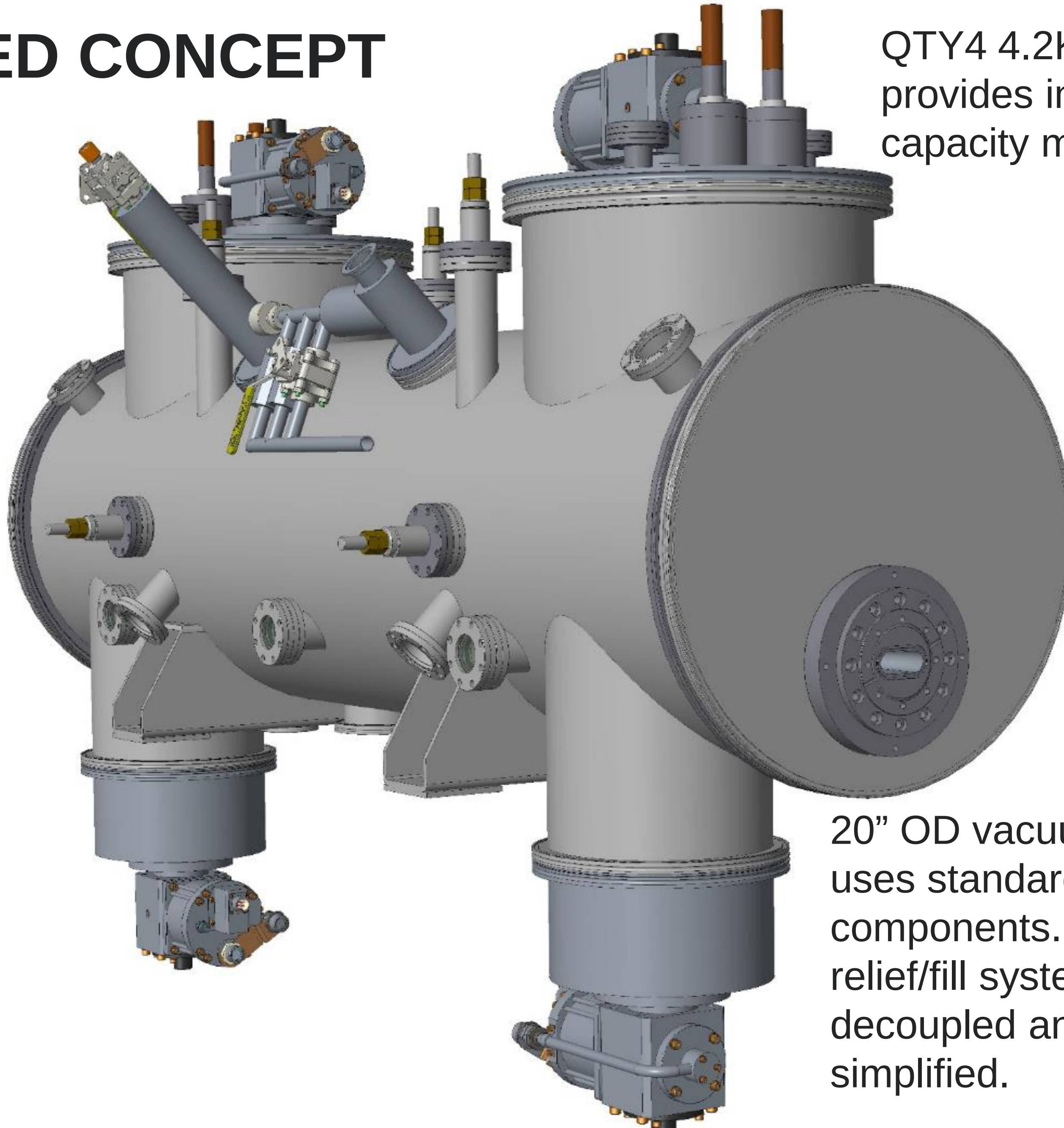
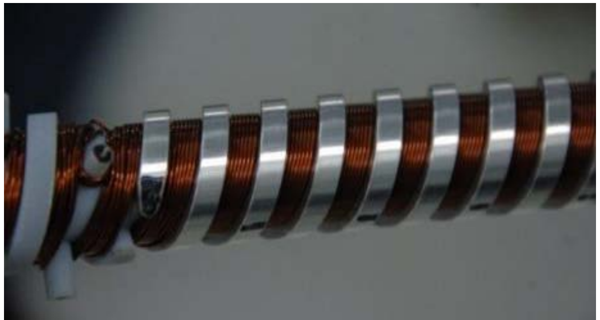
REVISED CONCEPT

