U.S. DEPARTMENT OF ENERGY
Office of Science

BERKELEY LAB

MARS

Development of a MARS superconducting cold mass for future generations of ECRIS

Damon Todd

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Acknowledgements

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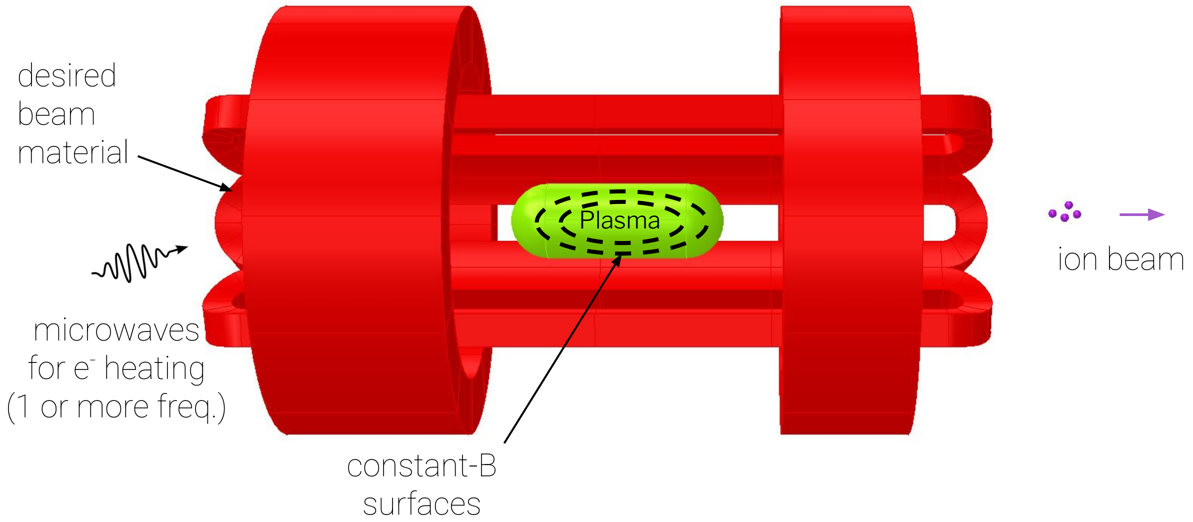
Presentation outline

- Electron cyclotron resonance (ECR) ion source introduction
- The MARS-D ion source
- Update on project deliverables and schedule for sub-projects:
  - superconducting coil construction (sub-project 1)
  - cryogenic system design (sub-project 2)
  - advance inductive oven design and construction (sub-project 3)
  - source design beyond MARS-D (sub-project 4)
- Annual Budget

Electron Cyclotron Resonance (ECR) ion source basics

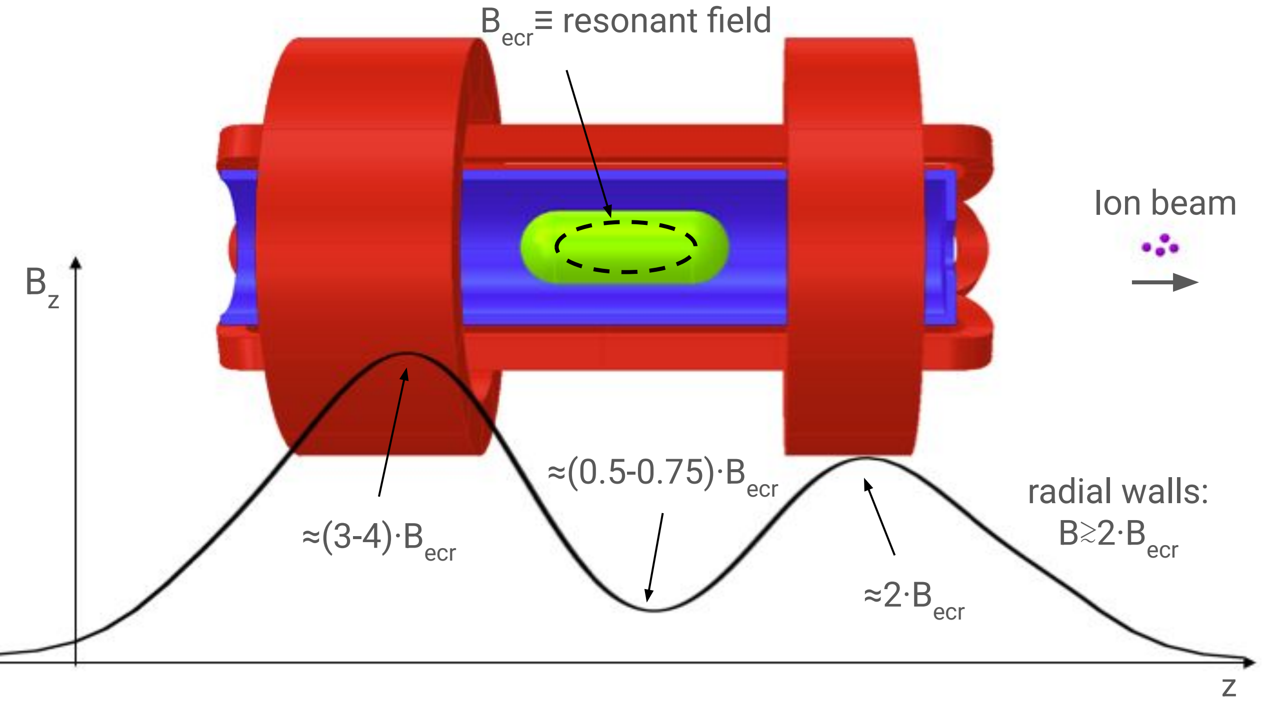


Basic superconducting ECR ion source

Why one should care about ECR ion sources:

- They can produce ion beams from any element
- They are the source-of-choice for most ion accelerator facilities around the world
- Better sources are a cost-effective means for facility upgrades
- The pathway to higher-performing sources is clear

ECR ion source construction cheat sheet

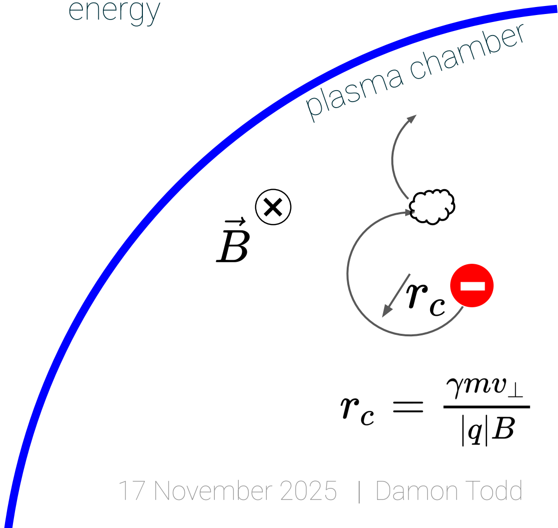


Rule:

- Higher B_{ecr} (and associated resonant RF) means higher performance

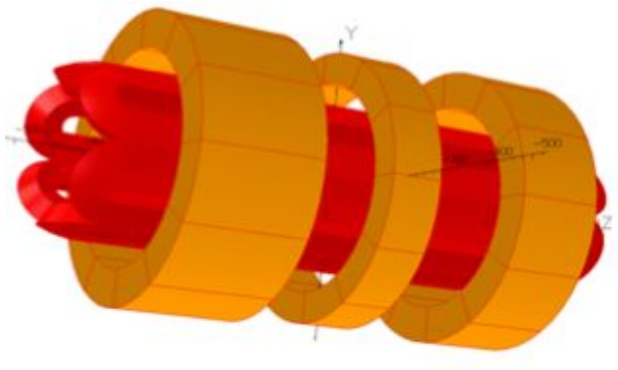
Simple why:

