DMRadio-50L Resonator Design

Collaboration Meeting 10/8/2025

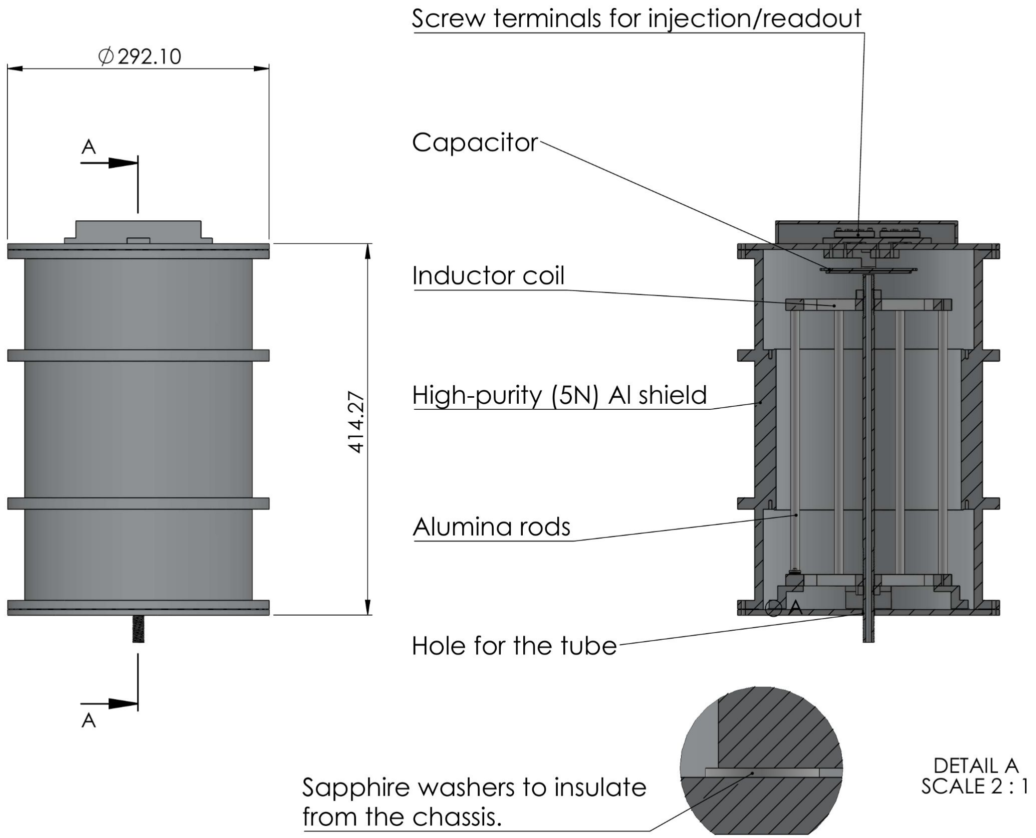
Resonator plan

- **Key points:**
  - Princeton resonator demonstrated Q~2 million at 250 kHz
  - Geometry and scale differ from DMRadio-50L resonator
  - Primary objective: establish a "recipe" (materials, connections, treatments)
  - DMRadio-50L resonator will build on these results
  - Initial testing will be at Princeton
  - Full-length device **does not fit** the Princeton cryostat
- **Two configurations:**
  - Compact Princeton variant (for cryostat constraints)
  - Full-size Stanford build: **extension** of the Princeton build
- **Status & Path:**
  - Design in progress (design freeze ~ 10/16/2025)
  - Stanford configuration will be **upgradable/modular** to enable rapid start

