Fermilab | U.S. DEPARTMENT OF ENERGY | Office of Science

MAGIS-100 Design Progress and Challenges

Terrestrial Very-Long-Baseline Atom Interferometry Workshop 2024

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4 April 2024

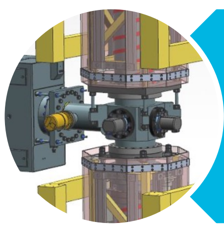
MAGIS-100

Overview

Experiment layout and site photos

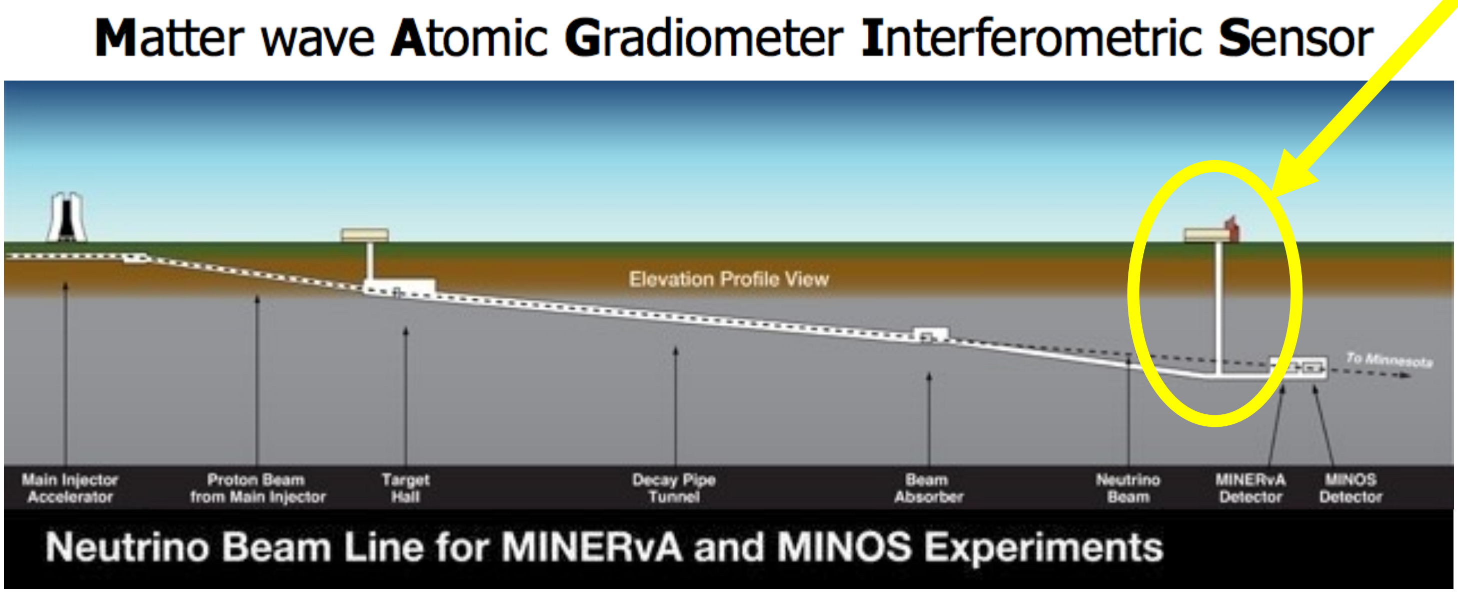
Construction in progress

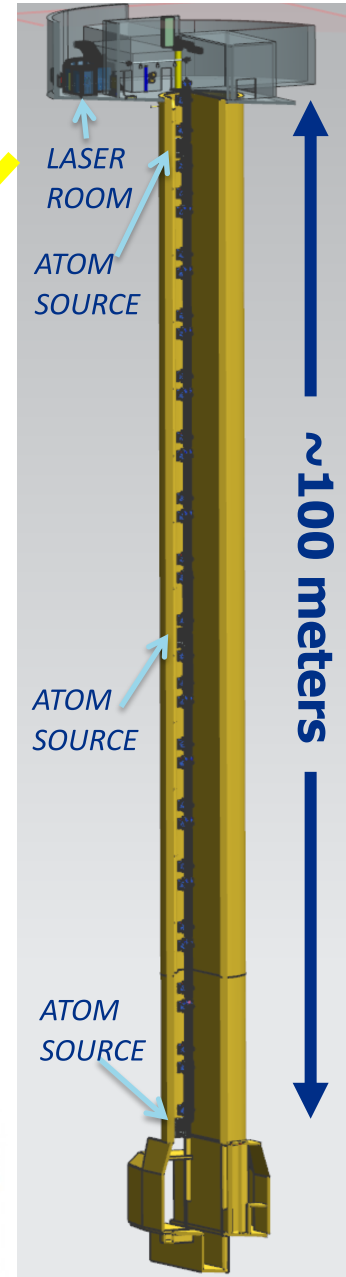
Installation and access challenges



System designs shaped by science and site

MAGIS-100 experiment design overview

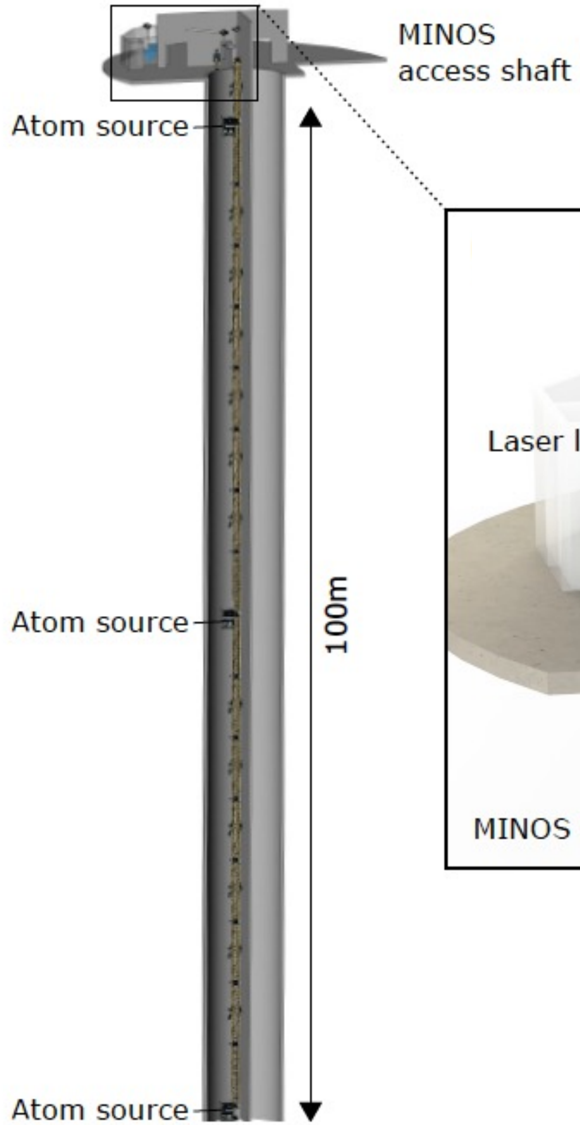


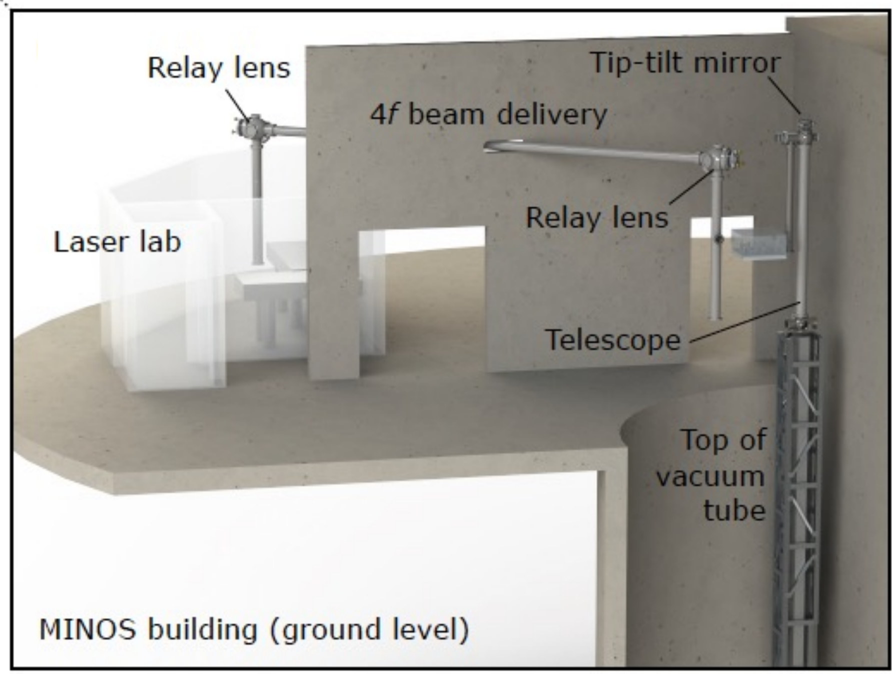


- 100-meter baseline atom interferometry in existing shaft at Fermilab
- Major sub-systems:
  - Clock atom sources (Strontium) at three positions
  - Interferometry laser system
  - 100-meter vacuum system and infrastructure

Stanford, Johns Hopkins University, Northwestern University, Fermilab, SLAC, Old Dominion University, University of Cambridge, Northern Illinois University, University of Oxford, University of Liverpool

