



Journey of the First Fermilab-designed PIP-II Cryomodule

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A Partnership of:

US/DOE

India/DAE

Italy/INFN

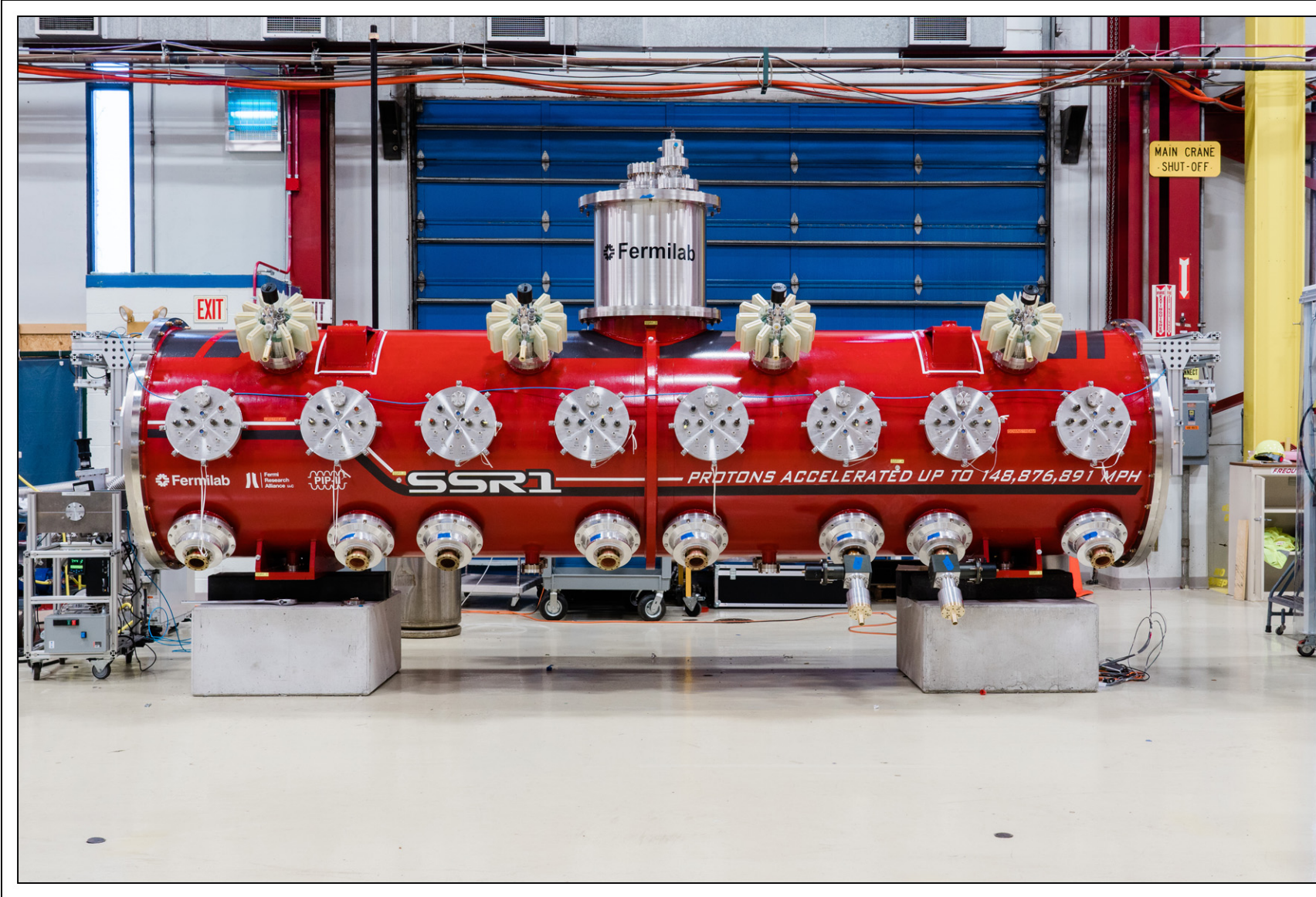
UK/UKRI-STFC

France/CEA, CNRS/IN2P3

Poland/WUST



First Fermilab-designed PIP-II Cryomodule

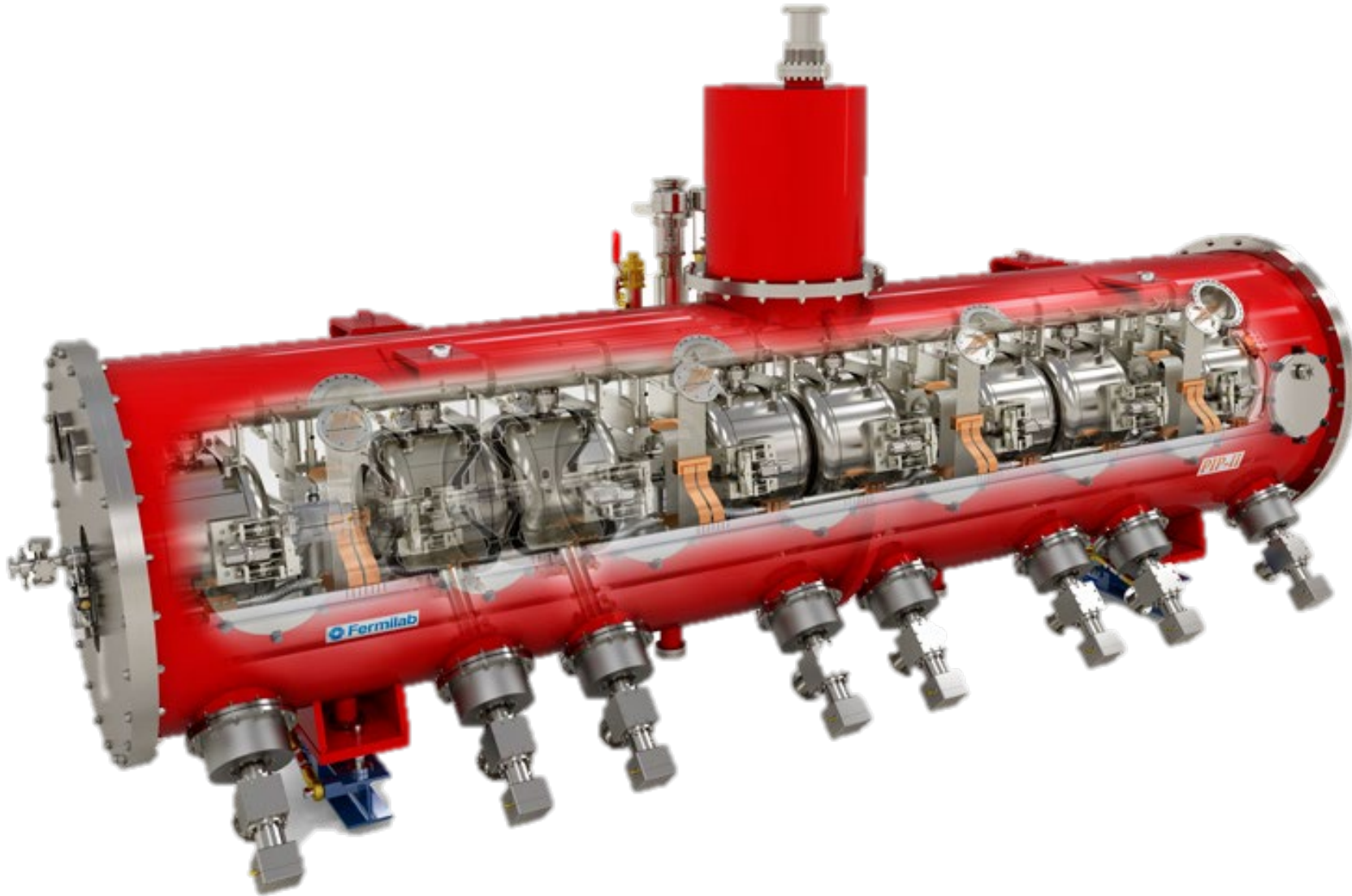


Prototype SSR1 Cryomodule

It is the first superconducting cryomodule fully designed, assembled and tested at Fermilab.