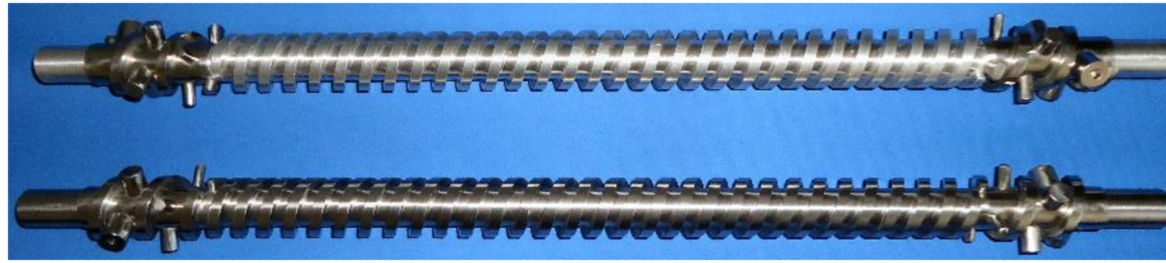


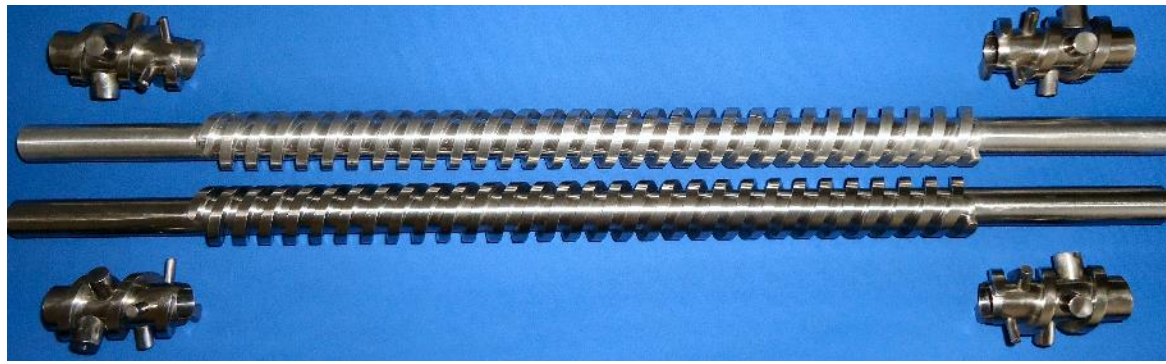
QTY4 4.2K cryocoolers provides improved capacity margin

20” OD vacuum vessel uses standard ISO LF components. Helium relief/fill systems are decoupled and simplified.

