Techniques for energetic ion assisted in-situ coating of long, small diameter, beam pipes with compacted thick crystalline Copper film

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About PVI:

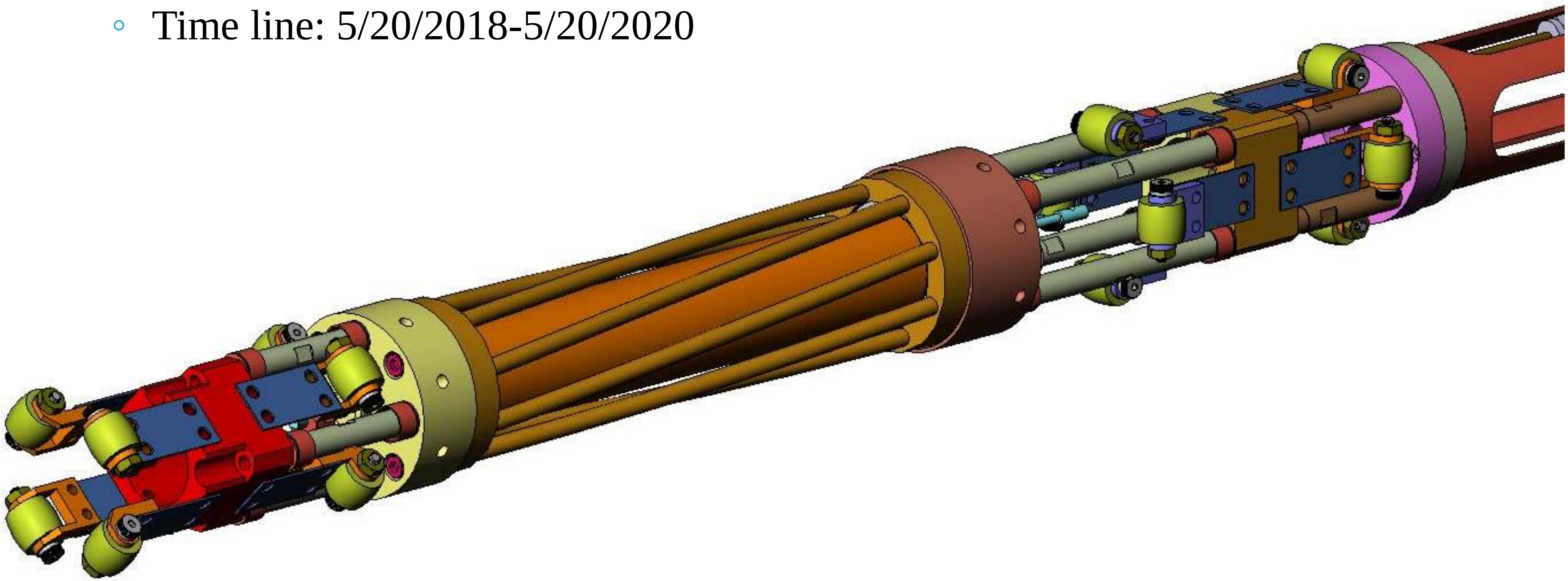
- PVI is a system engineering and manufacturing company specializing in high vacuum and thermal process technologies.

- Current and previous products include tools used for thin film deposition, thermal diffusion systems, rotating grade titanium processing systems, and a variety of high temperature vacuum processing equipment.

Thermal Diffusion and Research Furnaces

Phase II Primary Objective:

- Design, build, and optimize operation of a robotic IAD (Ion Assisted Deposition) device for in-situ coating of long small diameter tubes with defect free Copper films.
- Time line: 5/20/2018-5/20/2020



Integrated IAD Cathode Sputtering Magnetron

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- **Relevance:**
  - RHIC accelerator vacuum tubes are made from relatively high resistivity 304L stainless steel.
  - This results in ohmic heating and the formation of electron clouds resulting in beam instabilities.
  - A Copper film applied to the accelerator vacuum tubes will mitigate these issues, reduce the (Secondary electron yield) SEY and enhance luminosity.
  - Utilizing IAD sputtering will provide a compacted crystalline structure with improved conductivity at cryogenic temperatures.

Phase II Goals:

- Design and fabricate a small scale (15cm cathode) robotic cylindrical IAD magnetron for deposition of defect free Copper films.
- Modify existing tube coating system (TCS) and optimize IAD operation.
- Process samples for cryogenic testing at BNL.
- Scale 15cm cathode IAD magnetron to 50cm cathode. Optimize operation.
- Test with BNL dipole magnet assembly.
- Perform coating tests with thermal sensors and determine maximum deposition rate. (for thermal management).
- Design removable guides for cable bundle mechanism.

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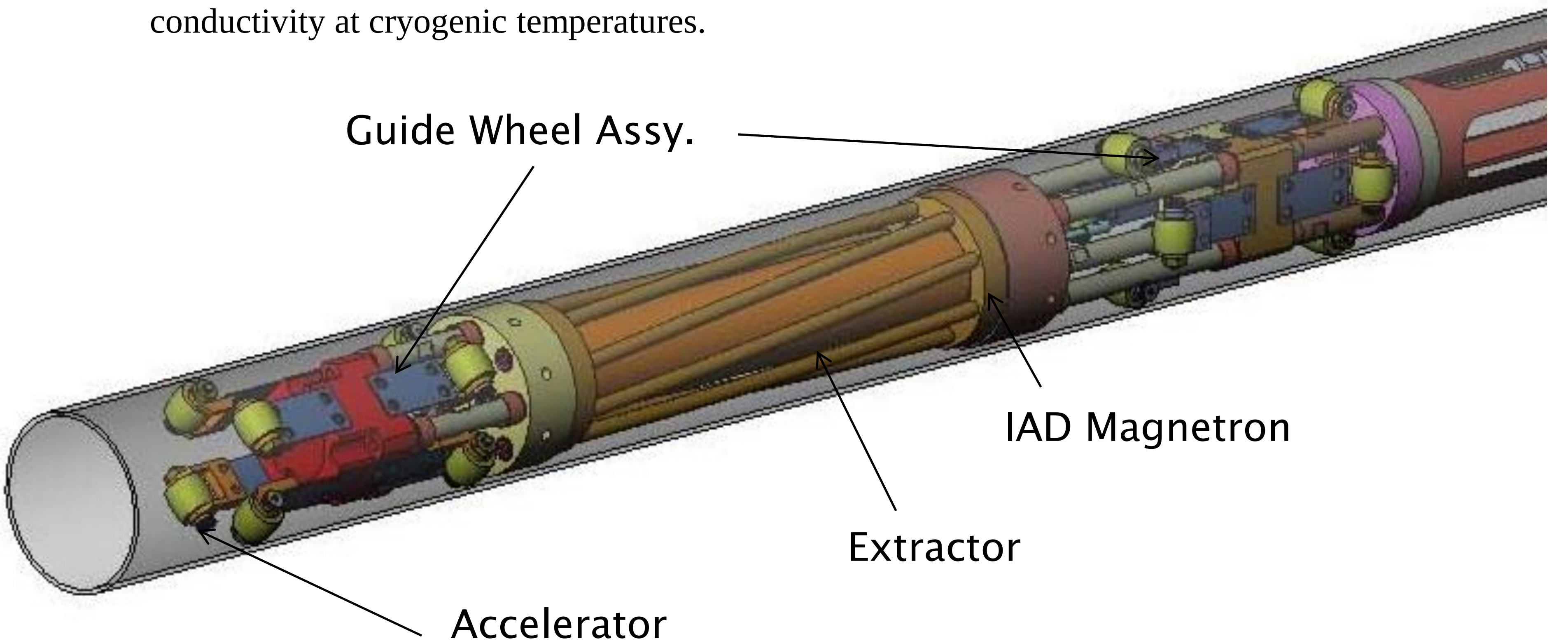
Methodology:

