Triton Beam Development

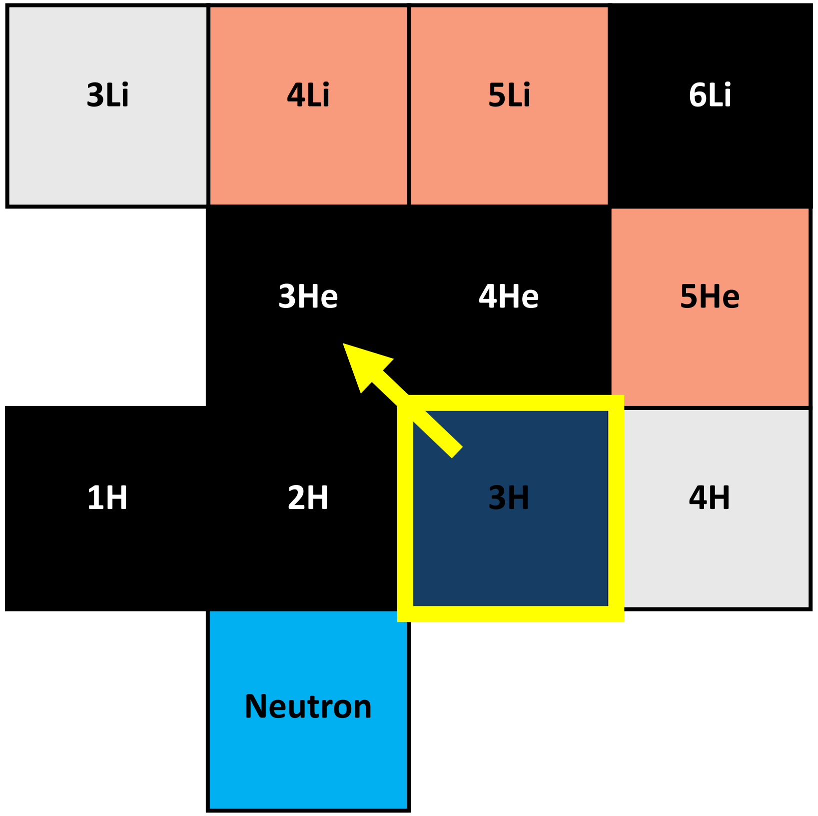
Ashton Morelock

Tritium Background

- No facility currently exists in the U.S. to produce pure, low energy (3-17 MeV) tritium beams.
  - (t,p), (t,n), (t,α), (t, ^{3}He), t+t
- There are a significant number of nuclear reactions involving tritium that are crucial for Stockpile Stewardship, Nuclear Fusion, Nuclear Structure, and Nuclear Astrophysics. For many of these, the cross-sections and the distribution of reaction products are either unknown or uncertain.
- Tritium was successfully and safely run in the past (UPenn and McMaster) using sputter (solid state) sources.
  - Tritium contamination was not a problem.

Tritium Background

- $t_{1/2}$ = 12.32 years
- $^3H \rightarrow {}^3He + e^- + \bar{\nu}_e$; Q(β⁻) = 18.6 keV
  - Travels less than 7 mm in air
  - Cannot penetrate dead layer of skin
  - Cannot penetrate clothing or gloves
- Internal exposure
  - Inhalation
  - Absorption
  - Ingestion

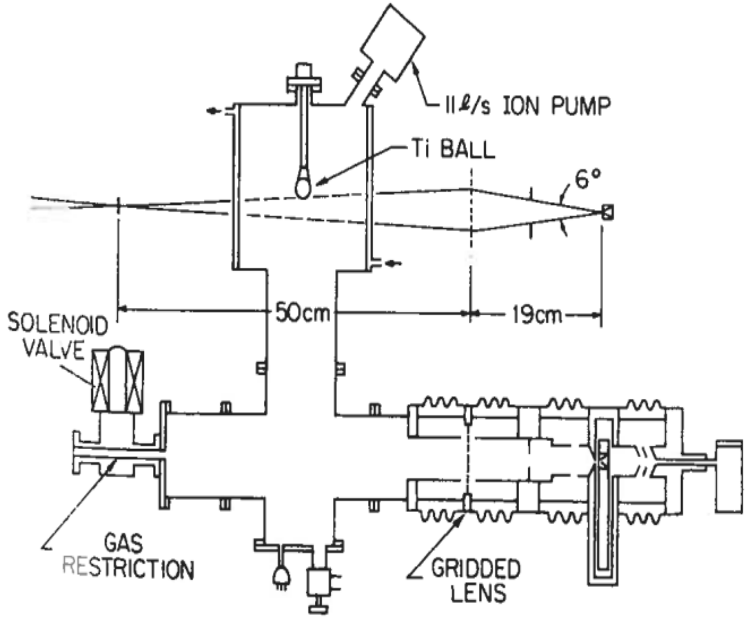


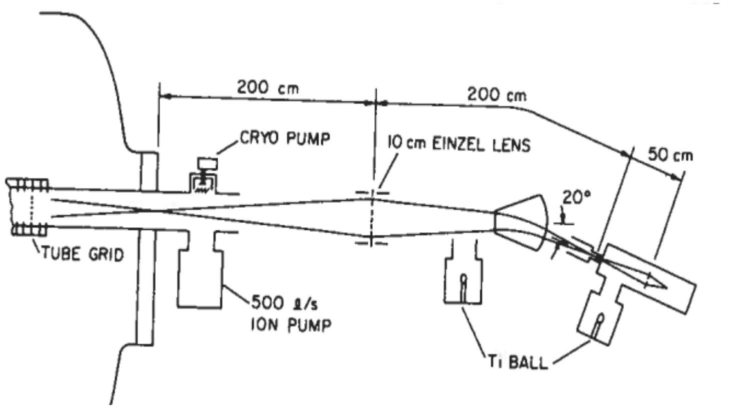
Triton Beam Project at FSU

- FSU-UTK-ORNL collaboration to install a dedicated MC-SNICS for triton beams at the John D. Fox laboratory, backed by NNSA and CENTAUR
  - **Safely** explore questions for Stockpile Stewardship, Nuclear Structure, etc. using tritium
- Paired with the new Super-Enge Split Pole Spectrograph (SE-SPS), safely produce and handle triton beams from 3 – 17 MeV for nuclear physics experiments

University of Pennsylvania Tritium Source

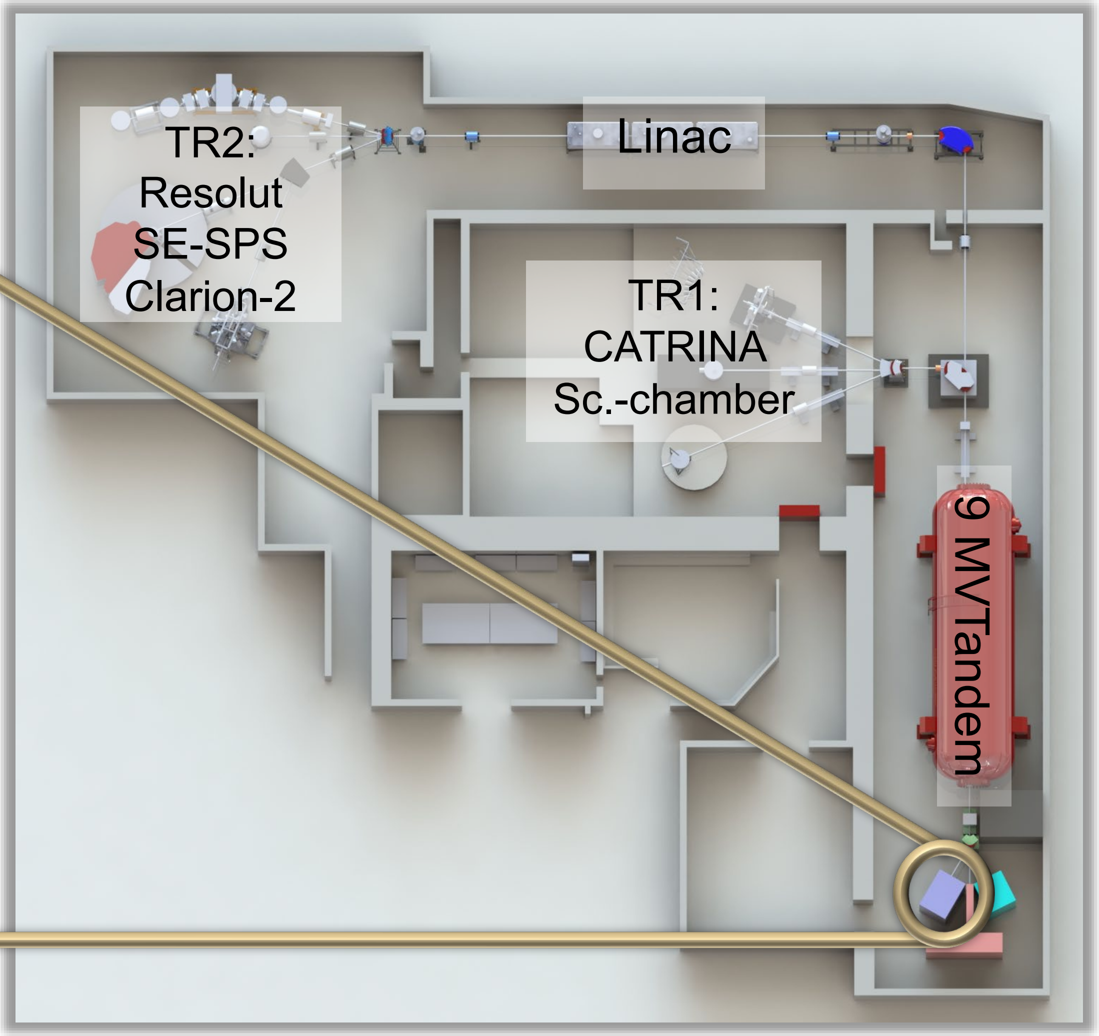
- Pioneered hydrogen beams from solid-state material
- Titanium Sublimation Pumps
- Beam current: 0.25 μA – 4 μA
- Transmission : ~75% - 33%
- Report negligible contamination of the accelerator
  - Report 5μC/cm^2 in inflector magnet





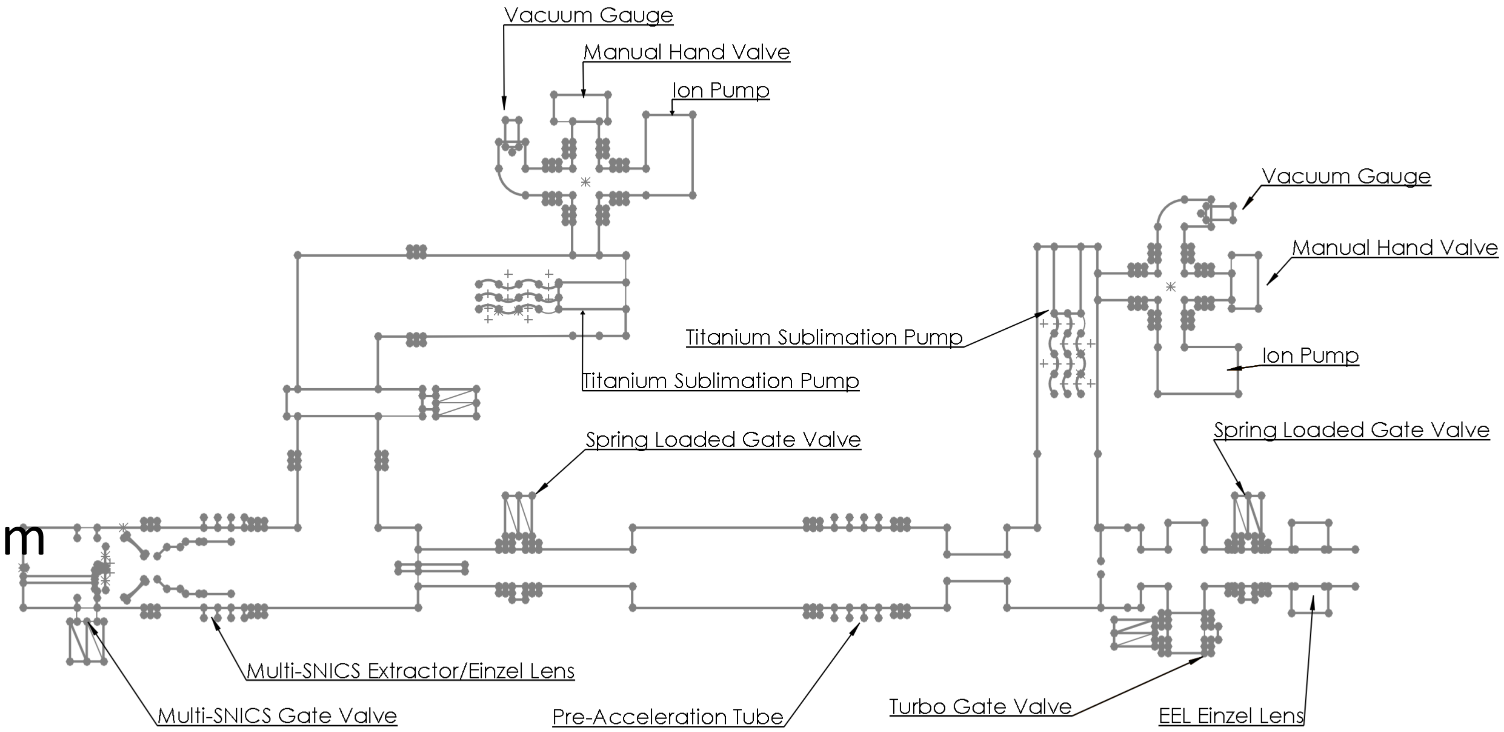
Middleton, Adams and Kollartis, NIM 151 41-46 (1978)