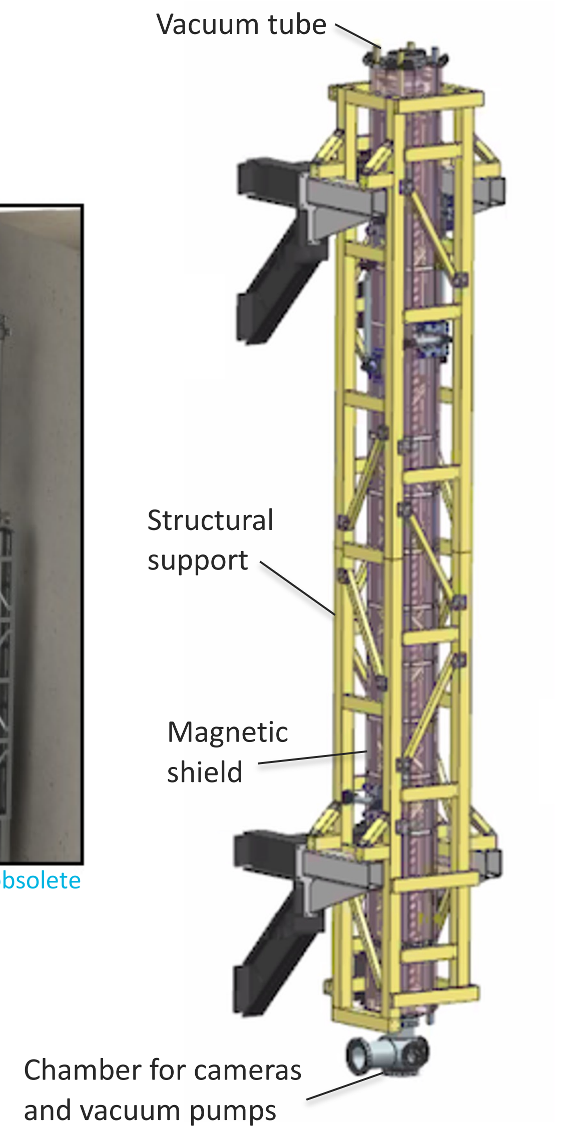
Systems overview



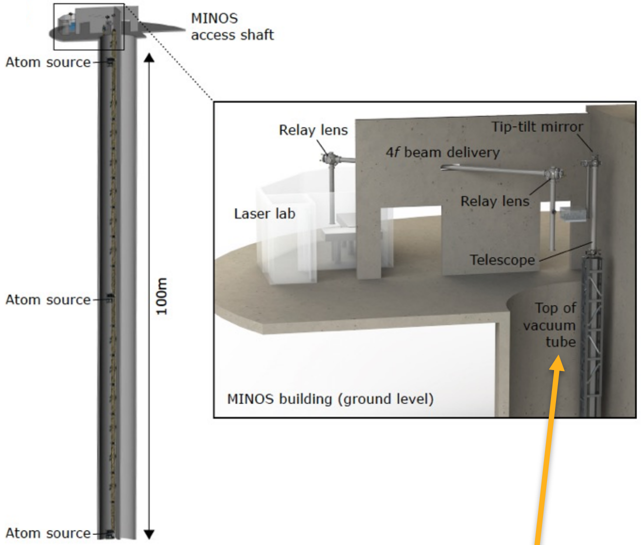


Some geometric details above are obsolete

In shaft:
3 atom sources
17 modular sections
1 mirror at bottom
2 vacuum roughing stations



Site – MINOS building



Laser lab being built behind this wall.

Ground level of MINOS building.

Site – shaft in MINOS building

Top and bottom of ~100m shaft. Proposed experiment location follows orange line.

Site – shaft in MINOS building

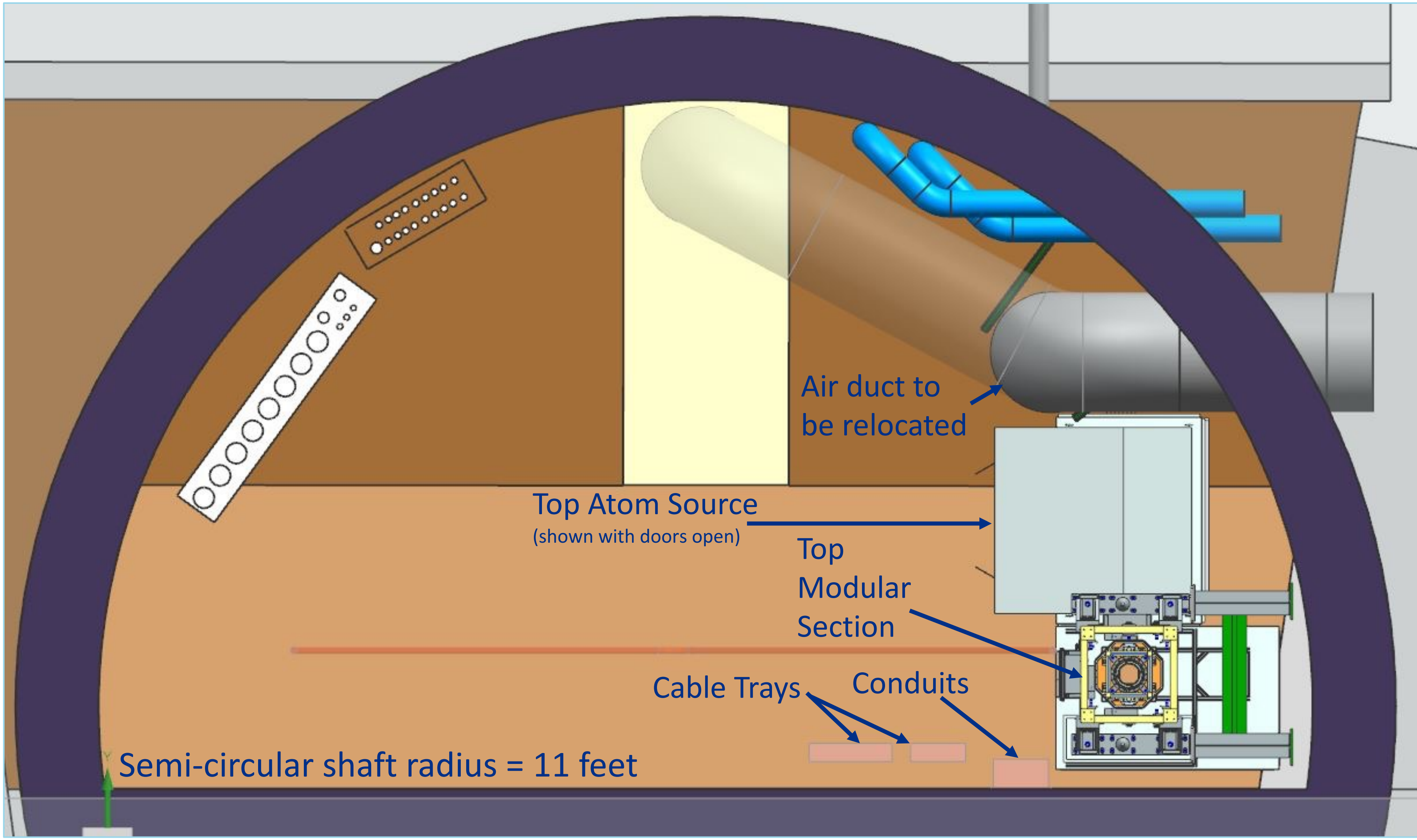
View from the top, perspective aligned with experiment location.

View looking up from inside shaft.

Challenges include:

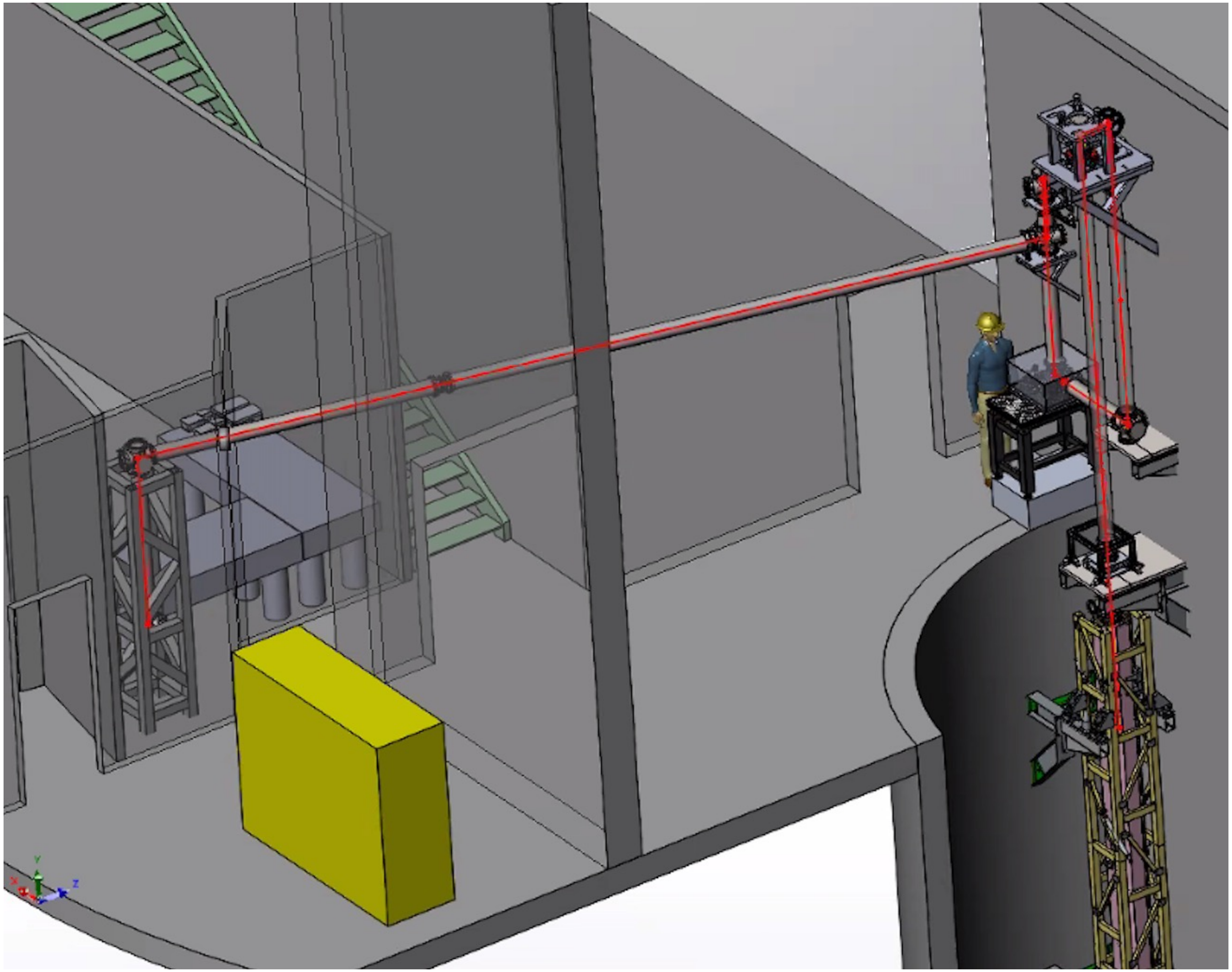
- **Small space**
- **Must accommodate other uses of shaft**
- **Curved wall for load bearing**
- **Environmental (water, thermal gradients)**
- **Installation and access (more on this later)**