- Integrated IAD (Ion Assisted Deposition) Sputtering Magnetron
  - Utilize previous developed cylindrical magnetron technology.
  - Integrate grid style extractor to cylindrical magnetron.
  - IAD assisted sputtering will provide a compacted crystalline structure with improved conductivity at cryogenic temperatures.



Phase I and Prior Phase II Accomplishments:

- Developed Cylindrical Magnetron which successfully Sputters uniform coating at challenging target to substrate distance of 1.5 cm.
  - Film thickness up to 10 µm.
- Sputtered Coating on close to 20 meter sections of accelerator tubing with 50 cm Magnetron utilizing automated tube coating system (TCS).
- Successfully developed guide wheel assemblies to drive Magnetron thru accelerator sections with bellows.
- Fitted Magnetron with motor drive to cycle internal magnet position to optimize target material utilization.
  - Up to 85% target utilization has been achieved.
- Developed discharge cleaning process to improve adhesion characteristics
  - Test samples exceed capability of 12 kg test fixture.
- Designed and fabricated cryogenic resonator (most components) for testing samples at BNL.

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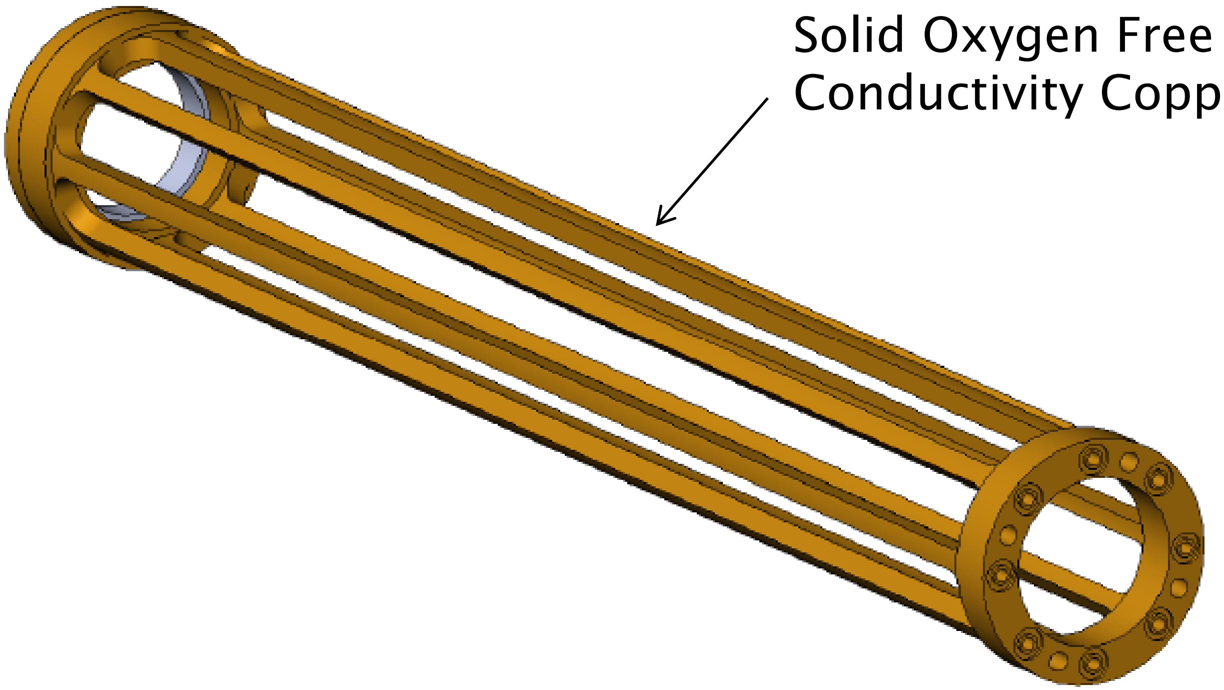
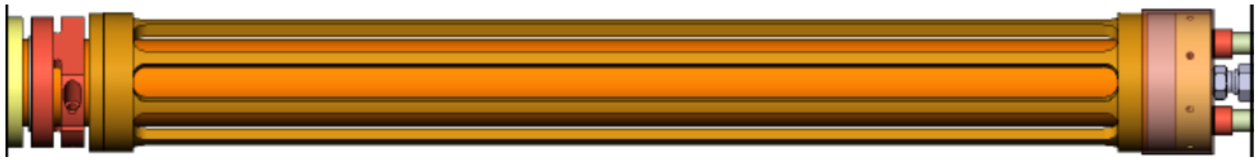
Design & Fabrication of 15cm Long Cathode IAD Magnetron

- The Magnetron design to this point has been iterative.
- The extractor, has gone from parallel grids to a twisted design to prevent a “shadow” during deposition.
- Anodes have also seen multiple changes to improve manufacturability.
- Guide wheel assemblies are now Copper and guide supports were changed from Aluminum to Stainless Steel.
- Water and vacuum leaks have also created delays as well as lead to design and manufacturing changes.