John D. Fox Laboratory at FSU



Florida State University Tritium Source

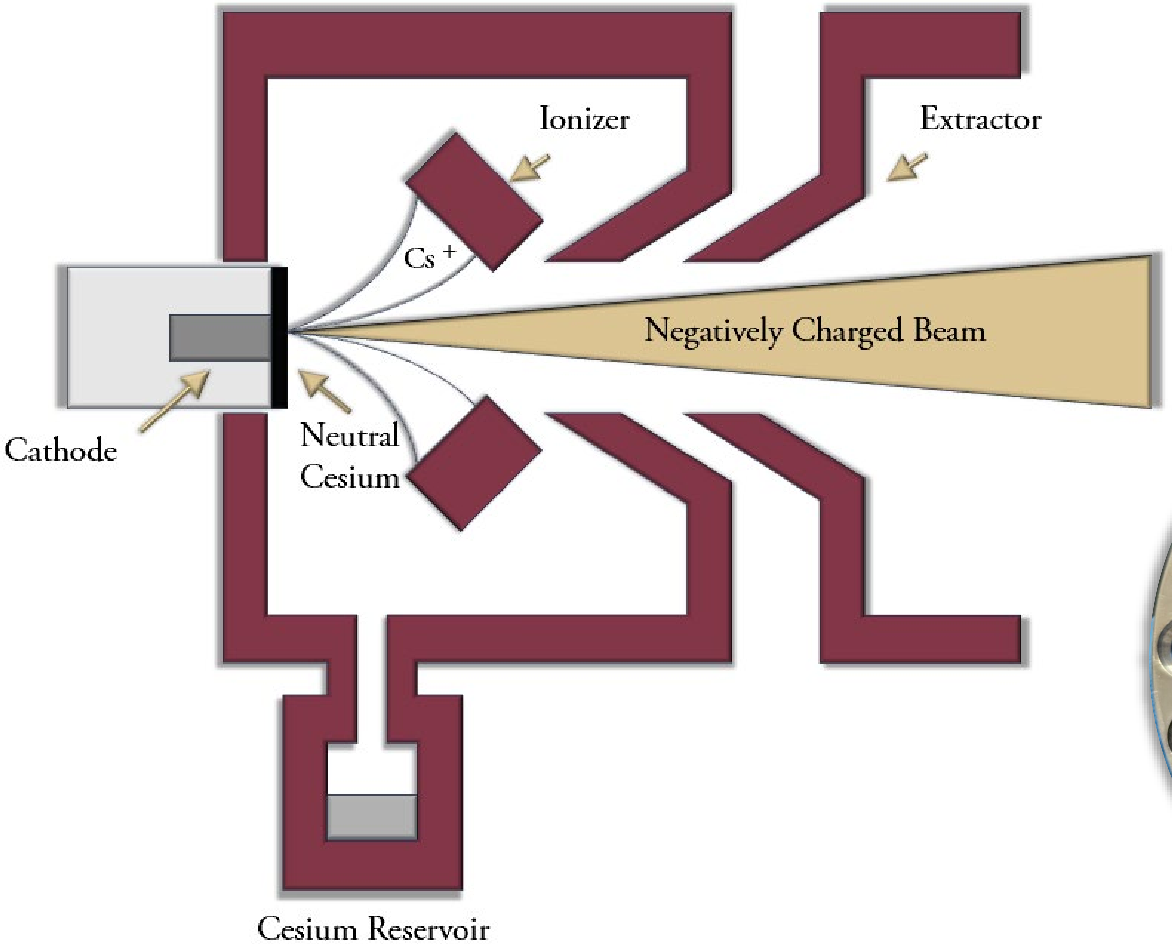
- Multi-cathode SNICS source
- Titanium sublimation pumps
  - 1st on potential
  - 2nd before inflector magnet
- Lower beam current: ~20 nA
- Higher transmission: >98% from source to analyzed beam
- Further **limit** and **negate** any tritium contamination.

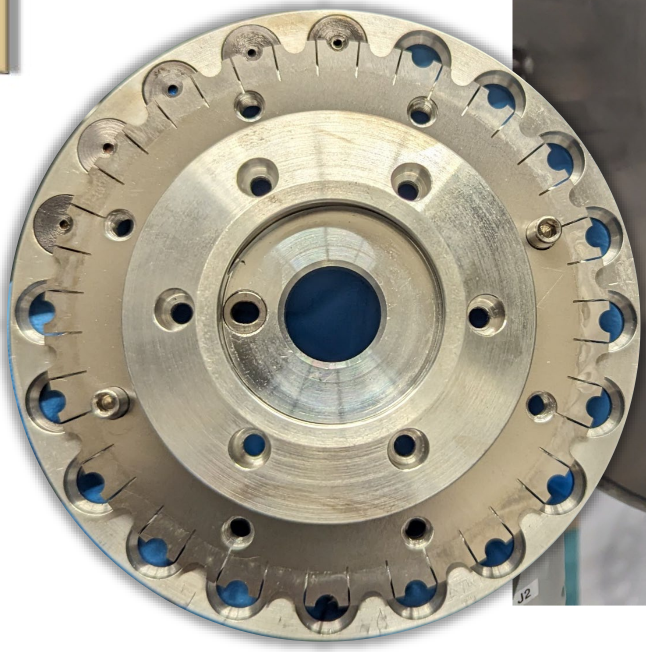


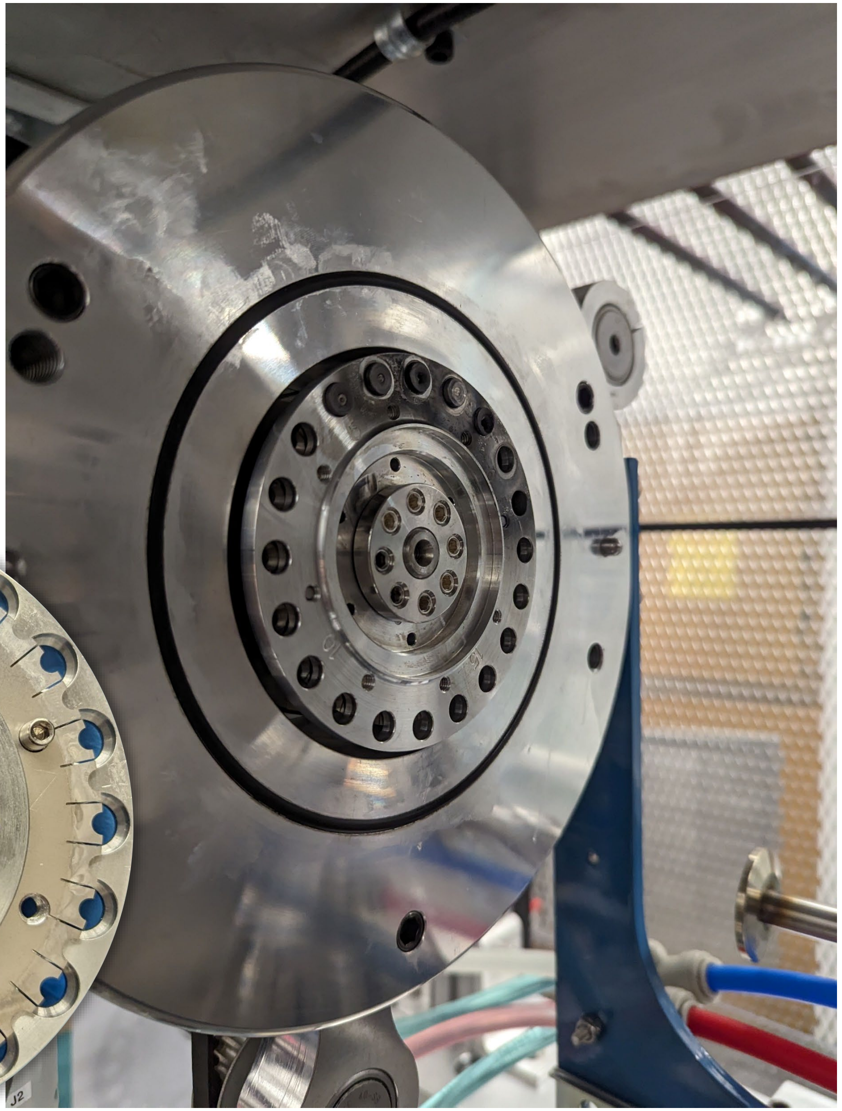
Safety Precautions

- **No** handling of gaseous tritium
- Negative Pressure Enclosure (fume hood) around source
- Tritium Monitor (sensitive to 1 $\mu C/m^3$)
  - Another monitor sensitive to 0.1 $\mu C/m^3$ will be installed
- Interlock System
- Titanium Sublimation Pumps
- "Unique" equipment for tritium campaigns
  - LE buncher
  - Slits
  - Beam stops

MC-SNICS

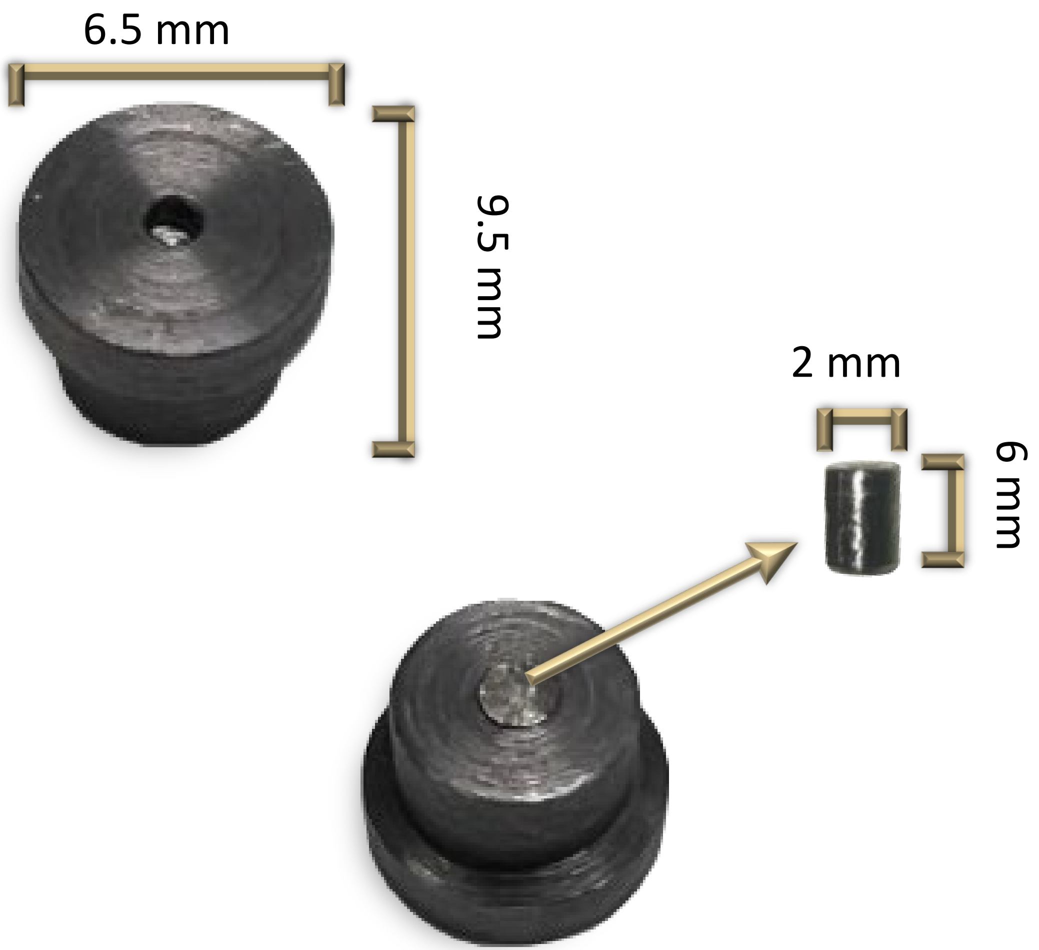

Ionizer
Extractor
Cs +
Negatively Charged Beam
Cathode
Neutral Cesium
Cesium Reservoir