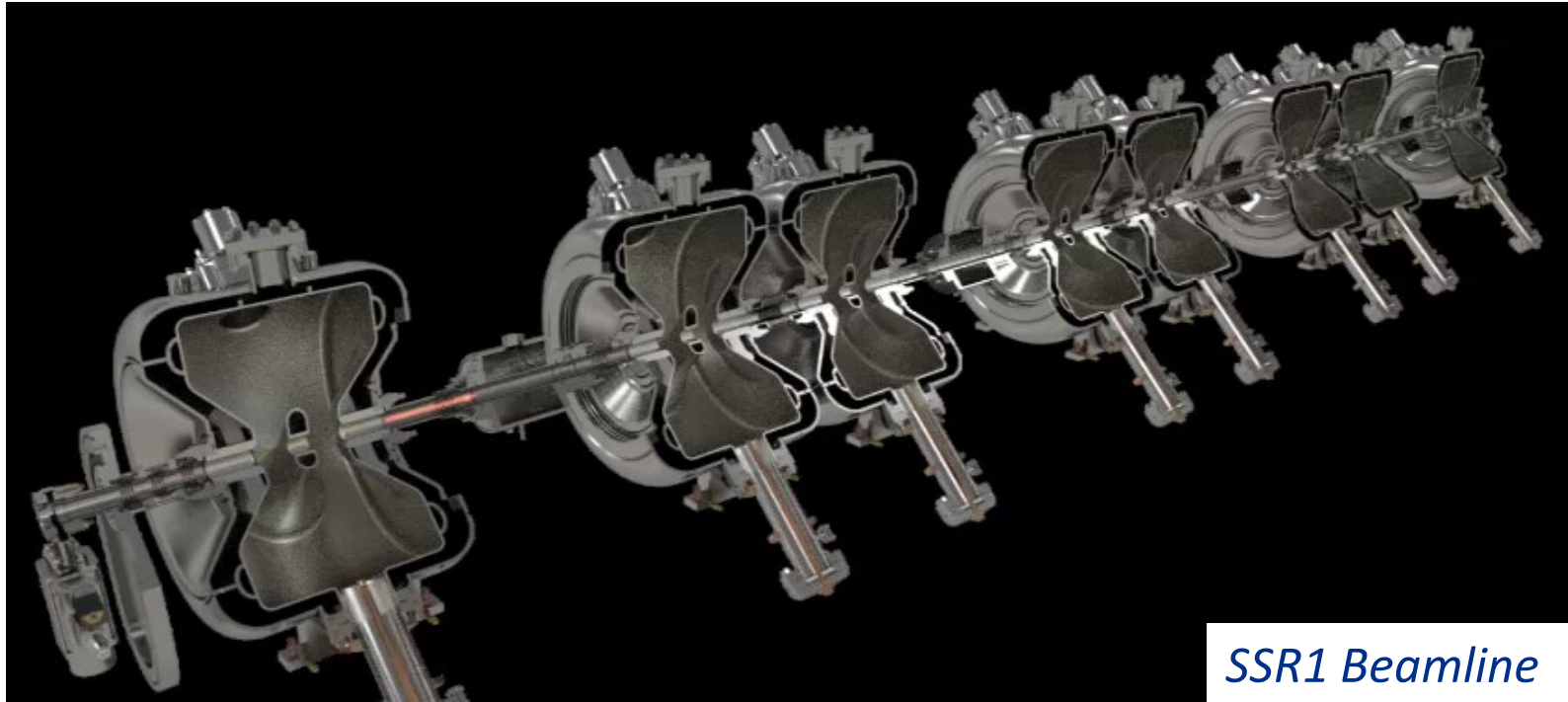
It represents a journey of technical challenges as well as opportunities for innovation in superconducting accelerator technology

Prototype SSR1 Cryomodule



- 8 superconducting Single Spoke Resonators type-1 (SSR1)
- 4 superconducting solenoids, correctors
- CM configuration: “Fine segmentation”

A Major Milestone for PIP-II and Fermilab

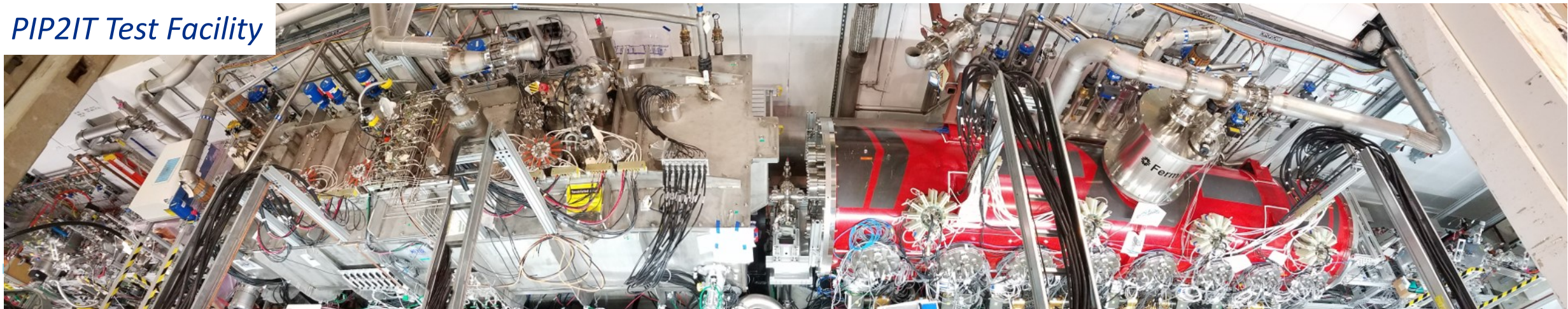


SSR1 Beamline

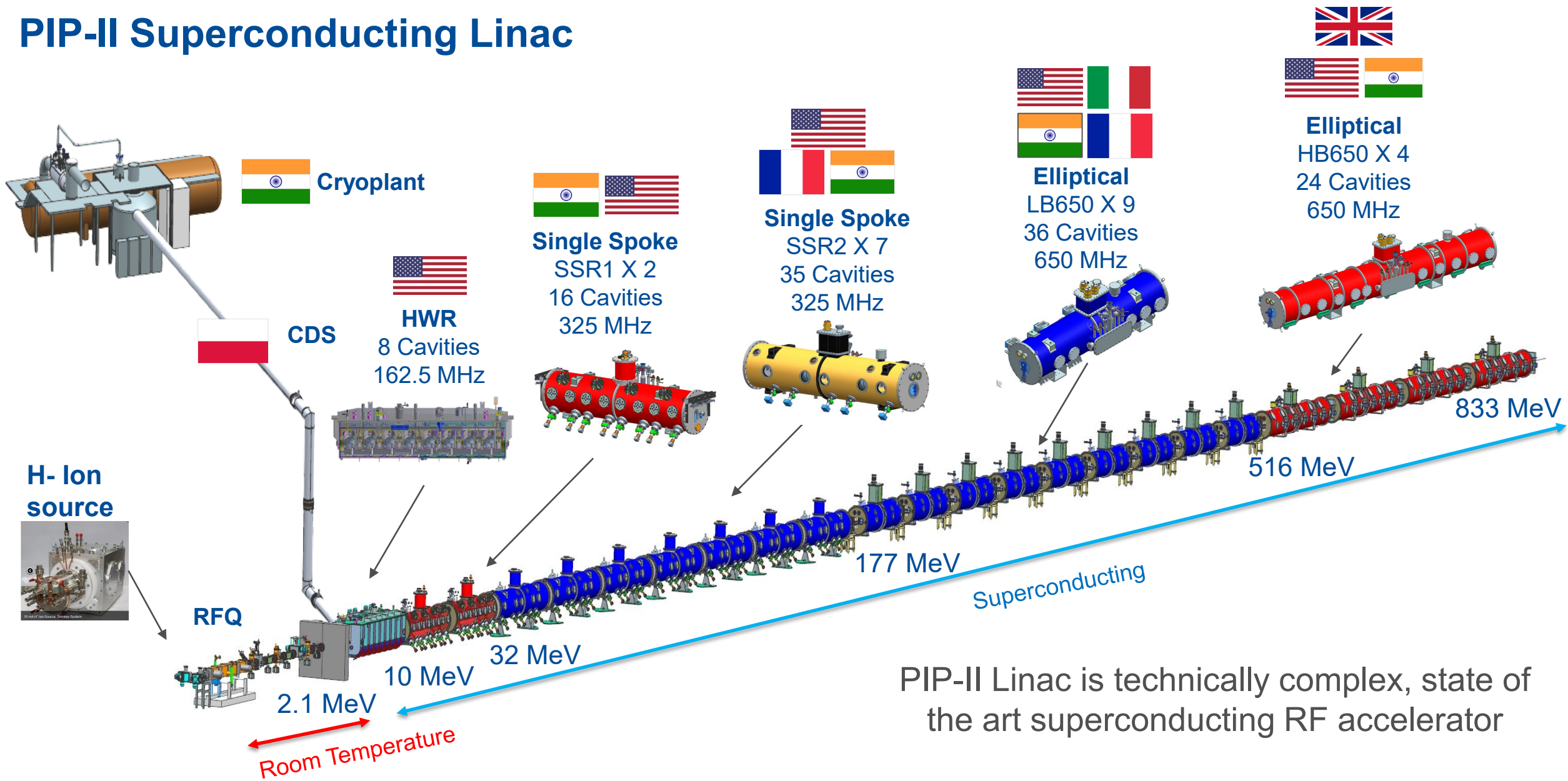
In January 2021, the phase-one testing of the prototype SSR1 Cryomodule was successfully completed at PIP2IT.

