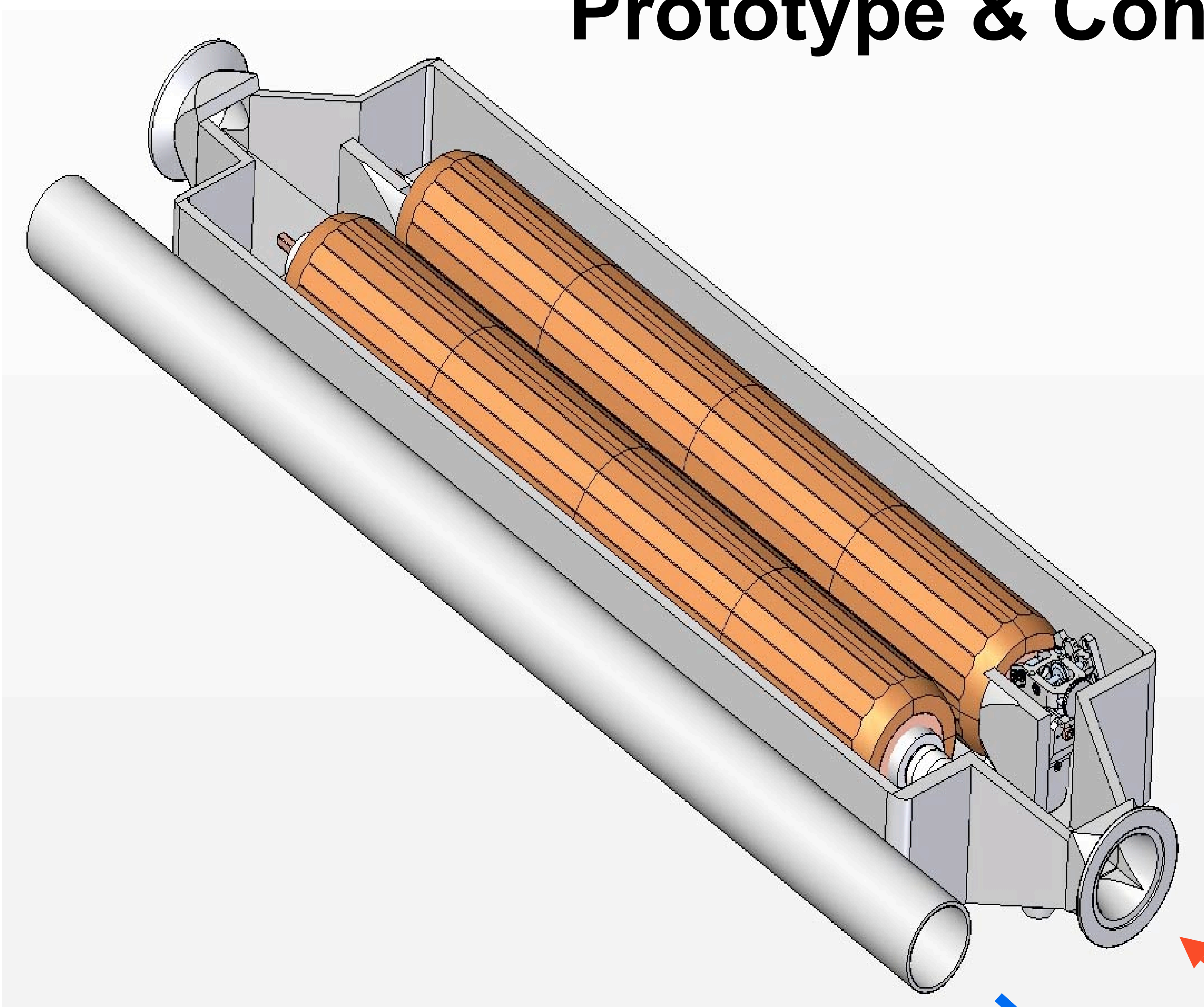
Status of Rotatable Collimator Prototype & Construction