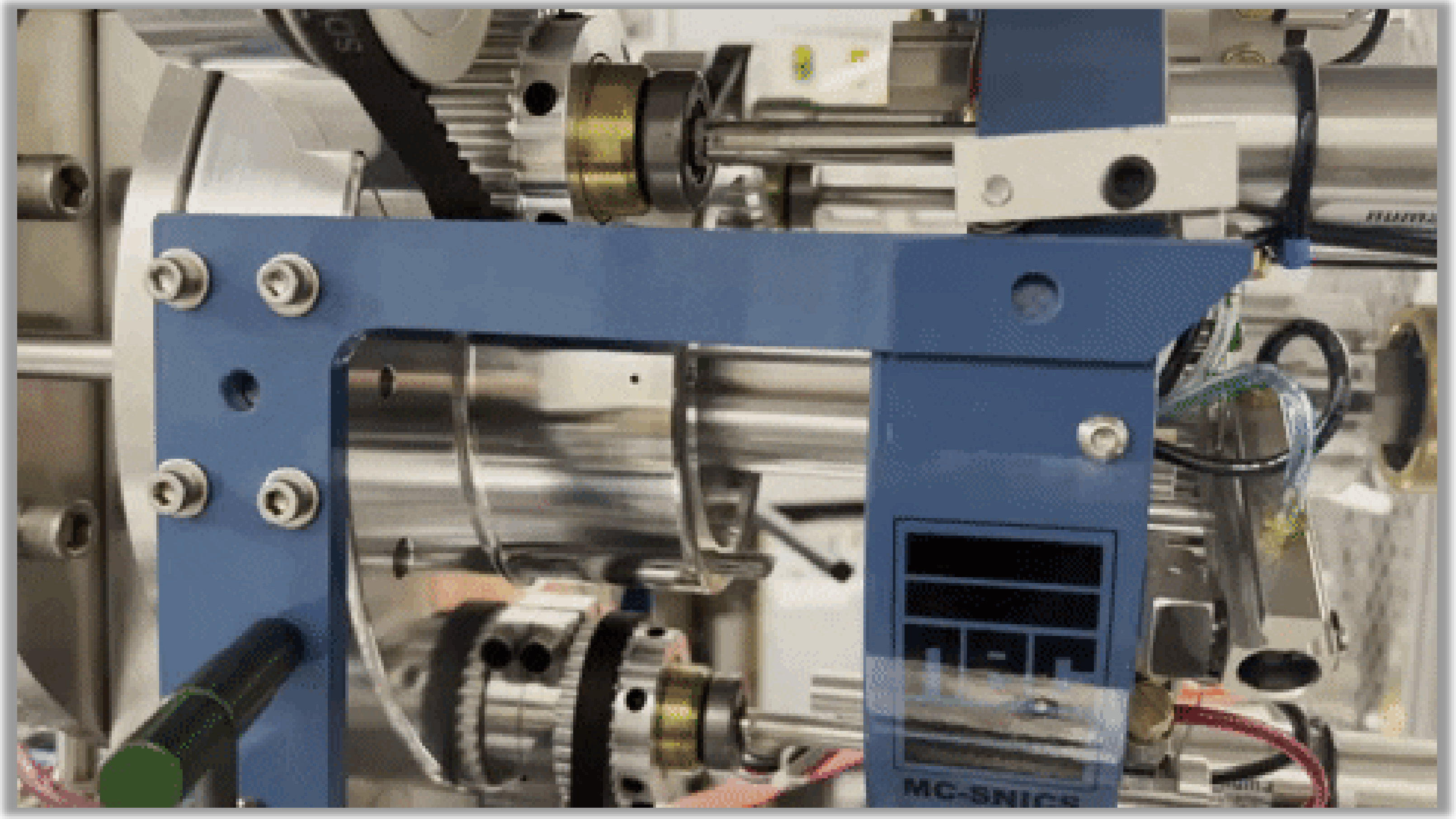


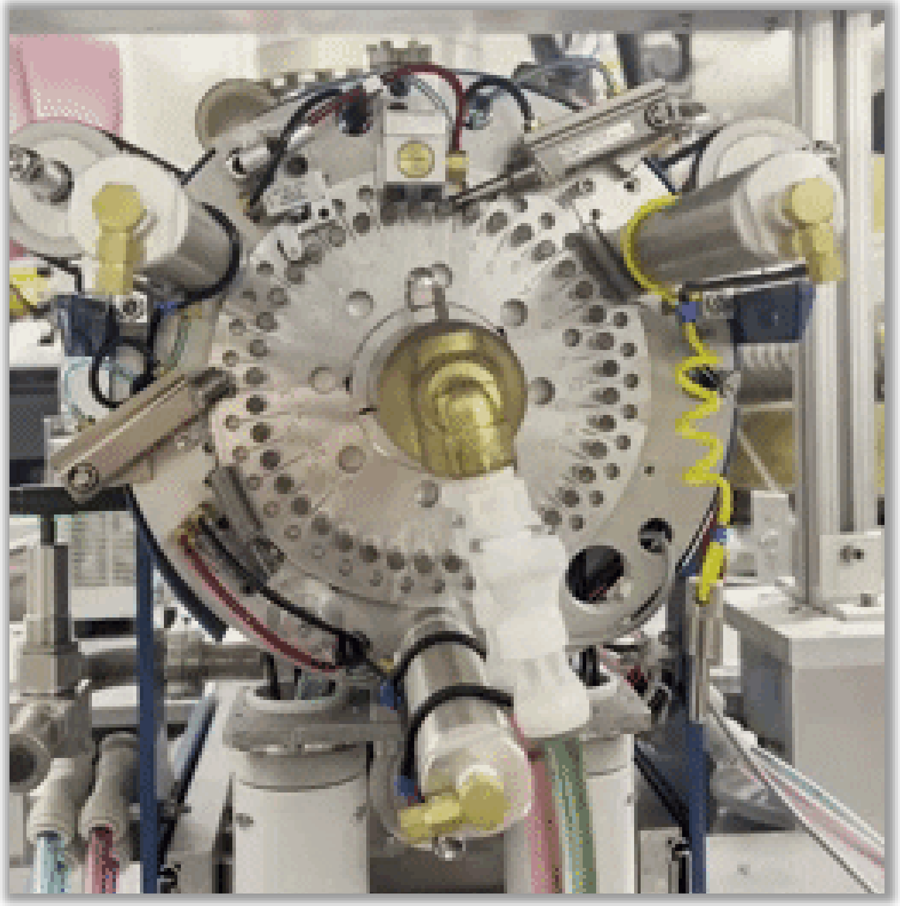
Cathodes

- 9.5 mm x 6.5 mm tantalum Jacket
- 6 mm x 2 mm titanium insert
- 5 tritiated cathodes
- 5 deuterated cathodes
- Carbon cathodes
- Up to 20 spots