Overview

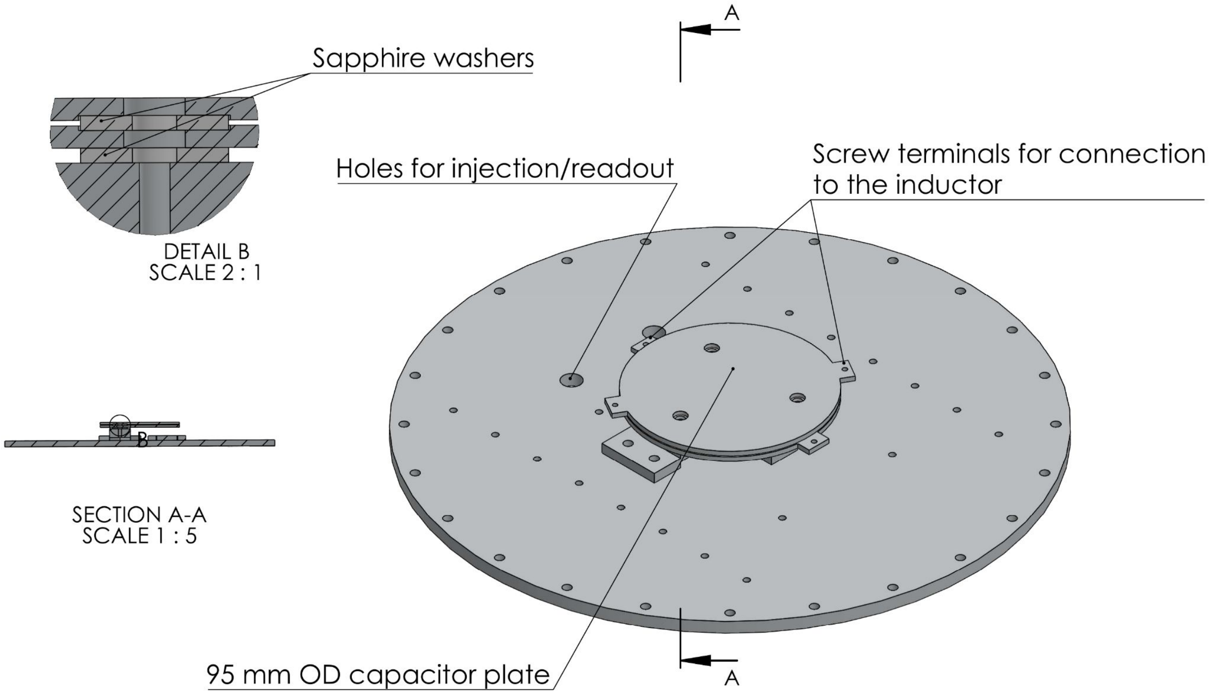
1. **Princeton Configuration (compact)**
2. **Extension Procedure (7 steps in 7 slides)**
3. **Stanford Configuration (full-length)**

Princeton Configuration. Overview



Princeton Configuration. Capacitor

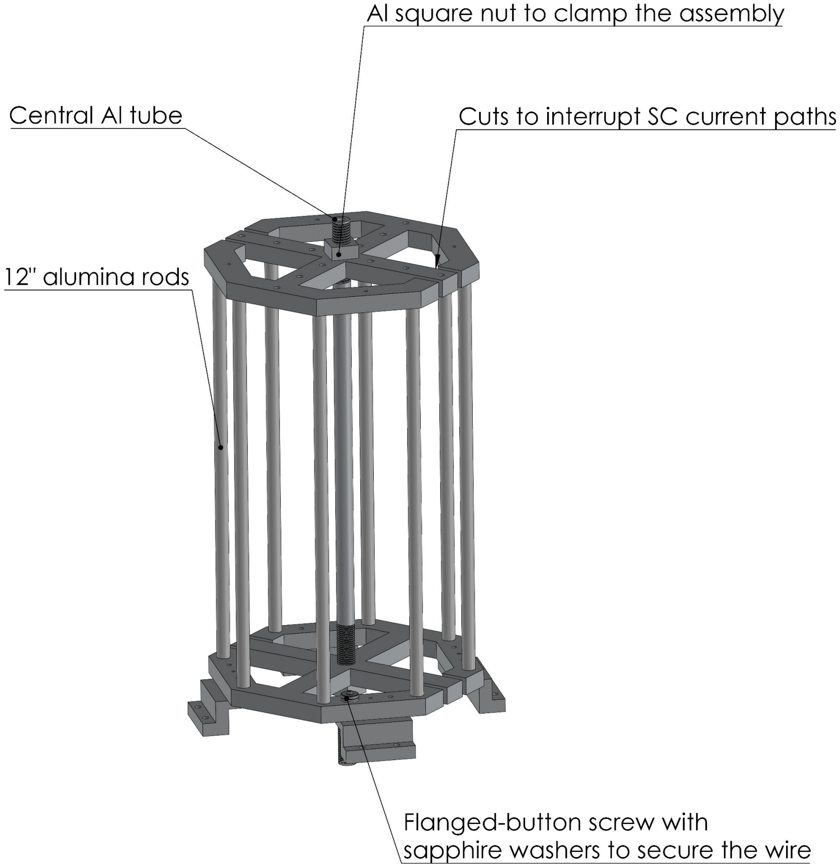
- d ≈ 0.6 mm
- OD = 95 mm
- vacuum separation
- C≈110 pF