- Cavities and Solenoids cooled down to 2K and performance met project's requirements and accelerated beam*

PIP2IT Test Facility



PIP-II Superconducting Linac



PIP-II Linac is technically complex, state of the art superconducting RF accelerator

PIP-II is the world's highest energy and power CW proton linac, and the U.S. first accelerator project to be built with major international contributions



Main Injector

Transfer Line

PIP-II

SRF Linac

Booster

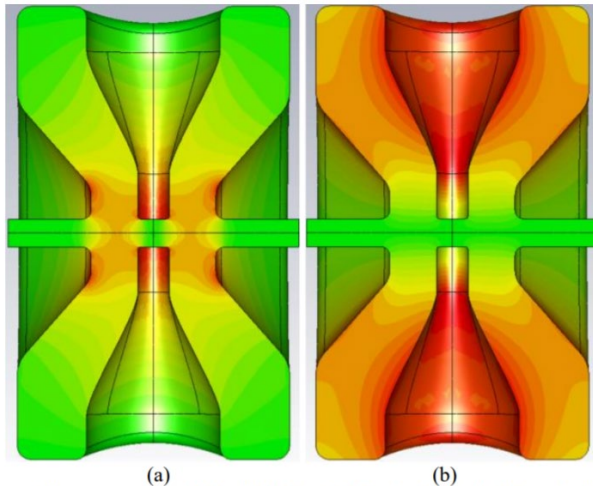
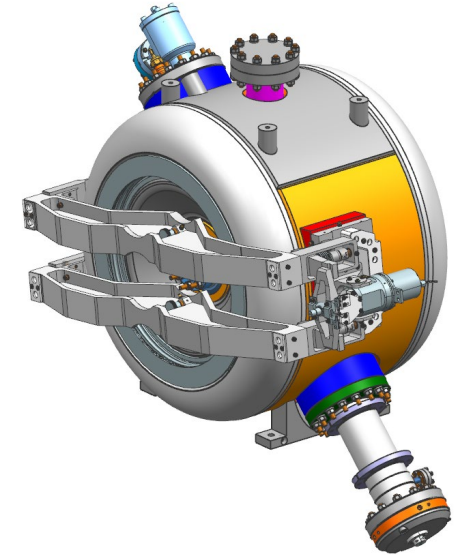
Turning challenges into opportunities



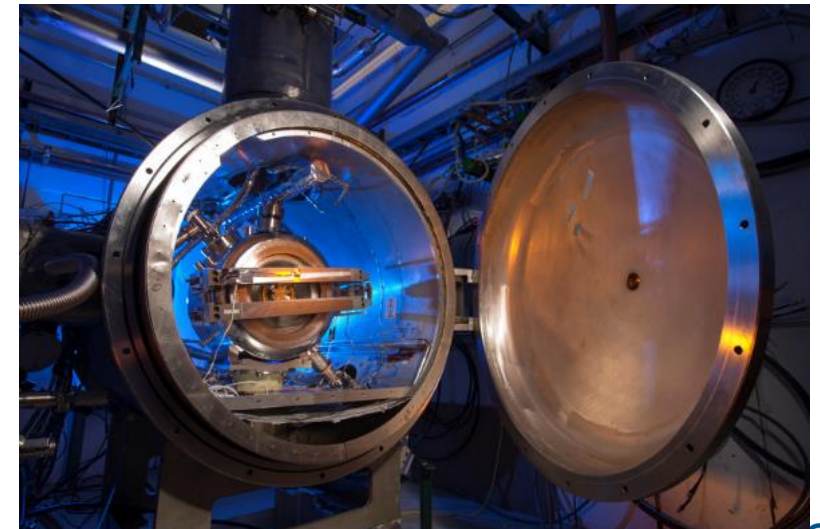
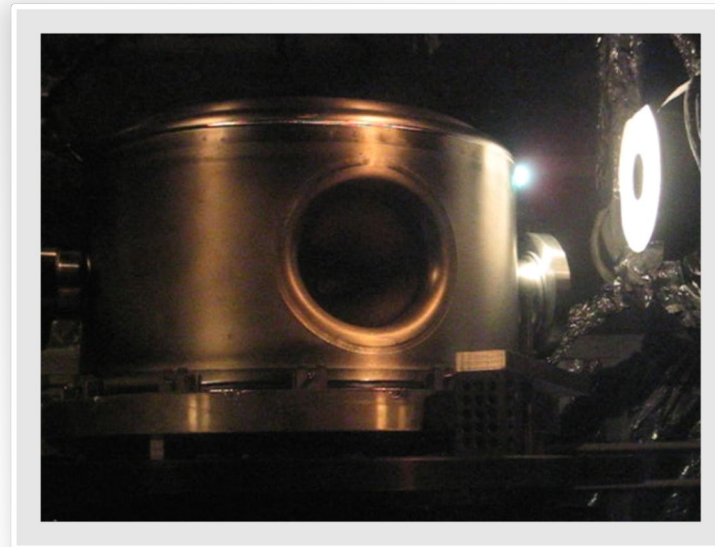
- Teamwork
- Collaboration
- Communication
- Motivation
- Tradition
- Innovation
- Vision
- Planning
- Perseverance

SSR1 cavities: a true international effort

- Designed at Fermilab (*multi-engineering skills*: RF, mechanical,...)
- 10 units were fabricated by US vendors (*Working with Private Industries*)
- 2 units were fabricated by BARC – India (*International partnership*)
- Chemically processed at ANL (*Collaboration with other DOE labs*)
- Cold Tested and Qualified at Fermilab (*Across Lab's Division: APS-TD, AD*)

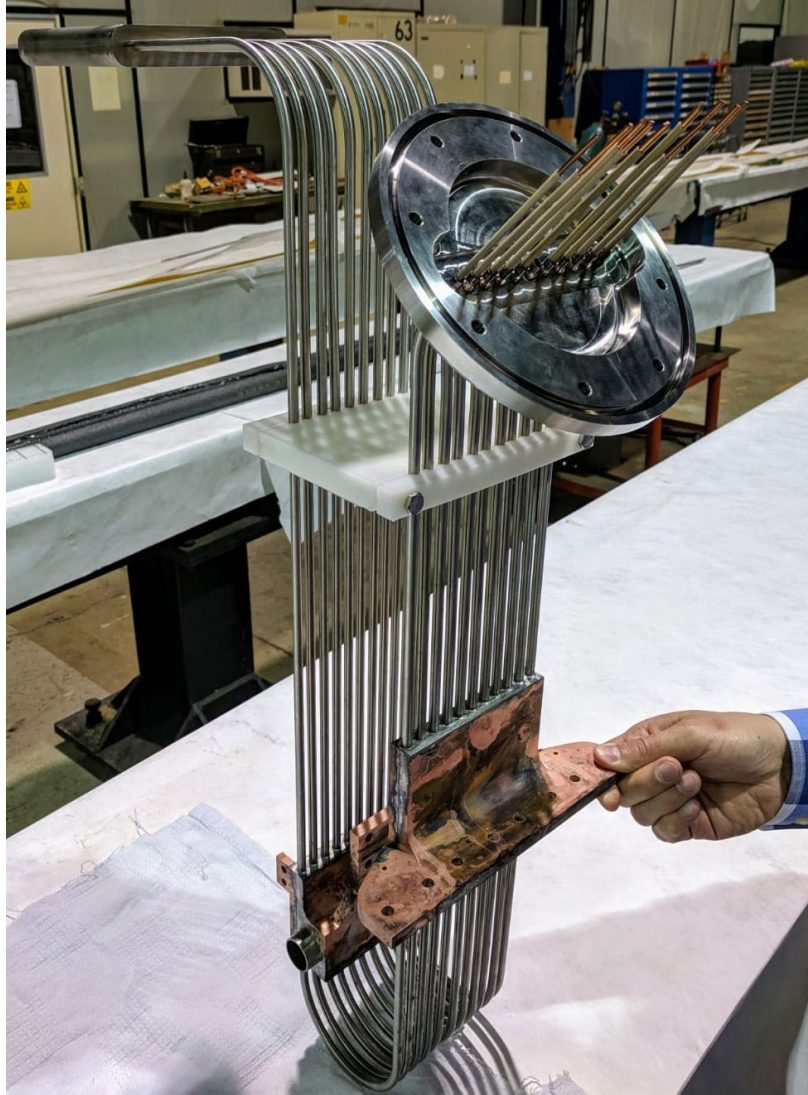
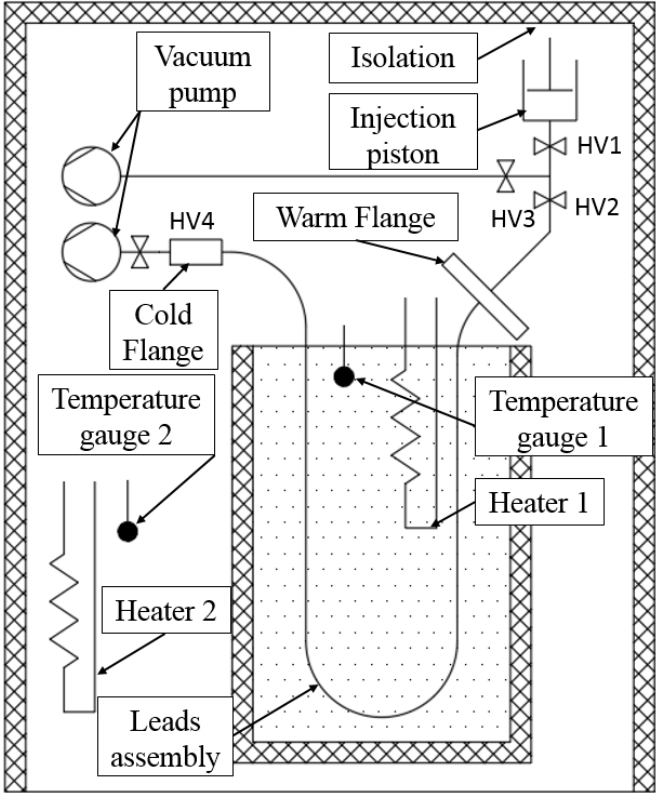