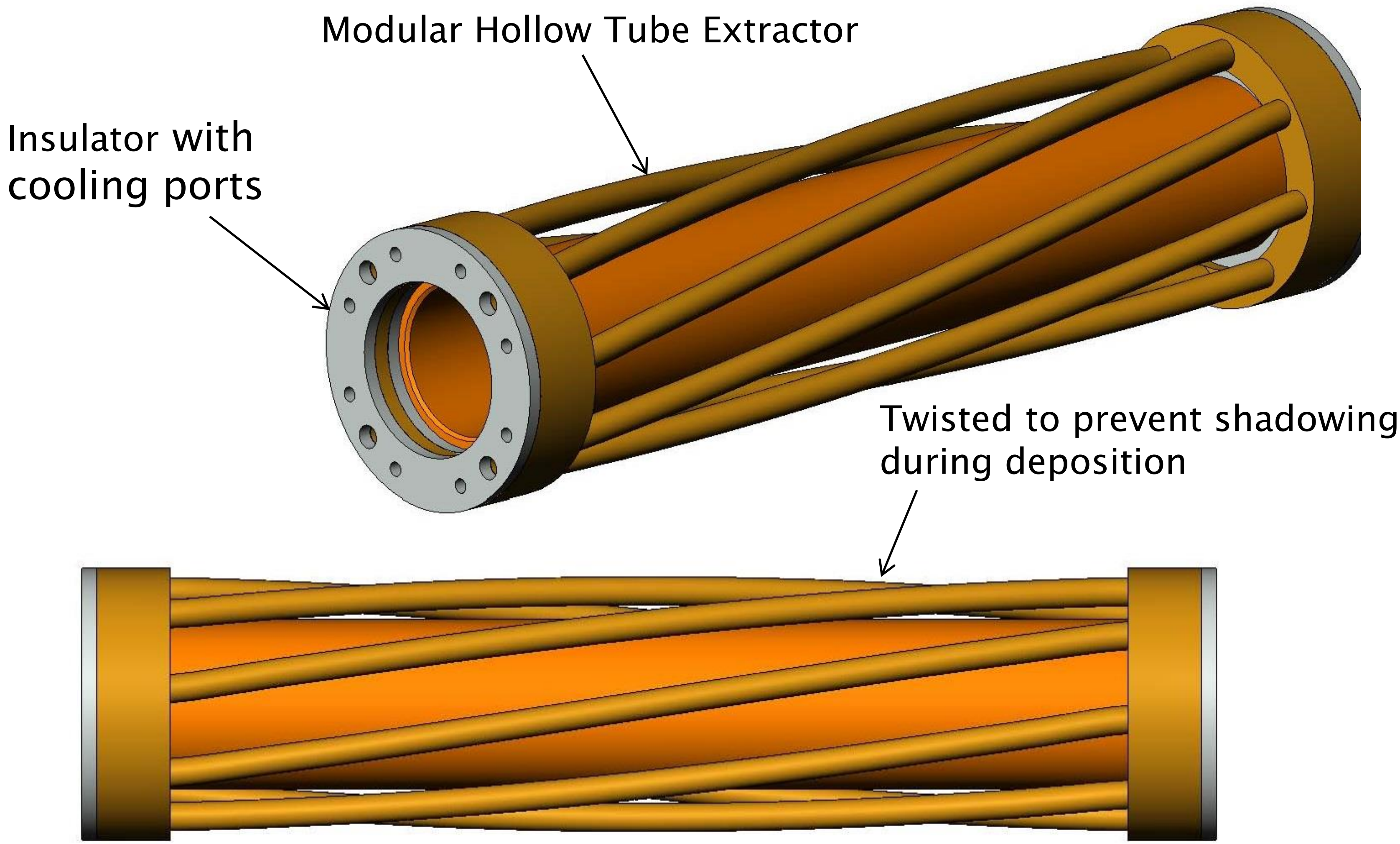
Original Ion Extractor Design



Solid Oxygen Free High Conductivity Copper (OFHC)

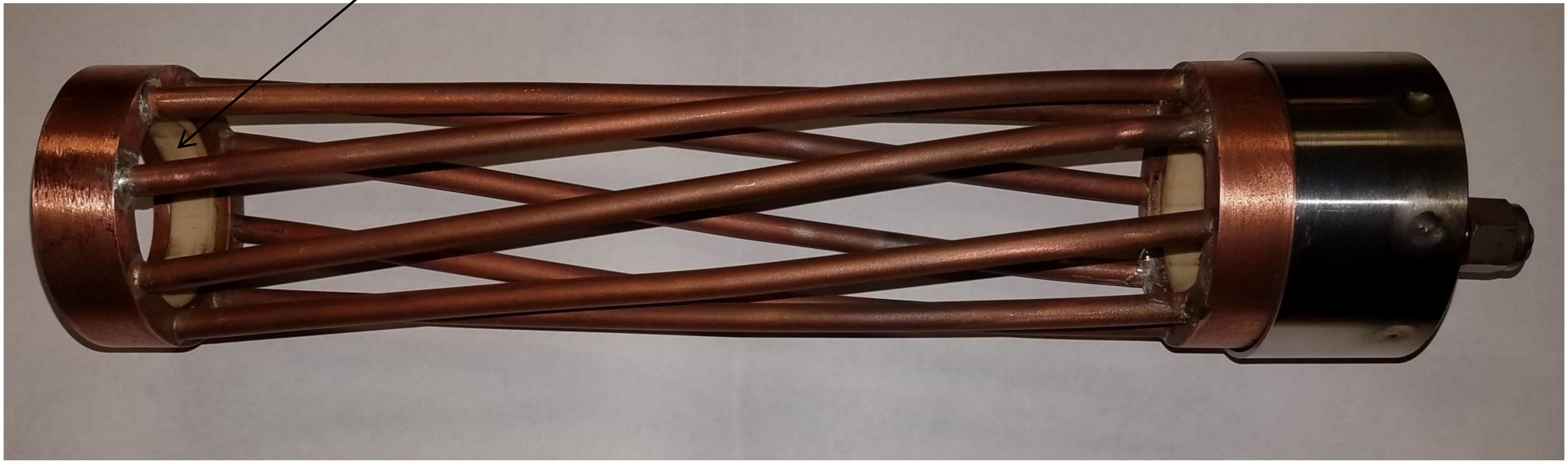


Revised Extractor Design



Revised Extractor with Single Anode

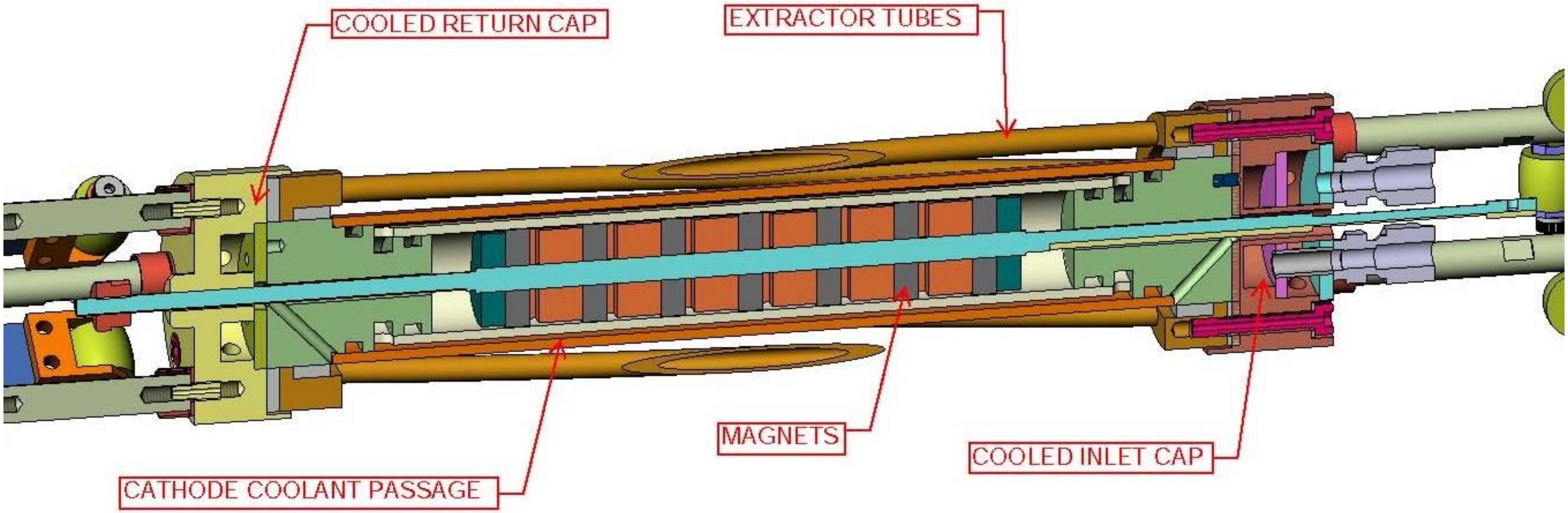
Note ceramic insulators isolating
cathode body from extractor



