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Field Installation of Cryomodule Vacuum Systems at Fermilab

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Cryomodules Built, Tested, and/or Operated at Fermilab

- 1.3GHz cryomodules
  - "ILC style" cryomodules incorporated in FAST/IOTA accelerator
  - Fermi-design cryomodules built for LCLS-II project at SLAC

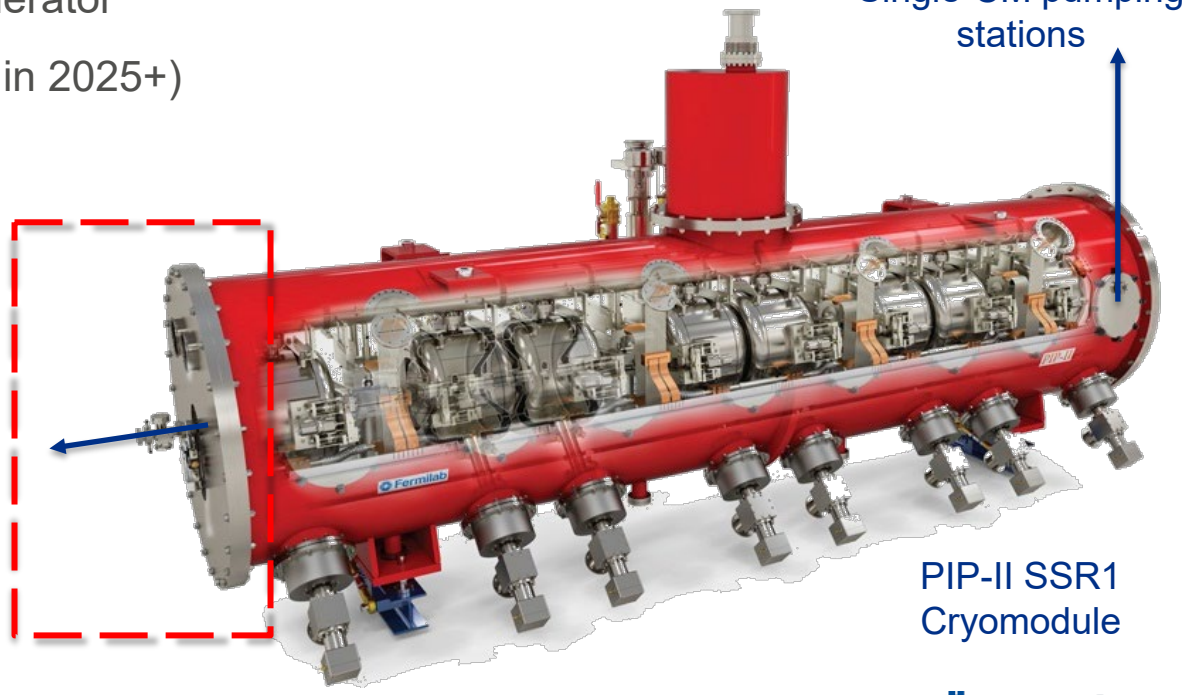
See Tug Arkan's Talk

- Fermilab-Style Cryomodules
  - 325MHz Single Spoke Resonator Cavity Cryomodules for Fermilab's PIP-II Linac
  - 650HMz Elliptical Cavity Cryomodules for PIP-II
- Others
  - ATLAS-style 162.5MHz Half Wave Resonator provided by ANL
  - 1.3GHz single-cell cryomodules in collaboration with DESY

PIP-II HB650 Cryomodule

Field Installation Scope

- Installation in Cryomodule Qualification Test Stands
  - CMTS1 Test stand for LCLS-II 1.3GHz Cryomodules
  - PIP-II Integrated Test Stand for PIP-II 325 and 650MHz Cryomodules
- Installation in Accelerators
  - FAST/IOTA
  - PIP-II Injection Test Accelerator
  - PIP-II Linac (installations in 2025+)



FAST/IOTA

Talk To:
Lucy Nobrega

- Fermilab's Accelerator R&D Facility
  - SRF accelerator chain supporting Integrable Optics Test Accelerator (IOTA) ring
  - 300MeV e- Linac
  - Two single-cavity 1.3GHz Cryomodules
  - One eight-cavity 1.3GHz ILC-style Cryomodule
- Conservative Vacuum Strategy
  - Cryomodules are stand-alone
  - Brute force ion pumping for beamline
  - Long low-particulate section lengths
  - Ion pumped coupler vacuum
  - Redundant turbopump stations for cryostat
  - Extensive diagnostics

ILC-Style Cryomodule

Cryomodule Test Stand 1 (CMTS1)

- Fermilab is building and testing cryomodules for LCLS-II at SLAC
  - At CMTS1, they are cooled down and powered
  - Cryomodules installed/tested on 1 month cycle
- Vacuum design informed by lessons-learned from FAST/IOTA
- Some simplifications relative to FAST/IOTA
  - Beamline vacuum connection at 1 side only
  - Simplified cryostat vacuum logic
  - Very clean interfaces to enable quick turnaround