Electromagnetic field of SSR1. (a) Electric field. (b) Magnetic field. The field strength increases as the color changes from green to yellow to red.



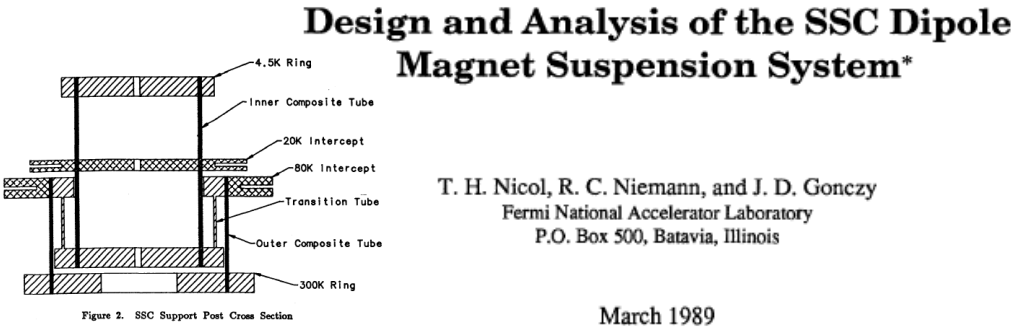
Current leads: sharing challenges across Lab's divisions

Design and built by engineers and technicians from APS-TD and PPD

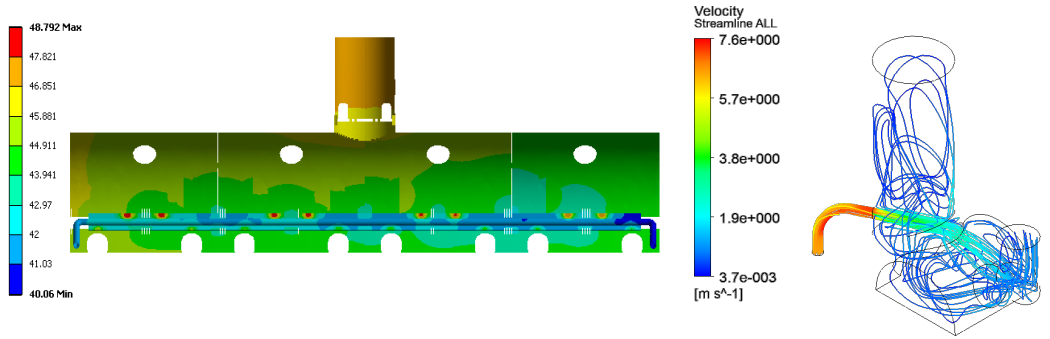


Design Solutions: the work of generations of engineers

Design solutions from past engineering "activities"