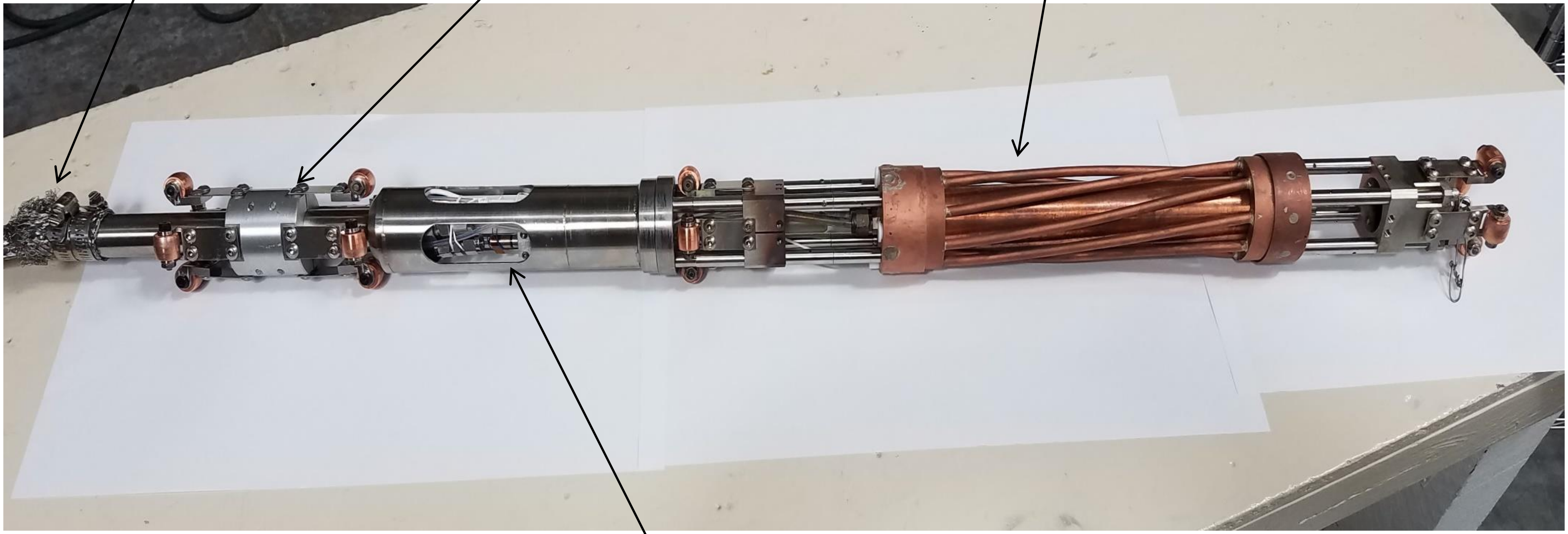
Assembled Magnetron with Extractor

First generation OFHC
anode weldments

IAD Magnetron Cross Section



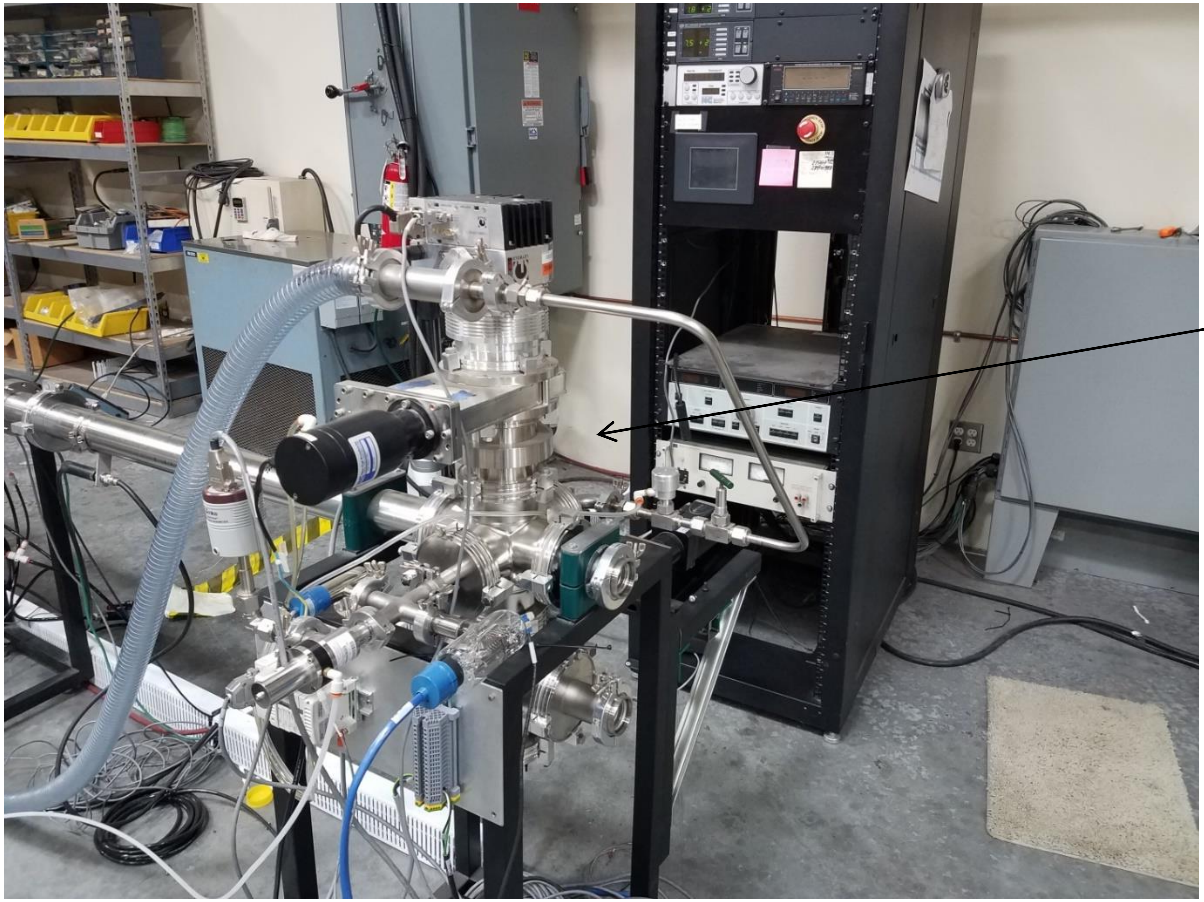
IAD Cylindrical Magnetron Prototype



Tube Coating System

- Umbilical and power supplies modified to work with IAD Magnetron

Power Supply, Chiller, and Take Up Reel for IAD Magnetron

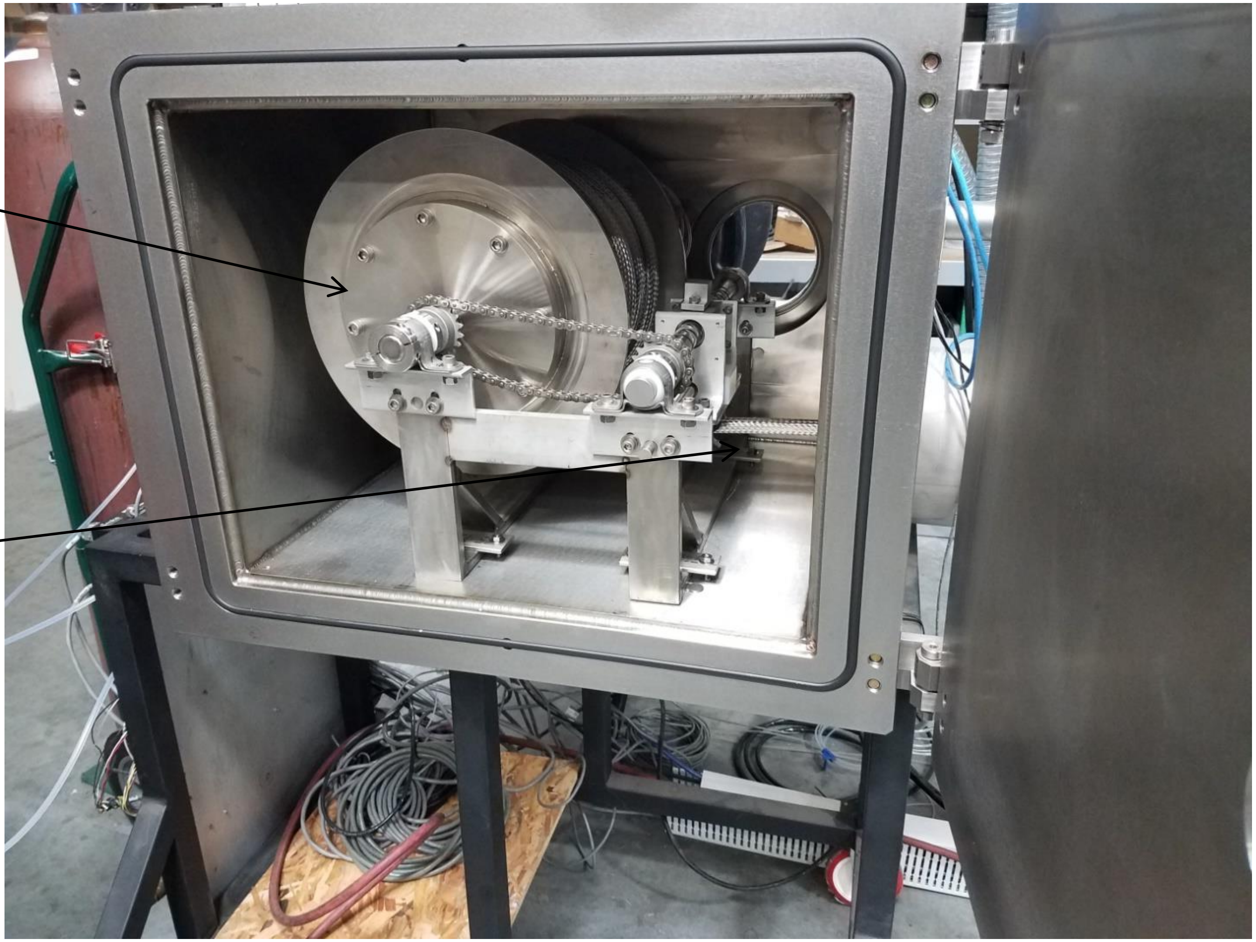


Servo Controlled Take Up Reel Mechanism

Chamber for Umbilical and Electrical, Cooling and Gas Delivery

Feed Reel

Umbilical with process lines



Initial IAD Testing

- Ignition of plasma at previous operating parameters was not possible.
- Typical deposition parameters are pressure of 5mTorr and voltage of 275 V.
- IAD Magnetron required ignition pressure of 300mTorr and operating voltage of 311V.
- Resulting samples were thinner then anticipated, target 5µm sample measured .276µm.
- The higher pressure likely resulted in most of the Copper vapor being diluted in the Argon gas and pumped away.
- Coated samples at higher pressure also appear to be amorphous black Copper that are not crystalline.
- Distance between cathode and extractor needs to be maximized to resolve this issue.