HELICAL SCU MAGNET R&D

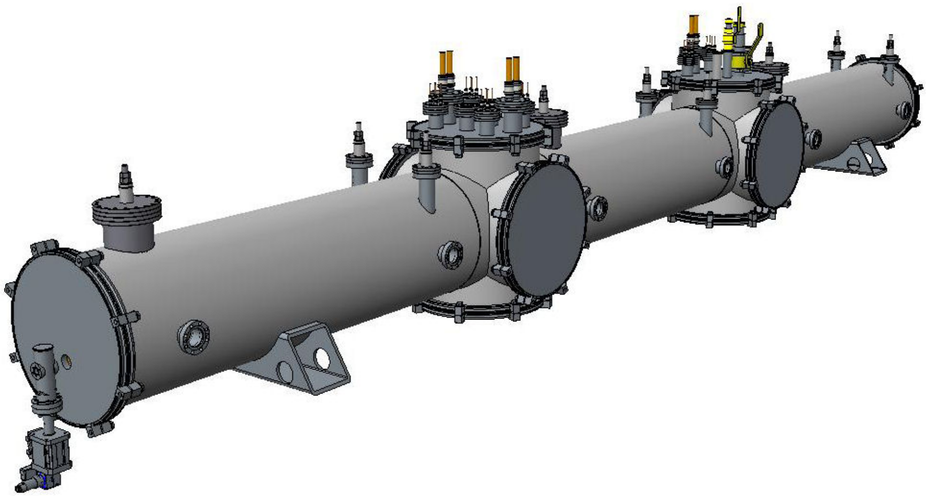




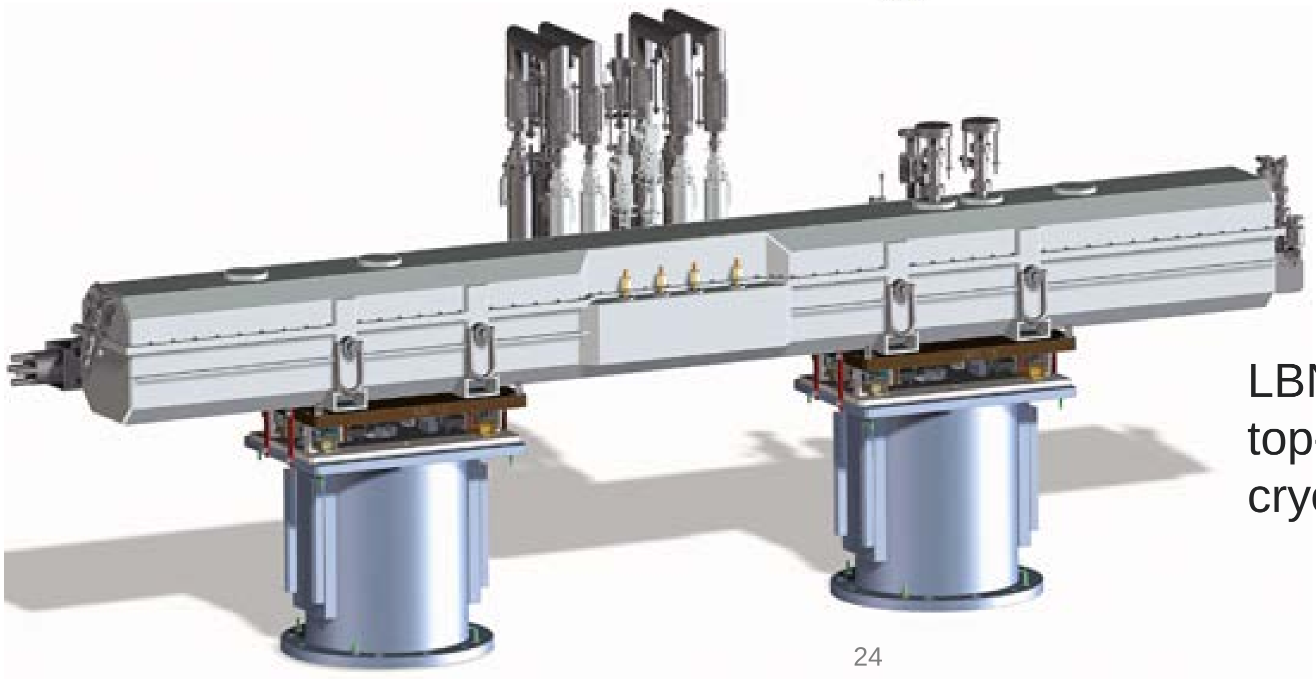


- Helical SCU magnet cores prototyped in plastic, Al & steel
- Conductor turn-around is proven with practice-winds.