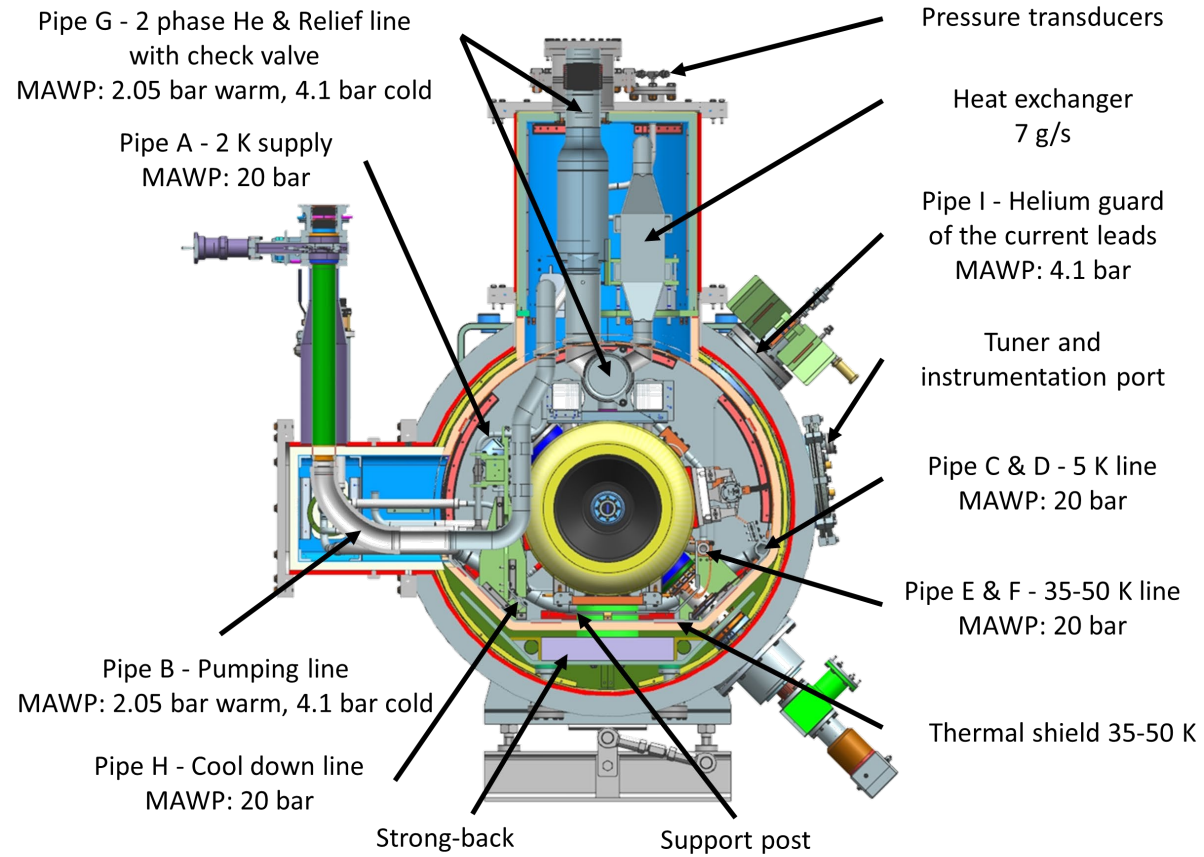


Analyses and Optimization with modern software



Innovative design solutions

Cryomodule Design Concept



Creatively adapt existing knowledge to a new assembly scheme

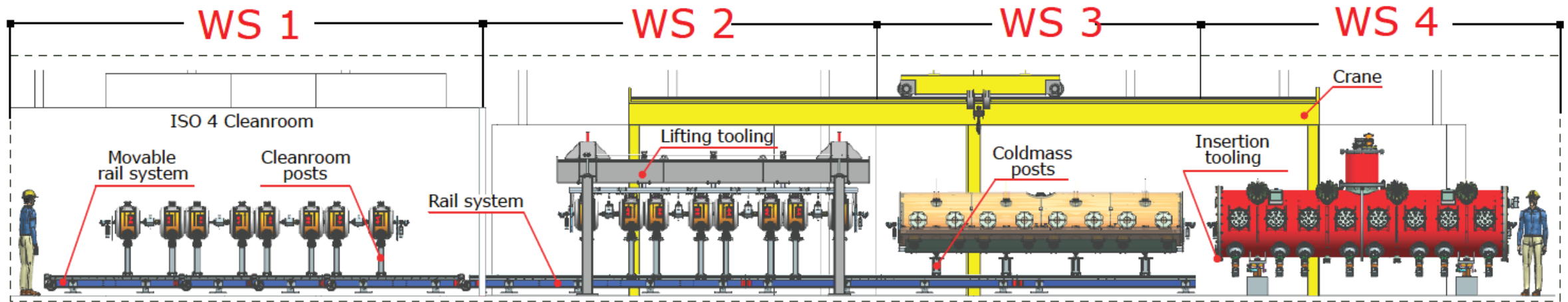
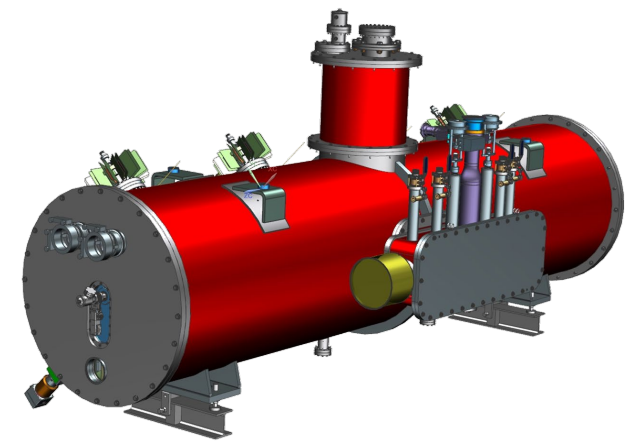
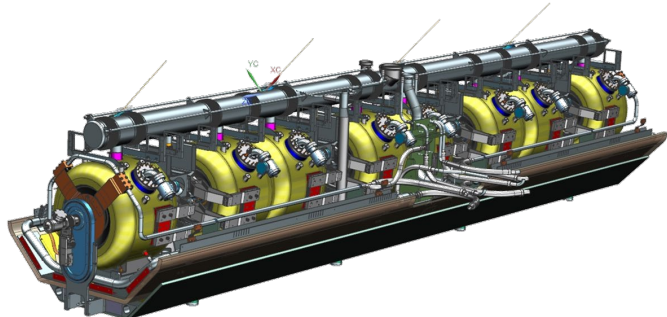
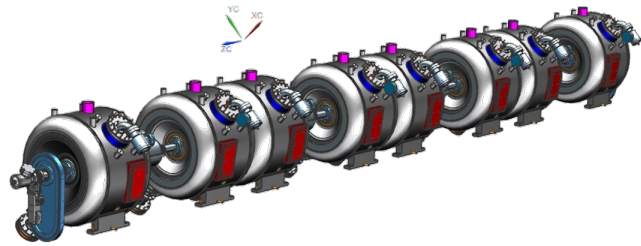
Cavities string assembly



Coldmass assembly

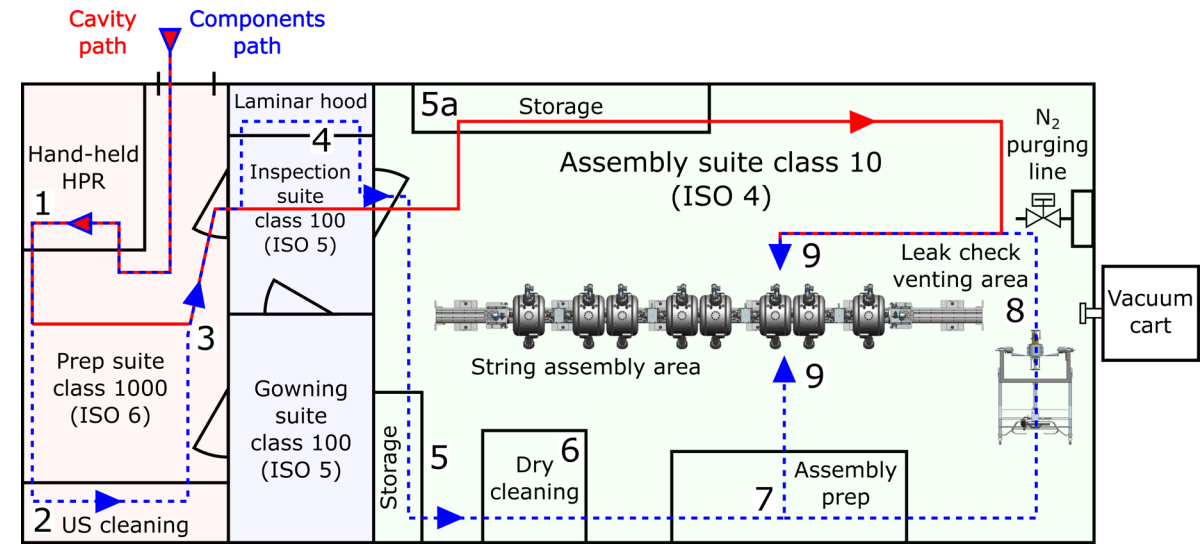
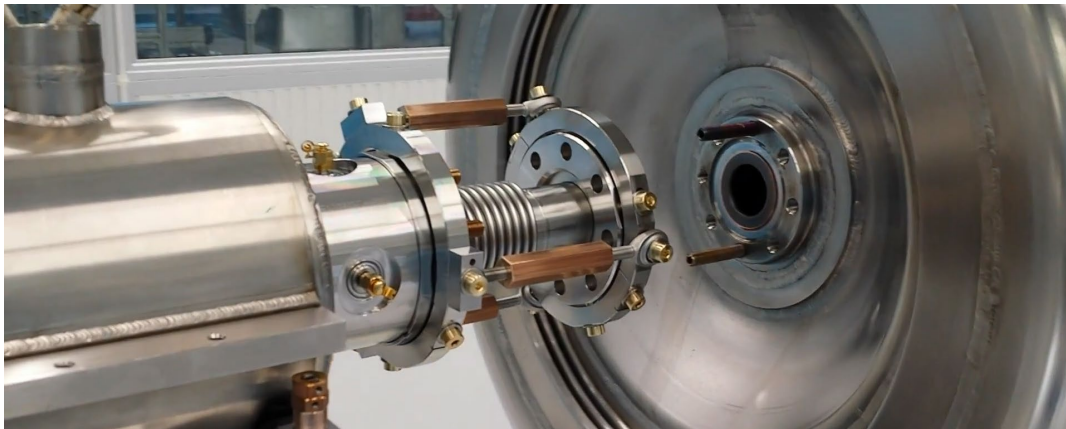


Cryomodule assembly



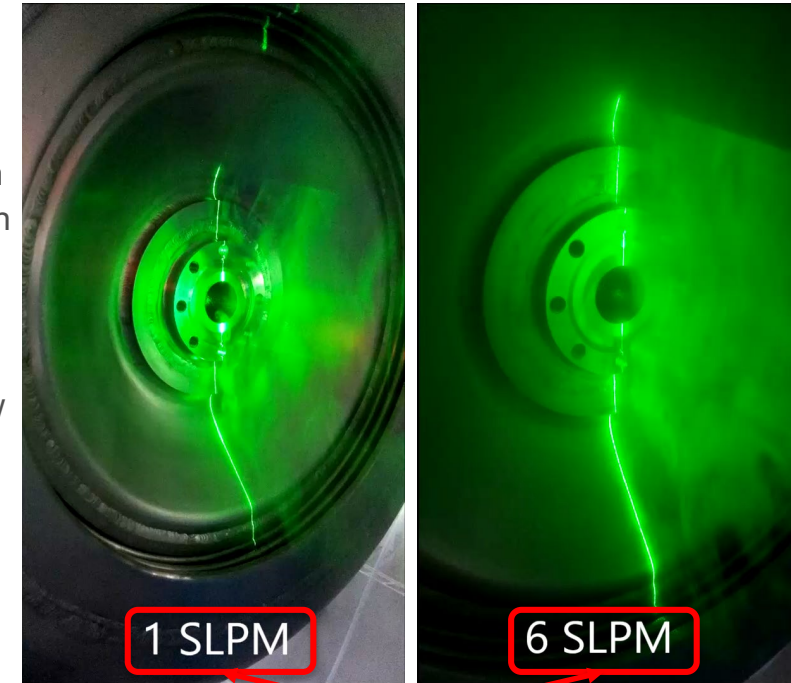
SRF assembly in Cleanroom

- Cleanroom assembly of SRF components represents a challenge requiring high precision and compatible materials
- Particle-free procedures, custom techniques, dry-runs, qualified personnel are some of the key-aspects to succeed.