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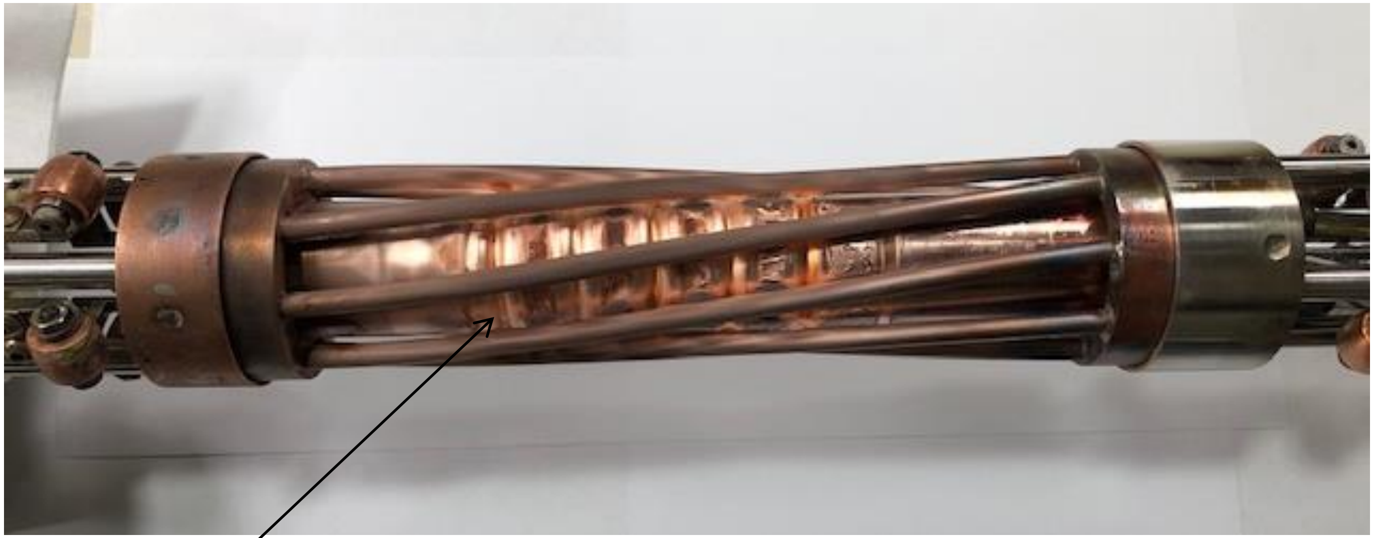
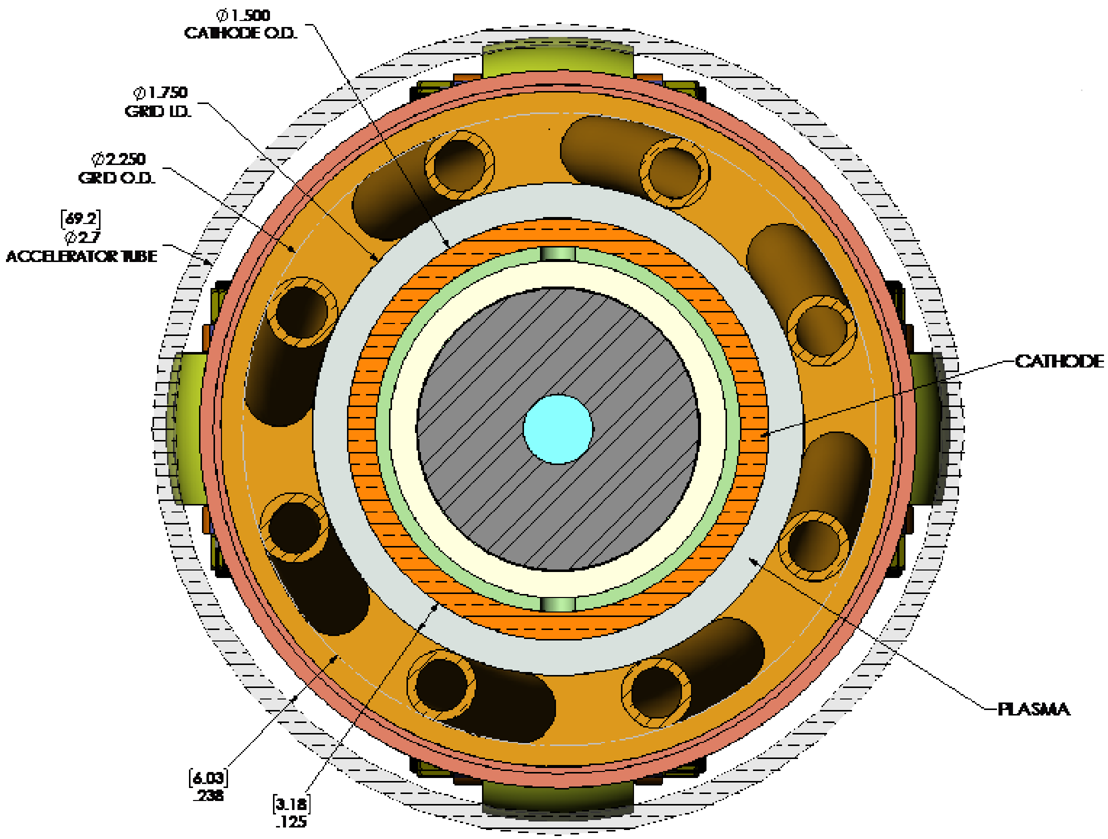
IAD Magnetron after Testing