Component layout in the shaft



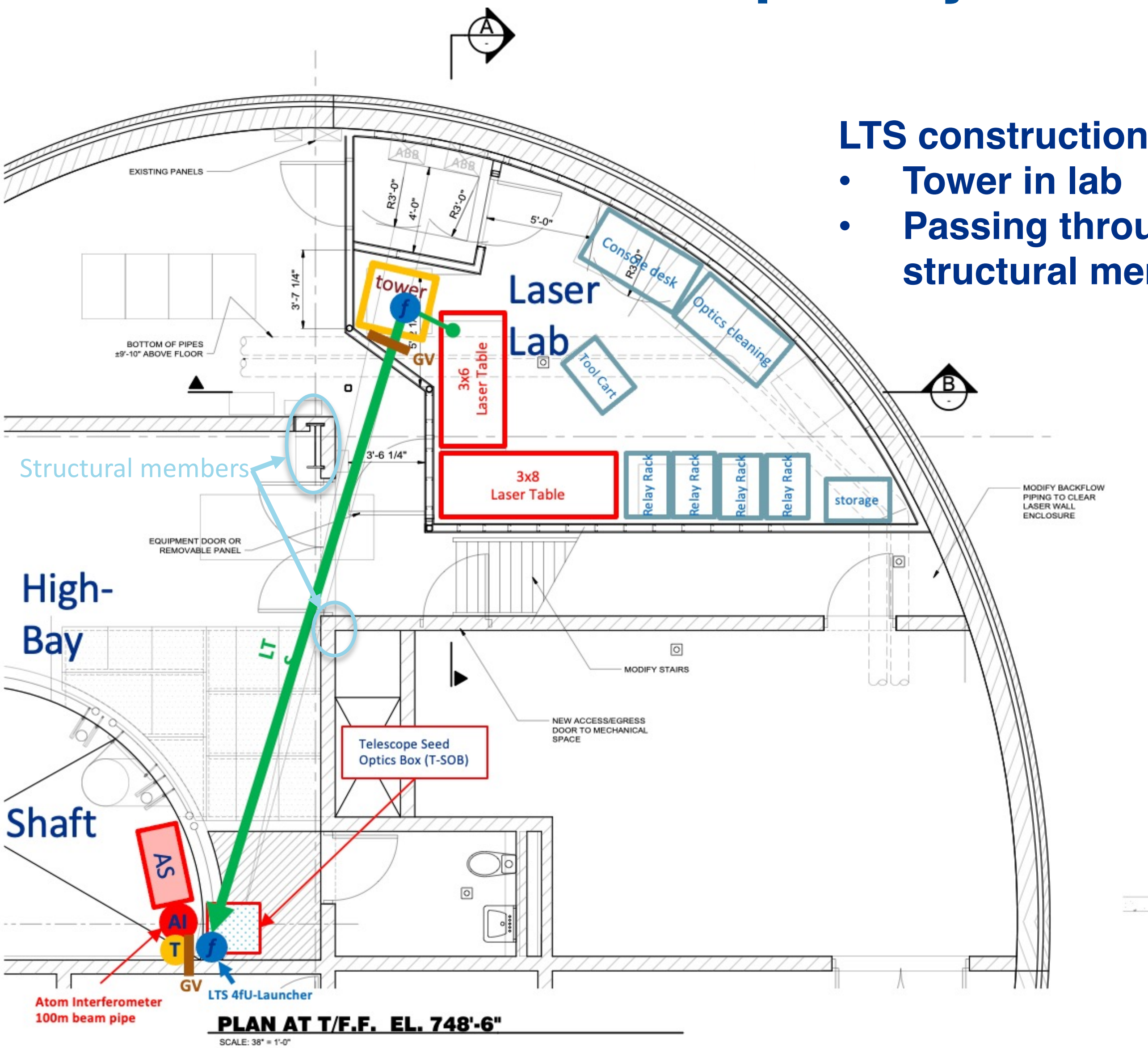
Plan view of the experiment in the shaft, without telescope shown.

Laser lab and laser transport system (LTS) layout



LTS optical route from Northwestern University team.

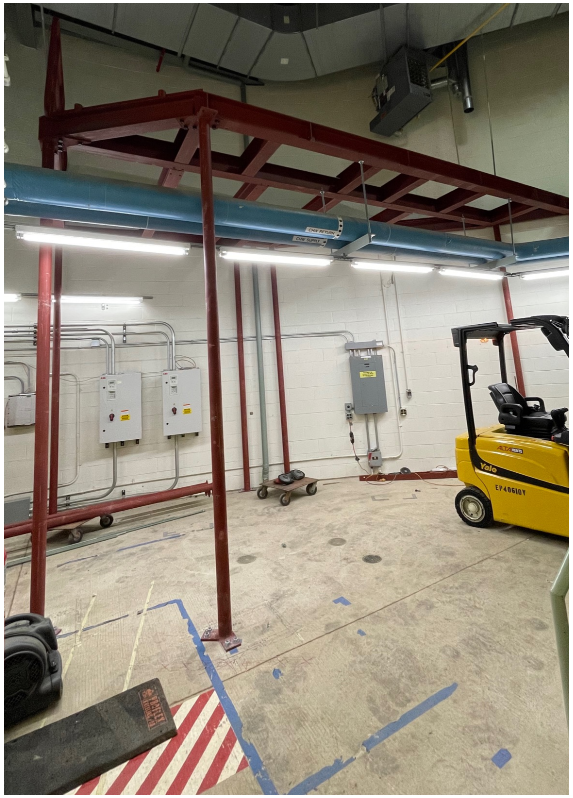
Laser lab and laser transport system (LTS) layout



LTS construction alignment challenges:

- **Tower in lab**
- **Passing through building wall between structural members**

Laser lab construction



Construction started in 2023.

Status April 2024.

Cutout for LTS to exit laser lab.

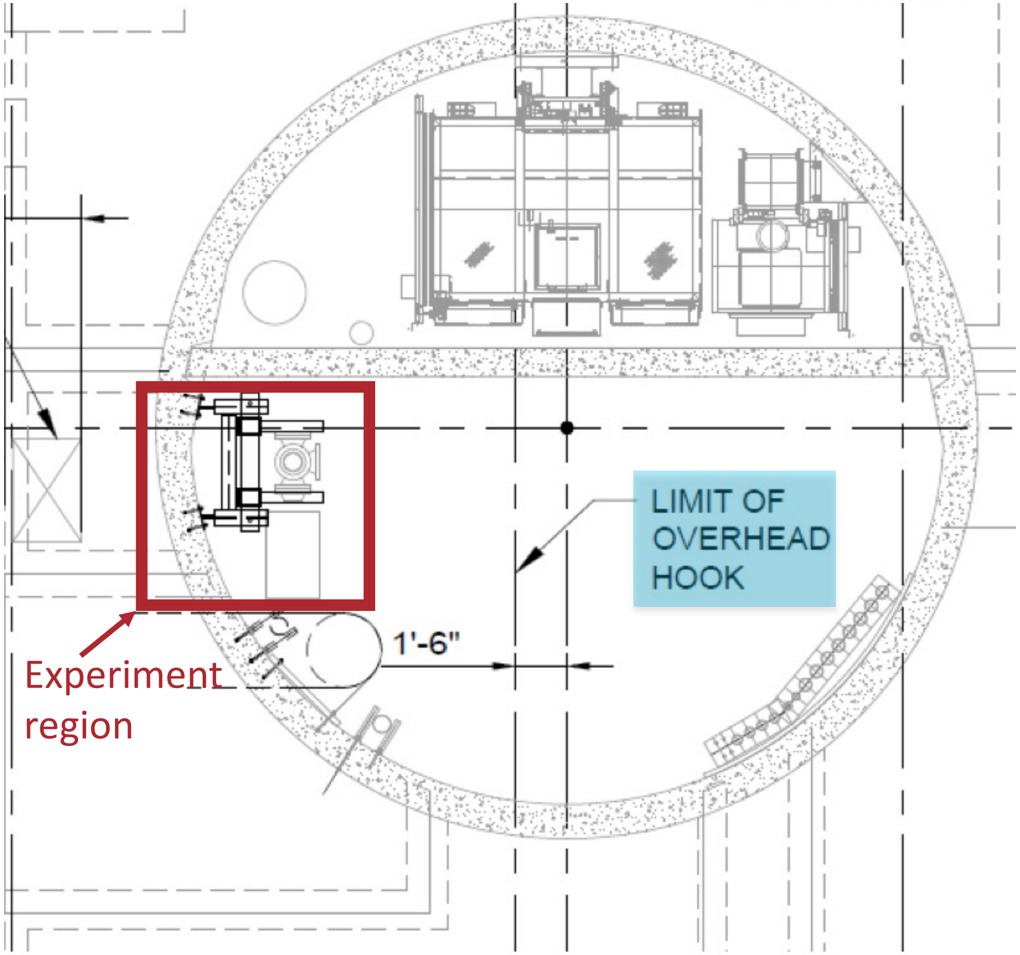
- **Optical tables and tower to be moved into room soon.**
- **Construction expected to be complete within 8 weeks.**

Welded tower and temporary construction opening in laser lab.