beam

beam

18 October 2007

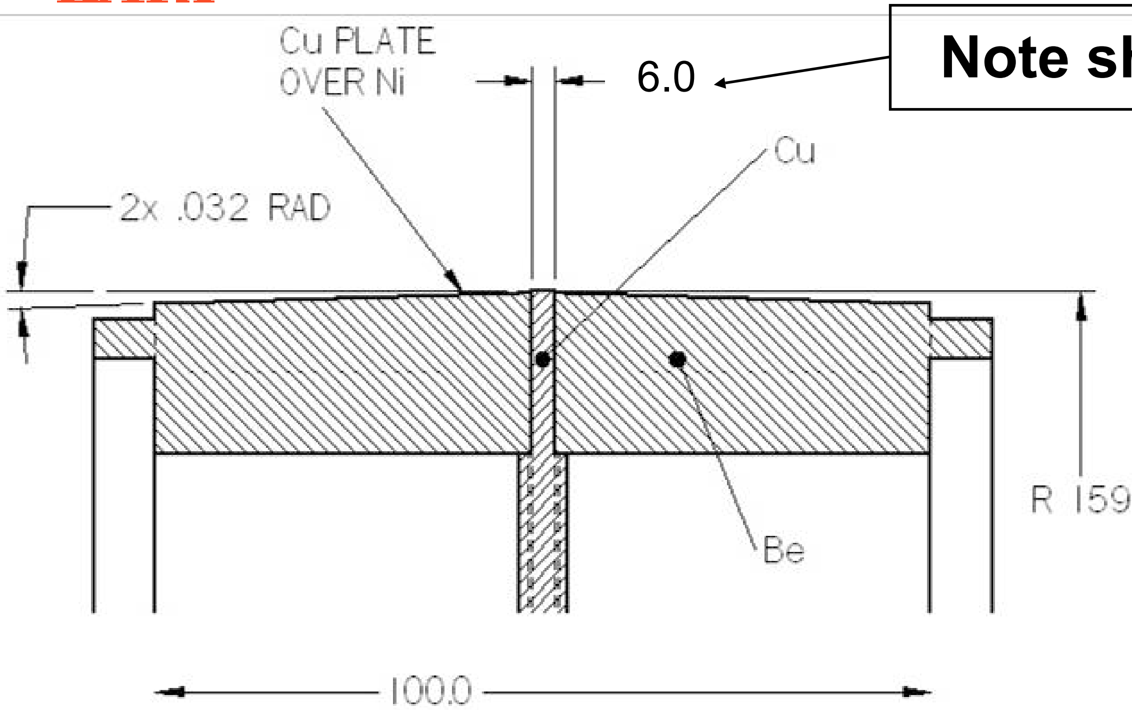
CM9 @ SLAC

Jeff Smith, SLAC

with Gene Anzalone,
Eric Doyle, Lew Keller,
Steve Lundgren &
Tom Markiewicz

Inspired by NLC Consumable Collimator

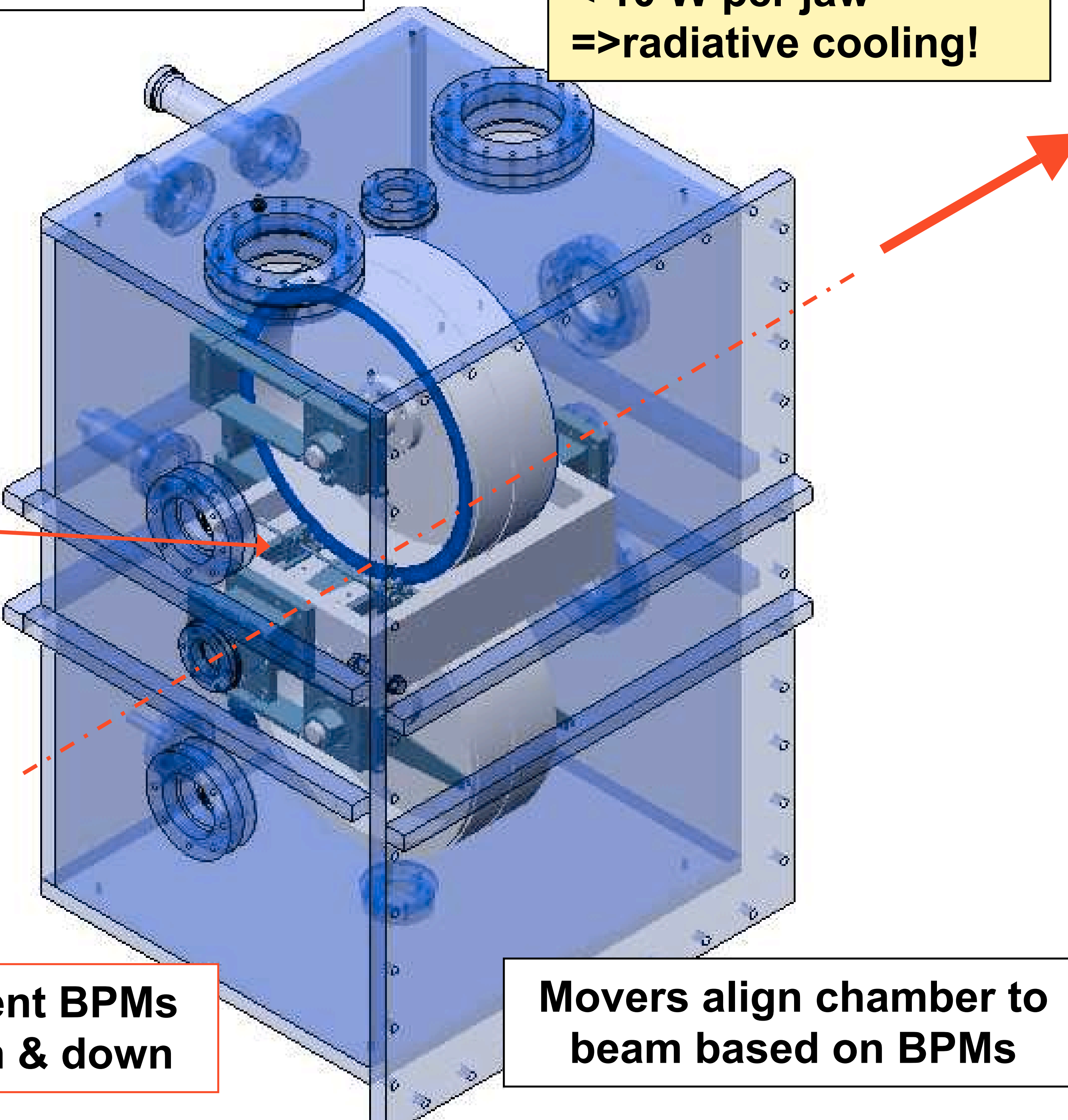
rotatable jaws – 500 to 1000 hits



Note short high-Z material.

< 10 W per jaw
=>radiative cooling!

Aperture control mechanism – 5μm accuracy & stability



Alignment BPMs upbeam & down

Movers align chamber to beam based on BPMs

SLAC Timeline for RC=Rotatable Collimator Prototype

Gene Anzalone, Yunhai Cai, Eric Doyle, Lew Keller,
Steve Lundgren, Tom Markiewicz, Jeff Smith

2004: Introduction to project

2005: Conceptual Design Phase II RC using FLUKA, Sixtrack and ANSYS, External Design Review, collimator test lab set up

2006 Improved Conceptual Design, hire full time ME and designer, fabricate tooling, 2D/3D drawings of test and final parts, braze two short test pieces