Princeton Configuration. Inductor

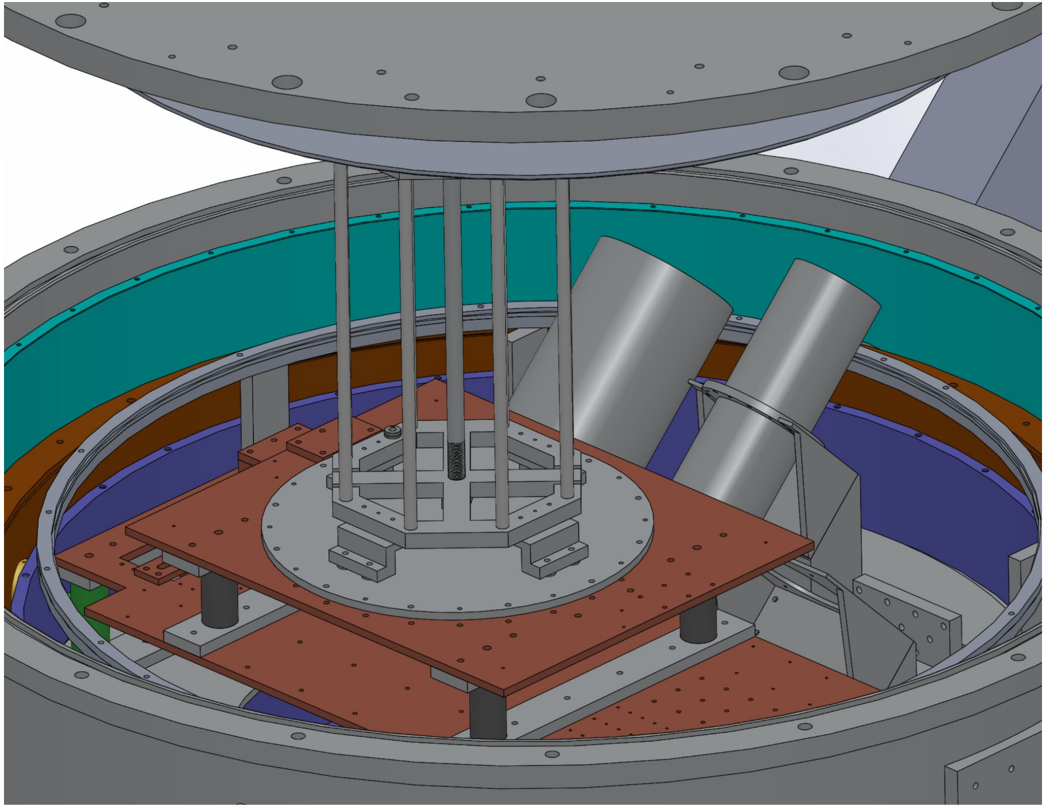
- l≈10” (254 mm)
- N≈130 turns
- L≲2.6 mH (expected lower due to screening from superconducting Al shield)

With L ≲ 2.6 mH (realistically about 1 mH) and C ≈ 110 pF, the resonance frequency is expected to be around 480 kHz. However, by winding the inductor more tightly, we could increase L and correspondingly lower the resonance frequency.



Princeton Configuration. Inside the Cryostat

- He3-He4 sorption fridge
- Resonator at ~302 mK



Princeton Configuration. Action Plan

1. **Phase 1 — Cryogenic cooldown**
   a. Mount ROX on inductor, capacitor, resonator shield.
   b. Verify cryogenic performance and baseline temperatures.
2. **Phase 2 — Q-measurement cooldown**
   a. Remove ROX sensors (and any leads/adhesives) to avoid added loss.
   b. Re-cool and perform Q measurements.