CMTS1

See Brian Hartsell's Talk

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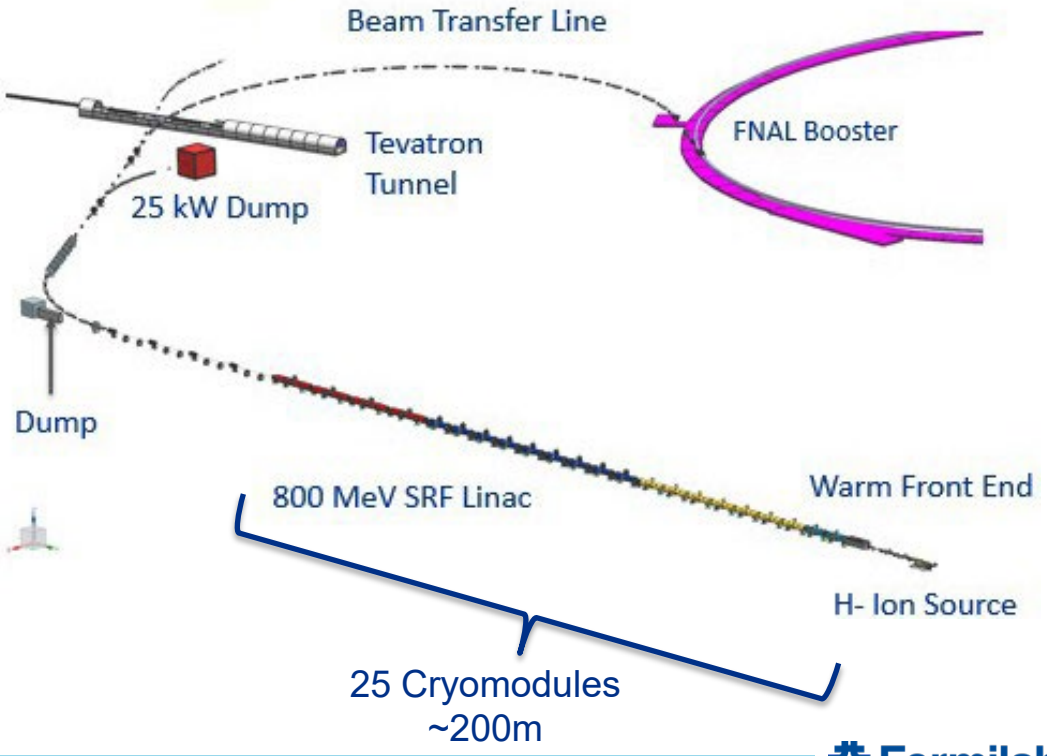
PIP-II Linac

- PIP-II is an essential upgrade to Fermilab accelerator complex to enable the world's most intense beam of neutrinos to LBNF/DUNE, and a broad physics research program for decades to come
- Construction underway, completion in 2029
- PIP-II Capabilities
  - 800MeV/1GeV H- Linac
  - 25 Cryomodules of 5 styles
  - All cryomodules are stand-alone (rather than strings)



See Raul Campos'sTalk

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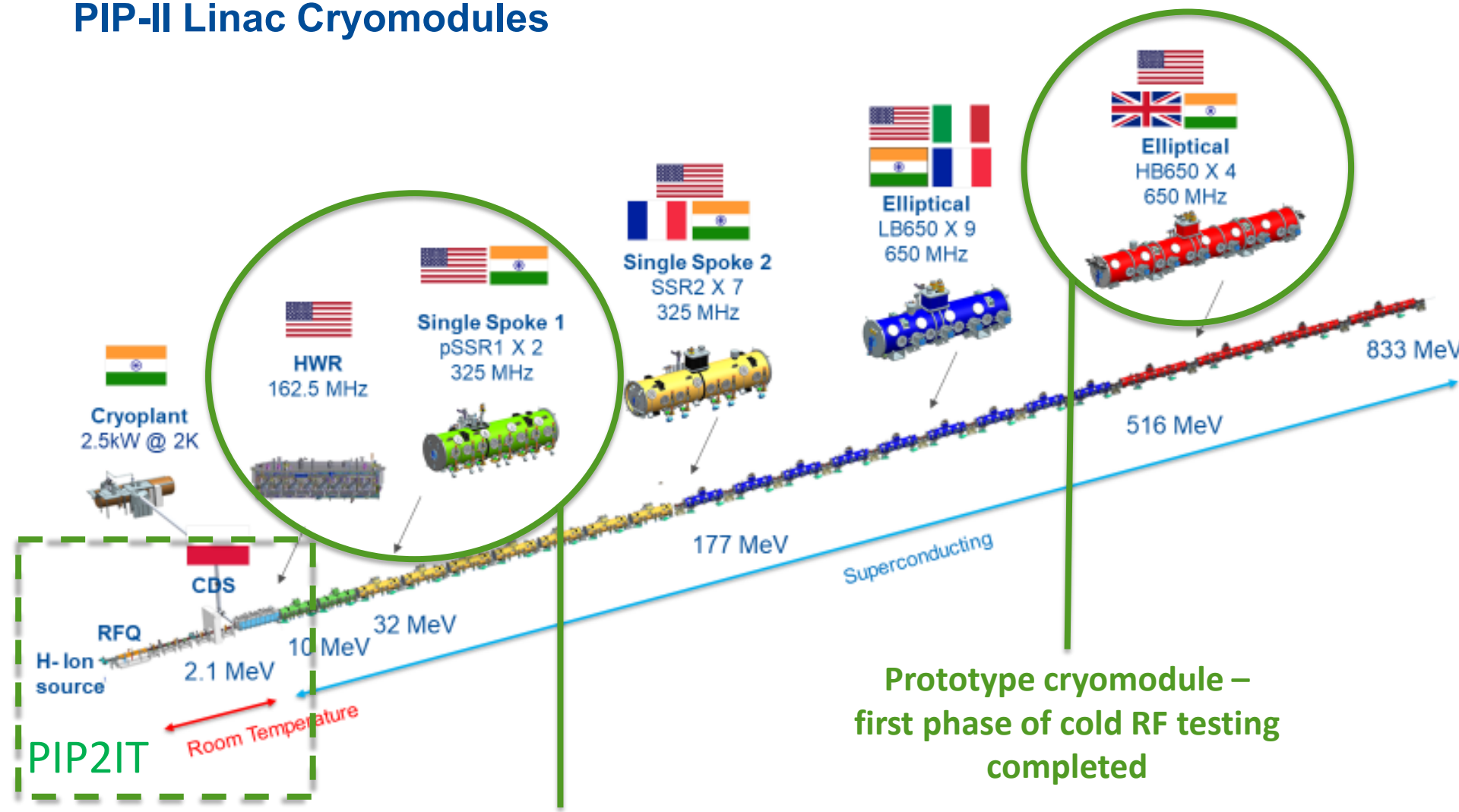
PIP-II Linac Cryomodules