Installation challenges

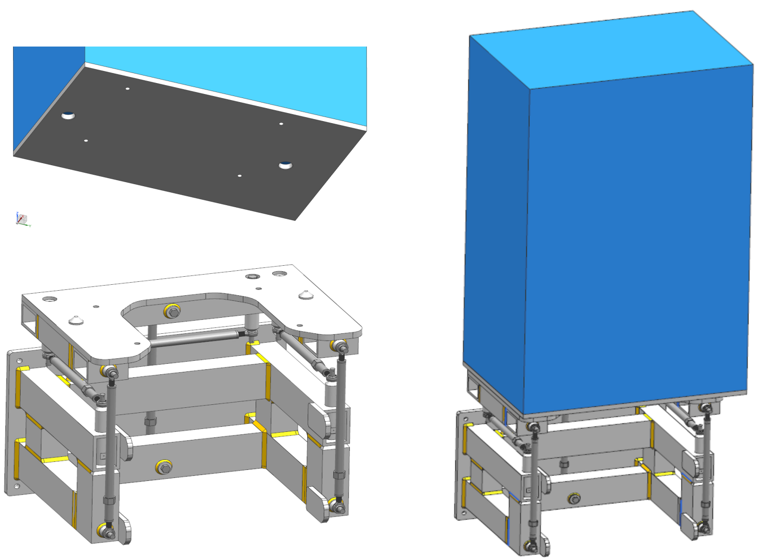
- **Vertical installation – the most obvious challenge.**
- **Added complexity – overhead crane does not reach experiment region.**


Crane unspooling into shaft.

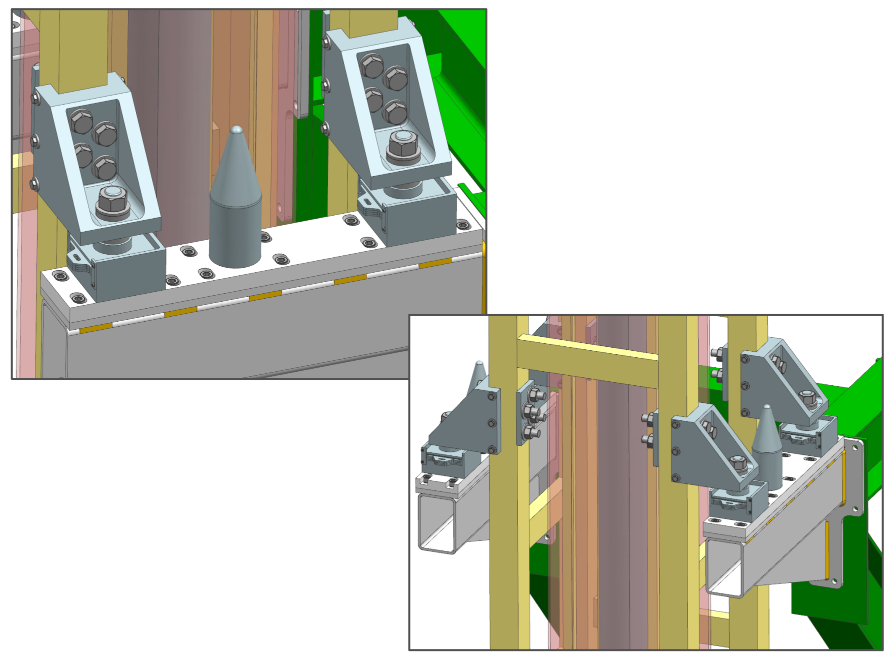


Component installation plan

- Wall supports will be installed through a civil construction contract.
- Conceptual plan to land components on wall supports with dagger system and cameras.
- Investigating rail systems, rolling carts, and other engineered methods for moving components accurately into place.
- Mock-up will be tested in advance of actual installation.



Atom source and adjustable wall support.

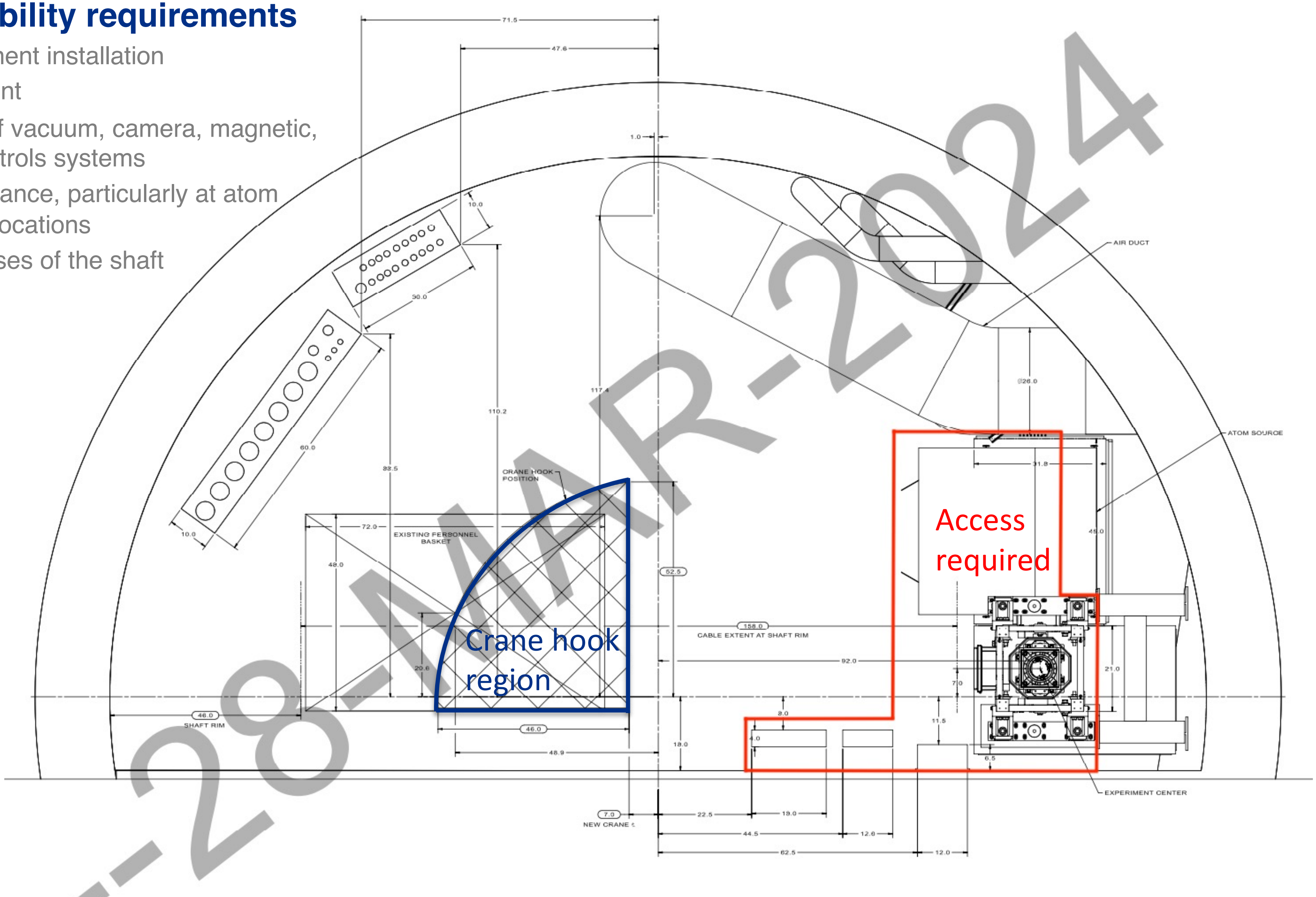


Modular section adjustable wall support.

Personnel access challenges

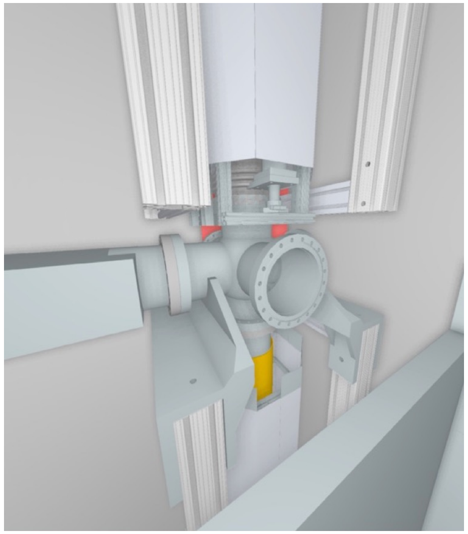
Accessibility requirements

- Component installation
- Alignment
- Setup of vacuum, camera, magnetic, and controls systems
- Maintenance, particularly at atom source locations
- Other uses of the shaft



Personnel access plan

- Confirming site space required by other users.
- Investigating concepts such as crane personnel basket, platforms, and motorized scaffolding systems.
- Virtual Reality (VR) model can confirm if components are able to be reached from access system or if special tooling must be designed.