- Higher B, slower radial diffusion and higher electron energy



$$r_c = \frac{\gamma m v_\perp}{|q| B}$$

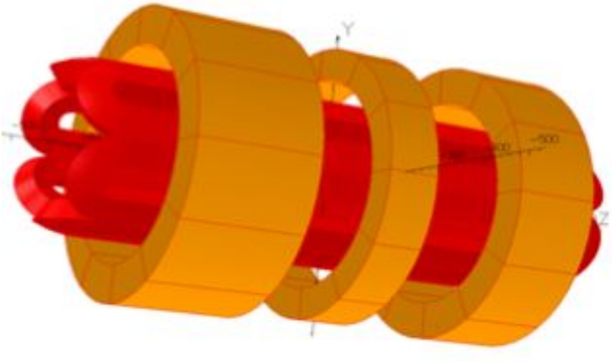
Moving to higher fields



LBNL's VENUS ECR ion source

- Maximum ECR fields using a conventional sextupole-in-soleniod design with NbTi
- Operation up to 28 GHz resonant RF

Moving to higher fields



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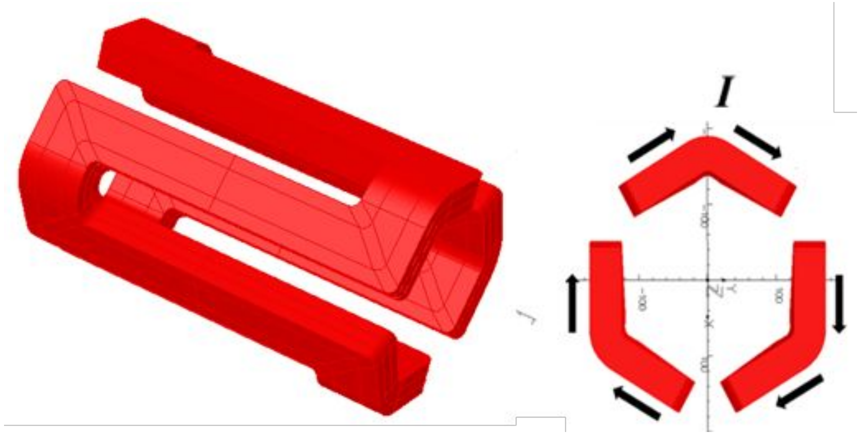


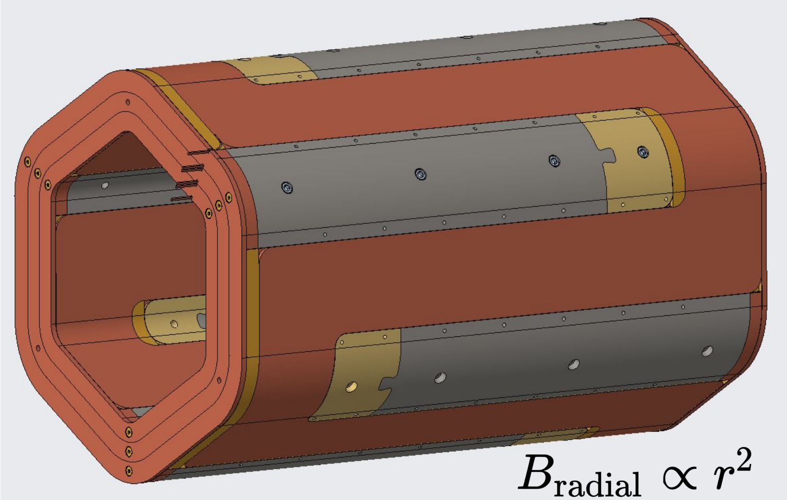
MARS-D (Mixed Axial and Radial field System - Demonstrator)

- Sextupole provides solenoidal field
- Using NbTi, reach ECR fields ~60% higher than VENUS
- Operation up to 45 GHz resonant RF

Constructing MARS-D at LBNL

LBNL experience constructing superconducting ECR ion sources:

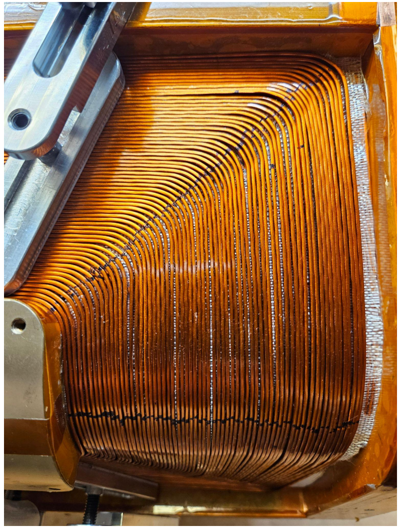
- VENUS
- FRIB's VENUS copy
- Two additional VENUS near-copies for FRIB being at least partially constructed



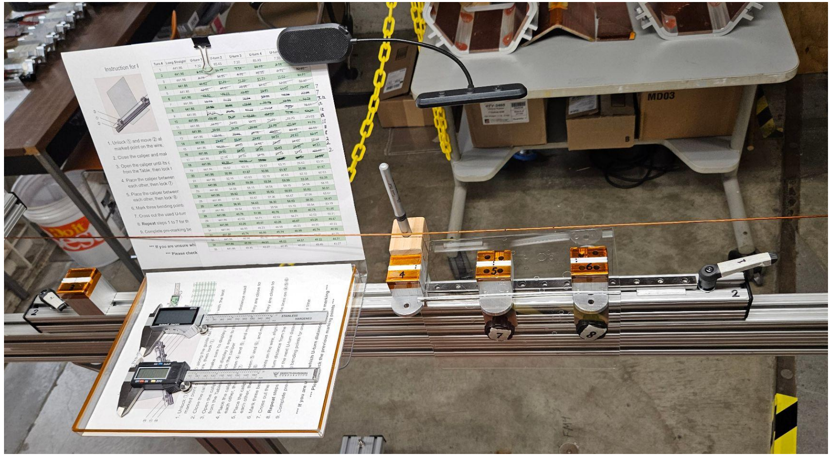
MARS-D Primary challenges:

1. Winding the closed-loop-coil
2. Hexagonal plasma chamber and cyrostat bore

Closed-loop-coil winding process



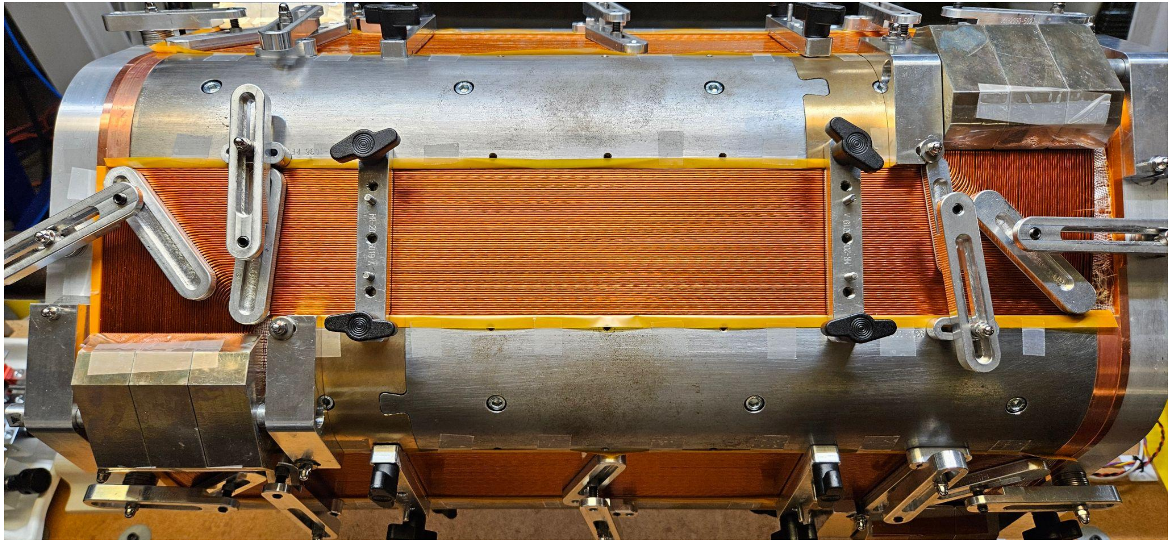
Tooling to bend ends



Improved technique:

- Use calculated bend locations to pre-bend wire
- Turn time reduction: 1.5 -> 0.6 hour/turn

Success: closed-loop-coil winding complete

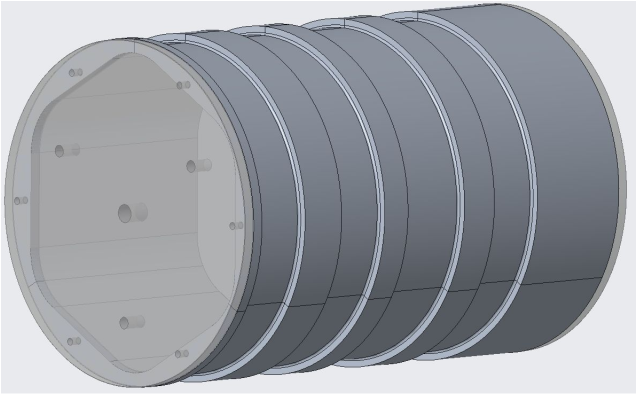


At 2024 NP Accelerator R&D PI Exchange Meeting, closed-loop-coil completion projected by August 2025

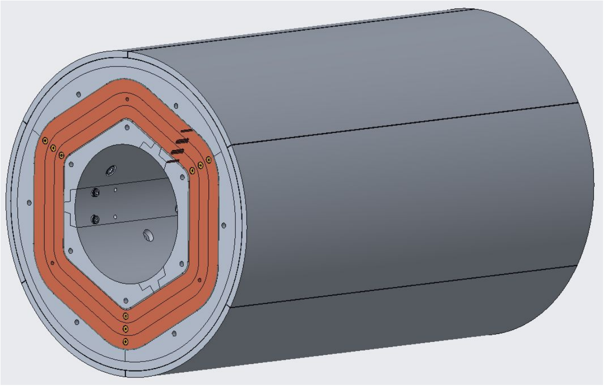
Update:
Closed-loop-coil complete November 2025

- 24 layers
- 64 turns per layer
- ~ 6 km of NbTi wire

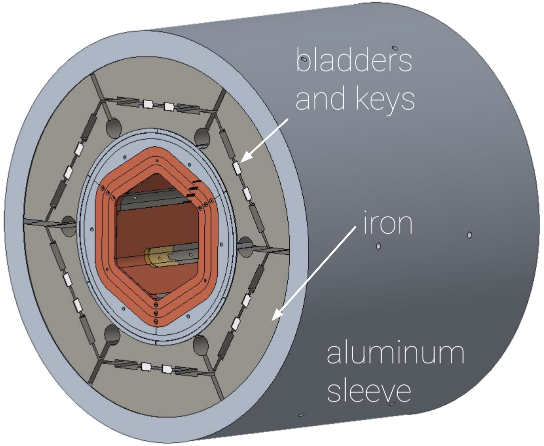
Some next steps for cold mass



- Solenoid mandrel construction (underway)

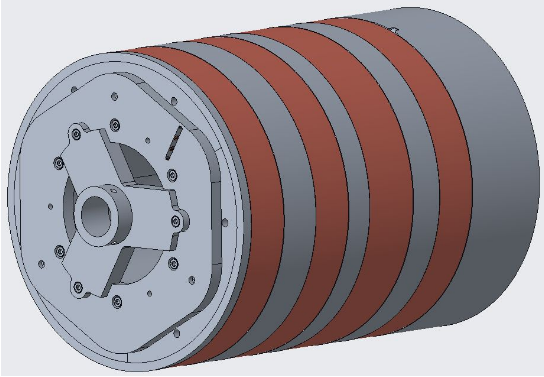


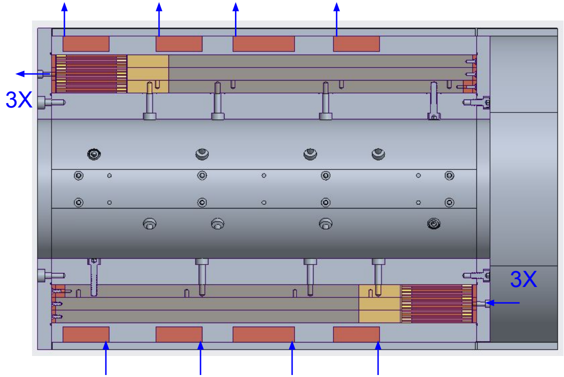
- Solenoid winding
- Seal system for epoxy impregnation

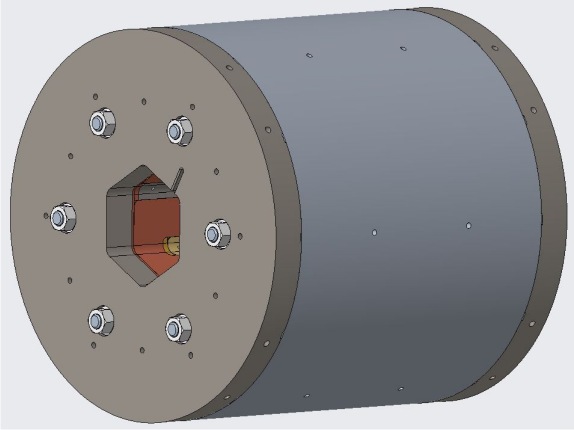


- Surround with iron yokes and a compression aluminum sleeve
- Pre-stress system with bladders and keys