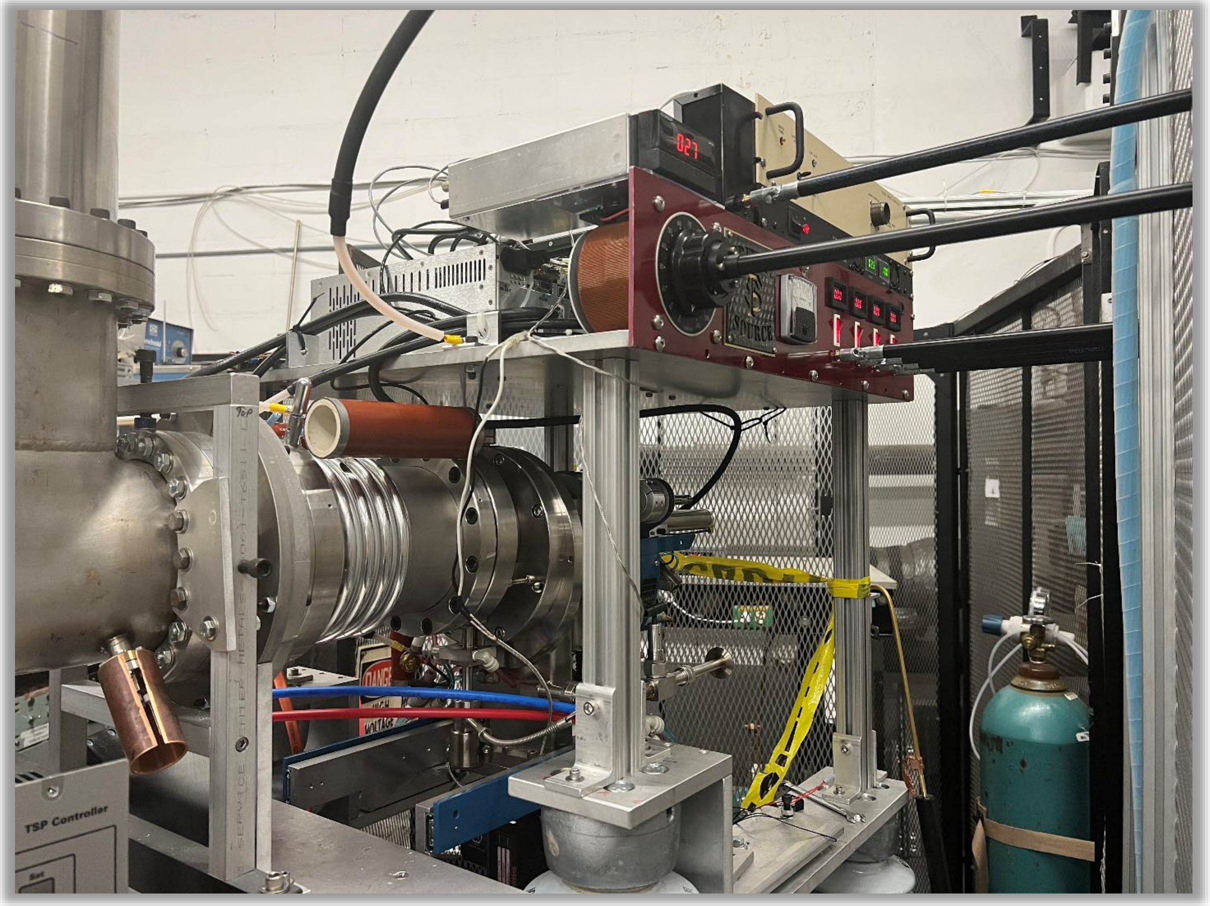


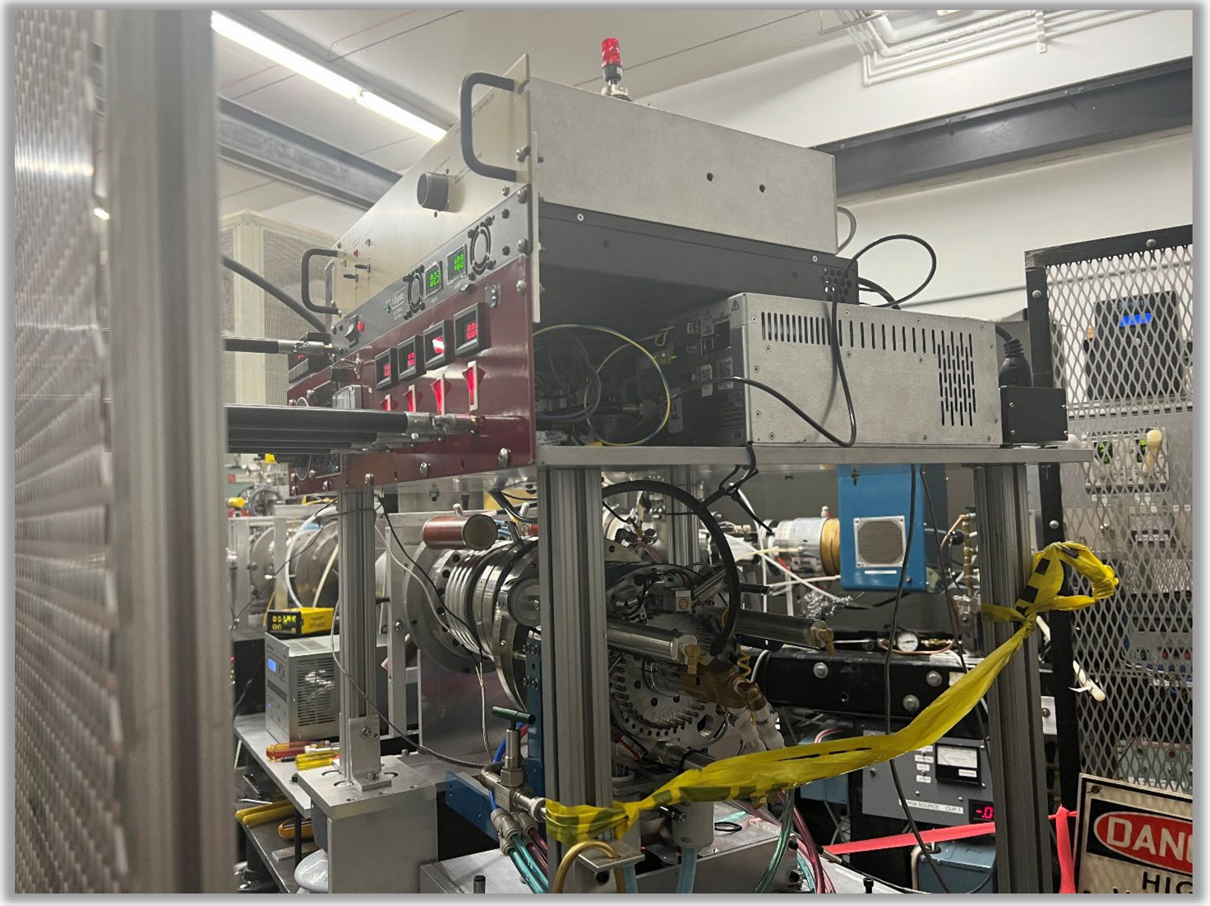
Pneumatics



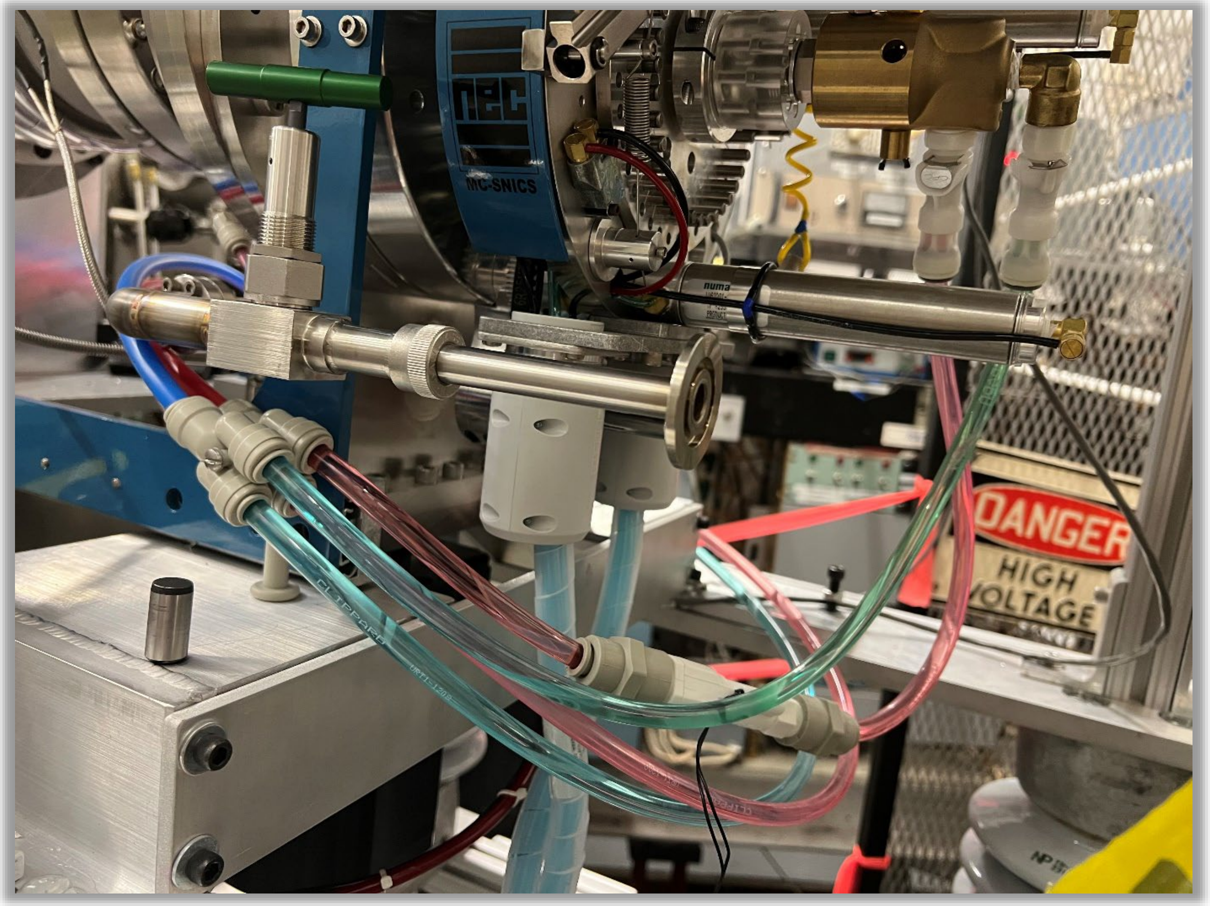


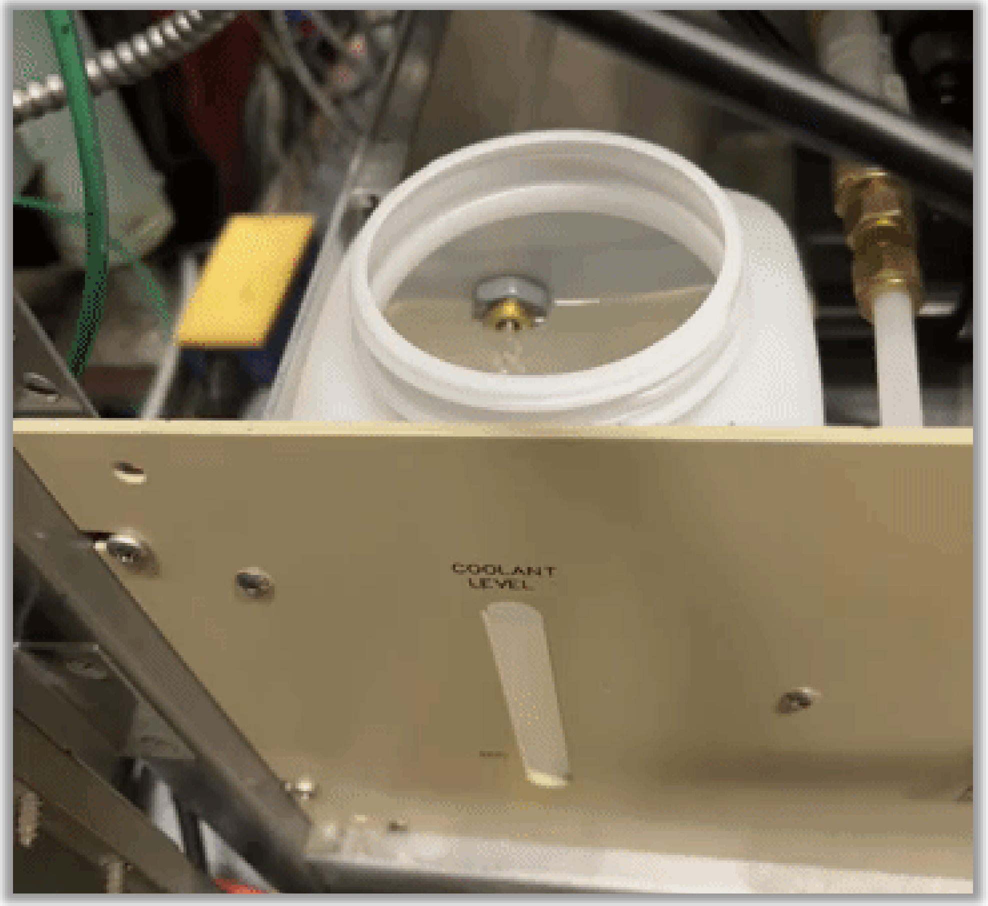
Power Supplies





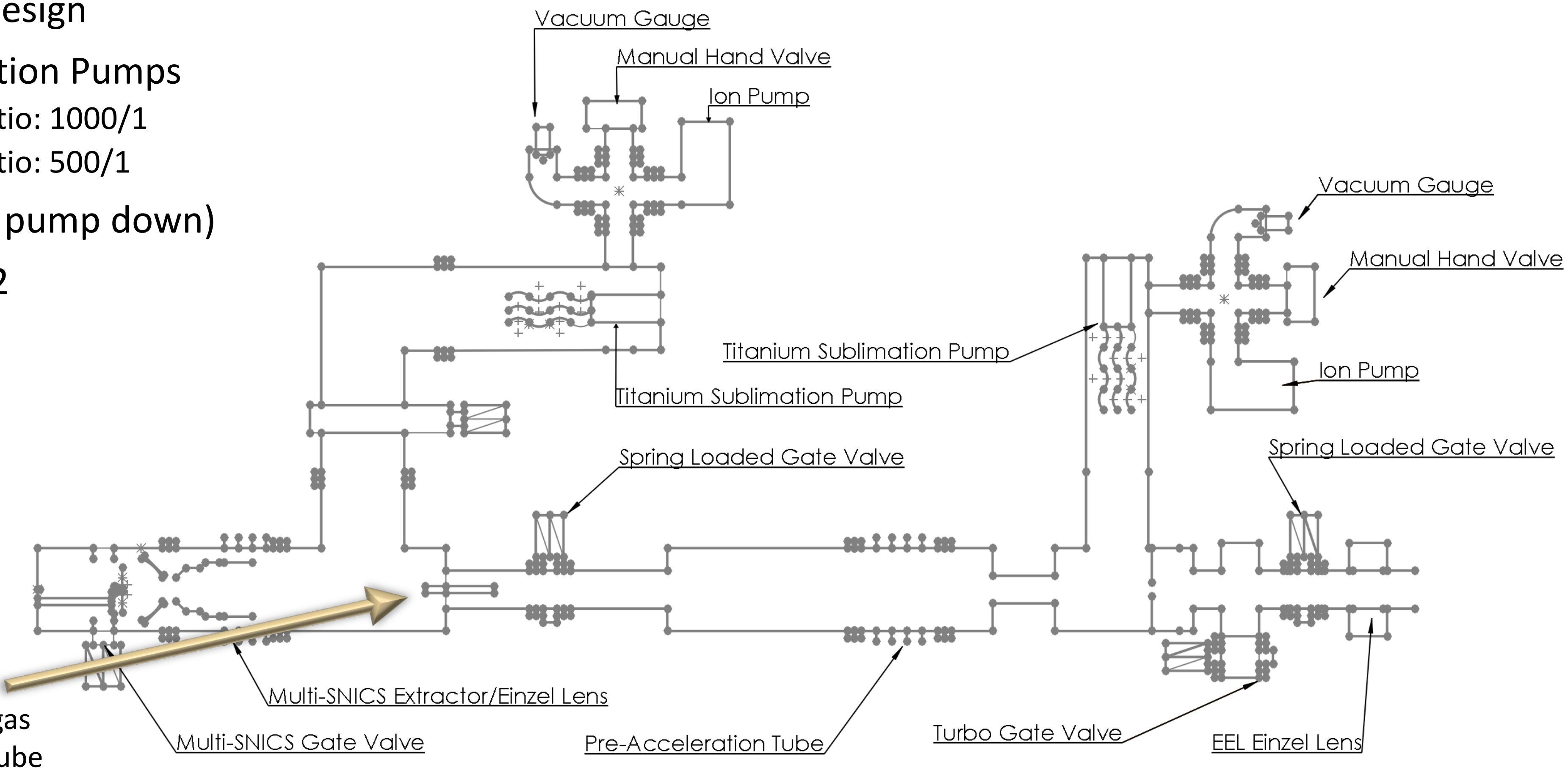
Cooling





Vacuum

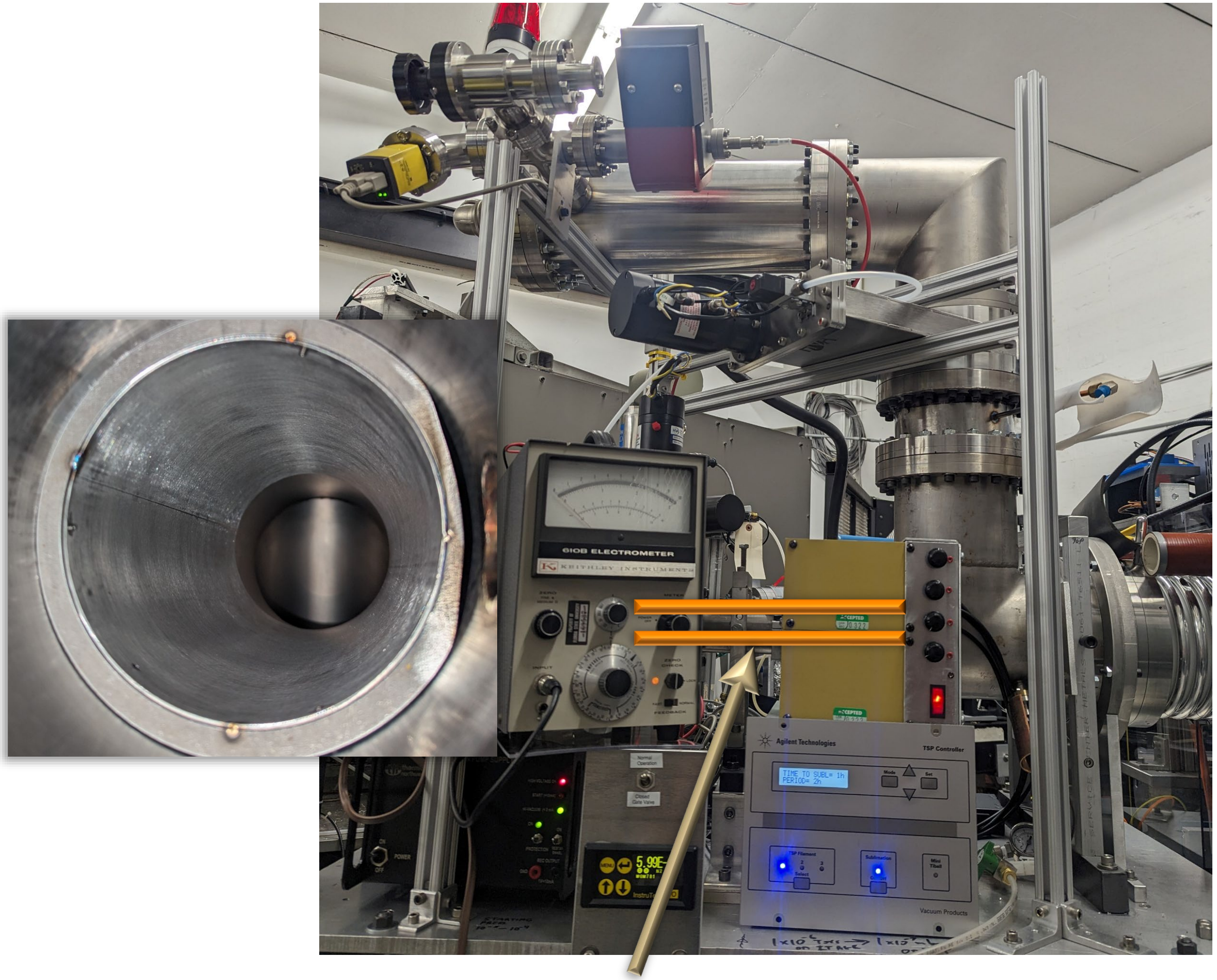
- Differential pumping design
- Two Titanium Sublimation Pumps
  - TSP1 conductance ratio: 1000/1
  - TSP2 conductance ratio: 500/1
- Two Ion Pumps (initial pump down)
- Turbo pump after TSP2



~0.25” x 1’ gas restriction tube

Vacuum

- Removeable liner inside of TSP to be declared as radiological waste → Smaller and cheaper removal



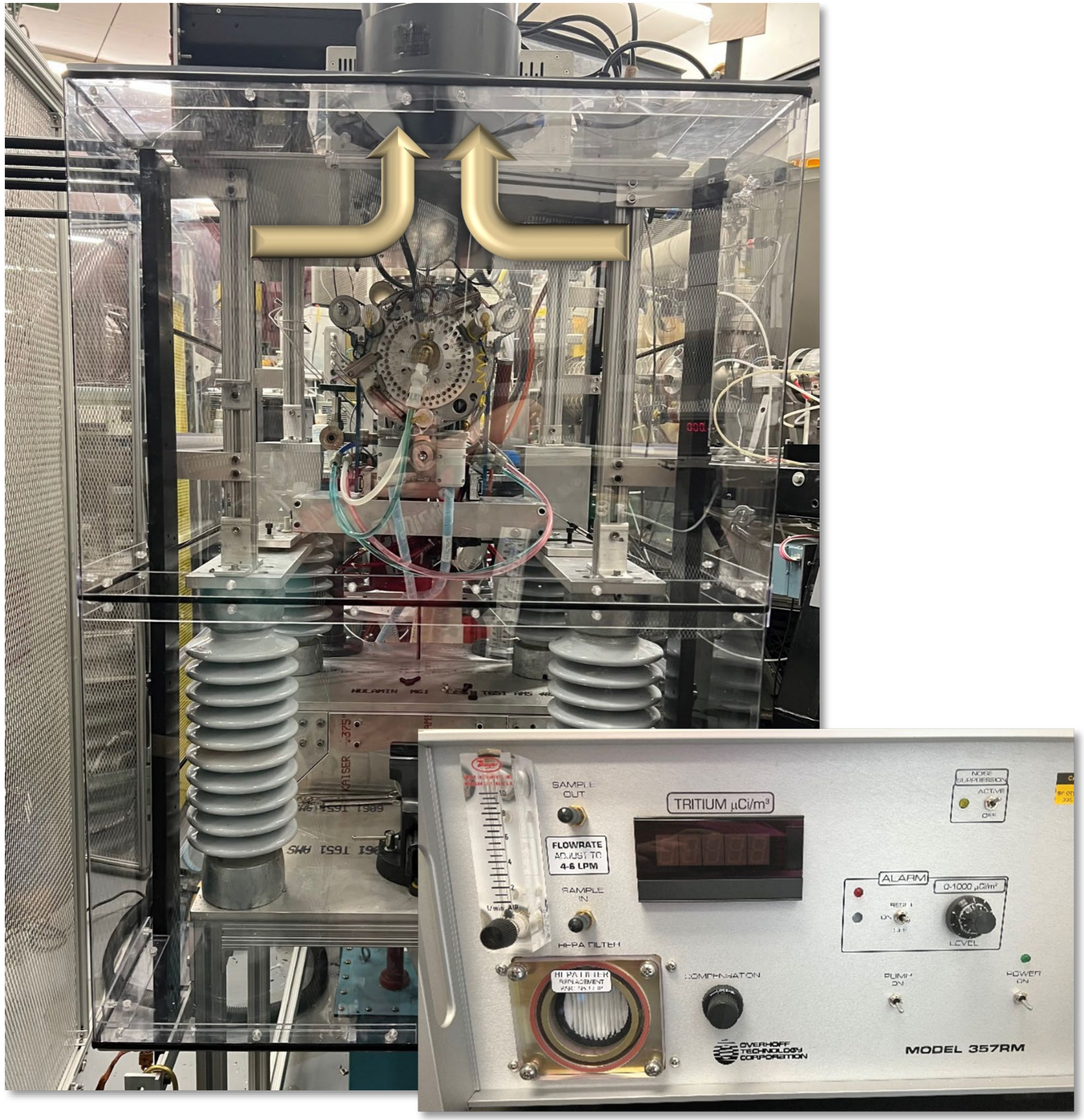