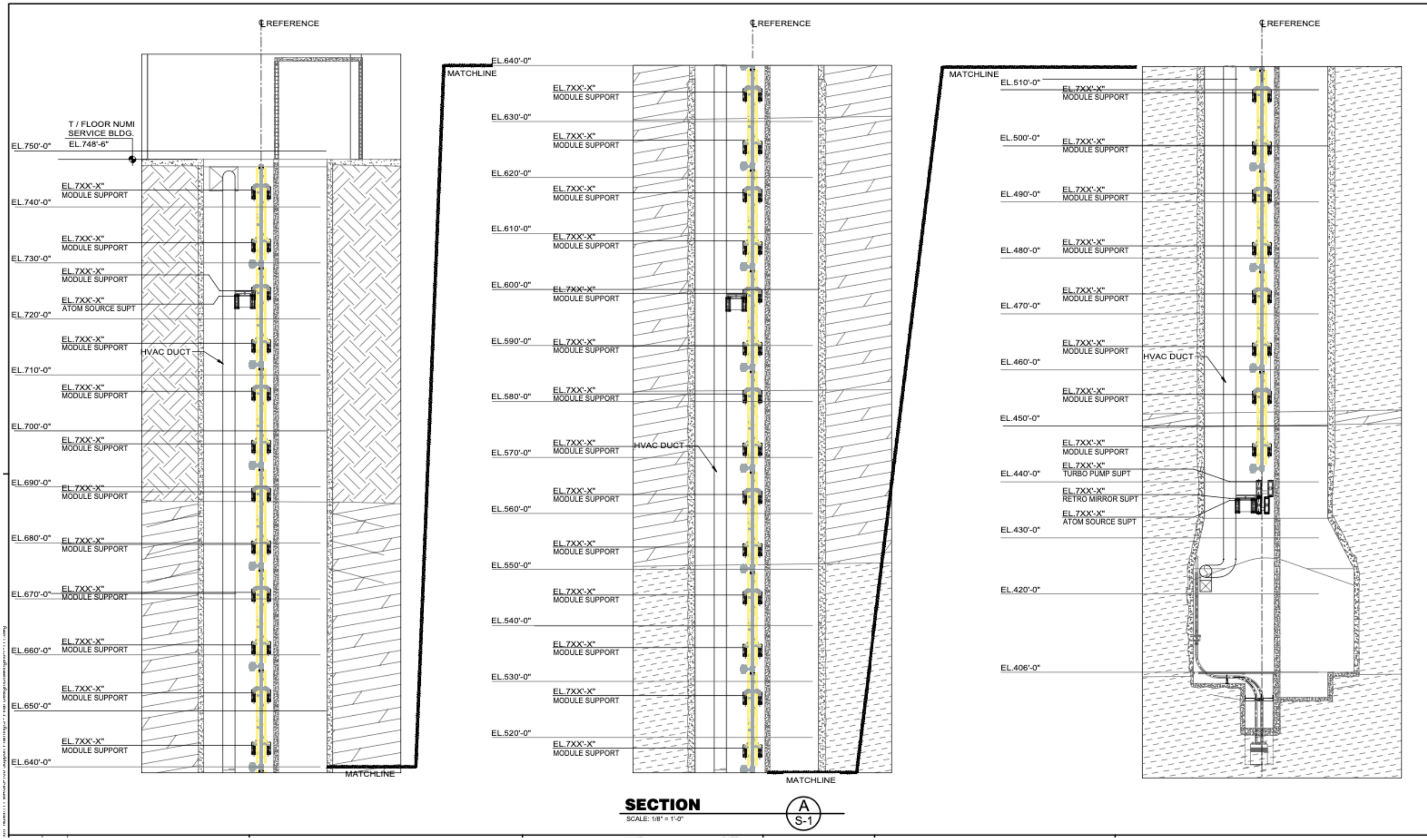


VR model image.

Existing personnel basket in use.

View from camera on top of personnel basket.

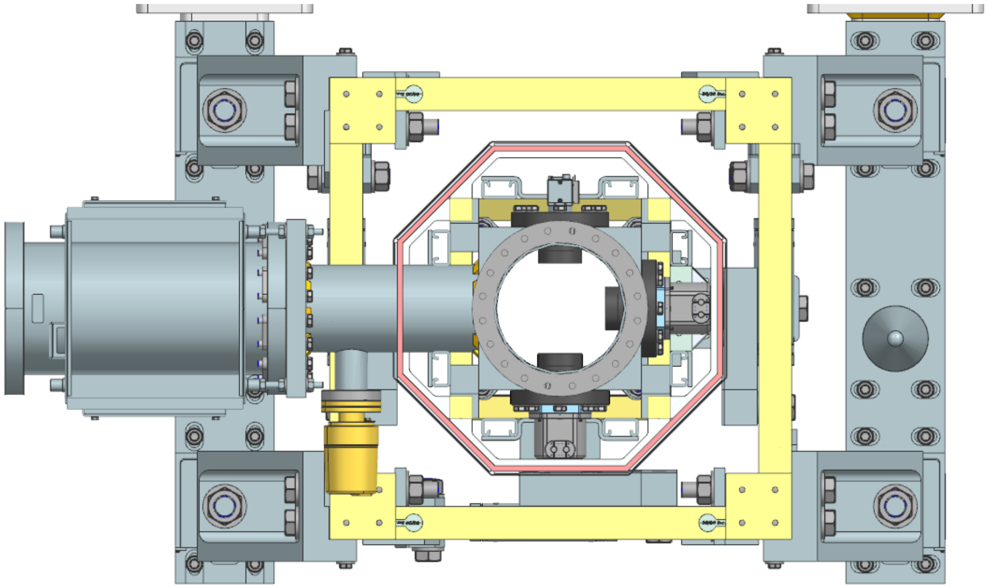
Civil engineering designs



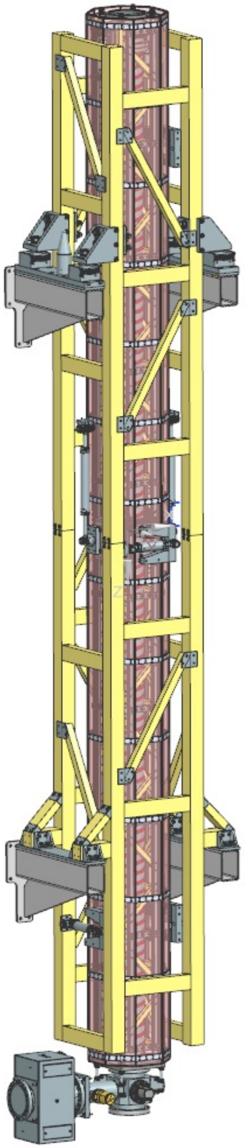
- **Preliminary drawings developed for installing shaft components.**
- **Compressed air and cooling water designs started, requirements to be finalized.**
- **Air duct relocation investigation started.**

Modular section design

- Modular assembly concept uses 17 sections, each ~5.2m (17') long and ~2,000 lb. weight.
- Eight sections between each atom source and one section above the top atom source.
- Each section has a support frame containing a 6" diameter vacuum tube, heating/insulation system with controls and temperature sensors, bias field coils, octagonal mu metal shield with support frame, and magnetometer.
- Vacuum pumps and viewports with cameras will be placed between tube sections.

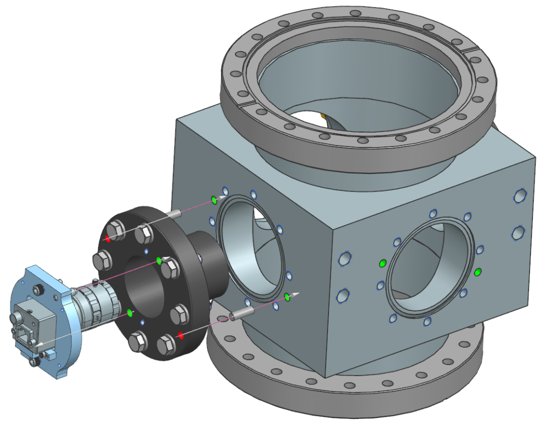


Cross section view.

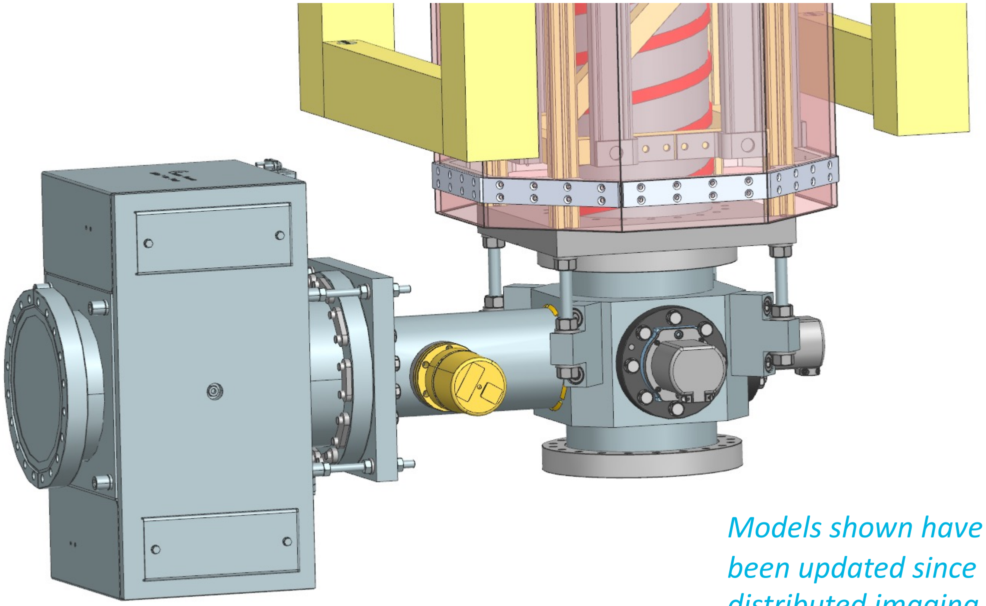


Single module with adjustable supports.

Modular connection node design

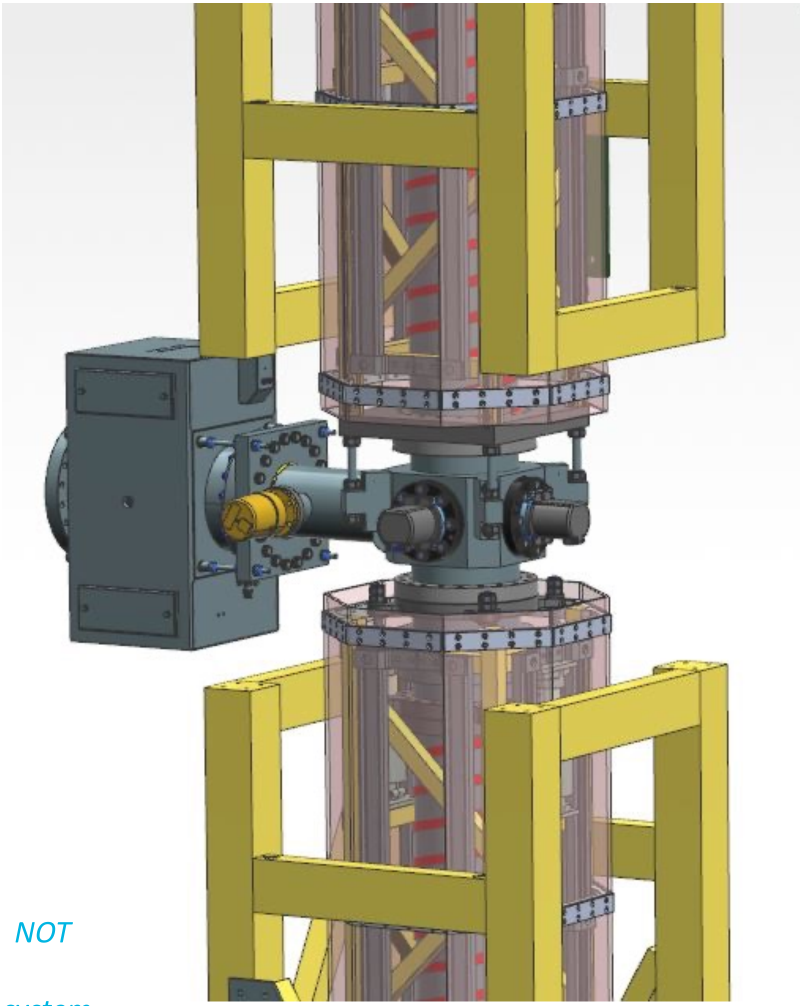


Cameras mount inside re-entrant viewports with light tight covers.