2007: Examine test brazes, braze and examine 3rd short test piece, develop and build rotation mechanism, design RF shield, fab 1st full length jaw; hire first postdoc

2008 Thermal tests of single jaw, fabricate two more jaws and assemble into a vacuum tank compatible with Phase I adjustment mechanism = RC

2009: Mechanically test RC, ship and install in SPS/LHC

2010: Collimator tests at LHC & Final drawing package for CERN

2011: Await production & installation of chosen design(s) by CERN

2012: Commissioning support

Main Deliverables

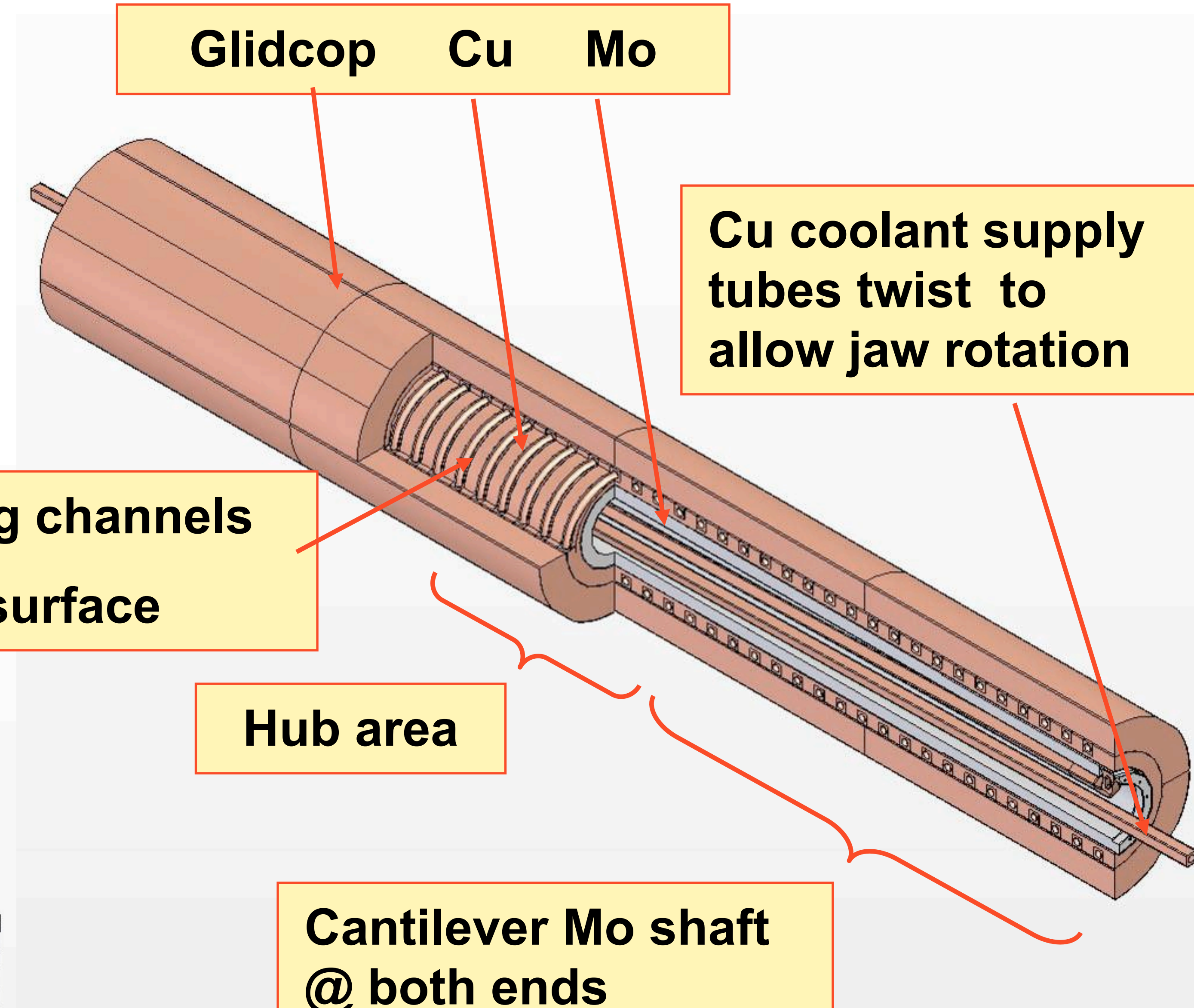
Thermal tests of single collimator jaw

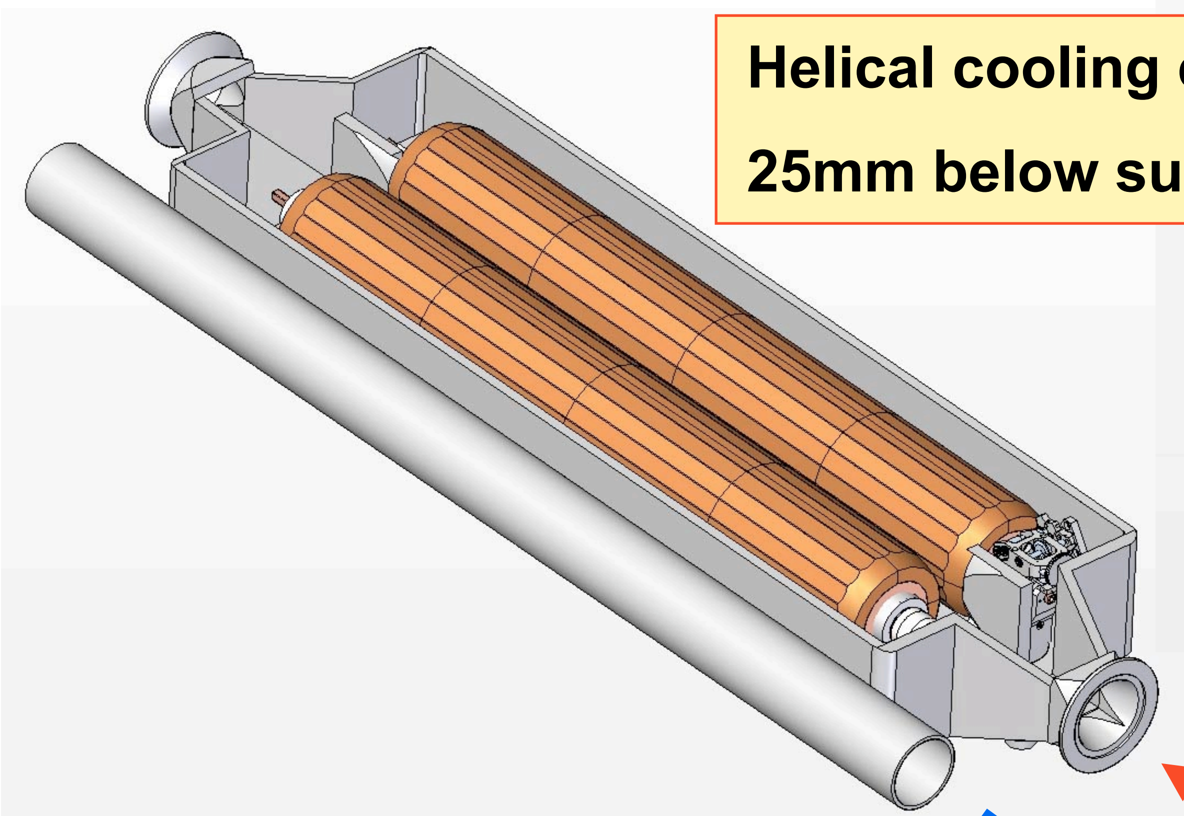
Construct and mechanically test full RC prototype to be sent to CERN