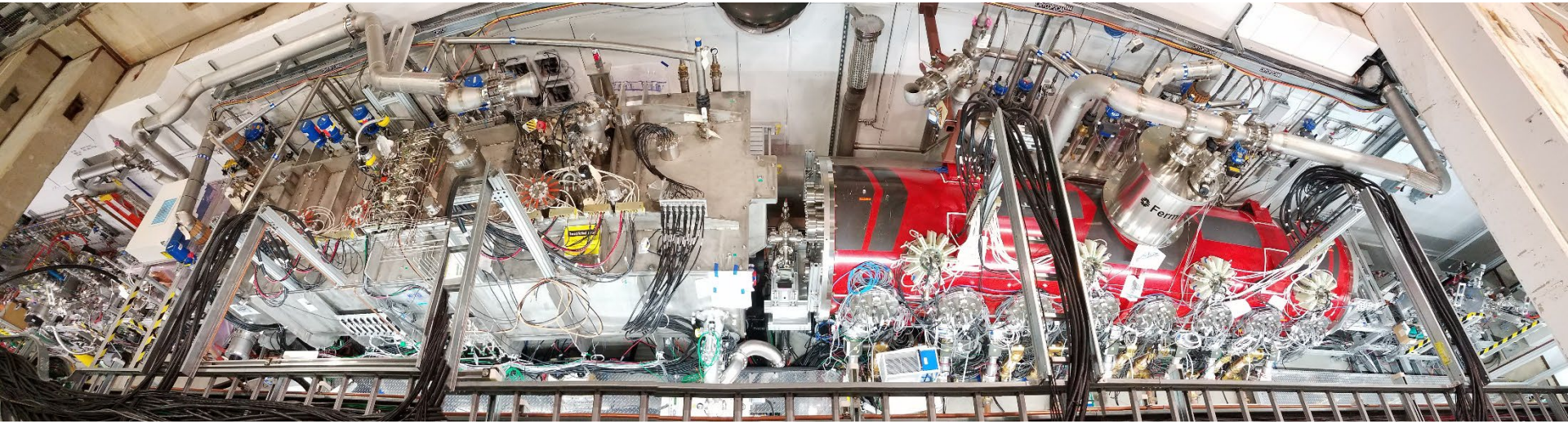
Prototype cryomodule – first phase of cold RF testing completed

First cryomodules tested with beam, demonstrated PIP-II beam parameters

PIP-II Injection Test Accelerator

See Alex Chen's Talk

- A full-up build of the upstream portion of PIP-II from the Warm Front End through the second cryomodule
- Allowed investigation of vacuum architecture for PIP-II
  - HWR Cryomodules unique vacuum systems
  - Beamline interlock and fast-closing valve implementation
  - More aggressive low-particulate lengths
  - Combination NEG/Ion Pumps (though not yet near the cryomodules in this system)



HWR 162.5 MHz Cryomodule

SSR1 325MHz Cryomodule

PIP-II Integrated Test Stand

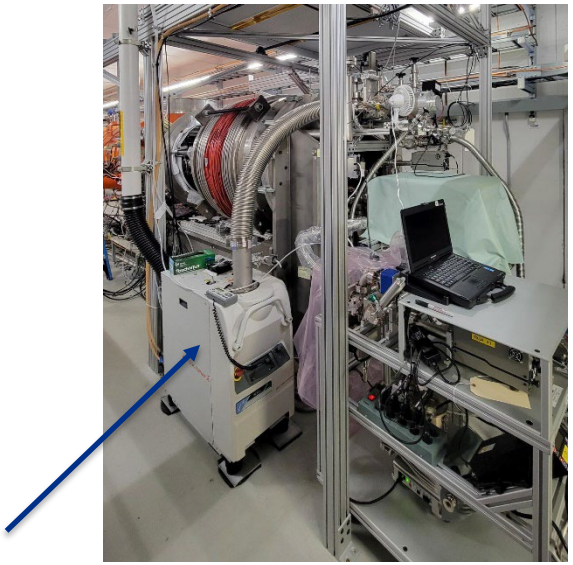
- The same physical space was repurposed as a cryomodule test stand
- Testing for prototype and production PIP-II Cryomodules
  - One test stand for 325MHz cryomodules, One test stand for 650MHz cryomodules
  - Testing ongoing now, continues until 2029
- Test stands have independent vacuum systems

HB650 650MHz Cryomodule

SSR1 325MHz Cryomodule

Cryostat Vacuum Field Installation

- Conventional High Vacuum Systems (~1E-5 mbar while warm)
  - Dry screw rougher for new “wet” installations
  - Turbopump stations for each cryomodule to achieve ultimate warm vacuum
    - Typically left on during cryomodule operation
    - PIP-II Integrated Test Sand – station interface is field connection
    - CMTS1 – station interface is permanent and cryostat bellows is field connection



Permanently installed rougher at CMTS1

Portable turbo station for 650MHz cryomodule test stand

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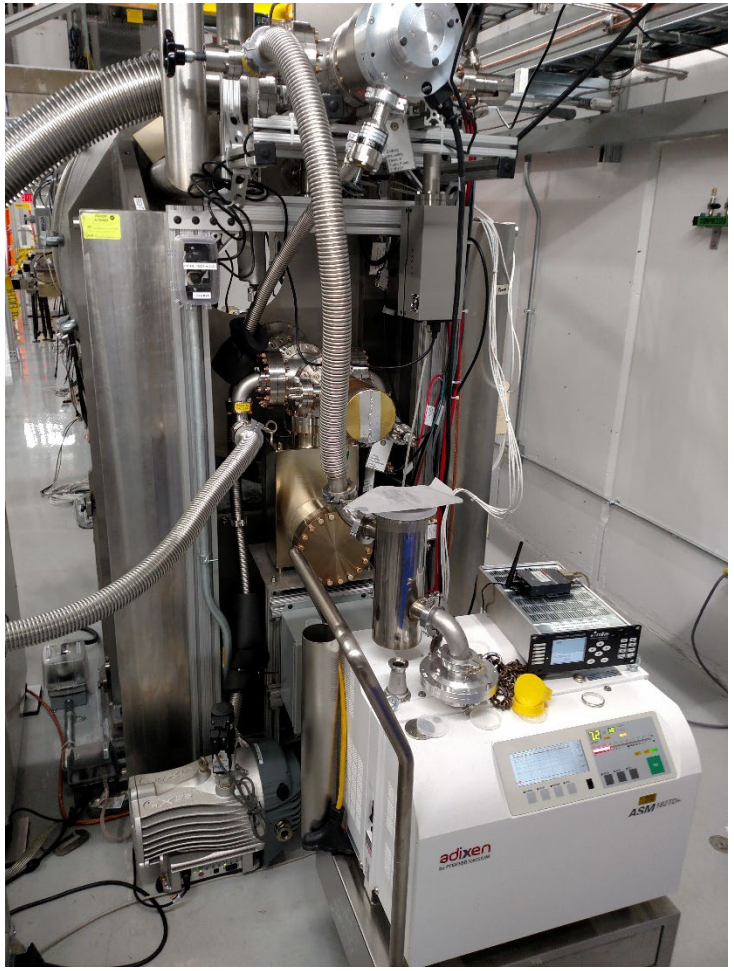
Cryostat Vacuum Field Installation