Detail of modular connection node.

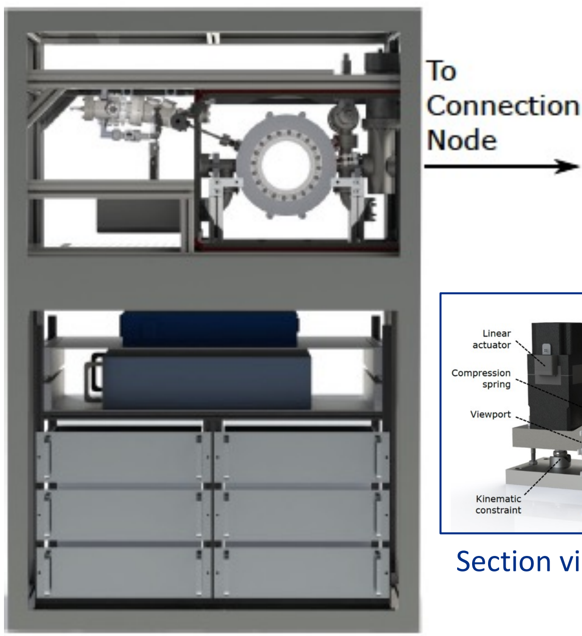
Models shown have NOT been updated since distributed imaging system (DIS) design review 8/1/23.



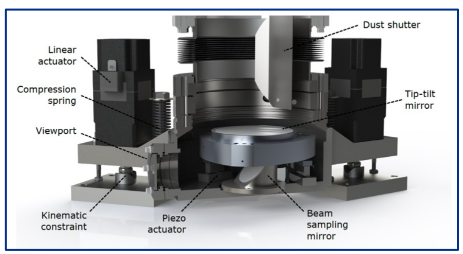
Two modules connected.

Atom sources

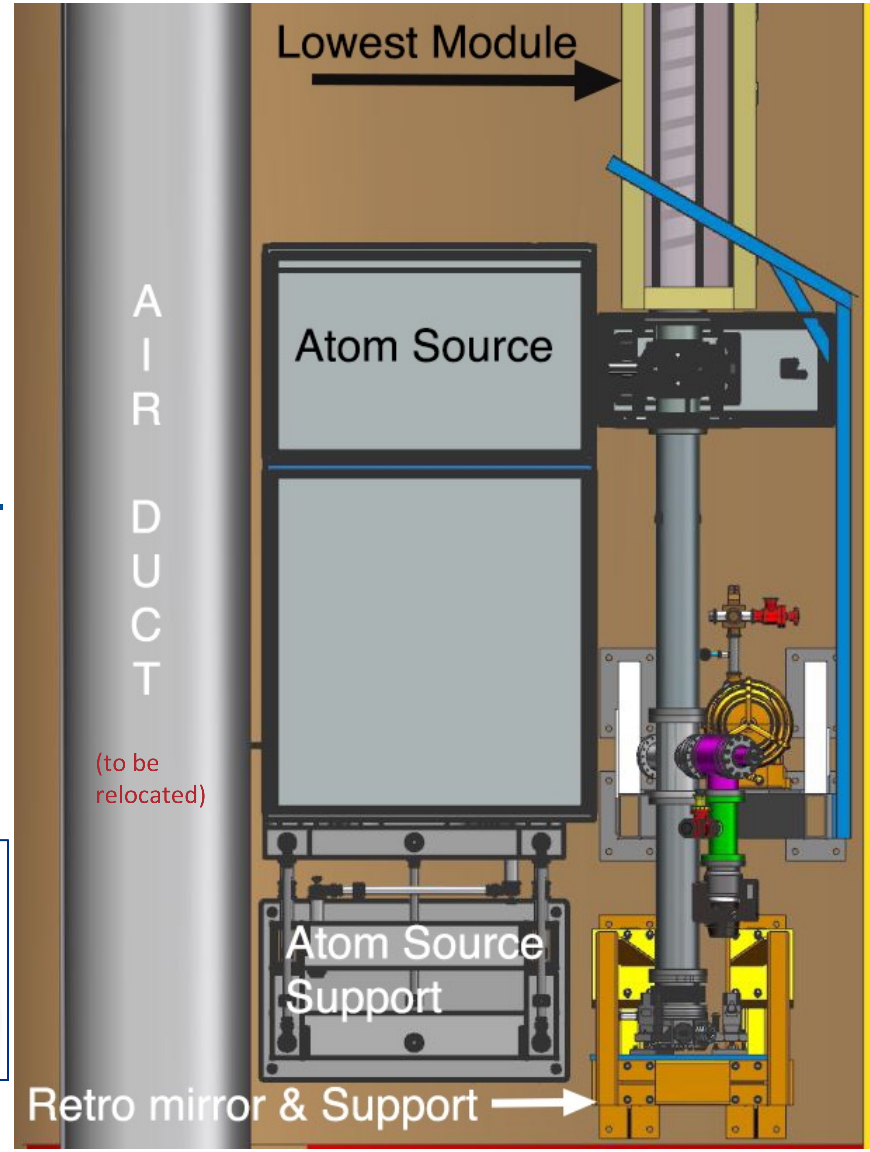
- Up to 1,000lb weight.
- Top, middle, and bottom of shaft.
- Last components installed.
- Approximate cost $1M each.
- Designed and built at Stanford University with access challenges considered.
- Transportation will be planned and tested.



Atom source detail.

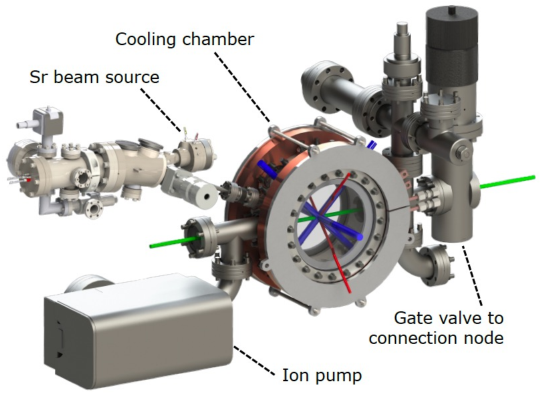


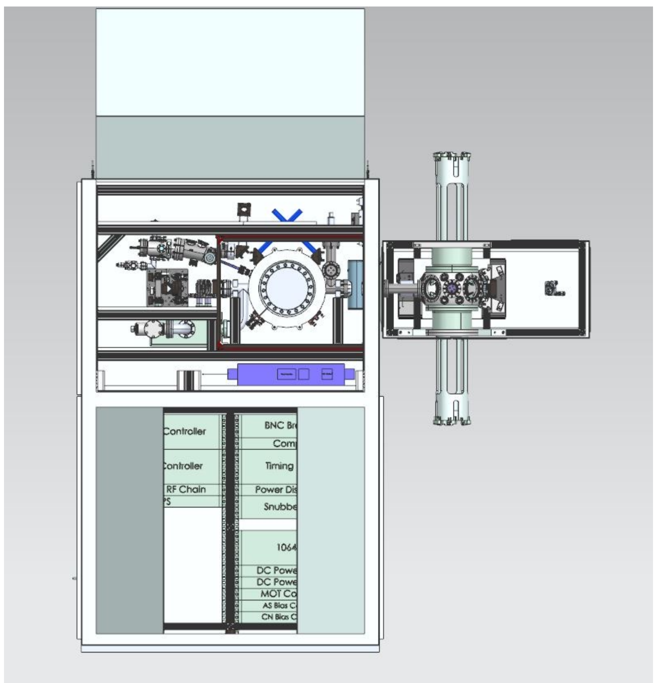
Section view of retro mirror.