~0.25” x 1’ gas restriction tube

Fume Hood

- Florida State University and CENTAUR sponsored duct work installed.
- Fume hood designed and built around the source for tritium evacuation
- ~300CFM → ~100FPM face velocity around the hood

Fume Hood

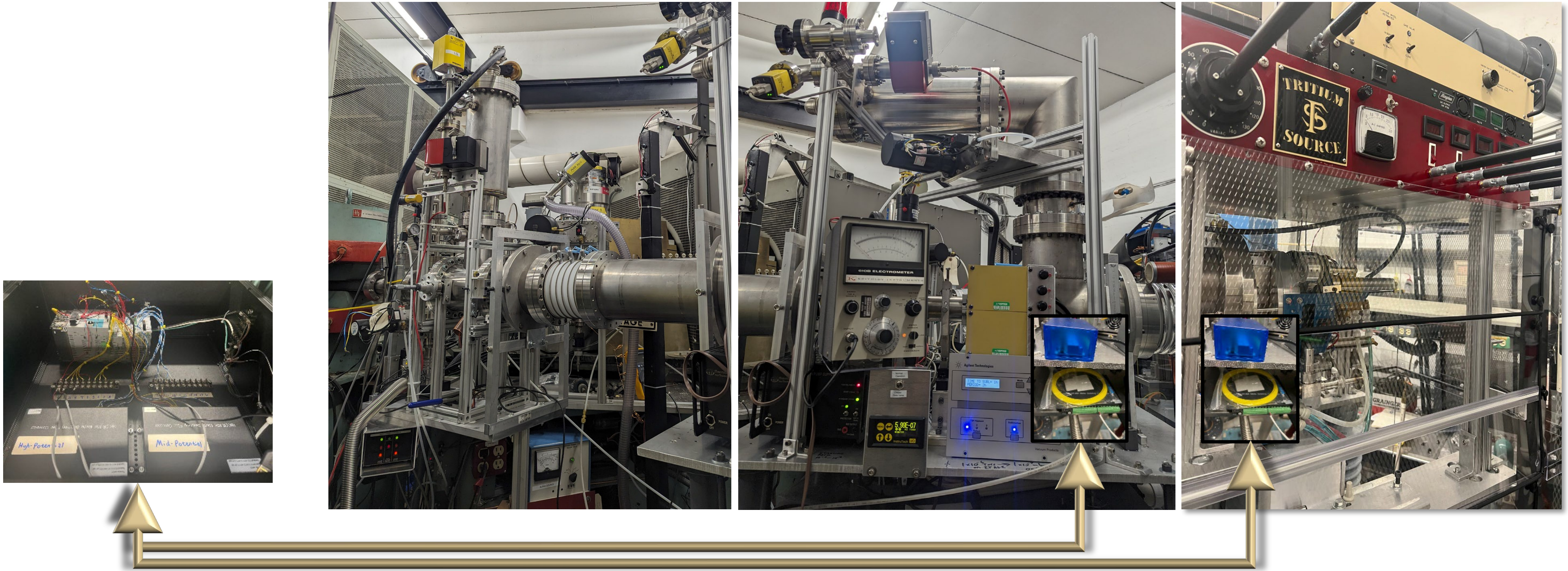
- Exhaust from roughing pump is released within fumehood
- Tritium monitor samples all outgoing air
  - Regulatory limit : 0.3 Ci /yr
  - Our goal: 200µCi/yr



Fume Hood

- All tritiated cathodes will be sealed until under the hood
- All cathodes and tritium related devices will always be under the fume hood
- Ports for accessing and working on both sides of the source