Talk To:
Ron Kellett

- Leak detection
  - Standard He Mass Spectrometer leak detection
  - High background / O-ring permeation
- Troubleshooting via conventional bag of tricks
- Cryo-to-vacuum leak check via pressurized cryogenic circuits
  - Rough localization via time of flight techniques

N2 bagged flange



Direct cryostat connection example

Cryostat Vacuum Field Installation: Clean Volumes

Talk To:
Dan Lambert

- Temporary clean volumes of various sizes are set up to connect at cryomodule beamline gate valves
- Training and experience critical to setup of volume, QC particle counter, and performance of work

Roll-around softwall cleanroom →

Particle-safe vacuum pumping cart

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Cryostat Vacuum Field Installation: Clean Volumes

We have used

- Permanent overhead filter units
- Roll-around soft-wall cleanrooms
- Glovebox setups

More ergonomic

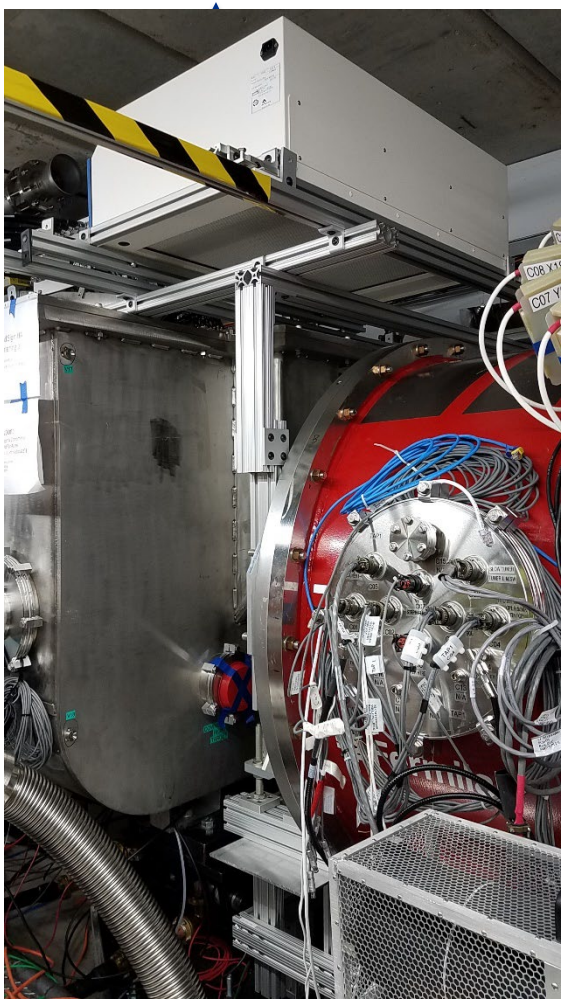
More flexible

Overhead filter carriage at FAST/IOTA

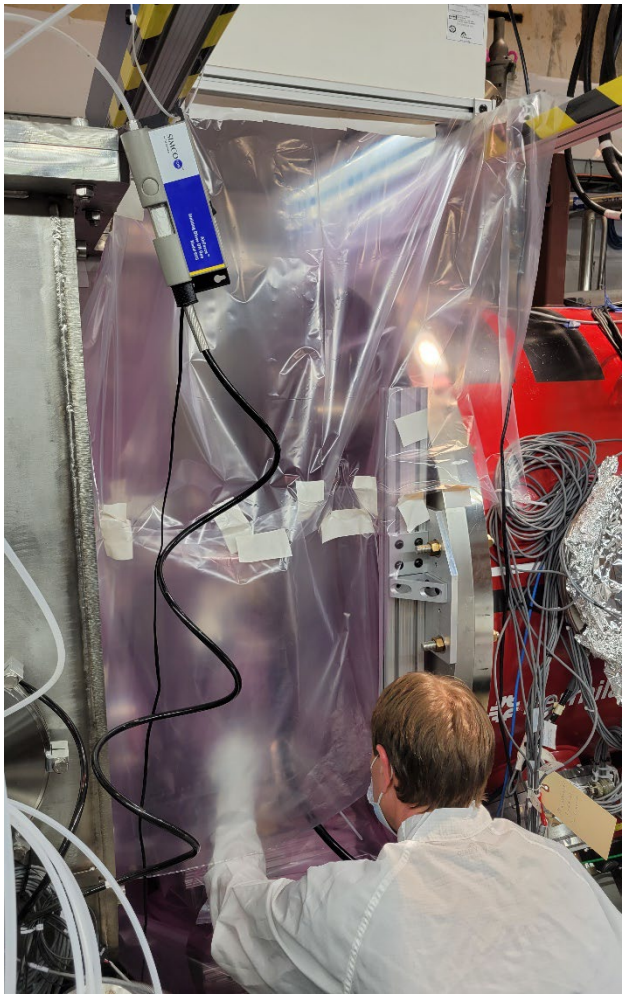