R&D ON CRYOSTAT CONCEPTS FOR AN FEL SCU ARRAY

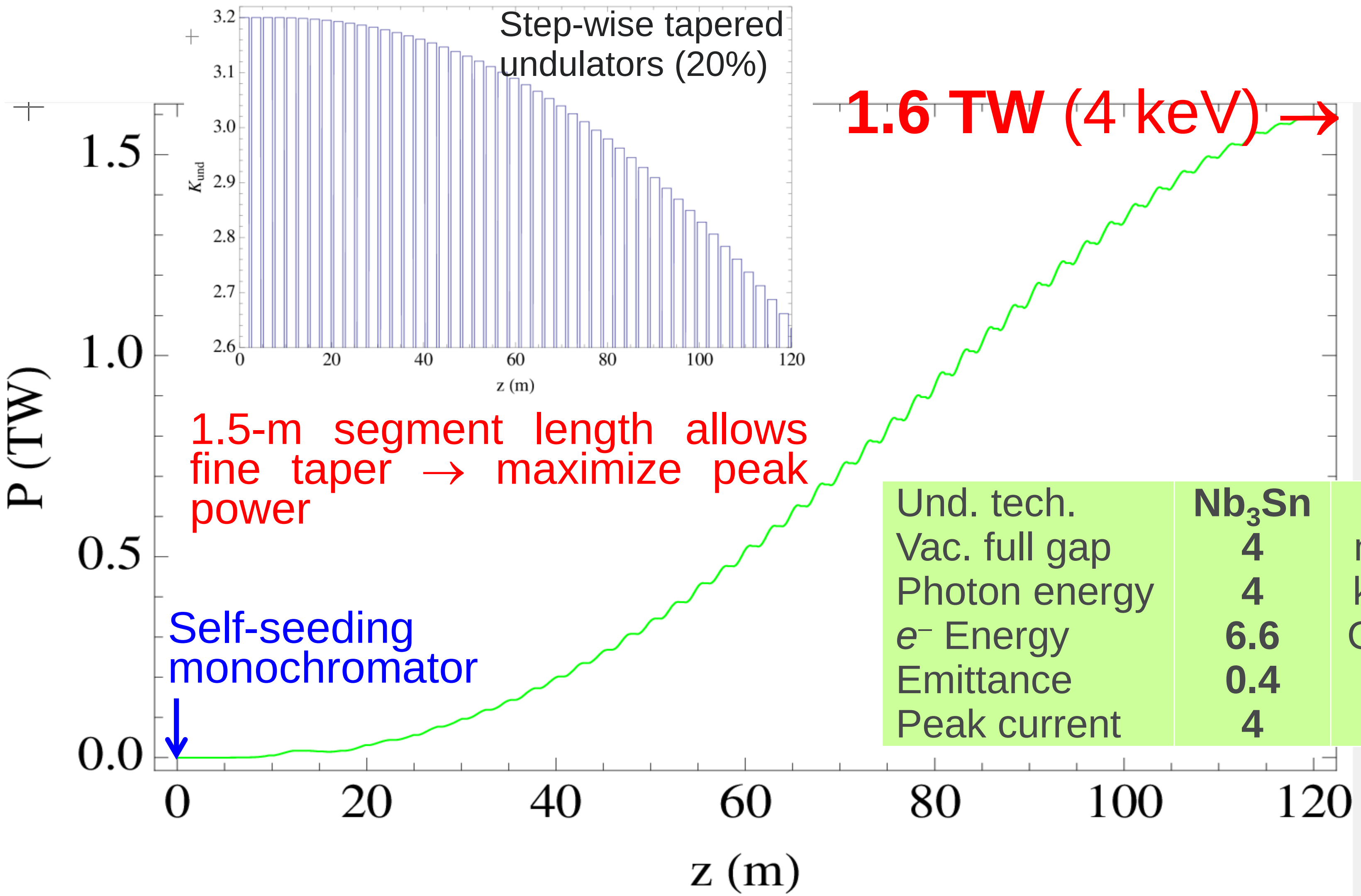


ANL concept:
end-loading cylindrical cryostat



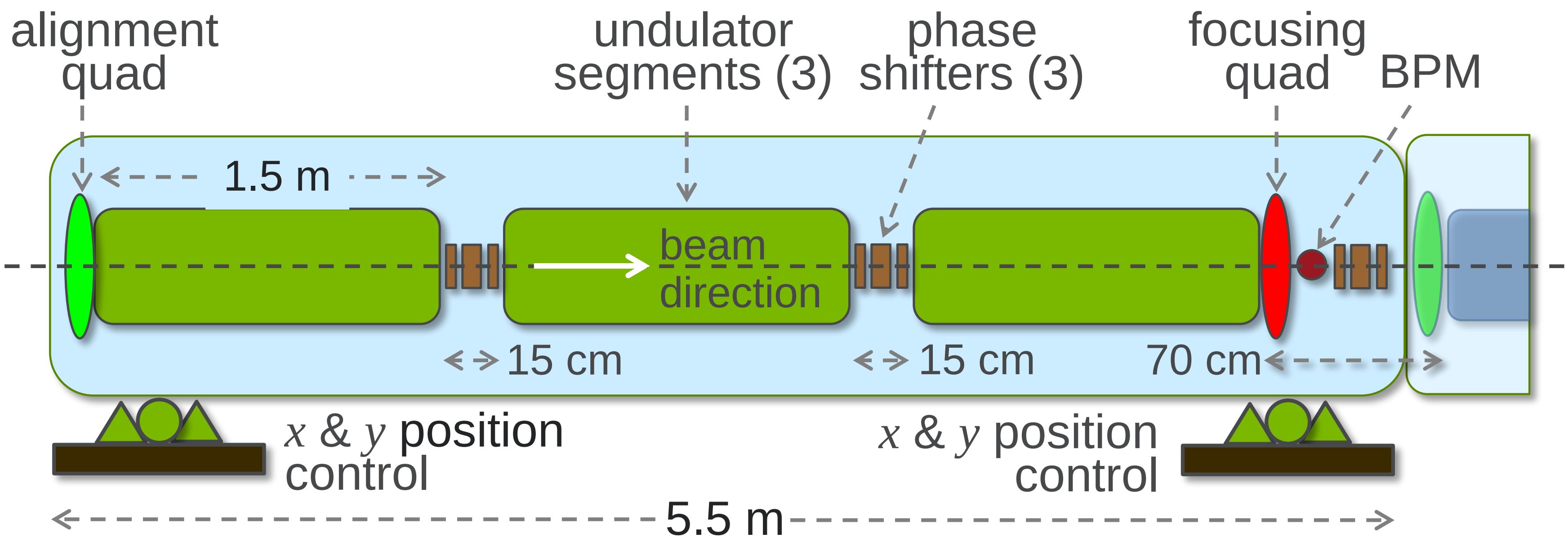
LBNL concept:
top-loading box cryostat

"TW FEL" WITH SCU AND CU-LINAC @LCLS-II (P. EMMA, SLAC)



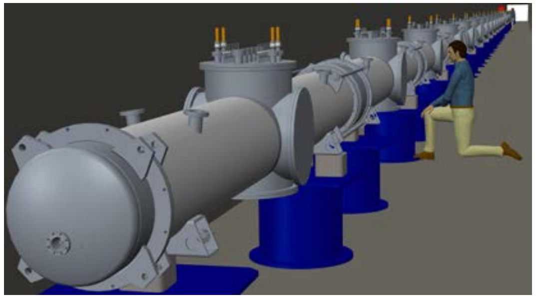
Und. tech.	**Nb_3Sn**	-
Vac. full gap	**4**	mm
Photon energy	**4**	keV
e^- Energy	**6.6**	GeV
Emittance	**0.4**	µm
Peak current	**4**	kA

FEL SCU CRYOMODULE CONCEPT (P. EMMA, SLAC + ANL/LBNL)