Interlock System



Ground

~60kV

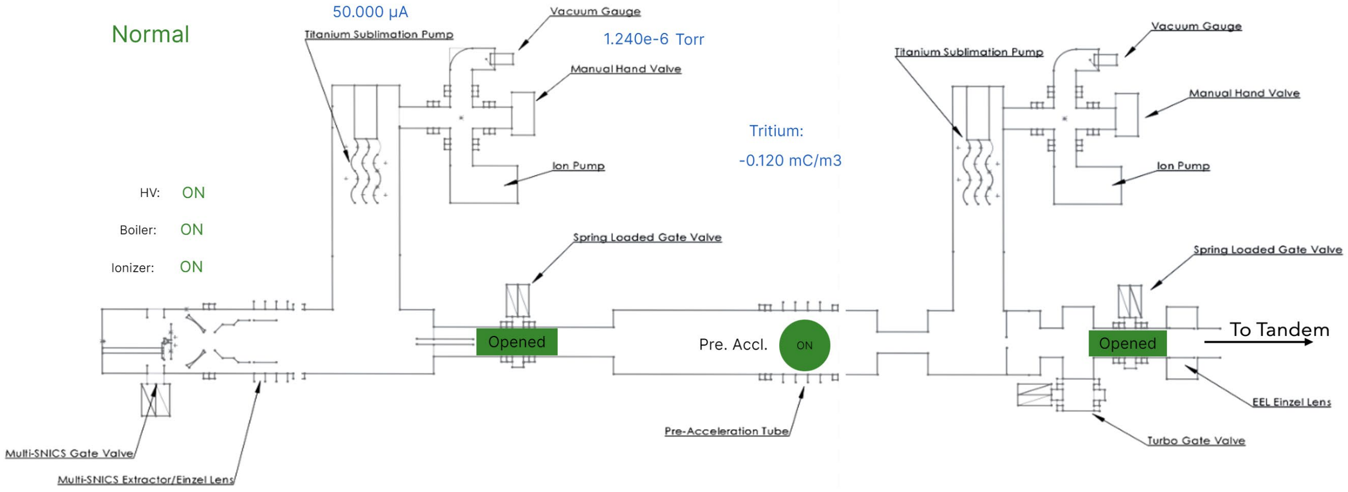
~75kV

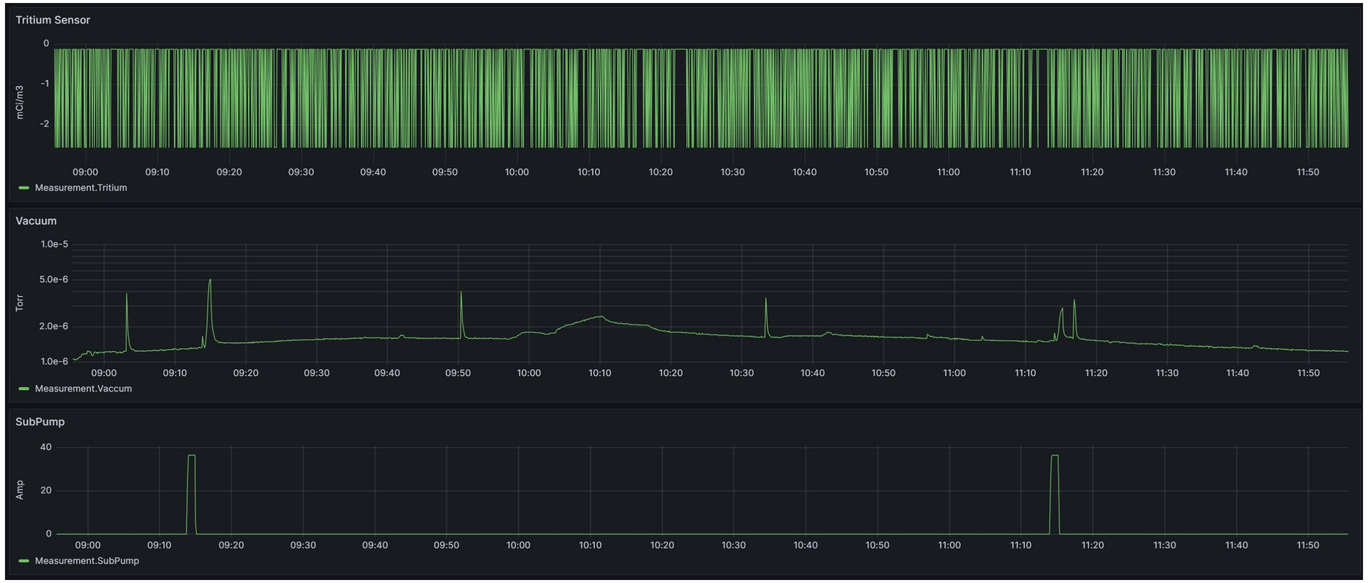
Interlock System

Exception Condition	Interlock Trip		
	Level 1: HV Off	Level 2: Vacuum Isol.	Level 3: Power Off
Cage door opened	X		
Vacuum above threshold	X	X	
Coolant flow supply trip	X	X	
Coolant flow return trip	X	X	
Smoke detector alarm	X	X	X
Fume hood flow trip	X	X	X
Tritium monitor trip	X	X	X
Power failure	X	X	X
Emergency button	X	X	X

Interlock System

- Grafana is used to monitor the interlock in the control room
- Record what caused a source trip and what level of trip occurred
- Record tritium levels, vacuum levels, and TSP1 current





Deuterium Cathode Fabrication

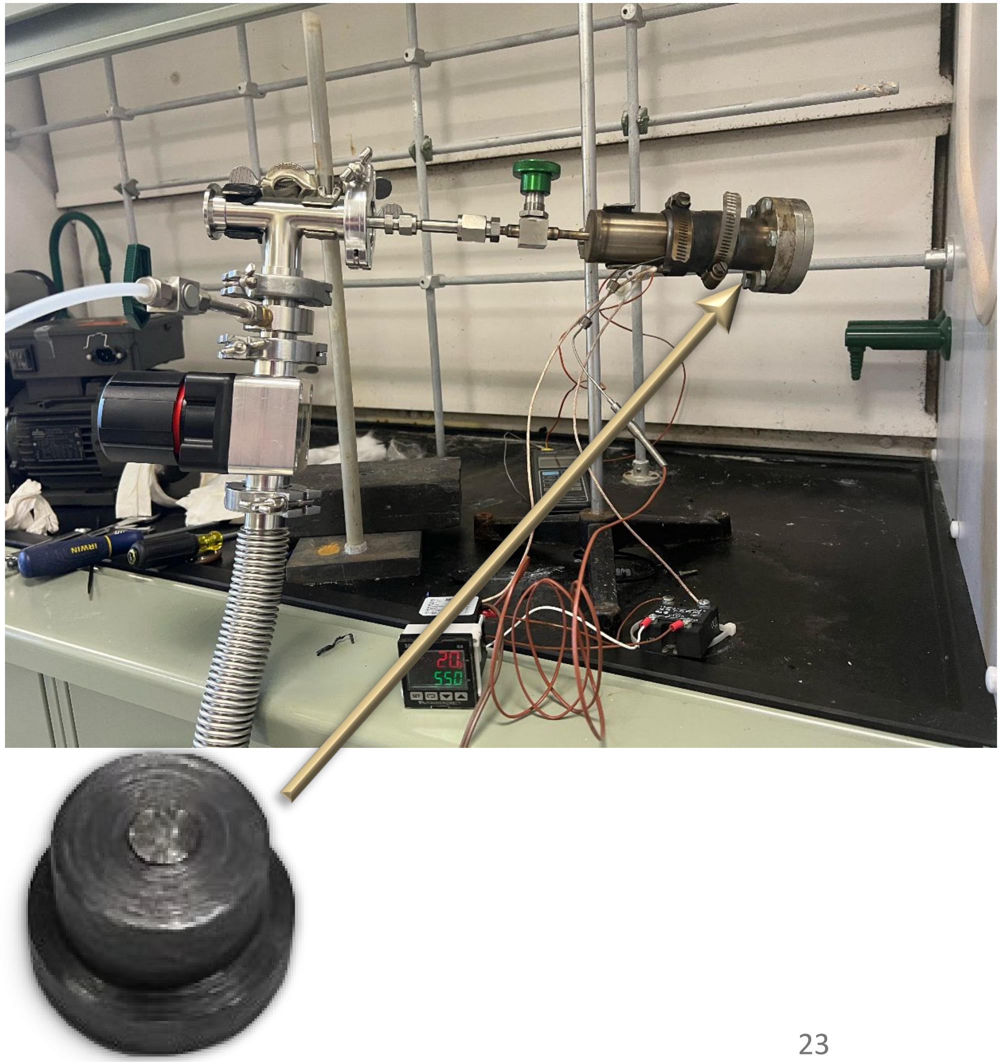
- Titanium absorbs hydrogen → Solid-state hydrogen cathodes
- In house deuterium loading, **<u>outsourced</u>** tritium loading
- ARC approved bottle design for their manifold
- How much hydrogen can we put into these cathodes?

Courtesy of Dr. Janard

American Radiolabeled Chemicals, Inc.

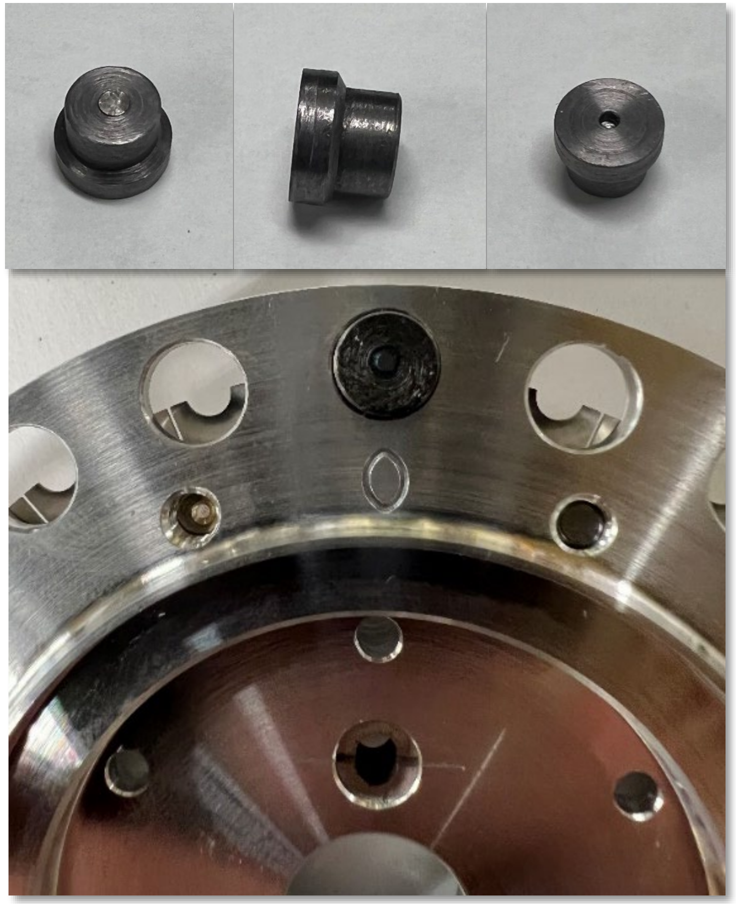
Deuterium Cathode Fabrication

- Insert titanium cathode into bottle and fill with ~500 Torr of deuterium
- Heat to >550^{o}C and bake for ~1h
- Allow to cool back to room temp. measure gas pressure difference (typically ~100 Torr)

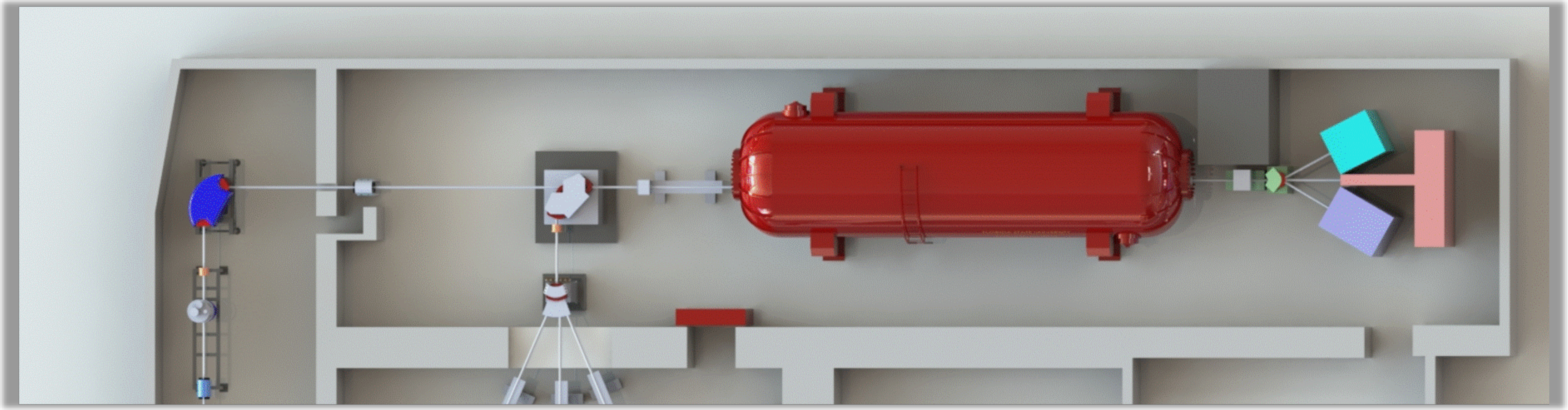


Deuterium Cathode Testing

- Always around a 1:1 ratio of deuterium to titanium determined by the loss of D as well as weight of cathode
- This method successfully produced a deuteron beam for experiments within the FSU lab.



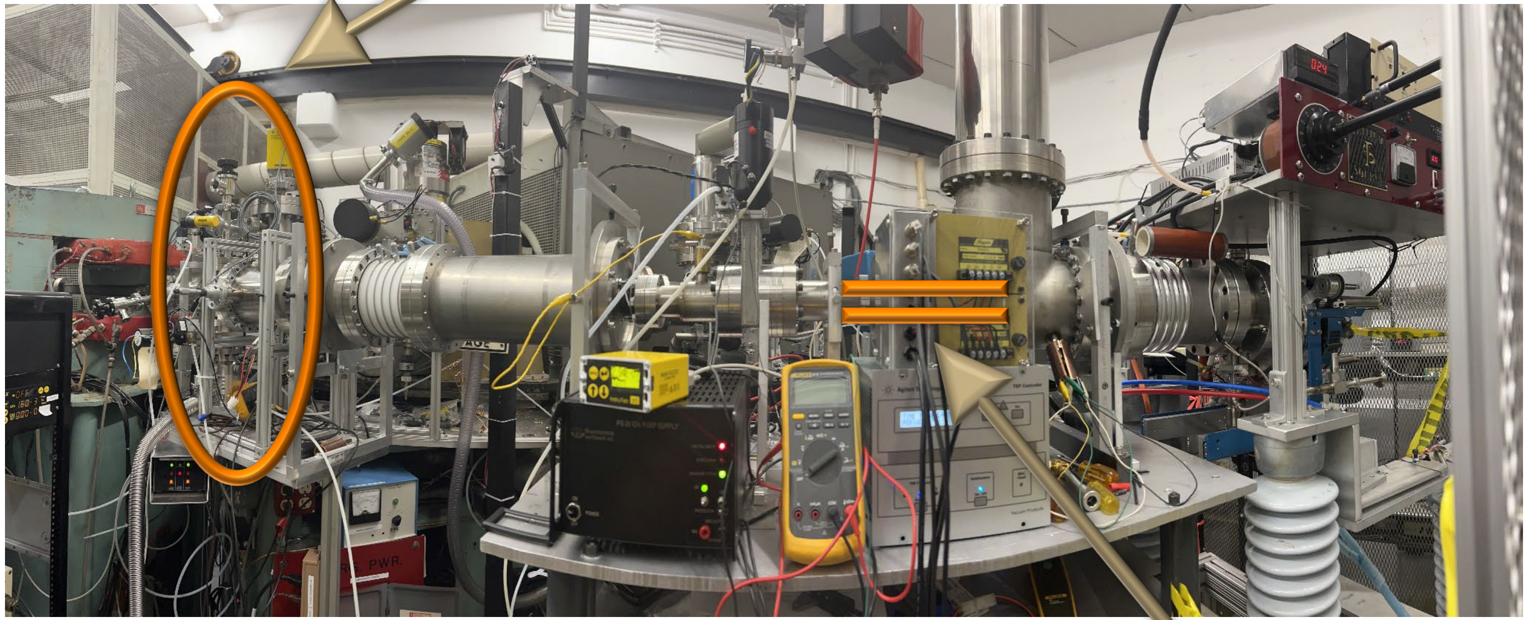
Initial Beam Extraction



Initial Beam Extraction

- Determine where deuterium goes →will be where tritium goes
- Residual Gas Analyzer to take measurements immediately after injector
- Show that very little deuterium makes it out of the source cavity