Overhead filter carriage at CMTS1

Glovebox Approaches: PIP-II HWR-SSR1 Connection

Connection Mockup



Filter setup



Installation

Glovebox approaches: PIP-II Integrated Test Stand

Talk To:
Elias Lopez

HB650 Connection to Test Beamline Vacuum Station

SSR1 Connection to Test Stand Beamline Vacuum Station

Clean Volumes for PIP-II

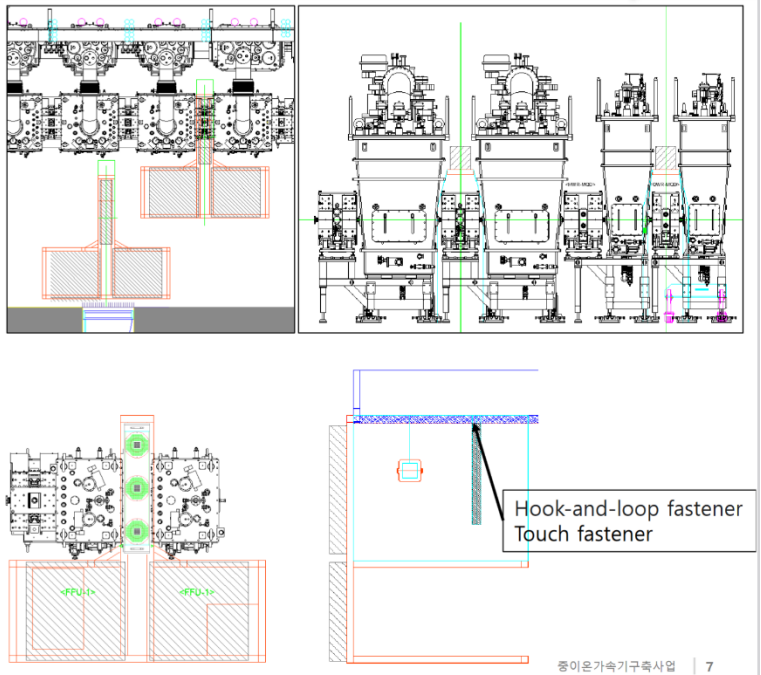
- For the PIP-II Linac, a mix of these approaches will be necessary
- We are studying RAON's T-shaped Clean Booth Concept

J. Kwon, Institute for Rare Isotope Science, TTC 2023

Clean booth

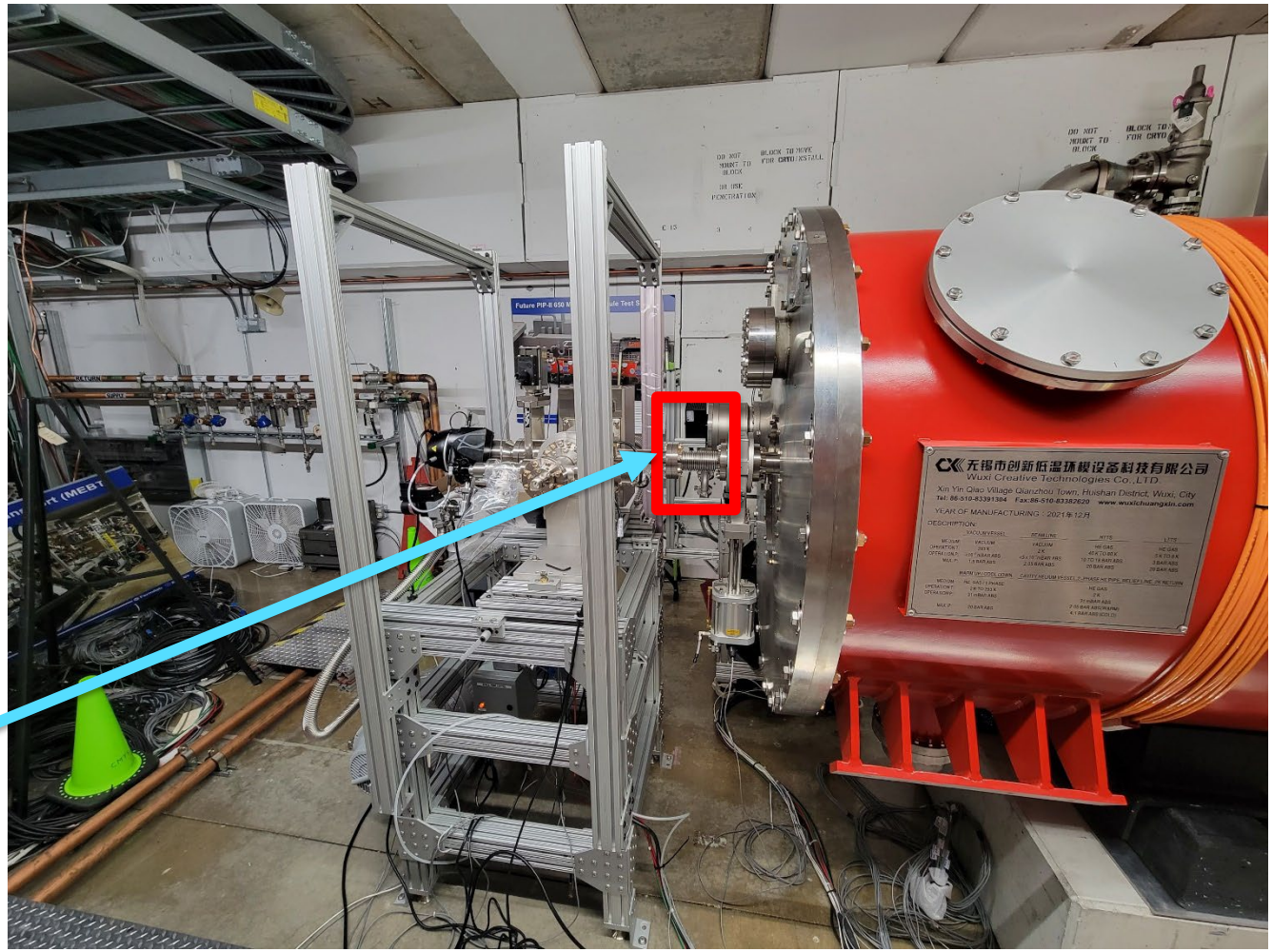
RISP

- 3rd (current) version of clean booth
  - HEPA FILTER
    - 2 * 1172-1172-200H
    - 1 * 350-1000-200H (**3 fans**)
  - Length 2900 mm (expandable 3430 mm)
    - The width of entrance 3000 from injector section
  - Width : 3000 mm
  - **Antistatic PVC** sheet around the booth
  - ☺ Easy to move around & out of tunnel
  - ☺ No support bar (CM side) required
    : Fits all (QWR, HWR-A, HWR-B)