Major milestones for cold mass







Complete solenoid winding

Milestone date:
- February 2025

Expected completion date:
- March 2026

Impregnate MARS-D coils

Milestone date
- December 2025

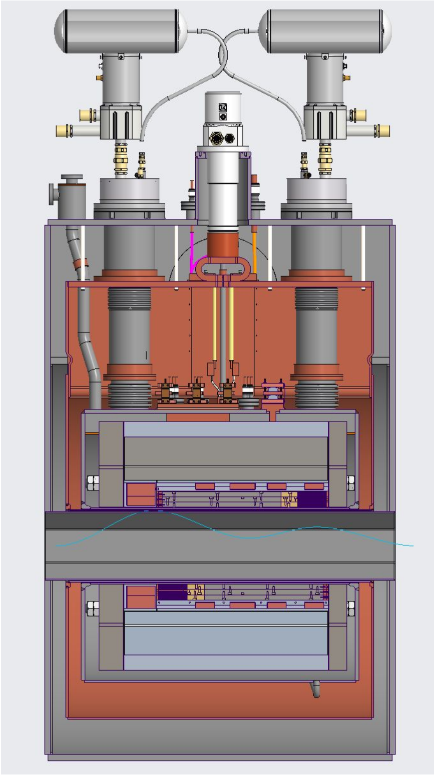
Expected completion date
- June 2026

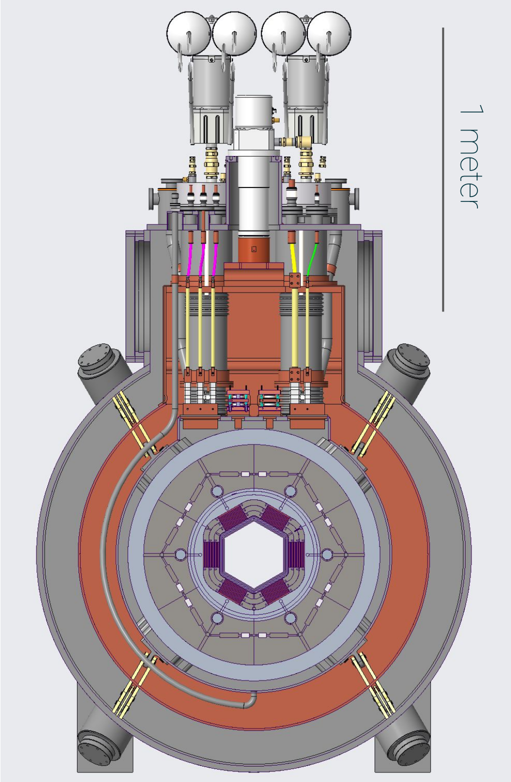
Fully energize MARS-D coils

Milestone date
- September 2026

Expected completion date
- September 2026

MARS-D Cryostat Design





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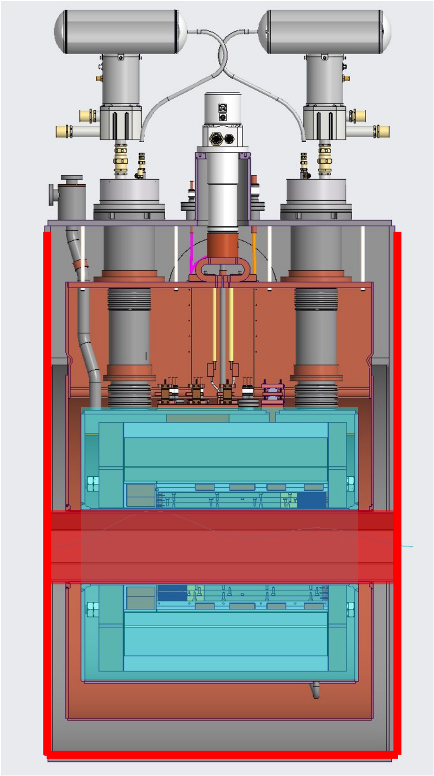
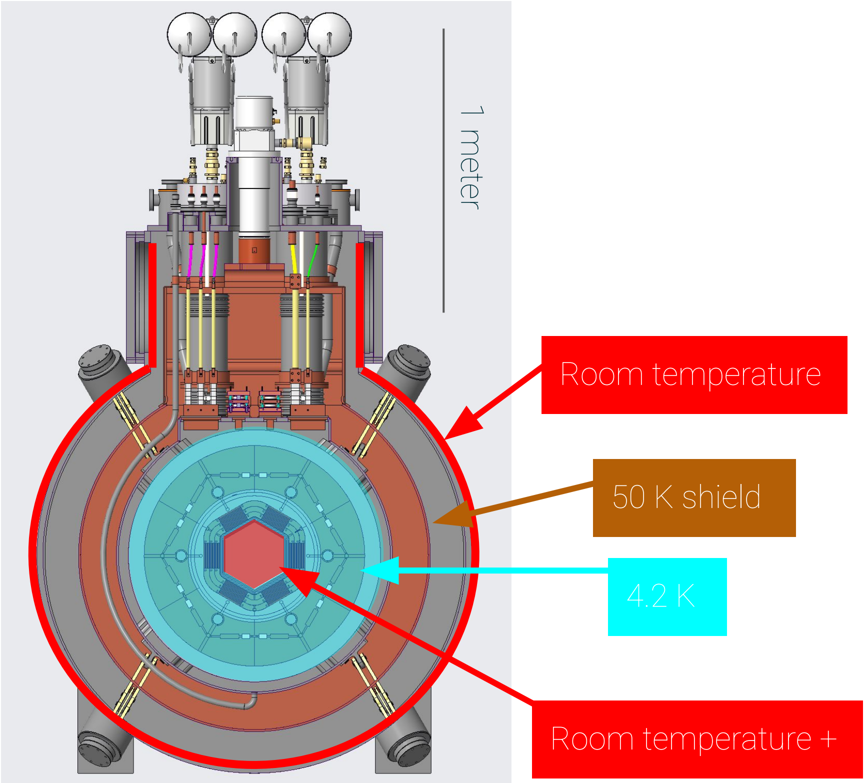