Steps in cathode from stationary magnets during sputtering

Coated Glass Slide

IAD Magnetron End Section View



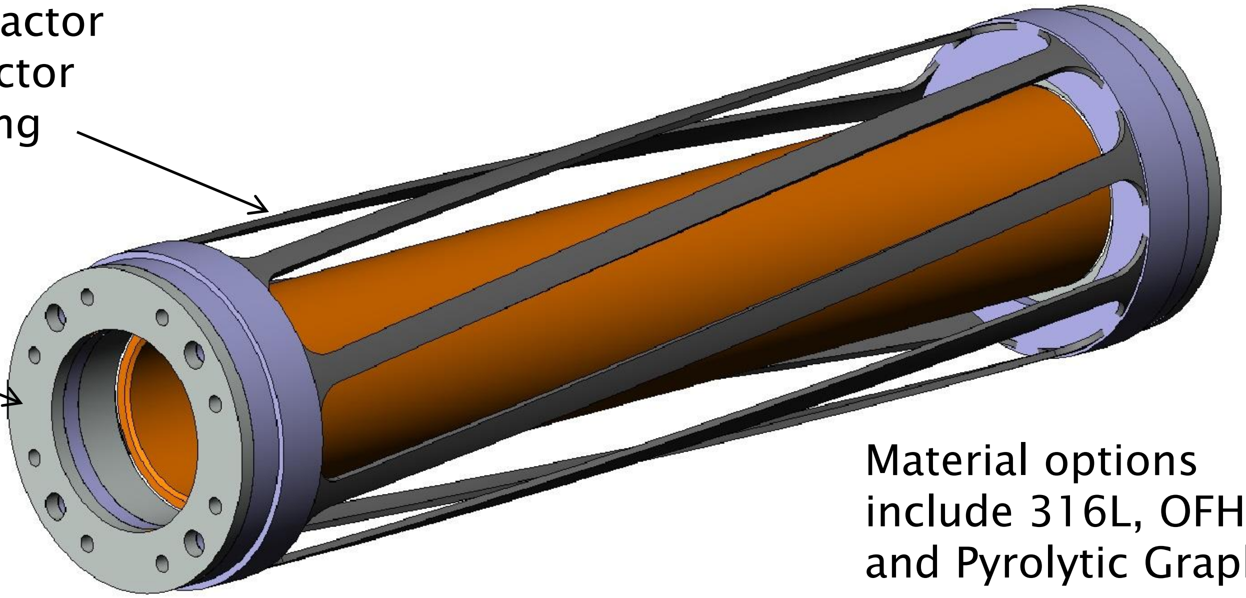
Magnetron
Cross-Section

Magnetron During
Deposition

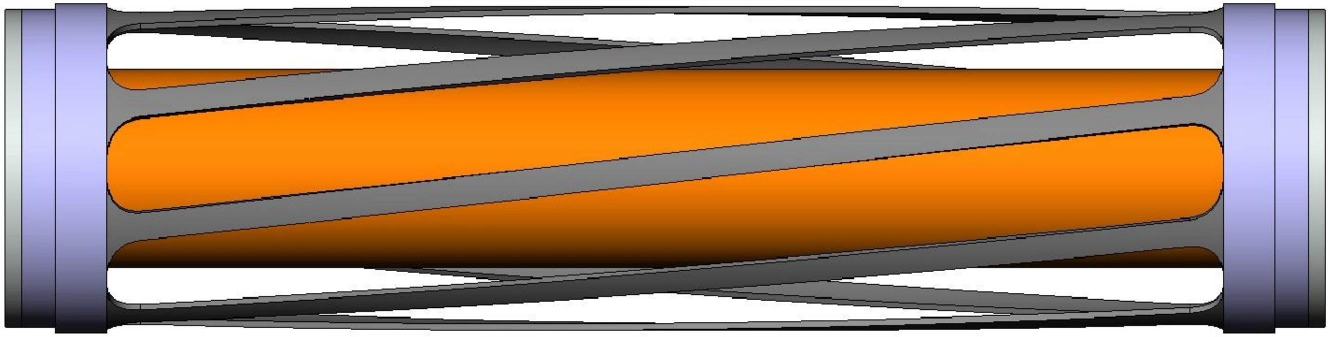
Latest Revision Ion Extractor Design

Thin section extractor maximizes extractor to cathode spacing

Cooled end caps



Material options include 316L, OFHC and Pyrolytic Graphite



Optimizing Non-IAD Sputtering

- Despite delays to IAD Magnetron testing continued with the conventional sputtering magnetron
- All magnetron non-copper components, which could be exposed to the plasma, were replaced with copper components, or copper shields were installed.
- Existing drive components were swapped for IAD Magnetron units.
- Stainless-steel RHIC tubing samples were coated at 5µm and 10µm thickness and sent to BNL for cryogenic resonator testing.

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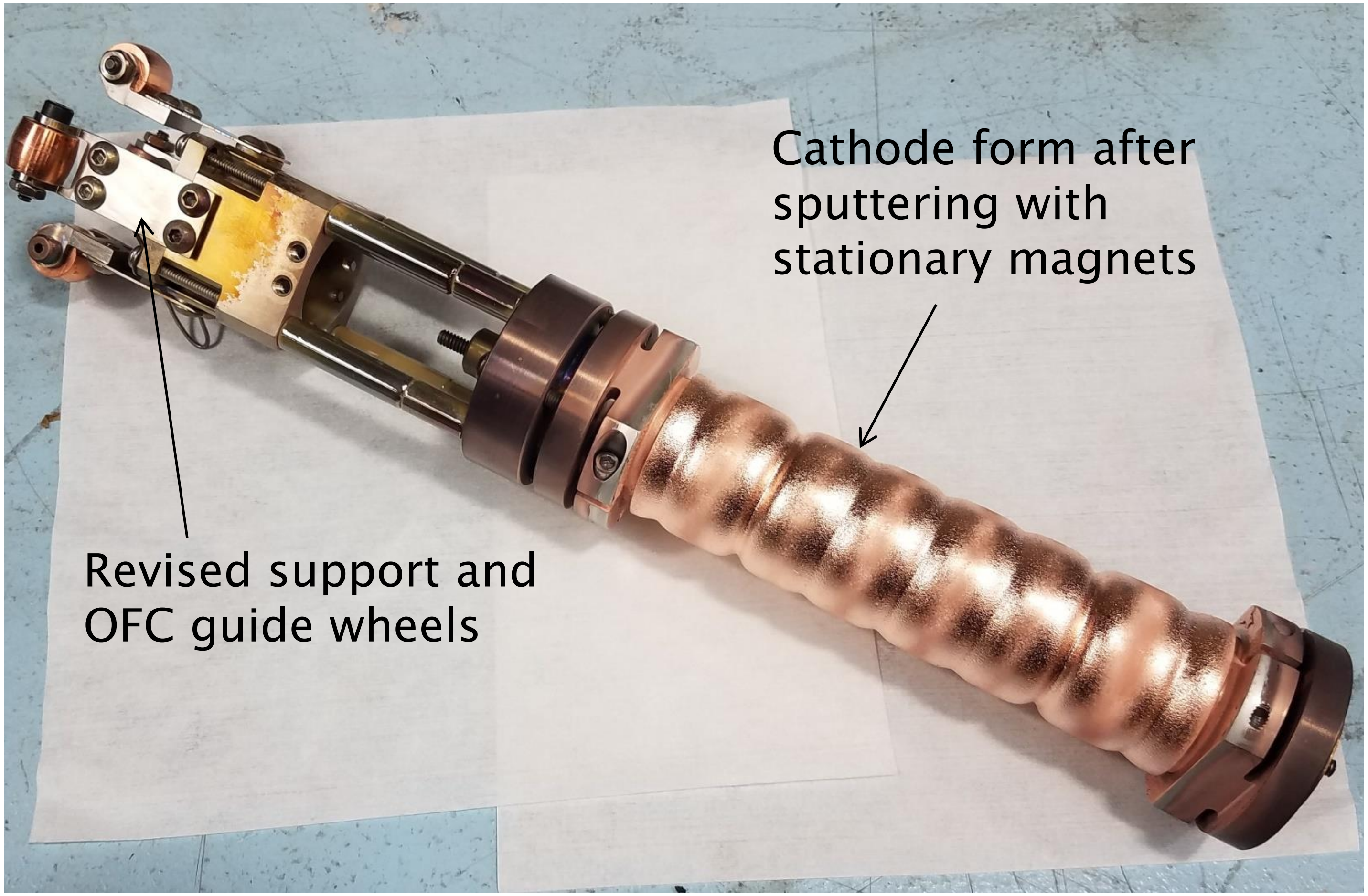
Existing Magnetron Assembly with Updated Guide Components



Latest Non-IAD BNL Test Results

- Conductivity enhancement of the RHIC tubes at 4 K with both 10µm and 5µm thick copper coating was 230% of its conductivity at room temperature; it's within a factor of 2 of what is needed for RHIC.

- The significance is that the 5µm thick copper coating would significantly reduce coating time of RHIC.

- Coatings have also stayed in tact with multiple cycles at cryogenic temperatures.