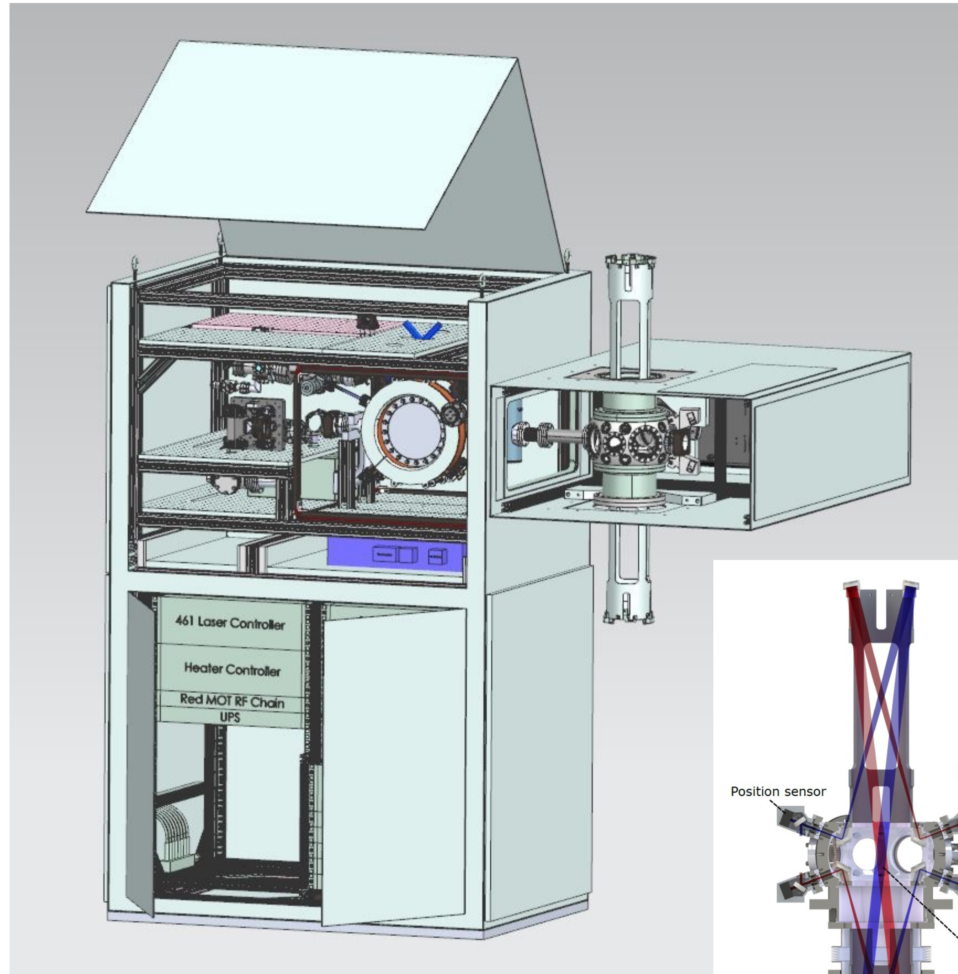


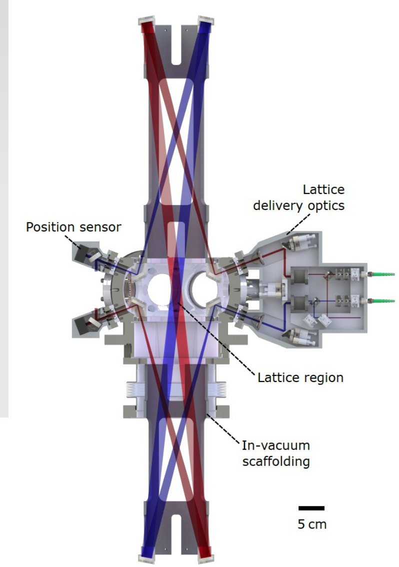
Bottom atom source, atom source connection node, vacuum rough pumping station, and retroreflective mirror shown.

Atom source design









Views inside the atom source enclosure and adjacent atom source connection node.

In-vacuum scaffolding extends into modular section vacuum tubes.

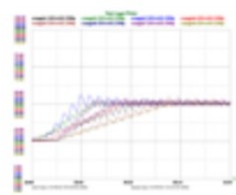
Ultra high vacuum (UHV) system

- **Required pressure e-11 Torr or better for interferometry region.**
- **Dual pumps (ion pump + titanium sublimation pump OR non-evaporable getter pump + small ion pump) will be on each modular section.**
- **Vacuum bake required to reach this pressure.**
- **Minimally magnetic 316L stainless steel tubes and non-magnetic heaters required.**
- **Tubes have been electropolished and will be hydrogen degassed.***

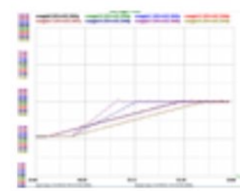
*Preparing magnetic measurements to determine if annealing necessary.

16-channel bake test setup.

Conclusion: no unexpected behavior, test is a success!



Temperature ramps SSR0-SSR7

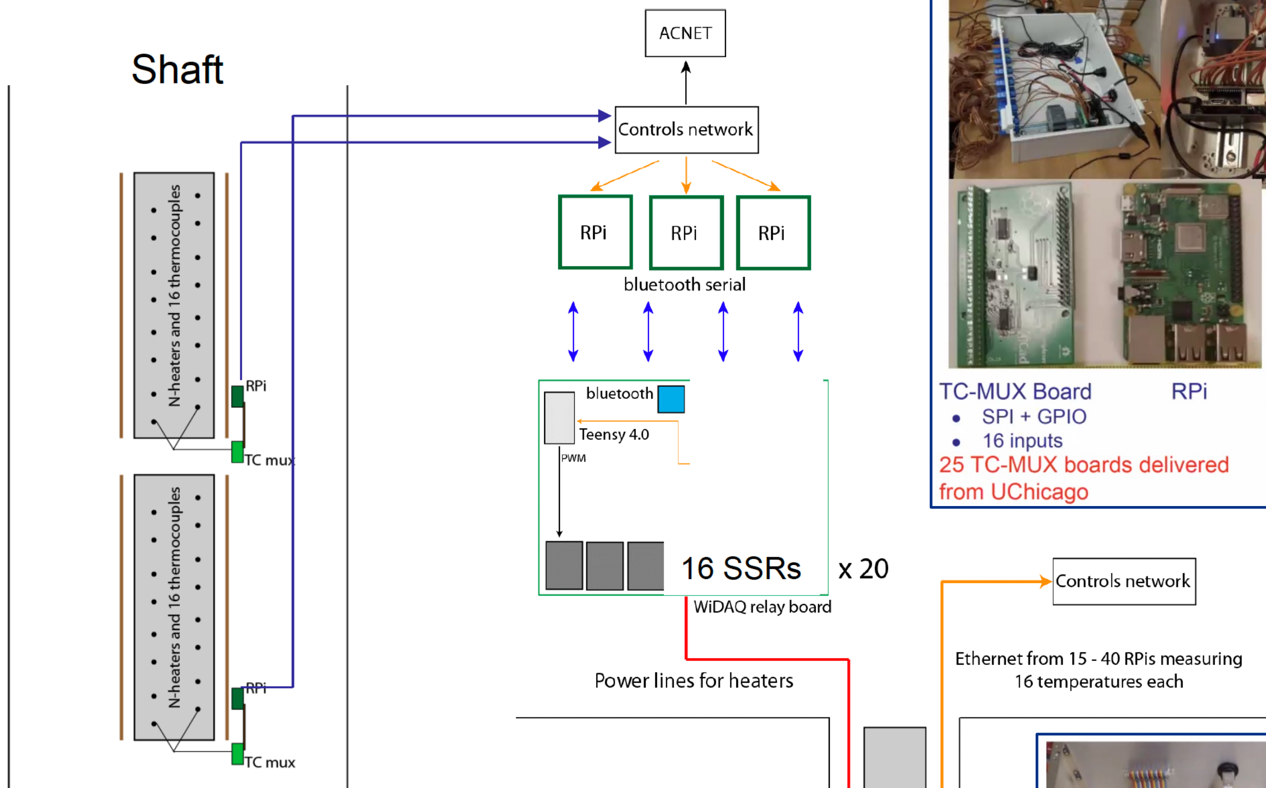


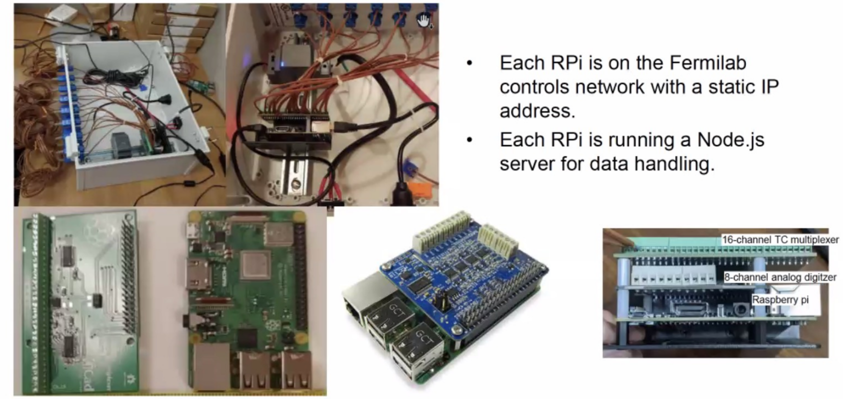
Temperature ramps SSR8-SSR15

Excerpt from bake test e-log.

6” OD vacuum tubes.

Bake out controls system





- Each RPi is on the Fermilab controls network with a static IP address.
- Each RPi is running a Node.js server for data handling.

TC-MUX Board
- SPI + GPIO
- 16 inputs

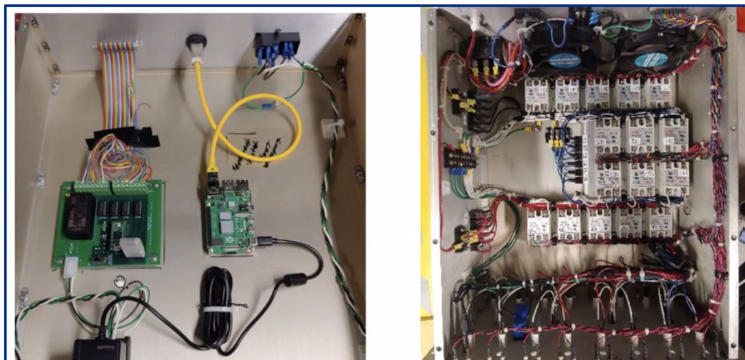
25 TC-MUX boards delivered from UChicago

RPi

MCC-118 ADC
- 8 analog inputs
- Stackable: expand to 64 channels

In shaft

Top of shaft



16-channel PWM

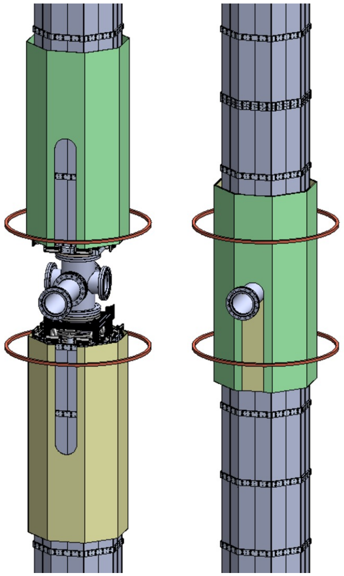
16-channel SSR

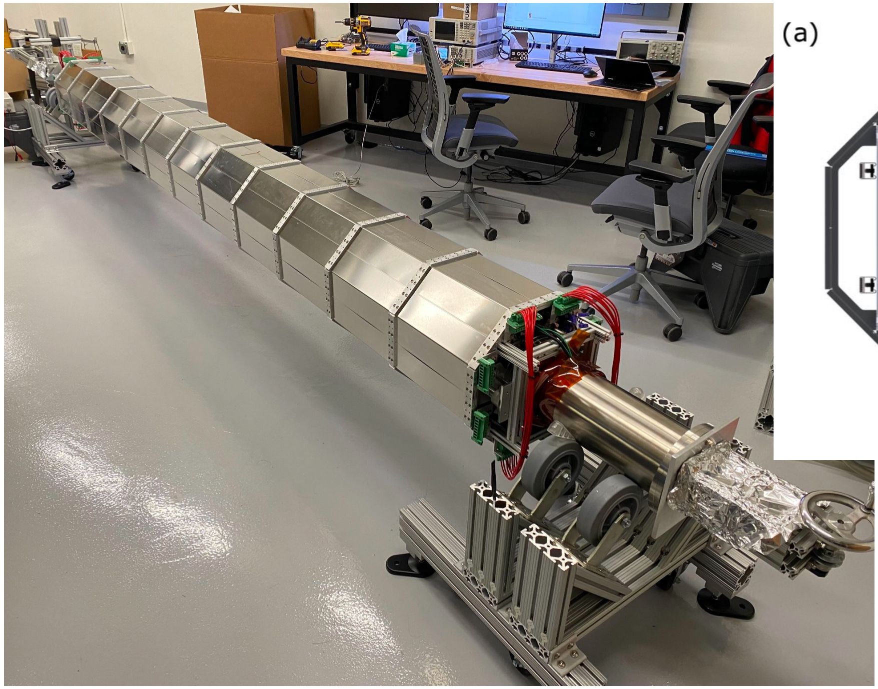
Bake controls system uses Raspberry Pis and thermocouples with a temperature module box on each section in the shaft and power control modules at the top of the shaft.