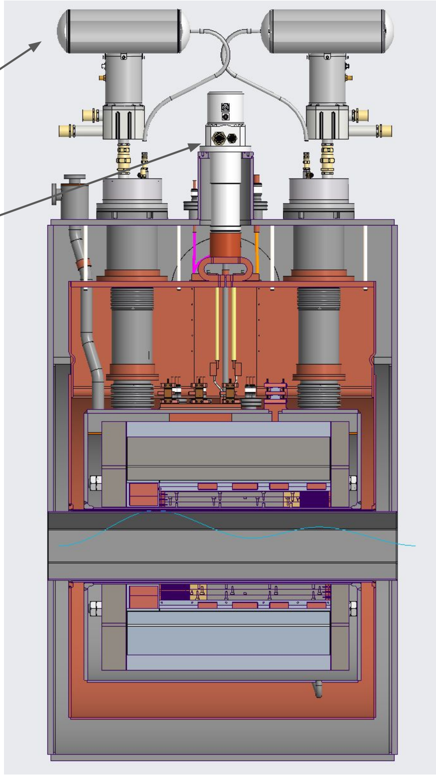


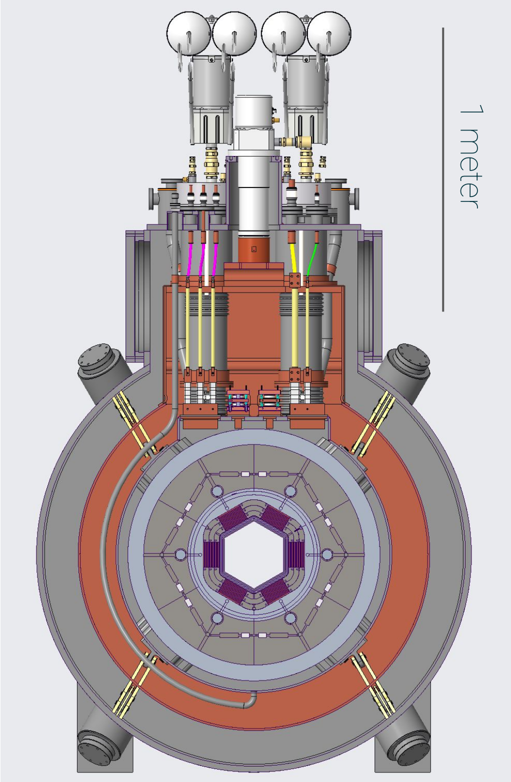
MARS-D Cryostat Design

Cryocoolers

Drop-in mode PT450 4x
5x0.9 W@4.2 K, total **18 W**
65x0.9 W@45 K, total 234 W

AL330
150W@45K





MARS-D Cryostat Design

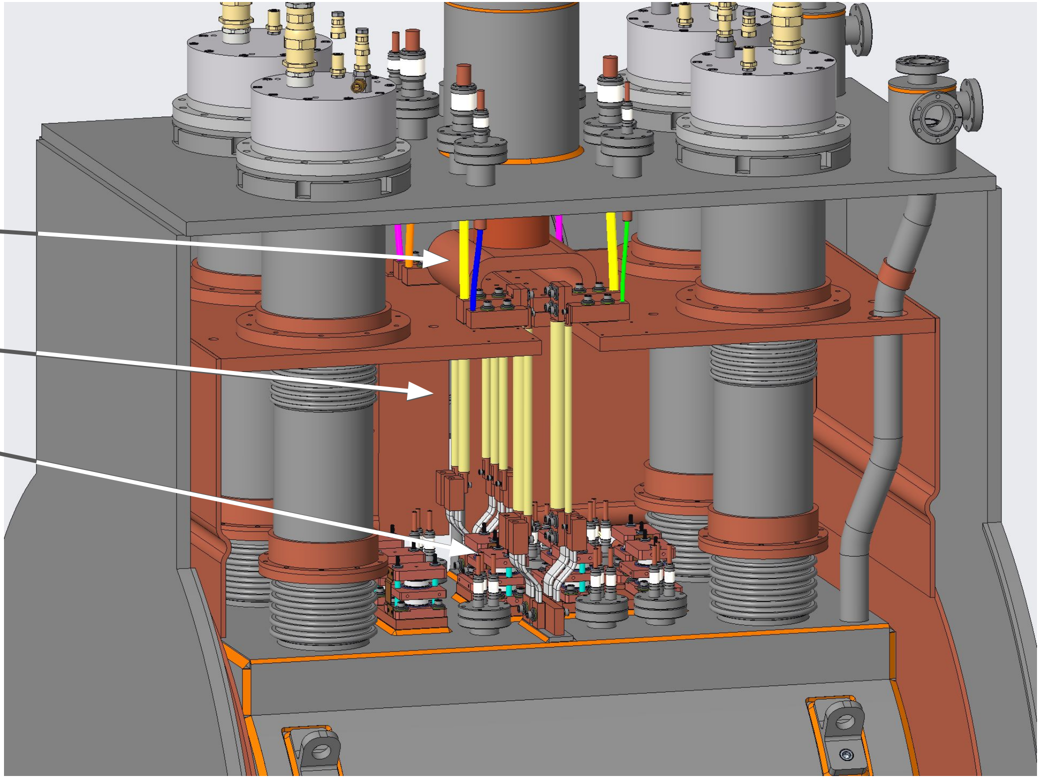
DC Current

9 feedthroughs

Copper current leads

High-temperature superconductor leads

Quench protection



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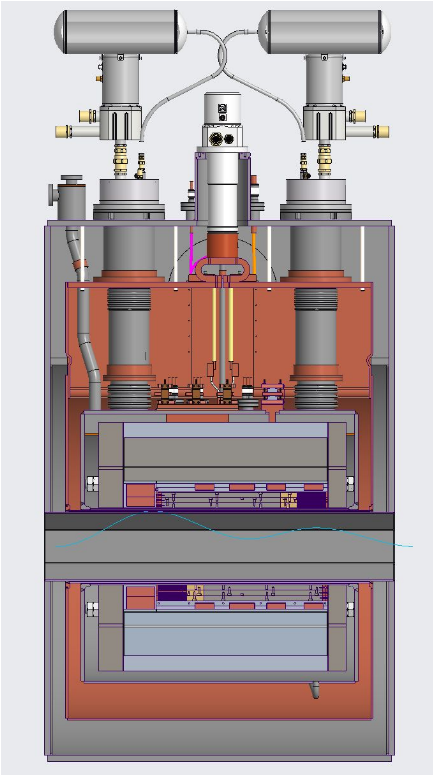
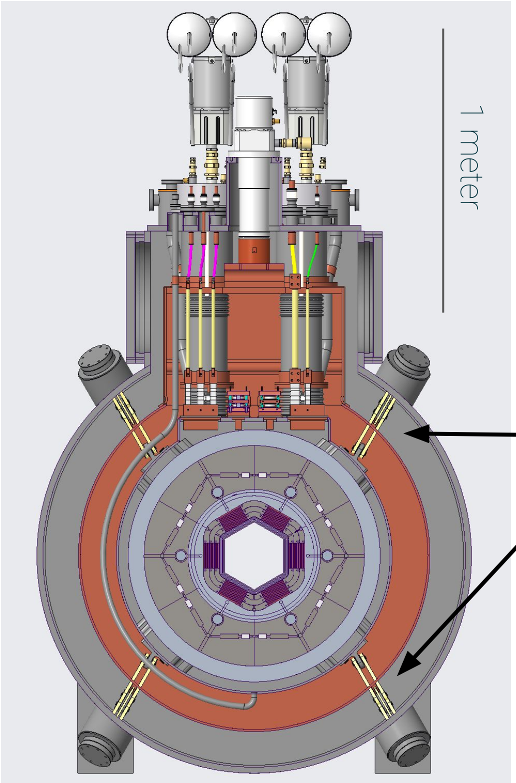
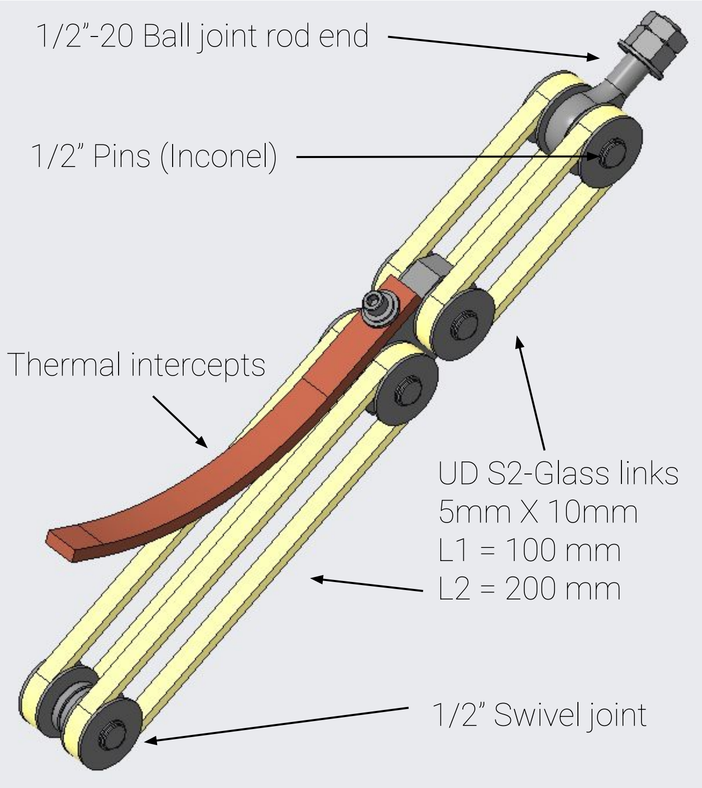
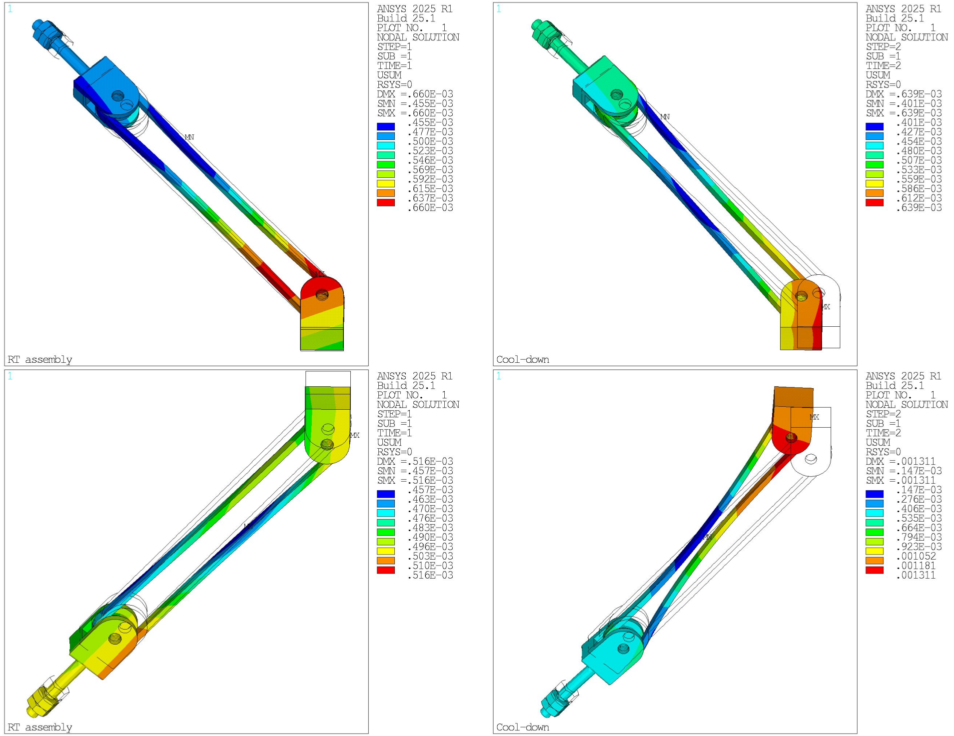