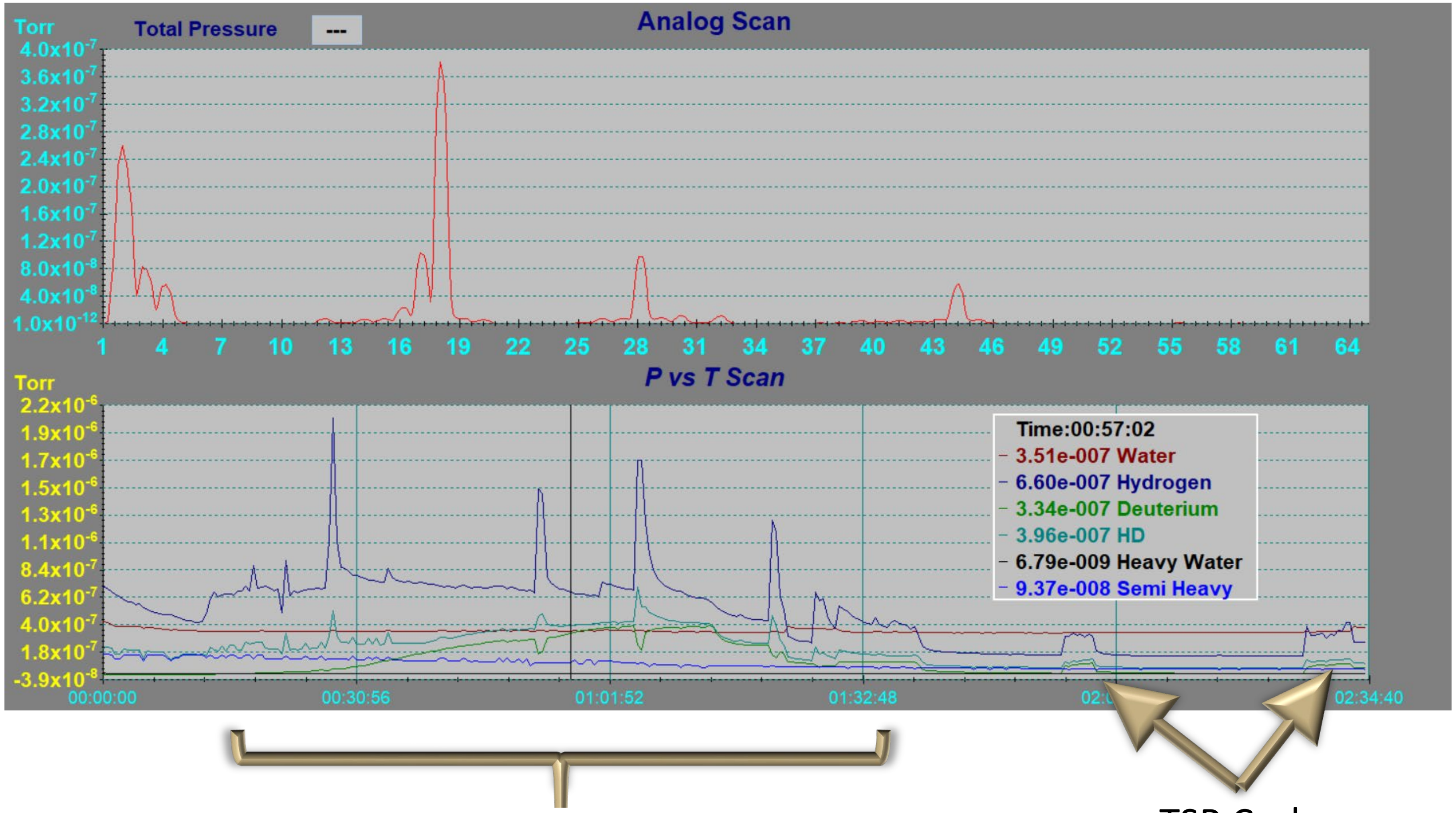
RGA Mount



~0.25" x 1' gas restriction tube

Initial Beam Extraction

- 99.9% of deuterium remains in source beamline
- RGA readings show that only on initial ionizer heat up and when TSP1 cycled does deuterium end up beyond the gas restriction
- Still <1x10^{-6} Torr, including HD,D, HDO and D_2O where TSP2 is placed



Initial Beam Extraction

- ~20-40nA used for about 5 days
- This consumed ~10% of a single cathode by mass of titanium
- →1000 hours of beam time per cathode @ 20nA
- 0.1% of the consumed cathode is ultimately accelerated

Tritium Cathode

- Inside the current geometry of a 2 mm x 6 mm Titanium pellet, about 20 Ci of tritium can be baked in per pellet
- → 100 Ci = 5 Cathodes
- Bottle was shipped to vendor, baked by vendor, backfilled with Argon, then sent back to us

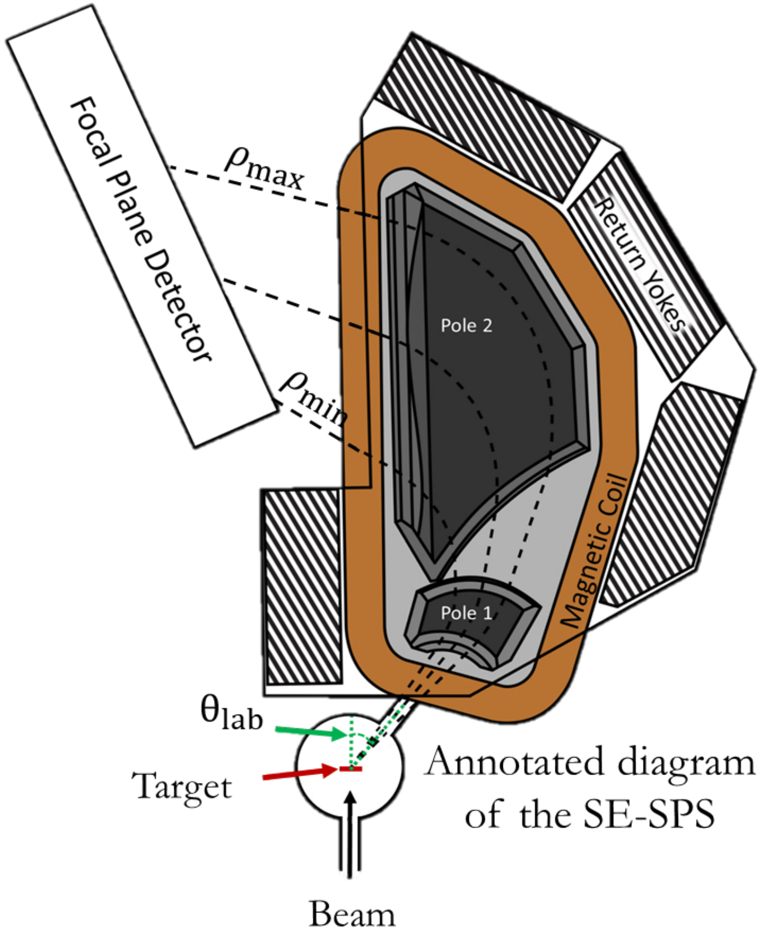
What does this mean for tritium?

- 90% Deuteron Transmission → 90% Triton Transmission (the rest ends up on disposable slits)
- Only about 0.1% of the sputtered deuterium ends up down the beam line → 99.9% of the sputtered tritium will be left in the source cavity and TSP1 based on RGA analysis
- We plan on ~20nA of triton intensity → ~3000h of beam time for a triton campaign (assuming half the tritium is usable)

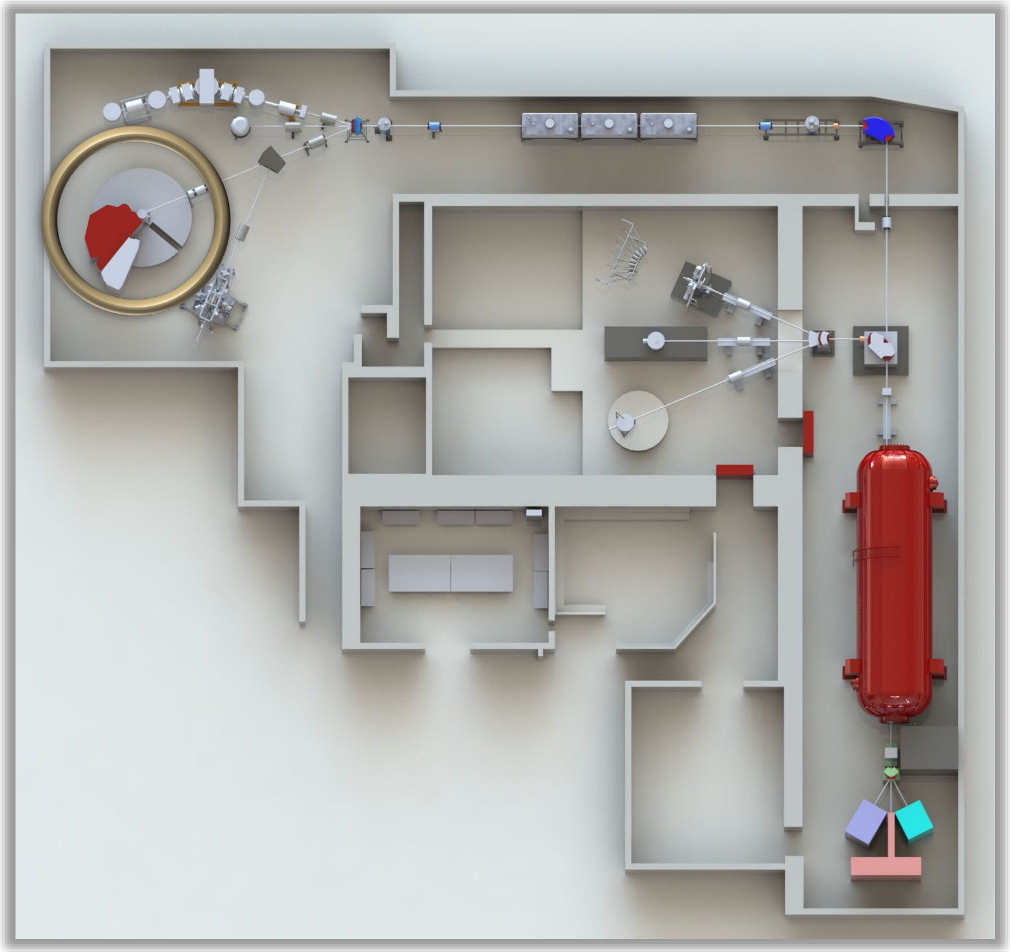
Campaign

- 3000 hours over two years
- ~20 nA estimated from observed deuterium consumption
- At end of campaign:
  - Remove tritiated cathodes
  - Remove TSP1 liner
  - Remove “unique” equipment
  - Radiation survey