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Cryogenic Test Setup at BNL

Sample with flanges

Photo showing test sample pulled out of Dewar and being warmed up

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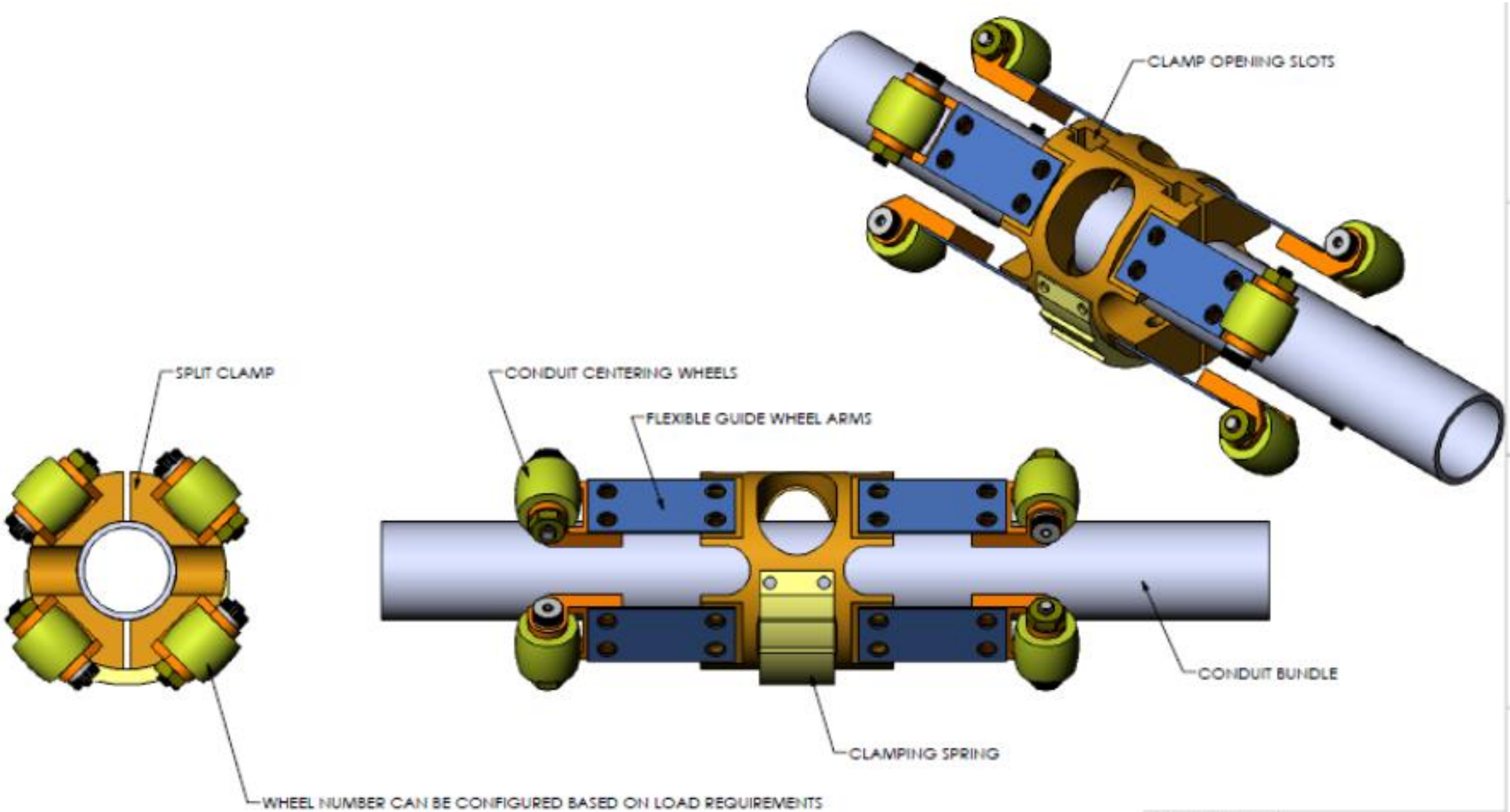
Cable Bundle Guide Wheel Assy. Design Concept



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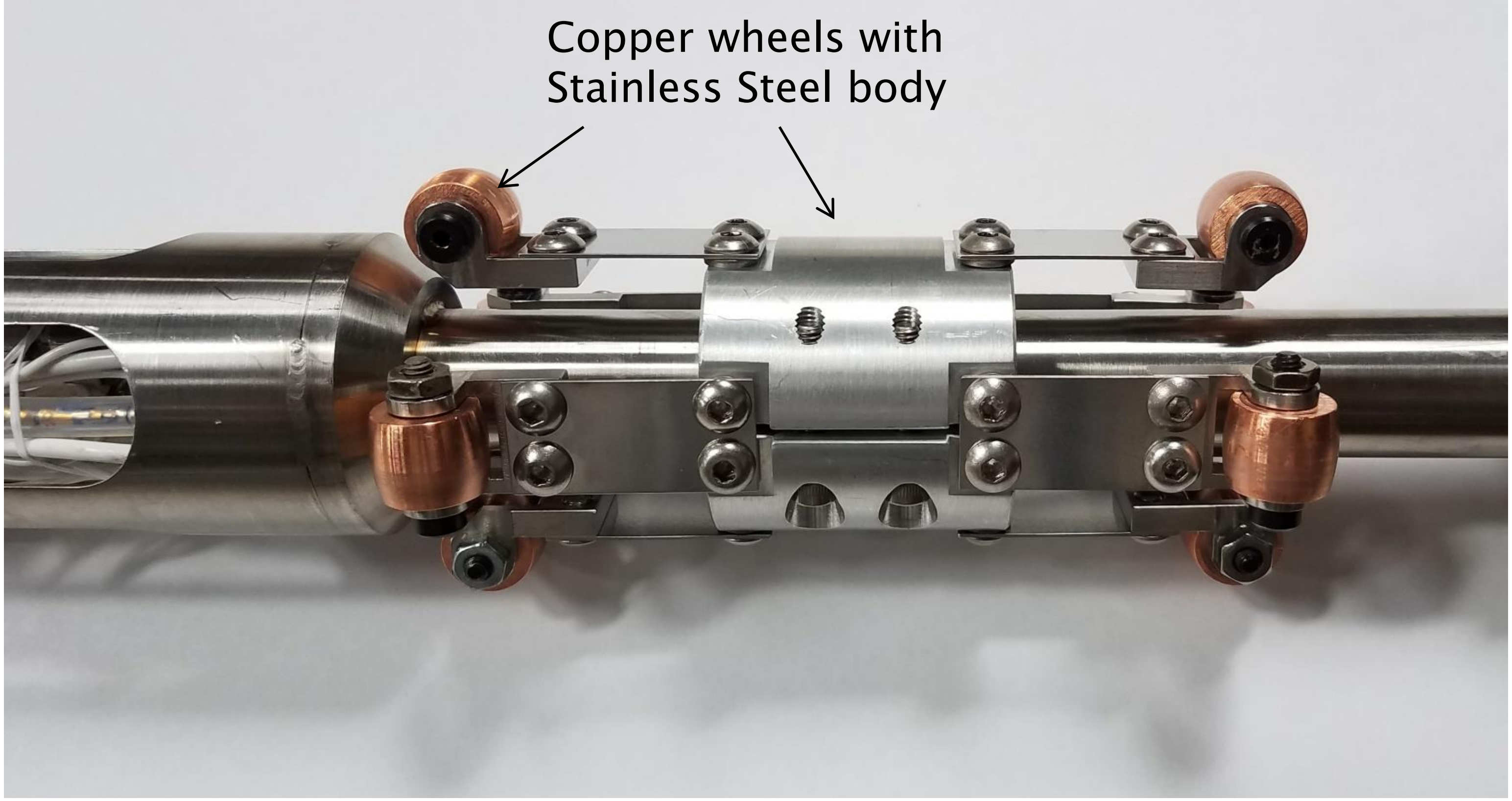
Prototype Guide Wheel Assy.



Going Forward 2019- 2020

- Continue work with 15cm IAD magnetron – Target completion Q1/2020.

- Extractor for 50 cm cathode & Full-scale IAD operation – Target completion Q2/2020.

- Test with BNL Dipole magnet assy./determine deposition rate max temperature – PVI to test at BNL 2020.

- Removable guides for cable bundle – Complete design Q1/2020.

- A no cost extension will likely be required.