Cold mass suspension x8

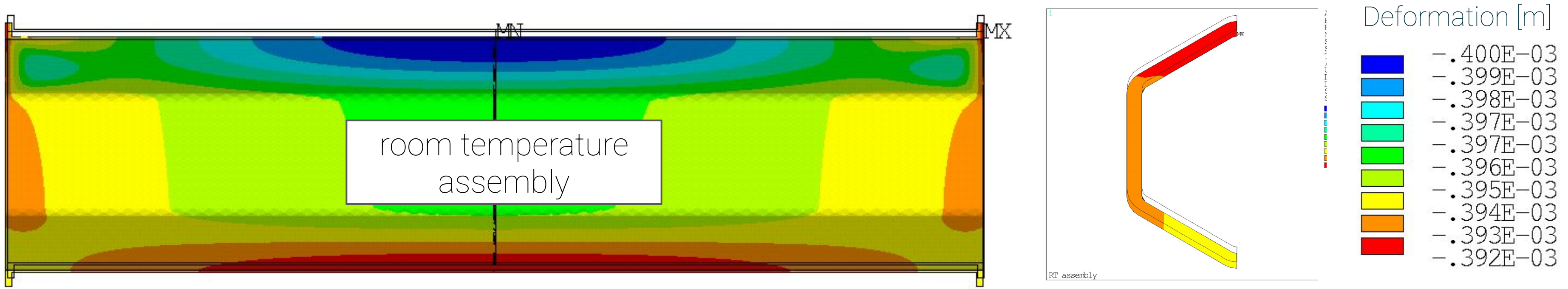
Example: cold mass supports

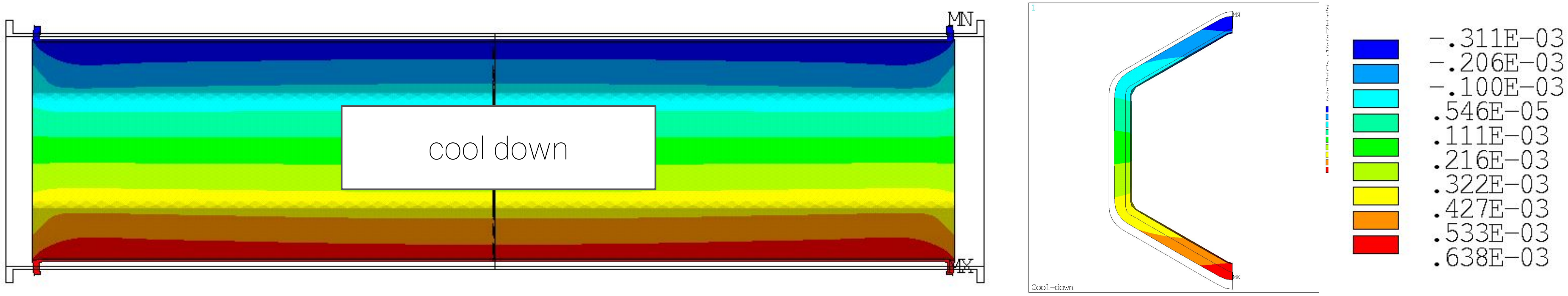




Support deformation studies

Hexagonal bore deformation calculations



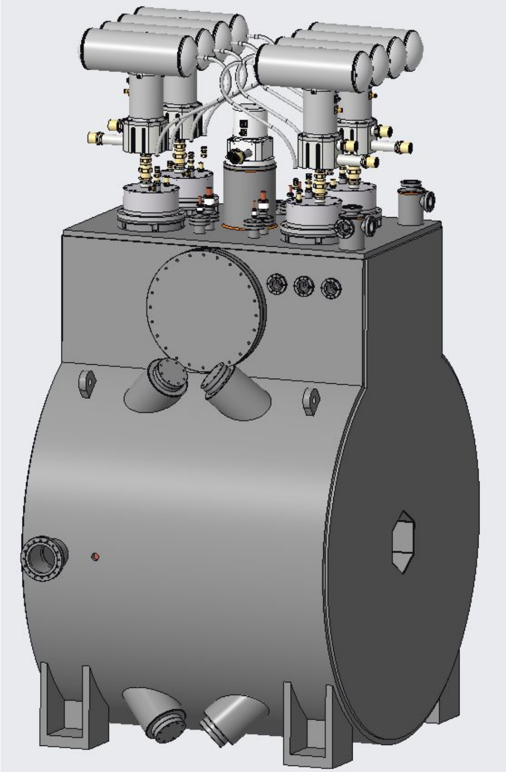


MARS-D Cryostat

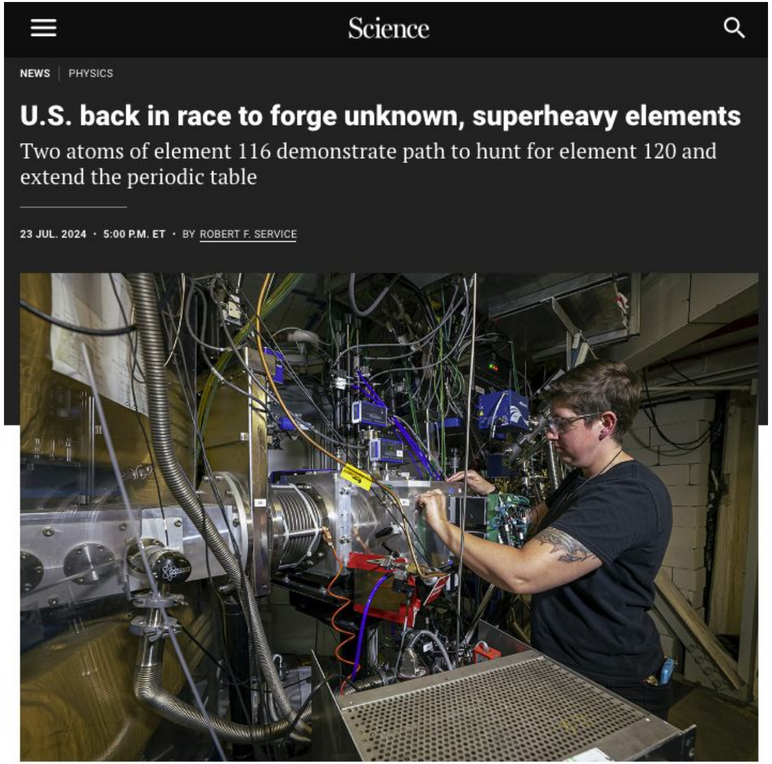
- Cryostat design well underway
- Primary challenges:
  - Hexagonal warm bore
  - Minimization of distance between plasma chamber and superconducting coils