Extension Procedure

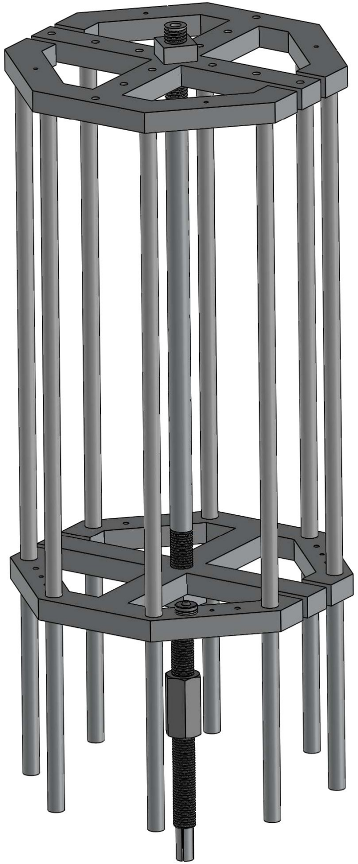
Key considerations:

- **No re-winding:** Princeton coil winding is final;
- **Full-length corset at Stanford:** Use the full corset geometry.
- **Why full length corset?** Corset self-inductance scales stored energy is with corset length for fixed $L_{\mathrm{corset}} \propto 1/l$. This favors full-length operation for axion-coupled modes $E \propto \Phi^2/L_{\mathrm{corset}}$.
- **Cooling at Stanford**: Al resonator must reach ≈ 20 mK → add a Cu core inside the Al tube to boost thermalization.
- Compatible with the current **puck design**

Extension Procedure. Step 1

- Remove feet

Extension Procedure. Step 2



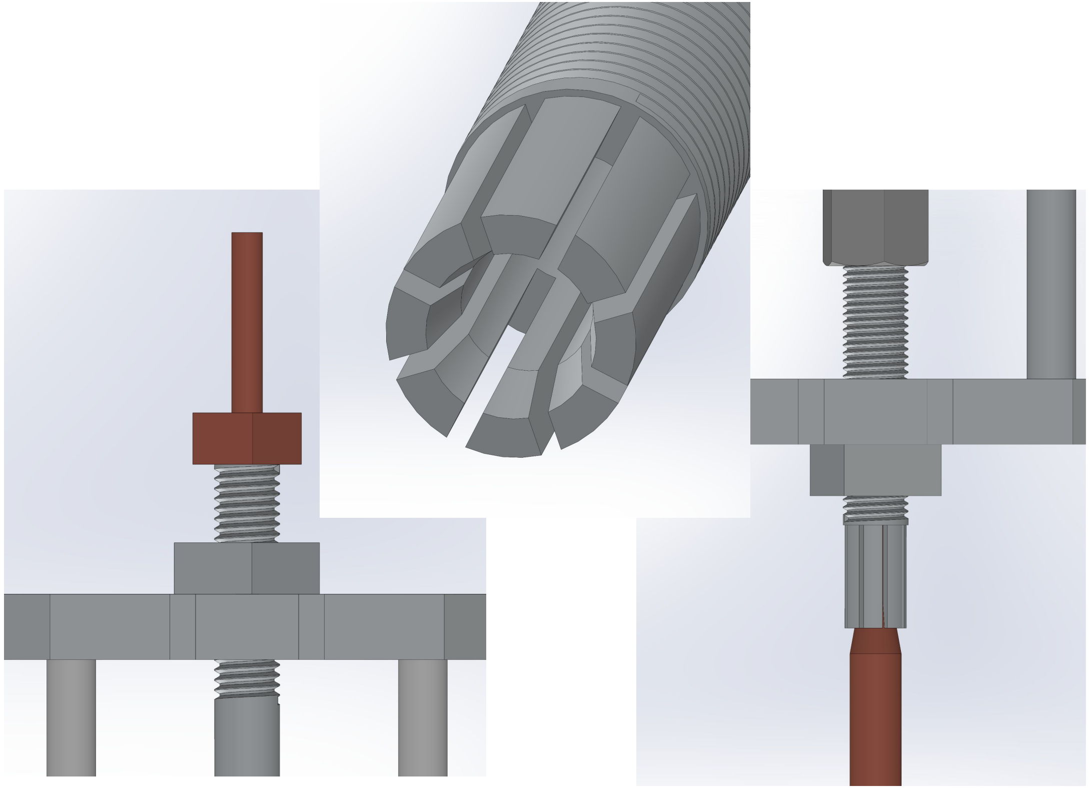
- Add extension rods
- Add extension tube
- Add coupling nut

Extension Procedure. Step 3

- Install the bottom flange.
- Clamp the flange with the bottom nut.
- Insert the central copper rod.
- Secure it with the top copper nut.