LHC Phase II Base Concept

physical constraints
current jaw design

- beam spacing: geometrical constraint
- Length available 1.47 m flange - flange
- Jaw translation mechanism and collimator support base: LHC Phase I
- >10 kW per jaw Steady State heat dissipation (material dependent)





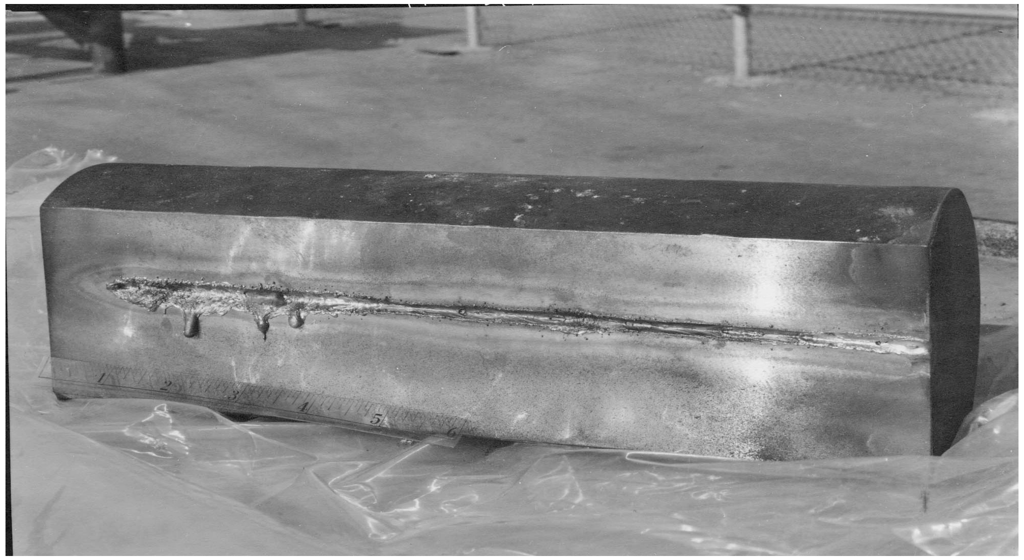
LHC Collimation Requirements

LHC Beam Parameters for nominal L=1E34cm^{-2}s^{-1}:

- 2808 bunches, 1.15E11 p/bunch, 7 TeV → 350 MJ
- Δt=25ns, σ~200μm (collisions)

System Design Requirement:

- Protect against quenches as beam is lost
  - "Steady state" collimator cooling for τ = 1 hour or 8E10 p/s or 90kW
  - "Transient" bursts of τ = 12 min or 4E11 p/s or 450kW
    - abort if lasts > 10 sec
- Accident Scenario : Beam abort system fires asynchronously with respect to abort gap - 8 full intensity bunches impact collimator jaws