Major deliverables on track:

- May 2026 final cryostat review
- September 2026 completed documentation



Inductive ovens at LBNL


Science

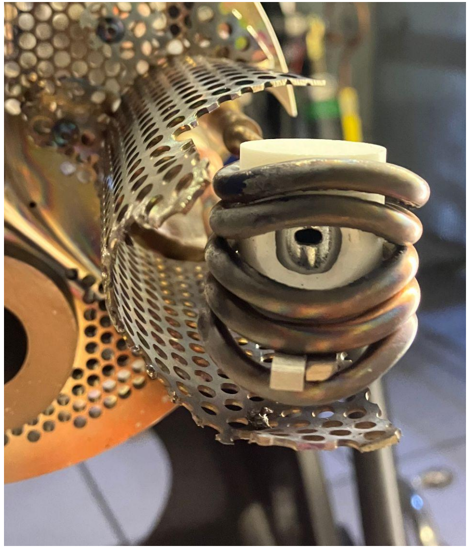
NEWS | PHYSICS

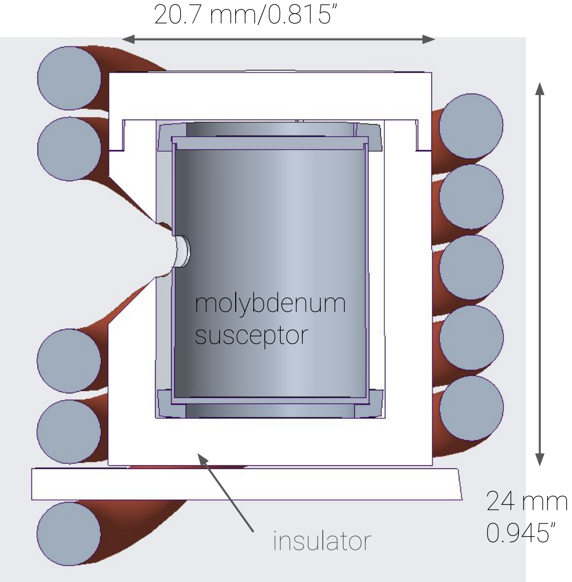
U.S. back in race to forge unknown, superheavy elements

Two atoms of element 116 demonstrate path to hunt for element 120 and extend the periodic table

23 JUL. 2024 • 5:00 P.M. ET • BY ROBERT F. SERVICE

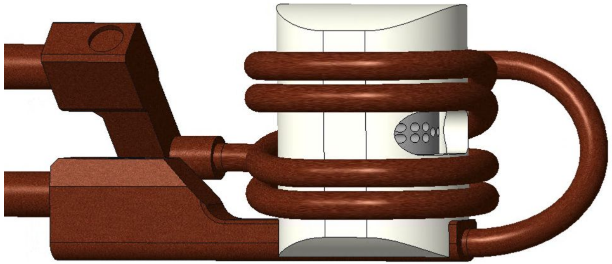
Jacklyn Gates leads superheavy element research at Lawrence Berkeley National Laboratory. MARILYN SARGENT/ LAWRENCE BERKELEY NATIONAL LABORATORY

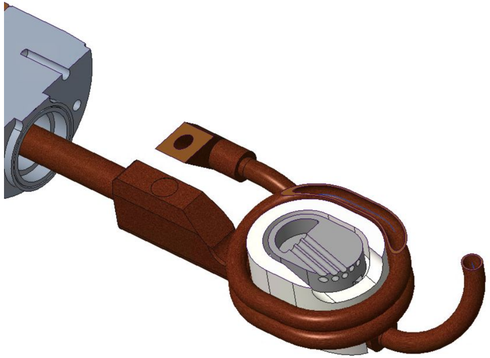


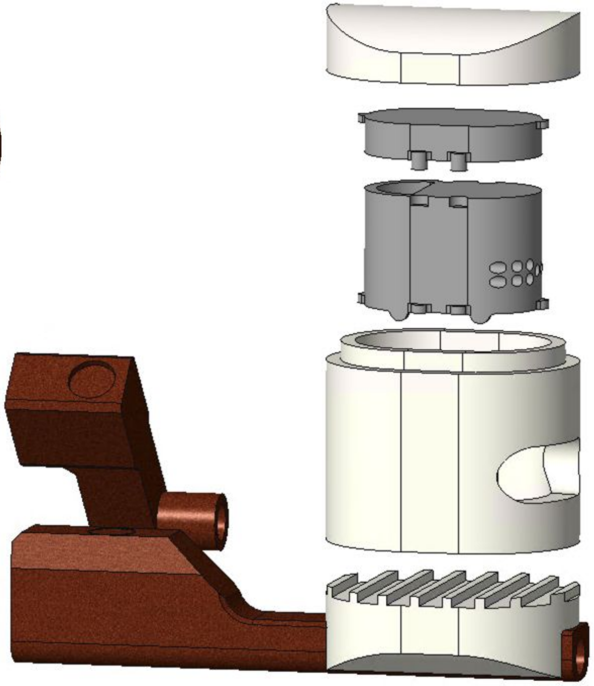


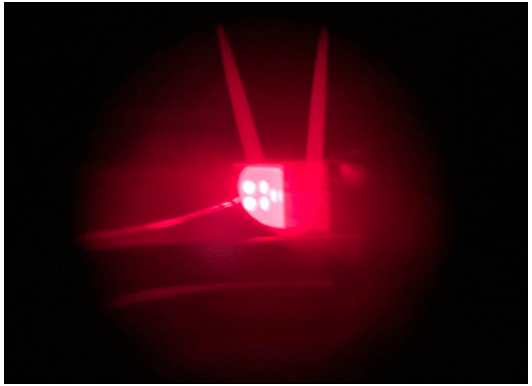
- up to 200 μA $^{50}Ti^{12+}$ beams from VENUS, 23.5 μA from cyclotron
- two element 116 particles produced, setting stage for 120 search
- goal: drop 50Ti consumption rates by 70-80% from ~4 mg/hour