Extension Procedure. Step 3. Copper Rod Attachment

- Copper rod (bottom shoulder)
  - Tapered shoulder: Ø6.35 → Ø10.0 mm
  - Top fastener: M6 nut
- Al tube (bottom)
  - Relief cuts: eight 20 mm leaves for flex
  - Chamfered ID to same angle as the Cu shoulder for improved thermal contact
  - Indium interlayer between Cu and Al
- Assembly action
  - Tighten top Cu nut → rod lifts → shoulder seats into Al tube
- Notes
  - Aim for elastic deformation of leaves
  - Chamfer + indium → higher real contact area and better thermalization

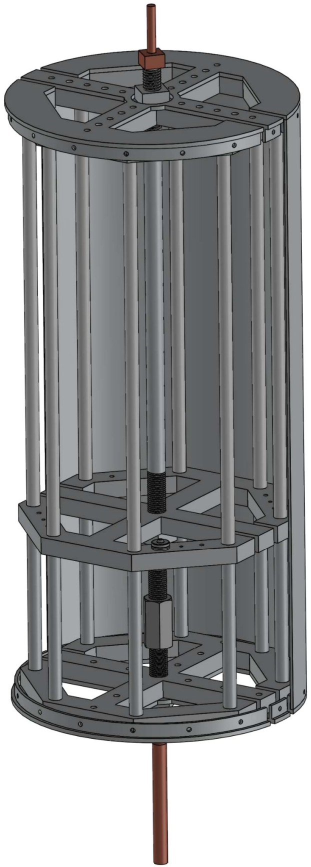


Extension Procedure. Step 4

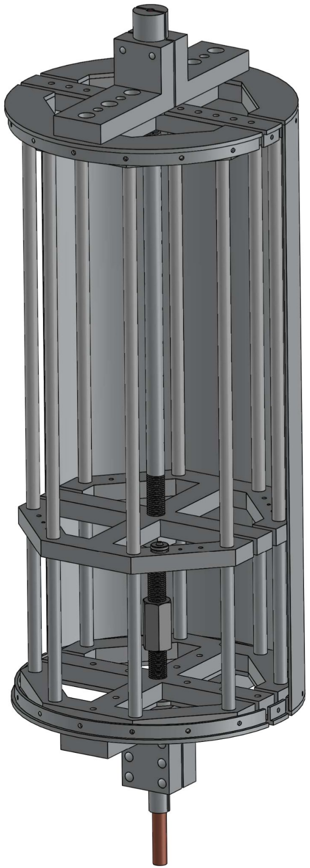
- Attach corset flanges

Extension Procedure. Step 5

- Attach corset



Extension Procedure. Step 6



- Attach Al heat clamps on top and bottom
- The clamps have pockets to house the nuts