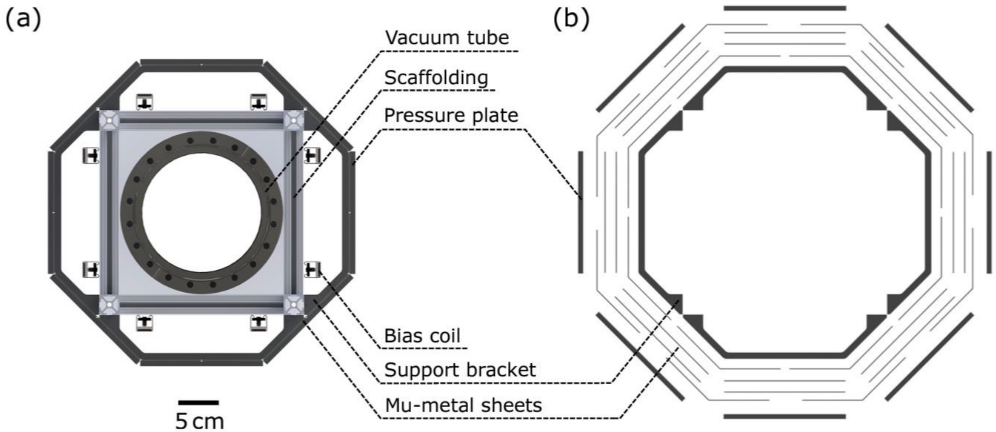
All images from Sergei Nagaitsev.

Magnetic field

- Magnetic field is controlled with mu metal shielding and optimally placed magnet coils.
- Mu metal cannot have mechanical stresses – creates magnetic “holes” in shield.
- Sections are longer than typical mu metal annealing furnaces.
- Adapted from an existing design, octagonal shield chosen with four layers of staggered seams using flat and angled pieces.
- Fixtures required for successful tight-fitting assembly.



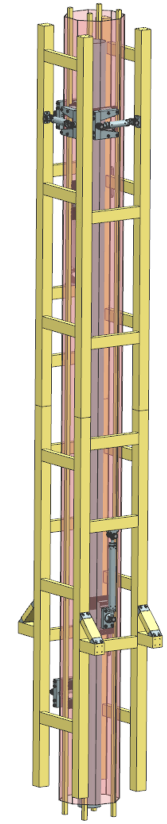


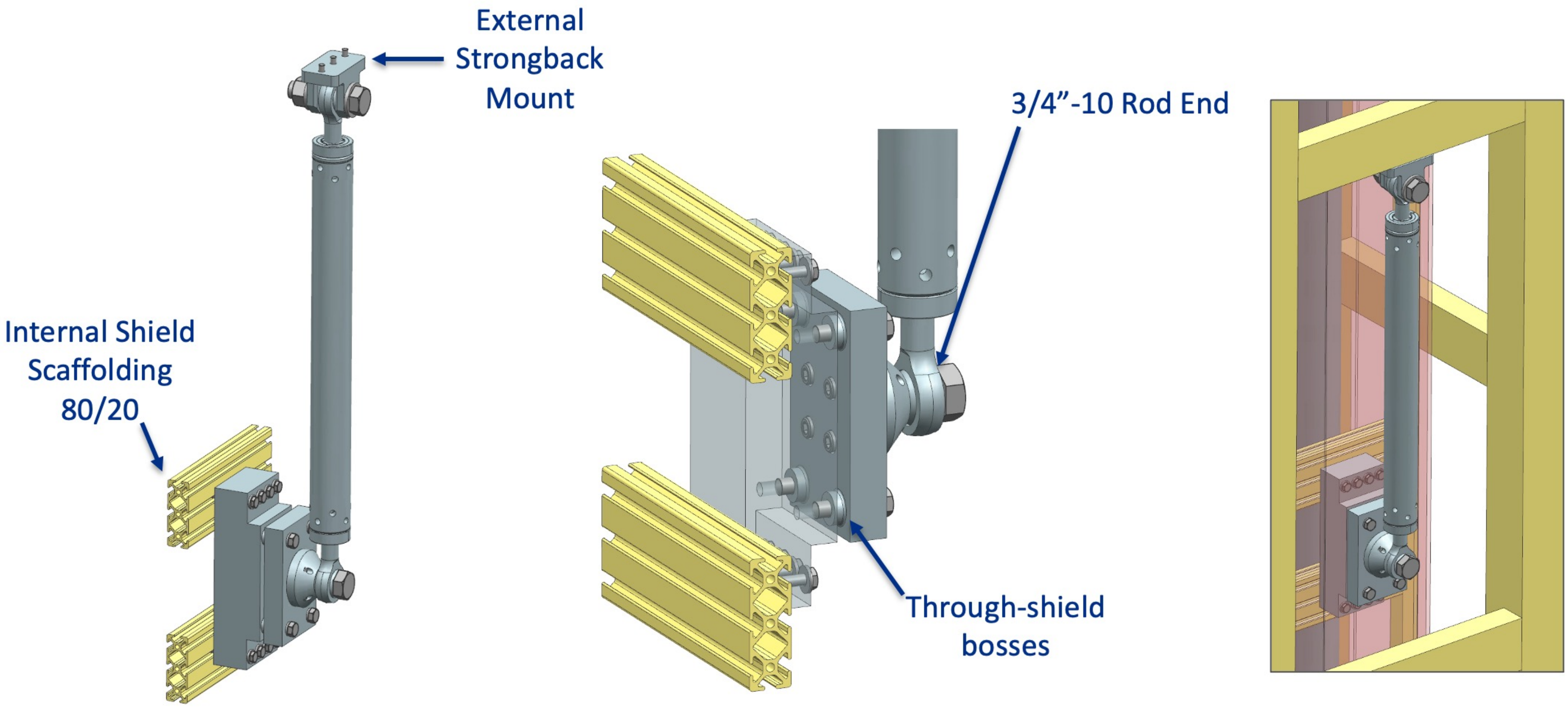


Left: Prototype section assembly at Stanford University 2022.
Above: Cross-section view of magnetic shield and bias coils.
Above right: Magnetic coupler and additional coils will be placed around modular connection nodes.

Structural challenges

- Adjustable supports required for alignment.
- Must minimize penetrations in magnetic shield.
- Six-strut system will be used for positioning modular sections inside frames, also for atom sources.
- Custom rod ends were ordered July 2022 because long lead time anticipated. Delivery expected May 2024.



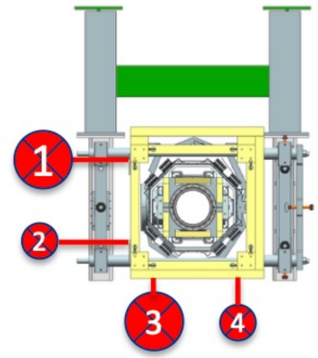


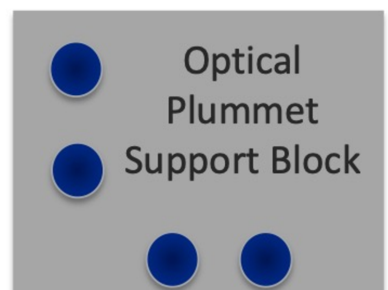
Fermilab MAGIS-100

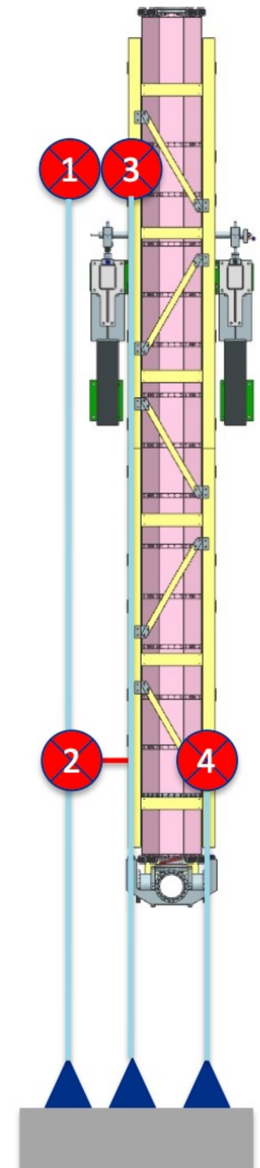
Alignment conceptual plan

Optical plummets will be mounted at the bottom of the shaft to achieve required alignment.

- **Mounting base must be sturdy.**
- **Bottom of shaft has metal plates which will flex and is also a “stay clear” zone. Original plan was to use concrete block.**
- **Consider if mounting base to elevator wall would work better.**







Summary

Site characteristics have significantly influenced designs for overall experiment layout and all sub-systems.

Installation and personnel access have been the most challenging engineering issues to address.

Despite challenges from both science and site requirements, designs for MAGIS-100 have been progressing well.

For additional information, visit magis.fnal.gov.