Inductive oven development



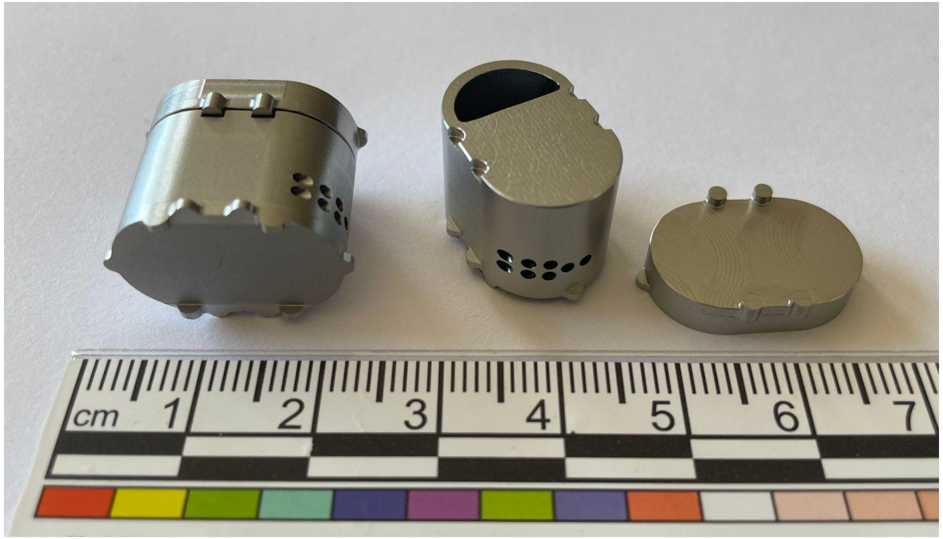






Experimental tests in 2025 of this type of oven showed exit holes hotter than surroundings

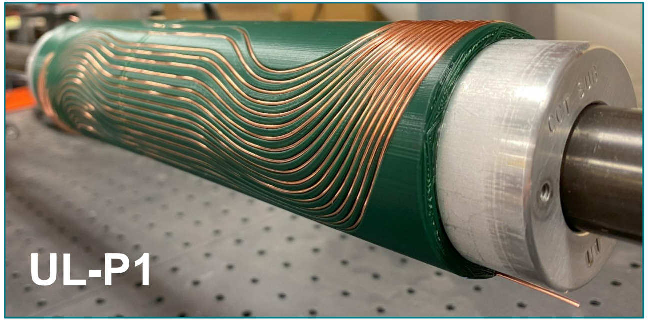
Inductive oven status

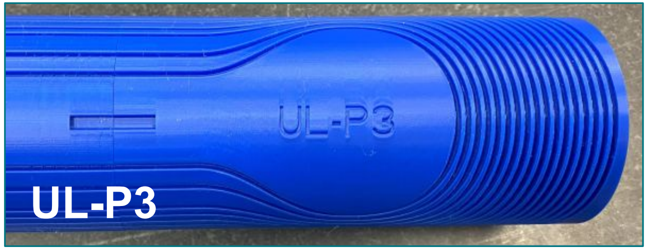


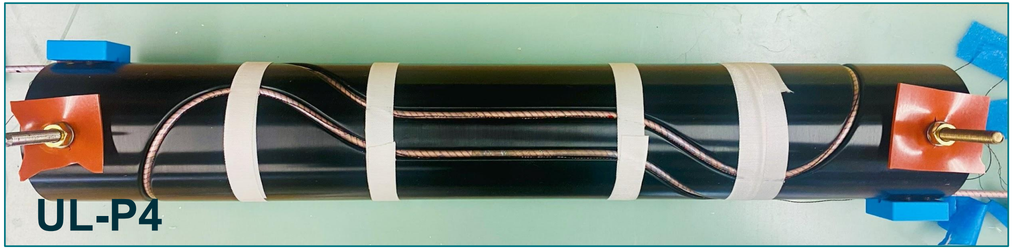
Major deliverables:

- December 2024: Design and construct aiming oven
  - Initial design designed and constructed on time
  - New design constructed November 2025
- May 2025: aiming oven test
  - Initial test: April 2025
  - New test: November 2025
- April 2026: Rhenium oven construction on track
- September 2026: Uranium beam production on track

Beyond MARS-D: Future ECRIS design



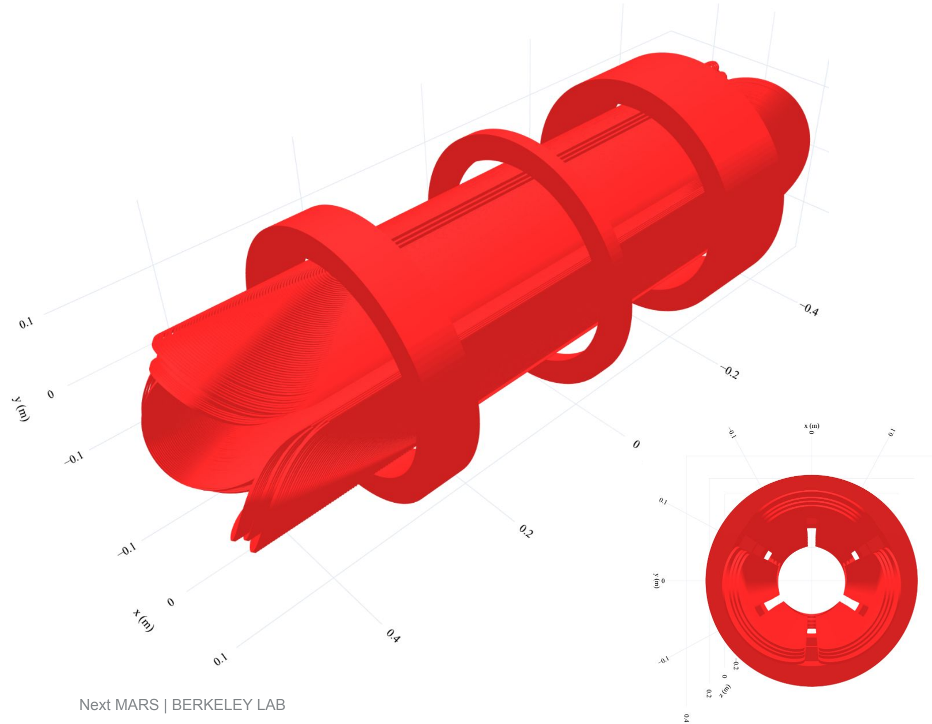




Apply uni-layer concept to ECR ion sources:

- Cable-in-groove simplifies manufacturing and assembly, similar to successful Canted Cosine Theta (CCT) developed at LBL
- Use multiple of these layers to form closed loop coil

To 60 GHz with REBCO?



Main magnet design

- 4-layer REBCO sextupole, ID 200 mm.
- Each layer of the sextupole is powered independently to SSL.

Magnet system

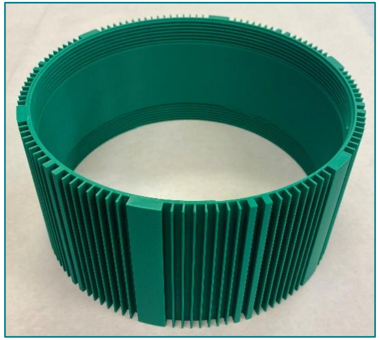
Frequency	60 GHz
B_{ecr}	2.14 T
B_{inj} (axial)	7.50 T
B_{mid} (axial)	1.71 T
B_{ext} (axial)	4.29 T
$B_{chamber}$	4.29 T

REBCO stack

Conductor type	see paper*
Tape thickness	0.1 mm
Stack width	4 mm
Stack thickness	2 mm
Number of tapes	20
Assumed B angle	⊥ (worst)

*Hilton, D. K., A. V. Gavrilin, and U. P. Trociewitz. *Superconductor Science and Technology* 28.7 (2015): 074002.

Beyond MARS: technology development

Segmented

- Segmented cable support design has been completed
- Design reduces overall manufacturing complexity and cost for final CNCed (computer numerical control) aluminum mandrel

Major deliverables on track:

- January 2026: complete 3D design for future ECRIS
- September 2026: fully documented design for future ECRIS

Expenditures by fiscal year

	2022 FOA		2024 FOA		
	FY23	FY24	FY25	FY26	Additional
Funds allocated (k$)	999	999	900	850	485
Actual costs to date (k$)	999	999	747	0	0

Thank you for your attention!