First Experiments

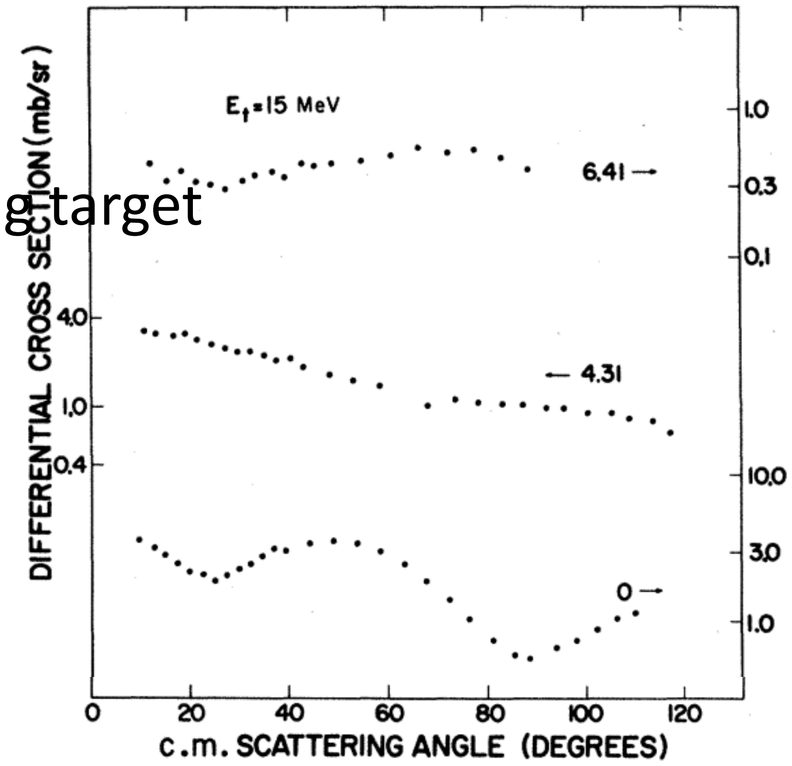


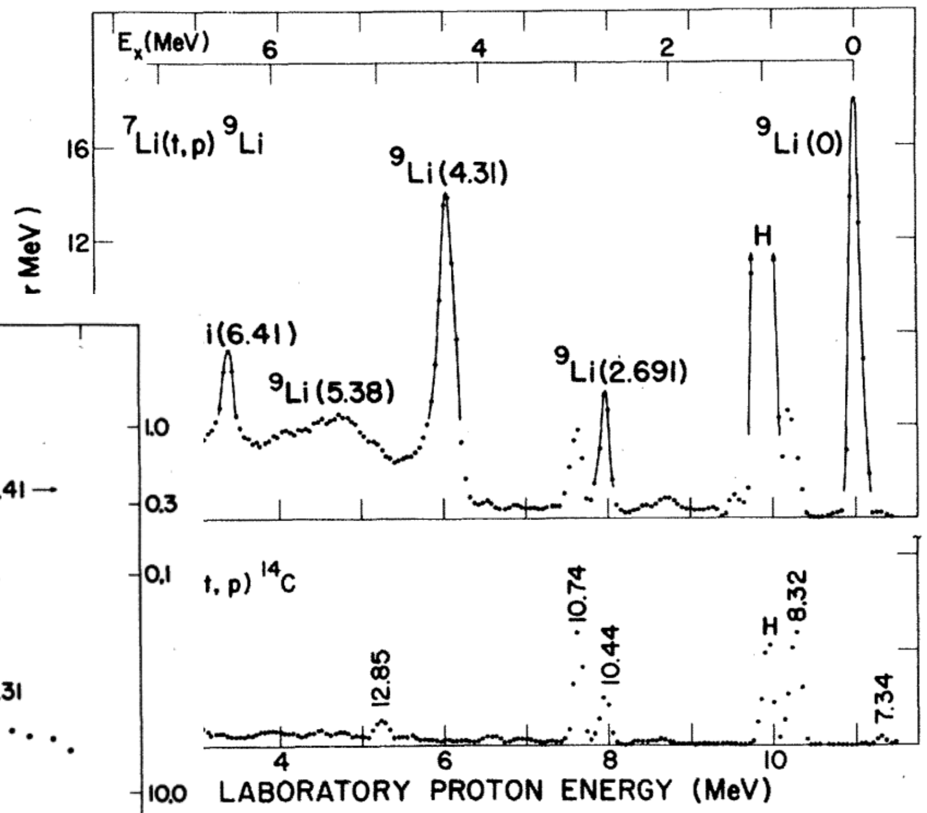
Annotated diagram of the SE-SPS



First Experiments

- $^{7}Li(t,p)\,^{9}Li$
  - Los Alamos
  - 15 MeV
  - 320 μg/cm^2 self supporting target

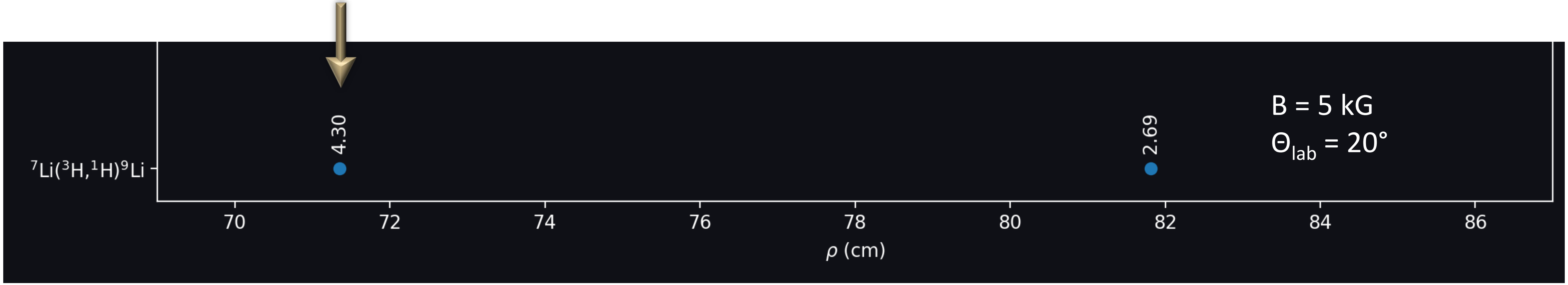




P.G. Young and Richard H. Stokes, PR 1597-1601 (1971)

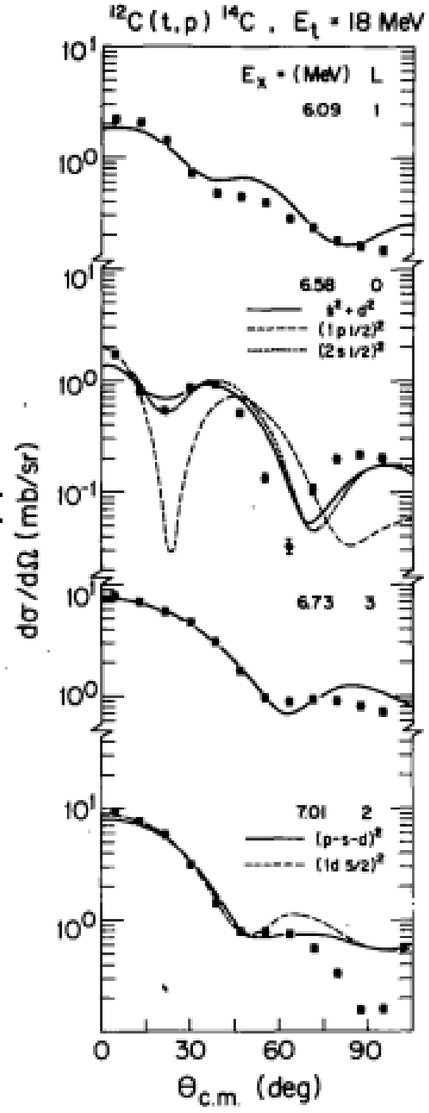
First Experiments

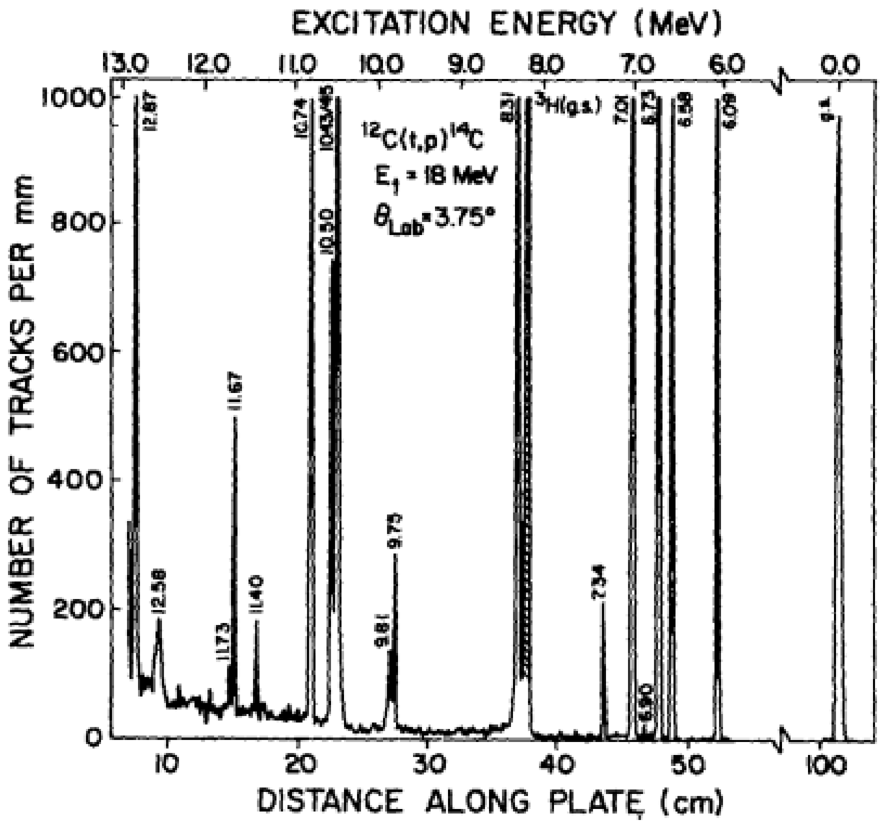
- $^{7}Li(t,p)\ ^{9}Li$
  - 15 MeV
  - 200 μg/cm^2 self supporting target
- For 10000 counts
  - $E_{ex.}$ = 0 MeV (B = 6 kG) ~1.3 hours
  - $E_{ex.}$ = 4.30 MeV (B = 5 kG) ~1.1 hours
  - $E_{ex.}$ = 6.40 MeV (B = 3.5 kG) ~10 hours



First Experiments

- $^{12}C(t,p)\,^{14}C$
  - Upenn
  - 18 MeV
  - 50 μg/cm^2 self supporting target



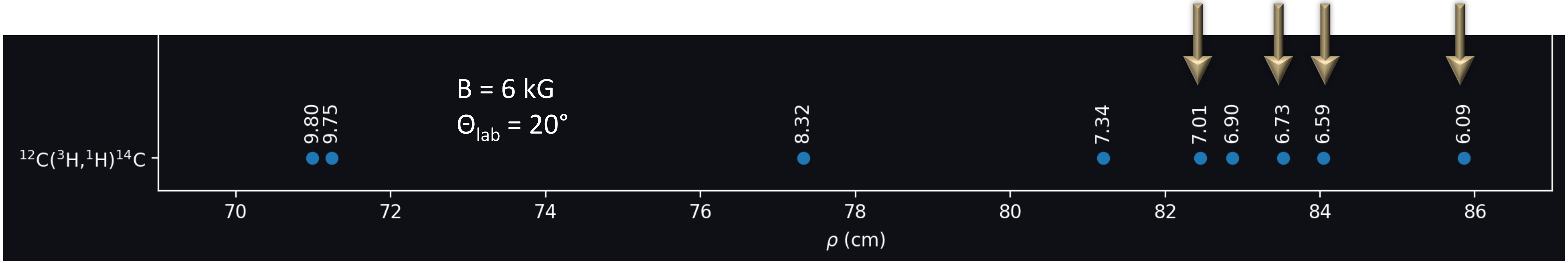


S. Mordechai, et al., NPA 301 463-476 (1978)

First Experiments

- $^{12}C(t,p)\,^{14}C$
  - 15 MeV
  - 50 µg/cm^2 self supporting target

- For 10000 counts
  - $E_{ex.}$ = 6.09 MeV (B = 6 kG) ~14.1 hours
  - $E_{ex.}$ = 6.59 MeV (B = 6 kG) ~35 hours
  - $E_{ex.}$ = 6.73 MeV (B = 6 kG) ~3.4 hours
  - $E_{ex.}$ = 7.01 MeV (B = 6 kG) ~3.2 hours



Summary

- A dedicated MC-SNICS has been installed at John D. Fox Laboratory
  - Complete with Infrastructure, vacuum, fume hood, interlocks
- Deuterium has been successfully implanted into a solid-state cathode
  - Tritium implantation was handled similarly but by an **outside vendor**
- Can easily produce expected ~20nA of beam for 3000h
  - Based on material loss in cathodes after deuteron beam testing
- Next: use a **single** tritium cathode to **safely** commission the source

Acknowledgements

- Alfredo Galindo-Uribarri
- Miguel Madurga – UTK PI
- Ingo Wiedenhöver – FSU Lab Director
- Brian Schmidt – FSU Sourcerer
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- Jonah Gibbons – FSU Electrical Engineer (Now at Naval Research)
- Rick Boisseau and Jason Aragon – FSU Machine Shop
- Ben Asher– Previous UTK postdoc

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FLORIDA STATE UNIVERSITY 1851 VIRES ARTES MORES
CENTER FOR EXCELLENCE IN NUCLEAR TRAINING AND UNIVERSITY-BASED RESEARCH (CENTAUR)
OAK RIDGE National Laboratory

NNSA Grant Number DE-NA0003841

20 Ci of tritium