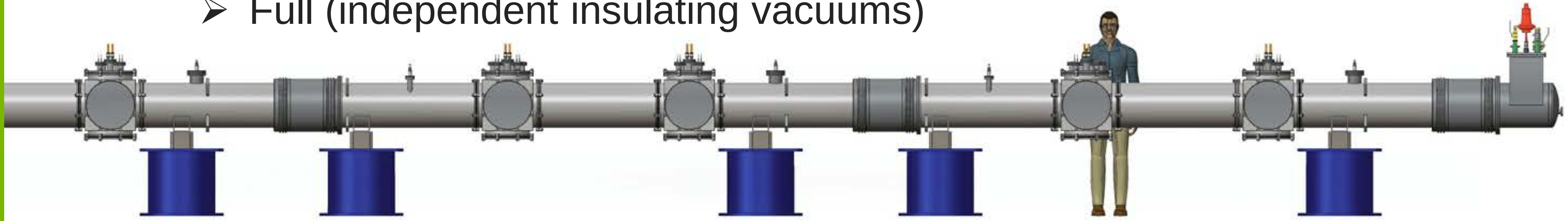


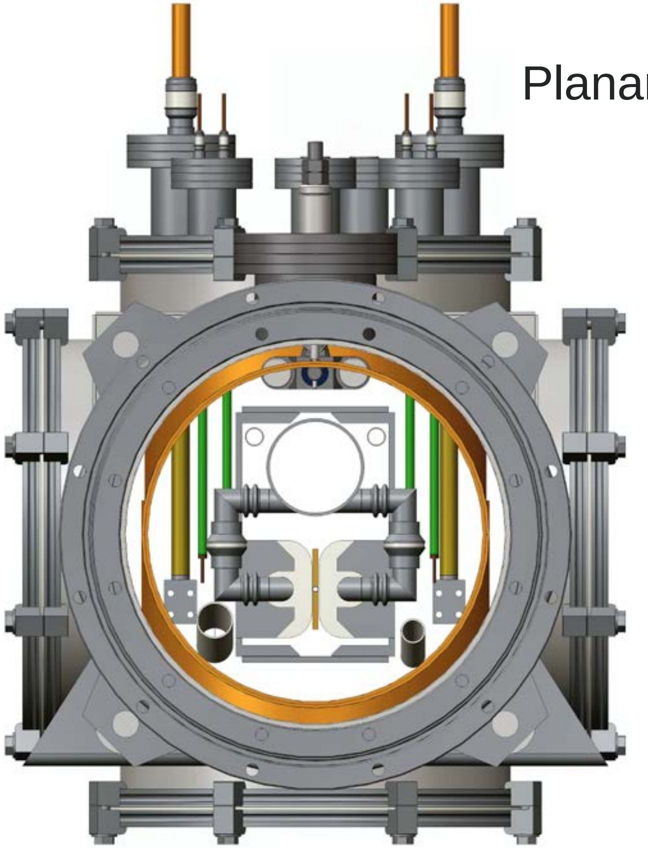
- Three 1.5-m long undulator segments in one 5.5-m cryostat
- Short segments (1.5-m) easier to fabricate, measure, tune, and taper
- Each segment independently powered to allow optimized TW-taper
- Ancillary components include cold BPM, cold phase-shifters, cold quads
- Cryogenic refrigeration/distribution system concept has been developed
- Magnet alignment is critical (300 K $\rightarrow$4 K)
- Beam-based alignment as final correction using motorized pads

FEL SCU ARRAY CONCEPT

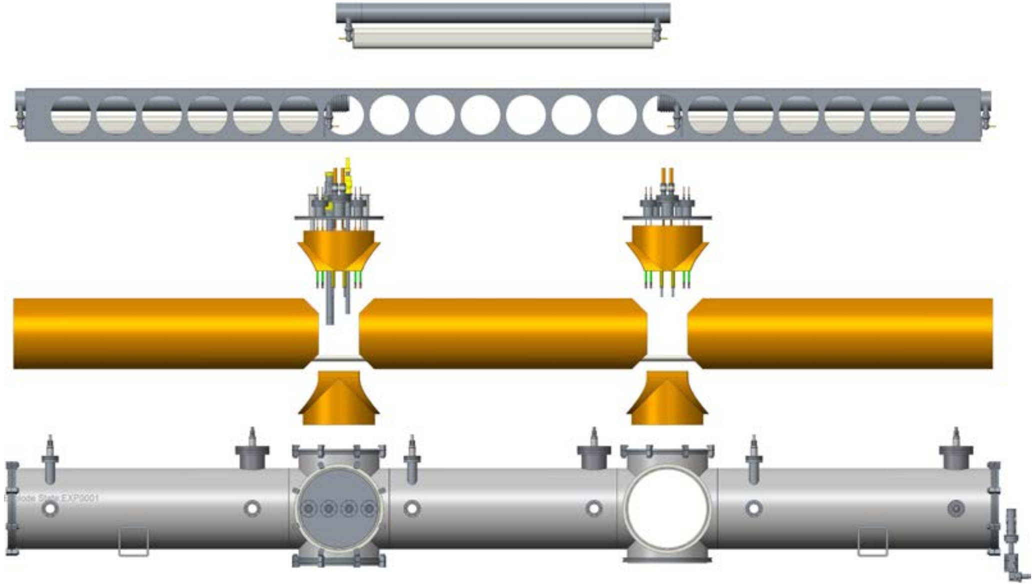


Array Segmentation:
- Minimal (common insulating vacuum)
- Full (independent insulating vacuums)





Planar, horizontal gap magnet shown (could be vertical)



MULTIPLE FELs IN A SINGLE CRYOSTAT

- 1.5-meter magnets
- 3 magnets per FEL segment
- 12 magnets per cryostat