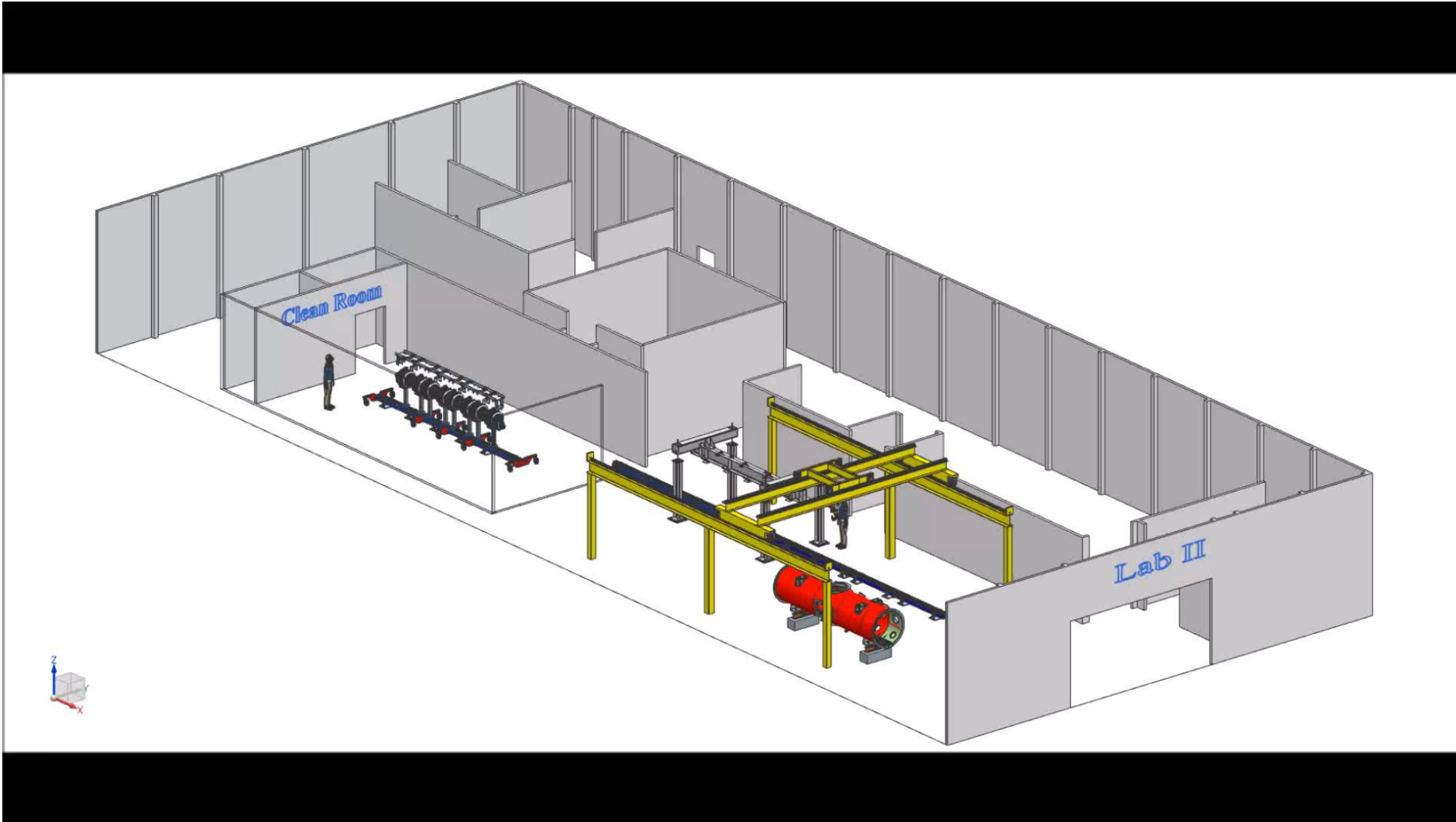
Particle Imaging Technique

- In aerodynamics this technique is applied to a wide range of flow problems: from the air flow over an aircraft wing to the vortex formation in gas turbines
- A laser sheet generated using lenses, combined with a fogger, enables the visualization of air flow near the critical assembly areas
- Properly adjusting the flow of Nitrogen through the cavity can avoid the introduction of contaminants during the assembly phases



Nitrogen flow through the cavity

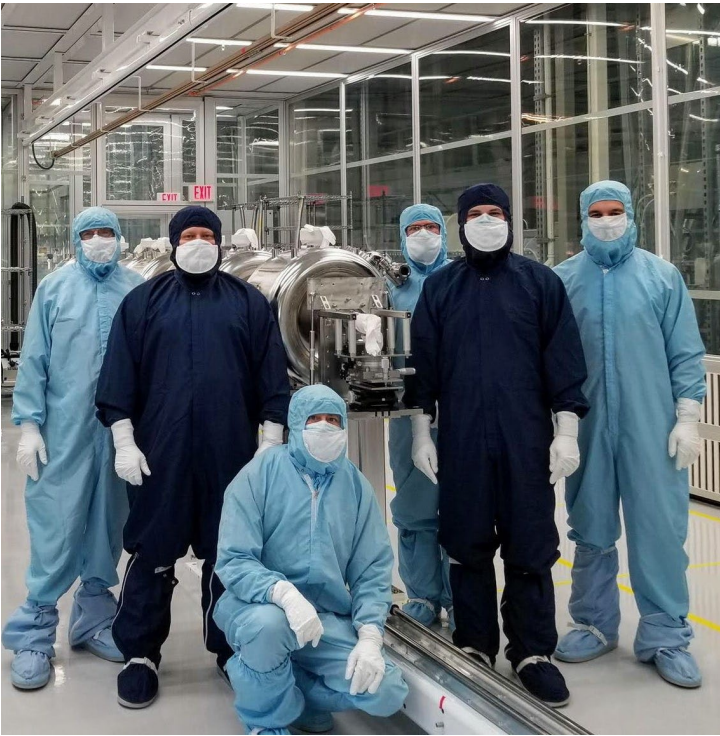
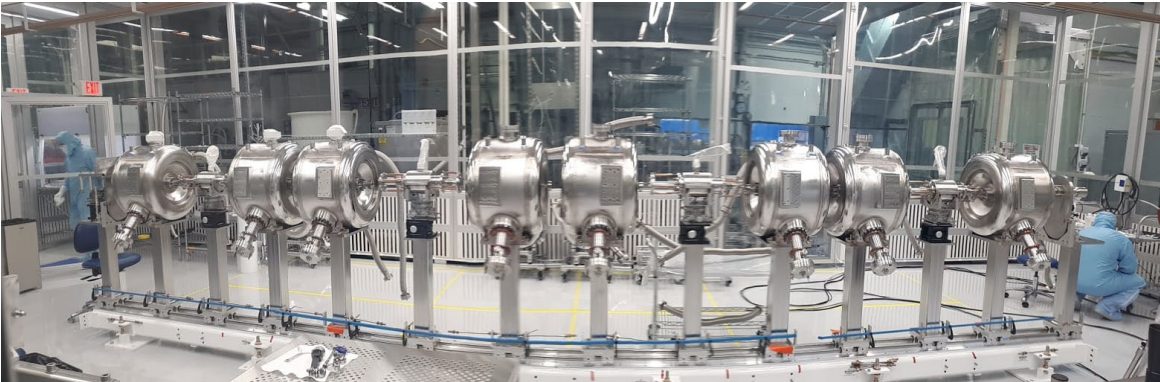
Cryomodule Assembly