Beamline Vacuum Field Work

We try to minimize scope of field work



HB650 Connection to Test Beamline Vacuum Station

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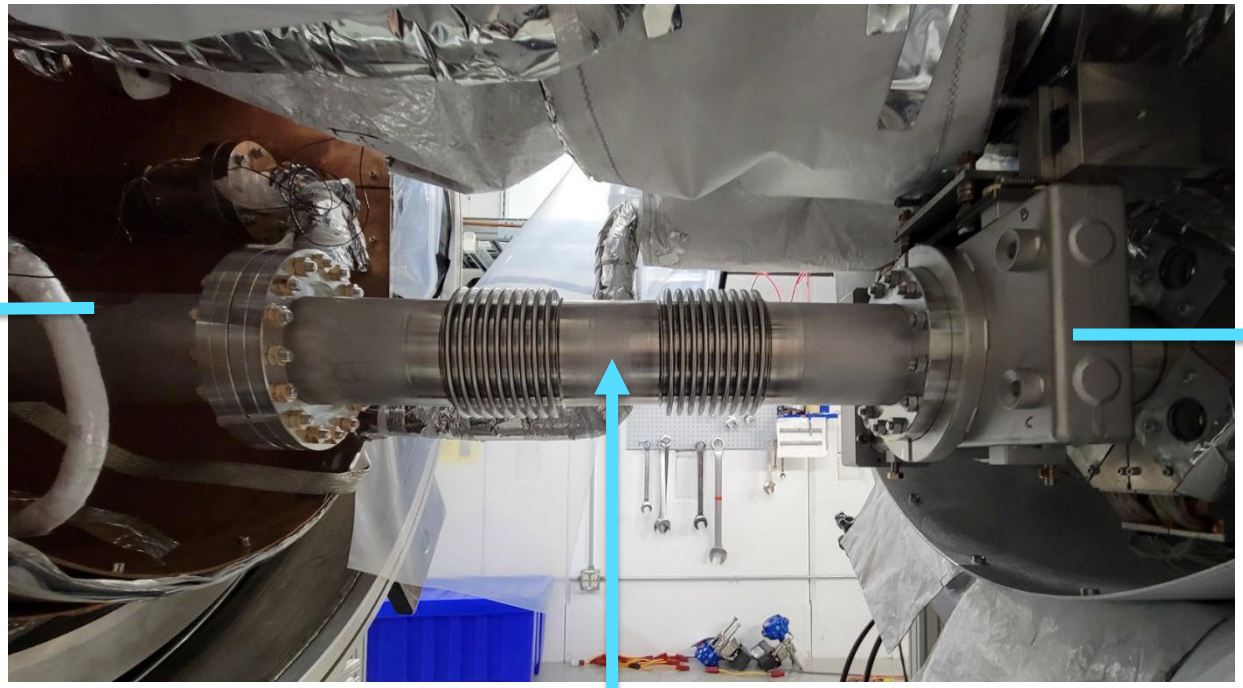
Cryomodule Connection In Test Stands

Talk To:
Brian Hartsell

- We avoid the field connection if possible

CMTS1 Beamline Vacuum



To Beamline Pumping Station

To Cryomodule

Field Connection Spool

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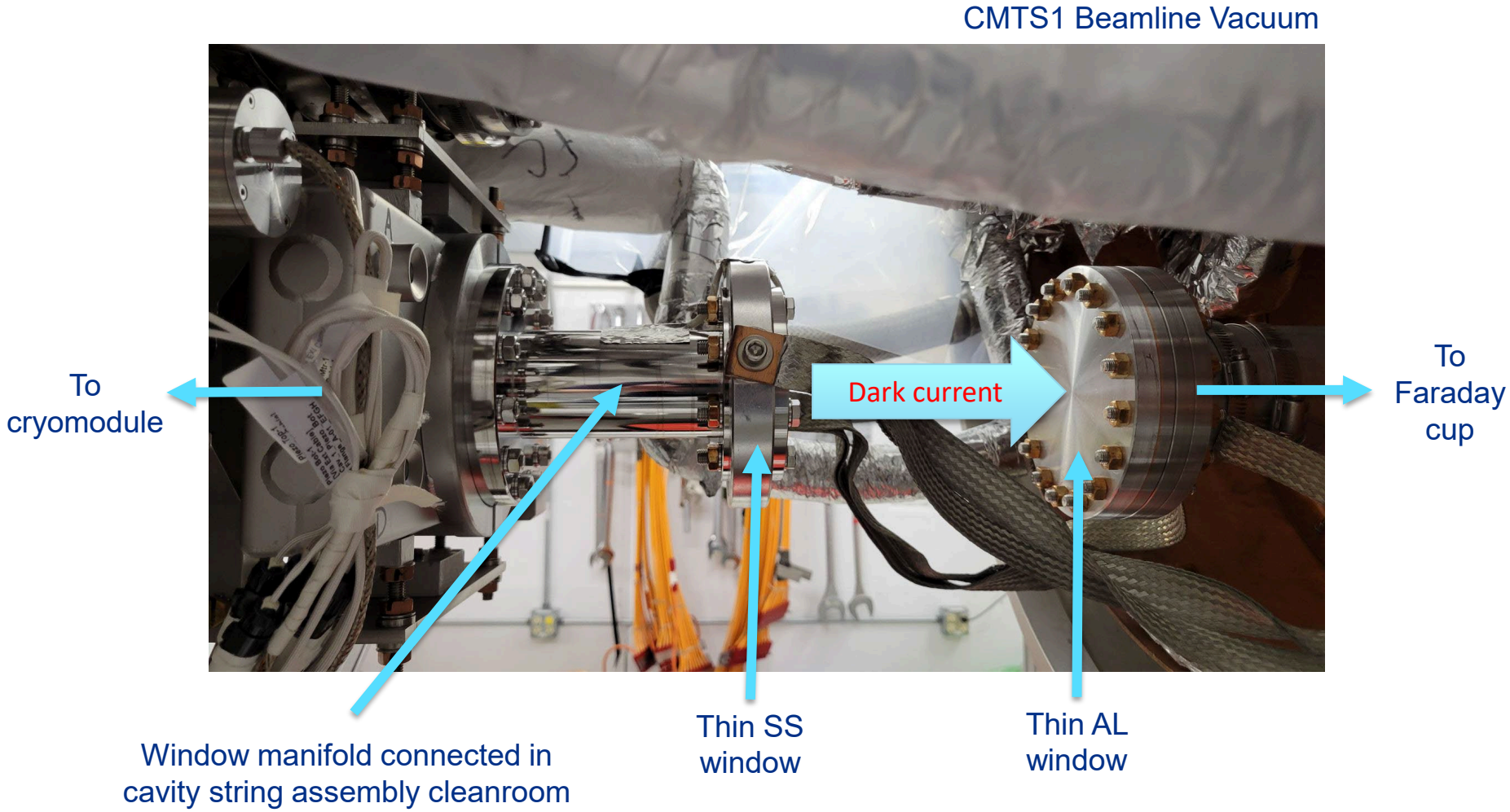
Cryomodule Connection In Test Stands