Extension Procedure. Step 7 🎉🥳

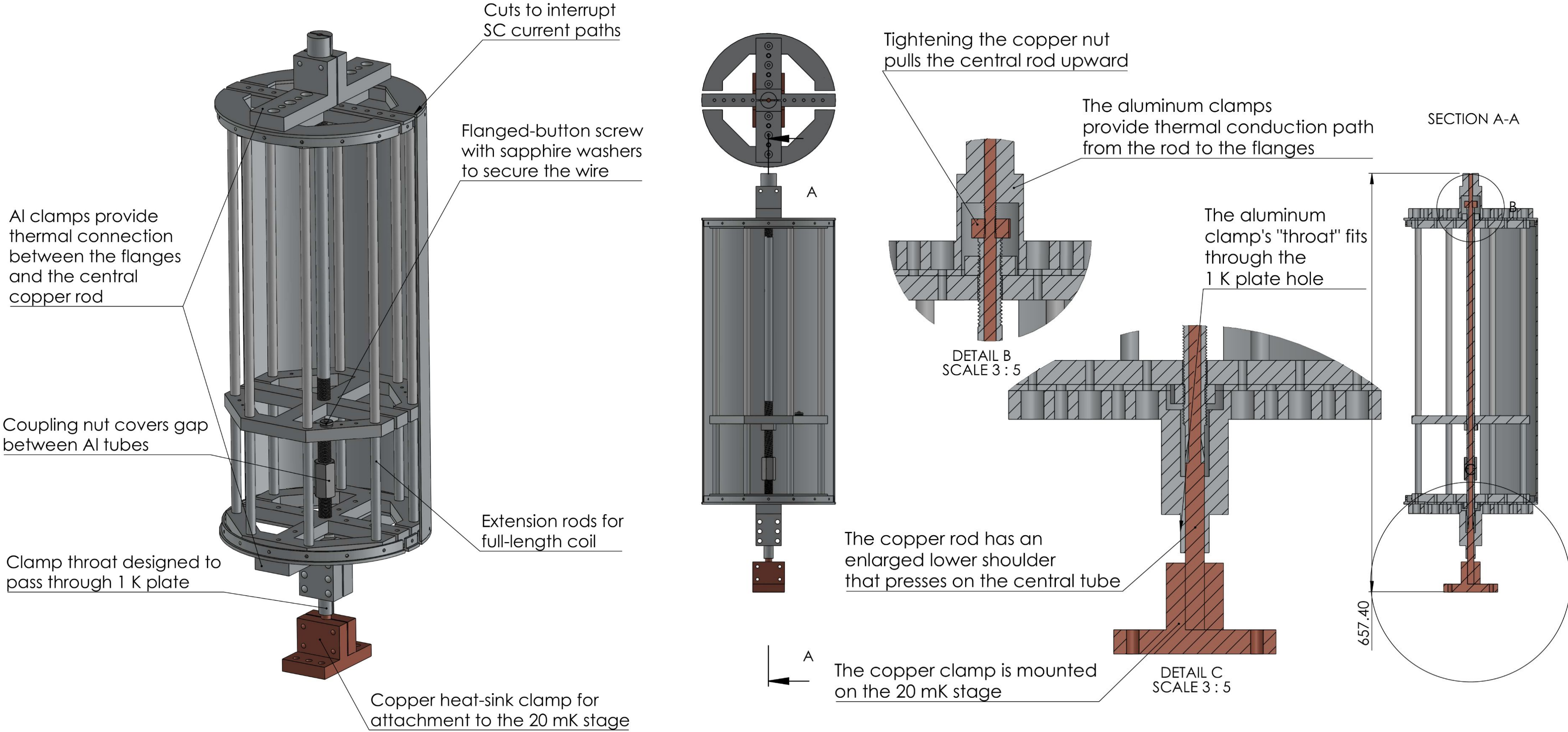
- Attach copper heat clamp at the bottom, anchored to the 20 mK stage

Primary cooling path:

- Bottom **Cu clamp →**
- **Central Cu rod →**
- **Al clamps (top & bottom) →**
- **Inductor frame**.

- **Inductor coil OD = 210 mm**
- **Magnet sheath ID = 290 mm**
- **~ 4 cm radial clearance**

Stanford Configuration



Action Items

- **Needs:**
  - **Verify Cu-rod ↔ Al-tube interface**
    – Confirm torque spec and mechanical/thermal interface
  - **Verify corset design**
  - **Decide on bottom copper clamp design**
    – Single-cut design versus 2-parts design.
  - **Ensure radial clearance:** inductor coil ↔ magnet sheath
  - **Ensure top puck compatibility**
  - **Create assembly procedure documentation**
  - **Asses all risks**
  - **Finalize full design**
    – Final review Oct 13 meeting.
- **Wants:**
  - **Re-draw all components in Fusion 360**
    – Update CAD models and ensure all dimensions and mates are current.
  - **Comsol simulations**

In Conclusion

- **Design not finalized**; changes expected before freeze (still actively working)
- **Design freeze: Oct 16, 2025**
- **Interim updates:** fixes / modifications / adjustments as needed
- **Input welcome:** insights and suggestions appreciated
- **In-person review at Stanford:** mid-October 2025 (target week of Oct 13)