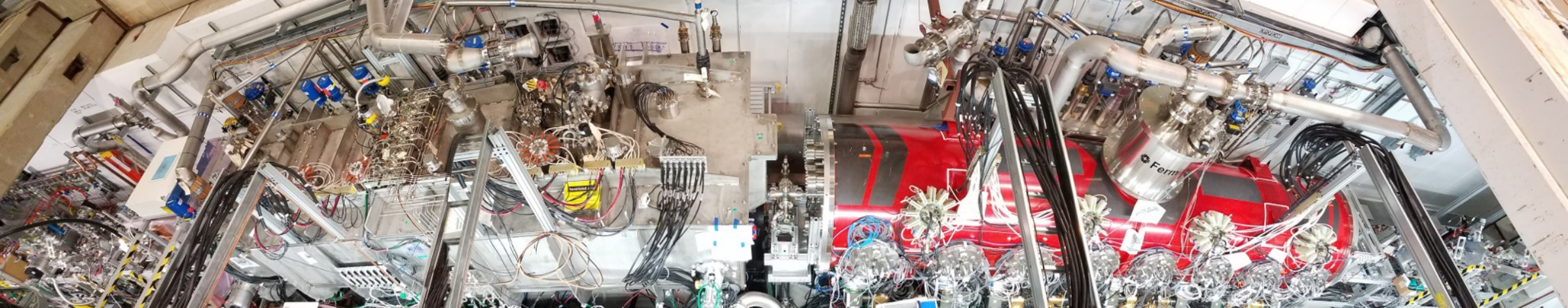
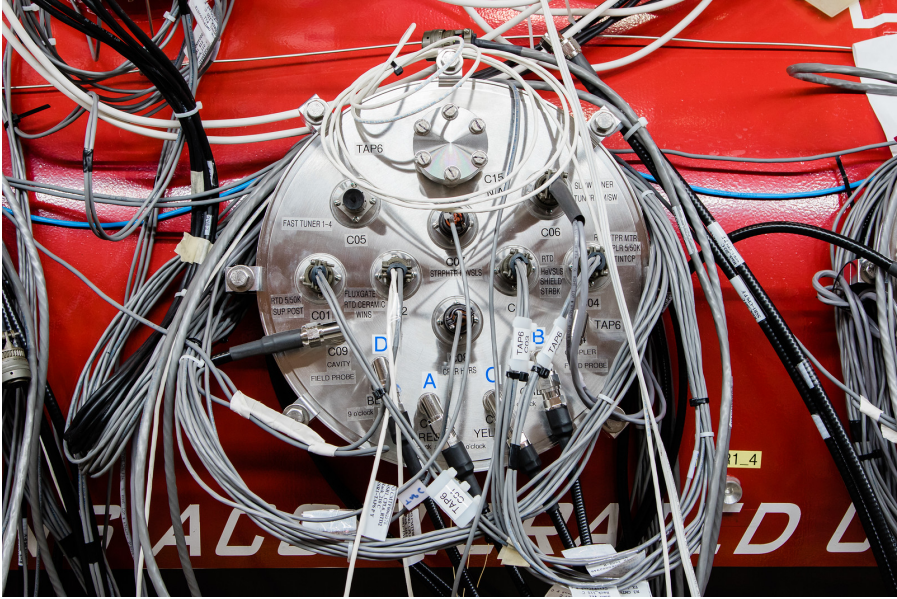
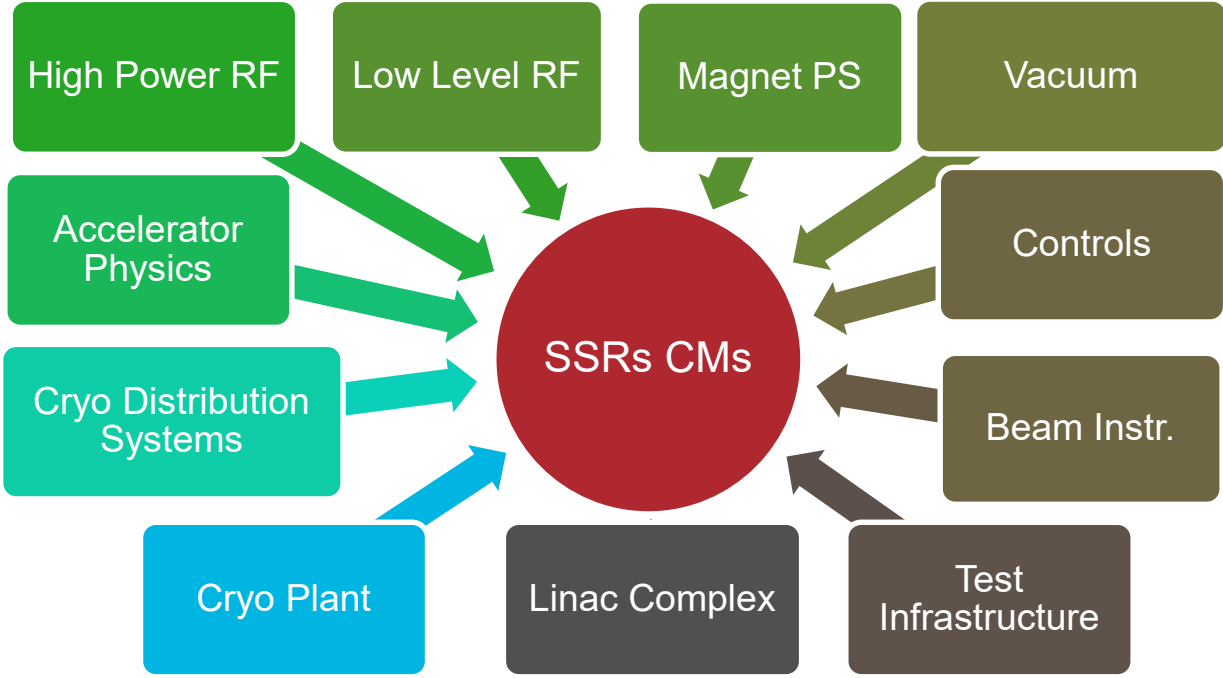
Important aspects to be considered beyond assembly sequence are:

- Quality controls (i.e. inspection of incoming parts, intermediate controls)
- Role and integration of supporting groups (i.e. instrumentation, alignment)
- Safety

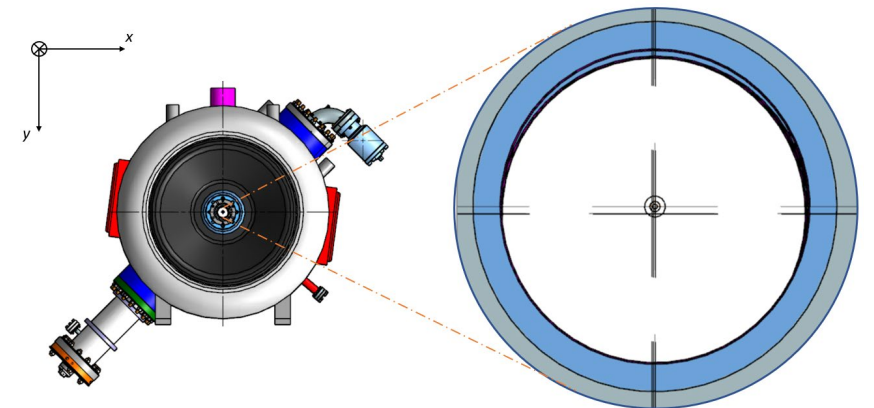
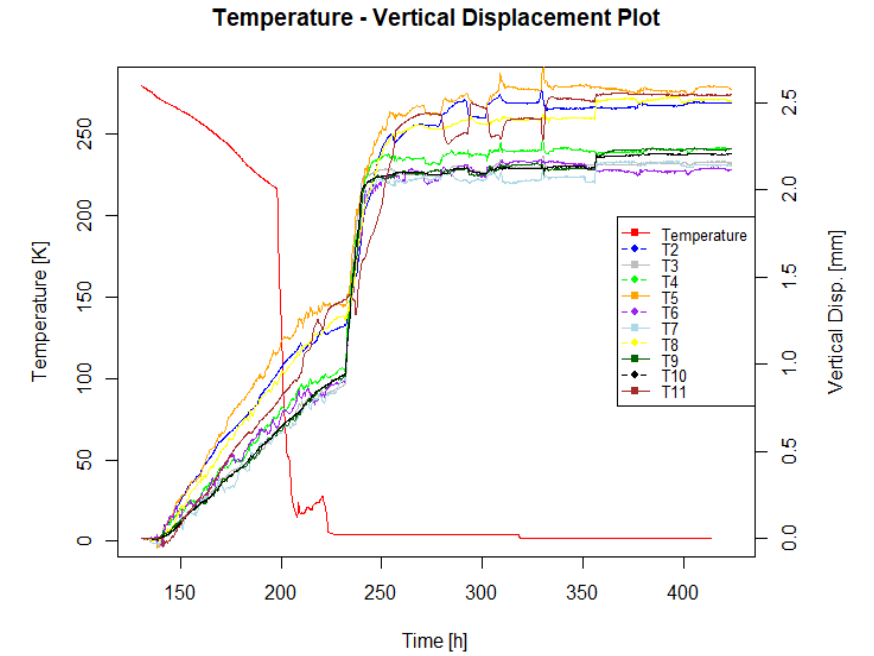
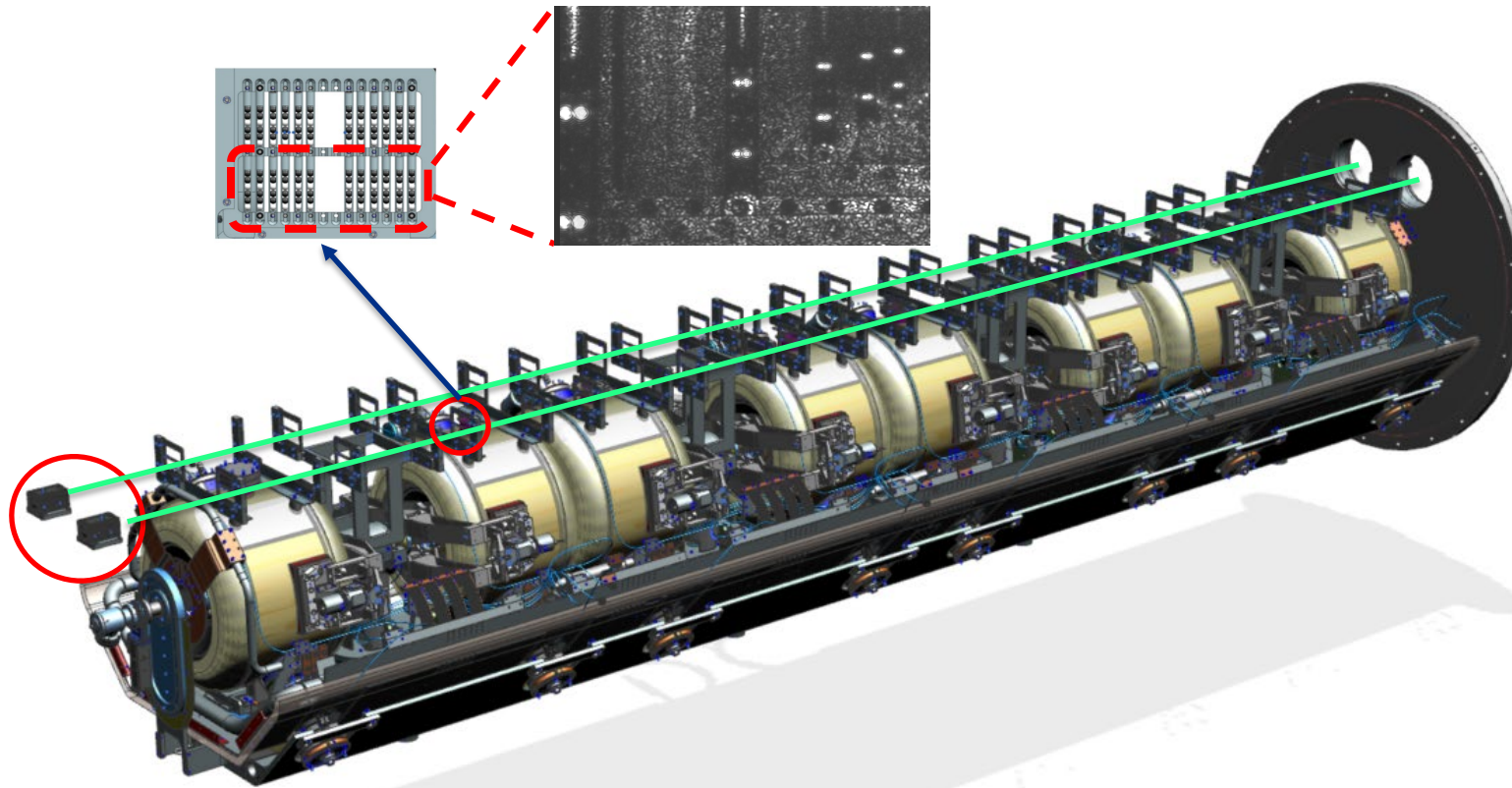
Teamwork and Communication