Talk To:
Brian Hartsell

- Pumping a cryomodule from one end has been sufficient



Cryomodule Connection In Test Stands

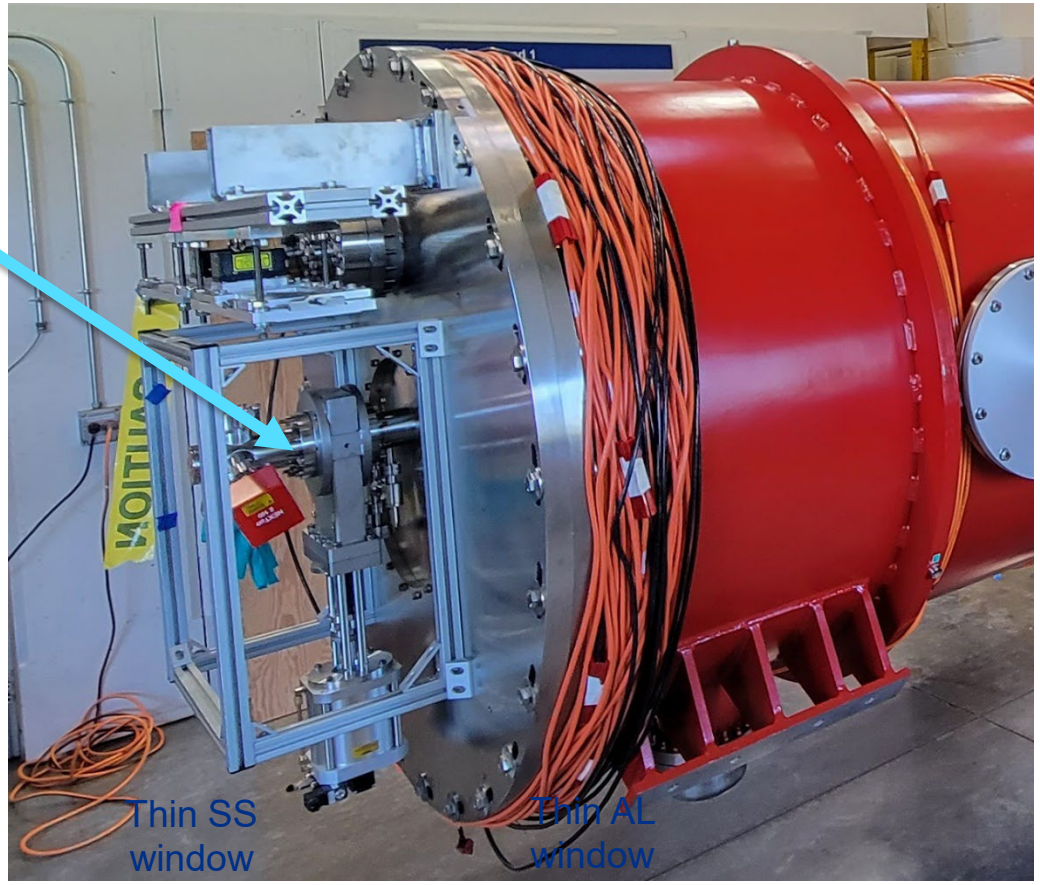
Talk To:
Genfa Wu

- Use of small NEG/IP pumps in low-particulate service has opened the door to reasonably-sized room-temperature pumping manifolds

PIP-II HB650 Cryomodule

Pump/Gauge manifold installed in cavity string assembly cleanroom

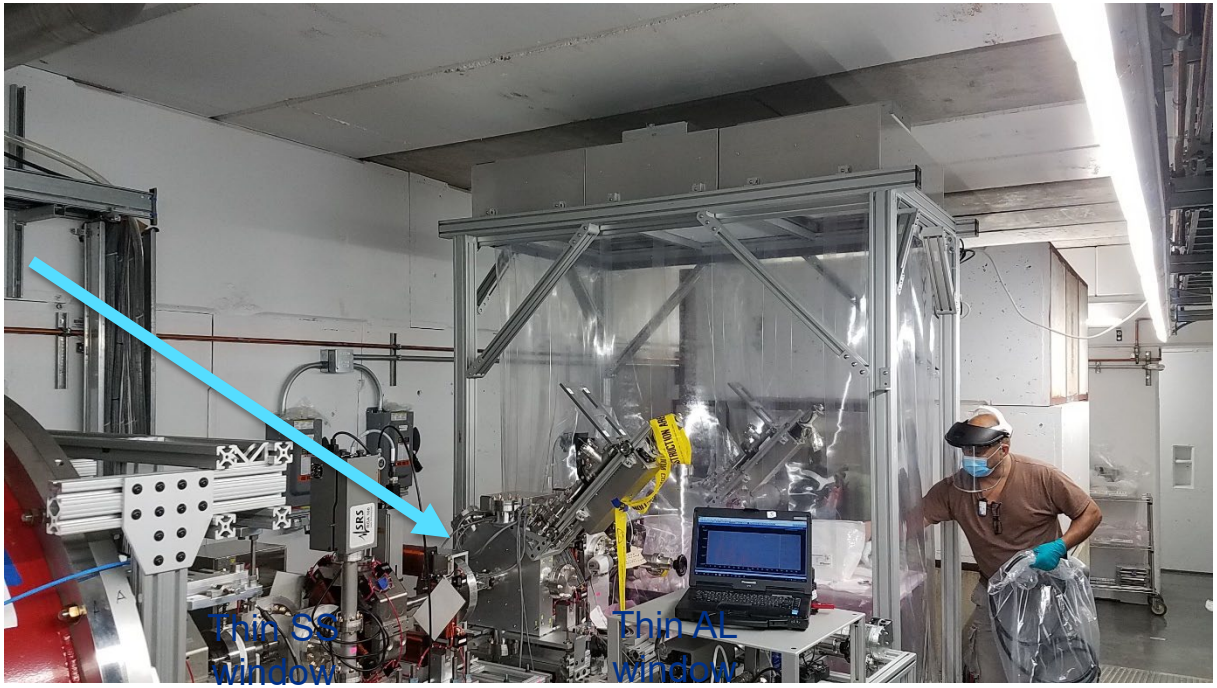
Rides along for
- Assembly
- Transport to test
- RF test
- Transport to PIP-II
- Installation of cryomdule