Interfaces: The devil is in the details

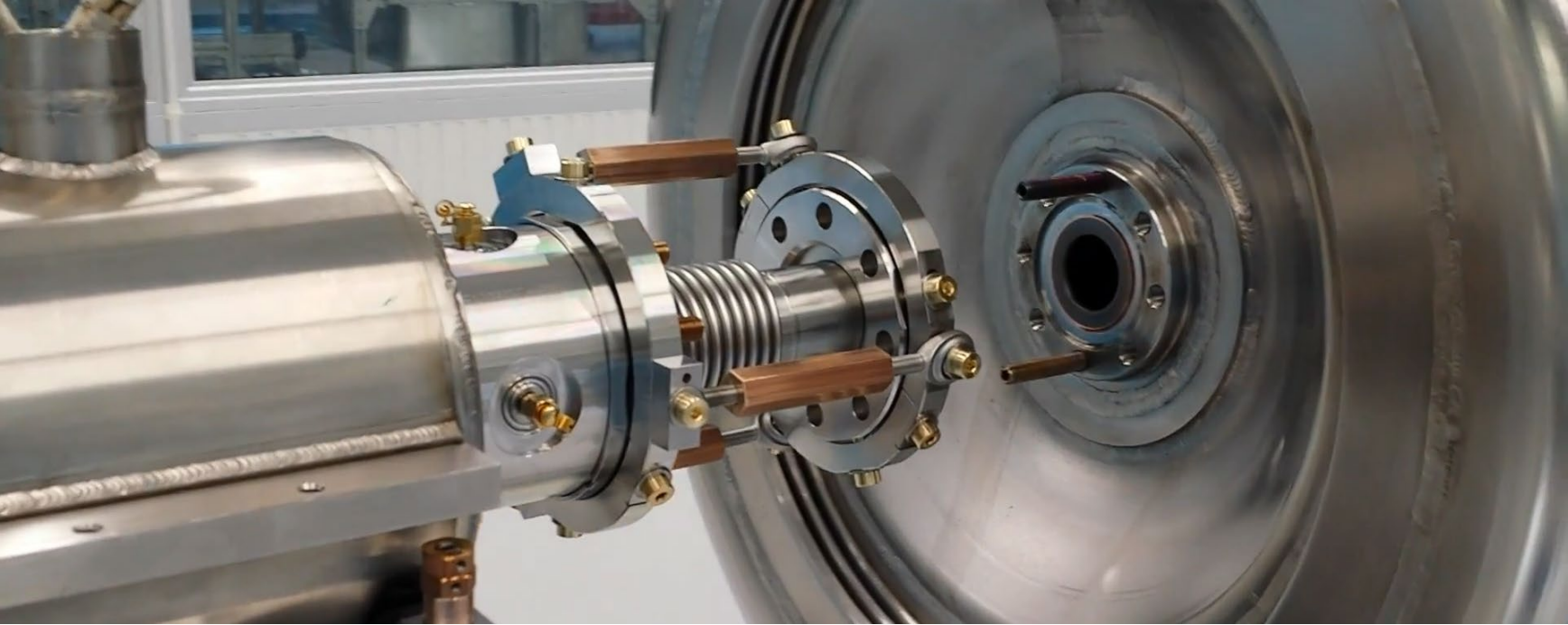


Beaming into the future: Computer Vision Technology



- Open-Source optical instrument developed by **Brandeis University**;
- Technology already adopted in the field of High Energy Particle Accelerators (**HIE-ISOLDE at CERN**);
- Technology successfully deployed at **Fermilab** to monitor **Prototype SSR1** alignment during Assembly, Transportation, and Cooldown.

Future work: Robot assisted technology in SRF assembly

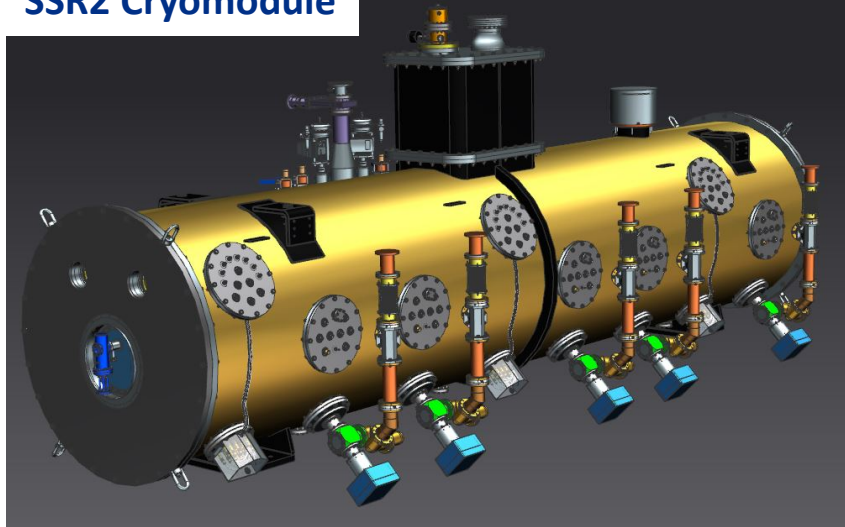


Future work: from Ferrari to Lamborghini

SSR1 Cryomodule



SSR2 Cryomodule



Conclusions

- A defined mission promotes interactions and collaborations across groups and divisions: we are “One Lab”.
- Innovation in engineering fields is as important as in other are to advance the development of new technologies. More synergies among “Research Programs” and “Project” should be established for engineering activities.
- The success of this prototype, therefore, is not only a milestone for PIP-II but a glimpse of things to come for Fermilab. It also reinforces Fermilab’s position as a leader in the global superconducting accelerator community and a valuable partner for future projects.

Thank you for your attention!

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