Adjacent Warm Beamlines

Talk To:
Alex Chen

- Low-particulate handling of adjacent warm beamlines has been trending less conservative
  - Many 10s of meters in FAST/IOTA
  - Just a few meters in PIP-II Injection Test Accelerator
- See Alex Chen's talk

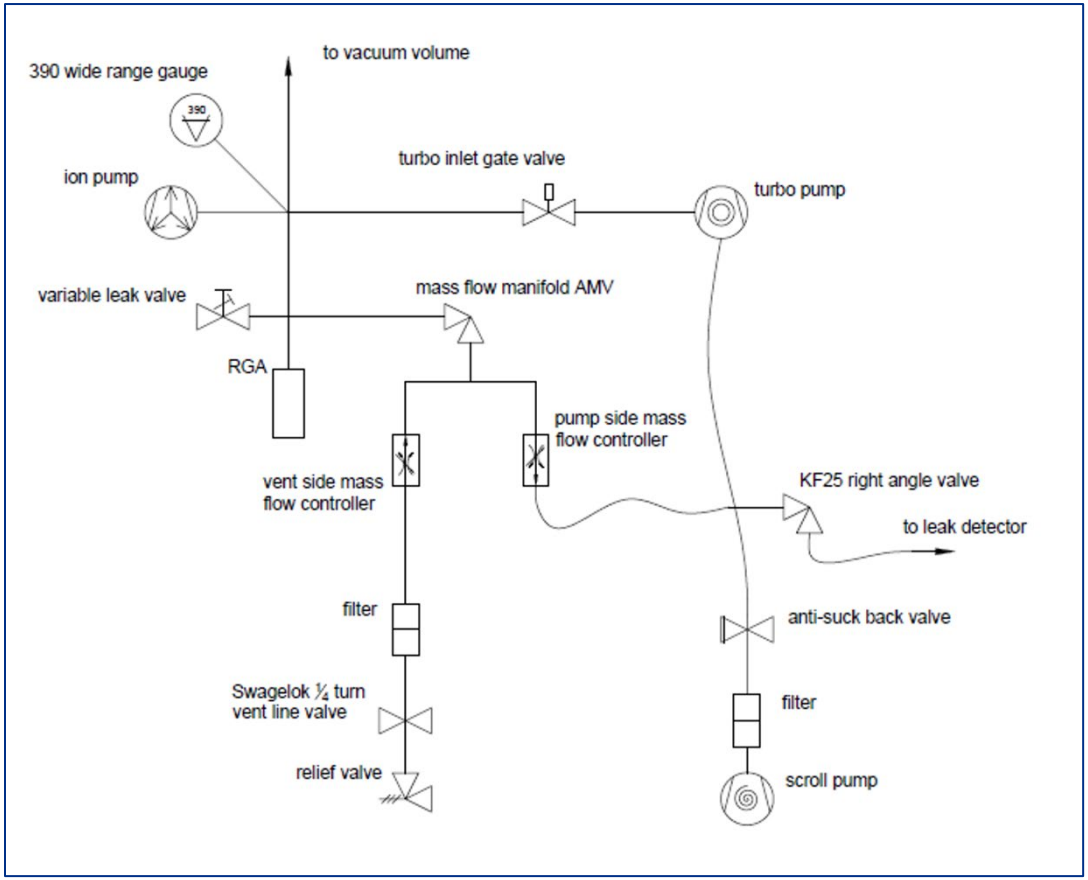


PIP-II Injector Test Accelerator

Particle Safe Vacuum Cart

Talk To:
Lucy Nobrega

- Mass Flow Control for slow pumping/backfilling in high pressure regime where particulate transport is more likely
- Standard design deployed across Fermilab
- Cart design includes
  - Mass flow controllers
  - Scroll, Turbo and Ion pumping
  - Gauges and Diagnostics



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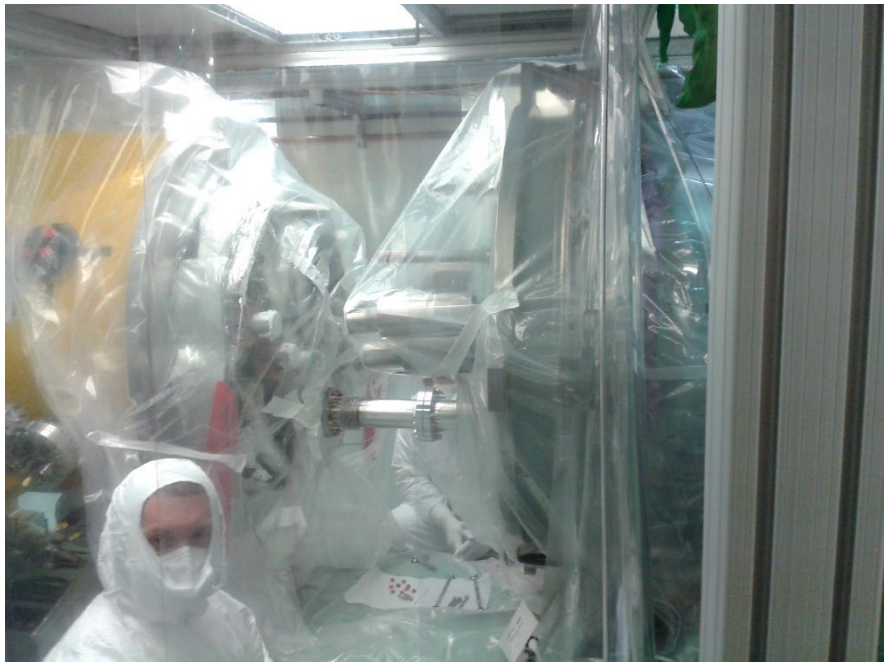
A skilled workforce is the key to success

- Skilled and dedicated technicians are essential to this work
- Developing and continuously improving these skills is a “must’
- Thanks to the OLAV organizers for this opportunity to cross-pollinate

Pay no attention to the man behind the curtain!



Do pay attention to the man or woman behind the curtain!

Thank you for your attention!

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