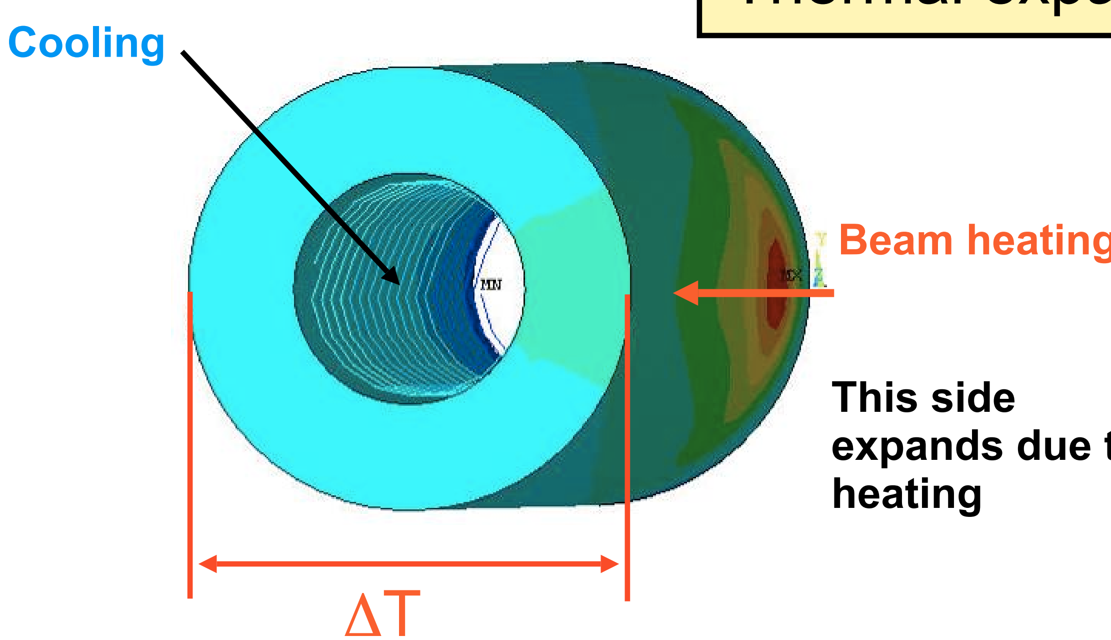


Dominant collimator specifications

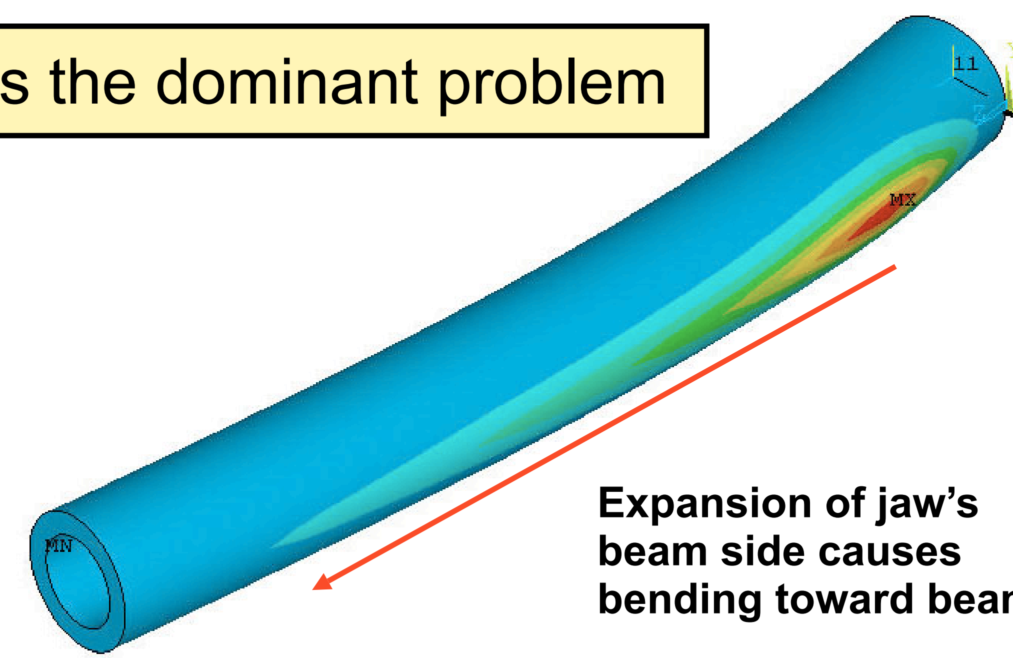
LARP

– 25μm maximum deformation toward beam
– 7 σ nominal aperture
  - The first long secondary collimator may be set at 8σ to ensure 25 μm intrusion with respect to 7 σ
– 45 mm minimum aperture jaws fully retracted
– Beam spacing limits transverse dimensions
– Maximum length predetermined: 1.48 m flange-flange
– No water-vacuum joints

Thermal expansion is the dominant problem



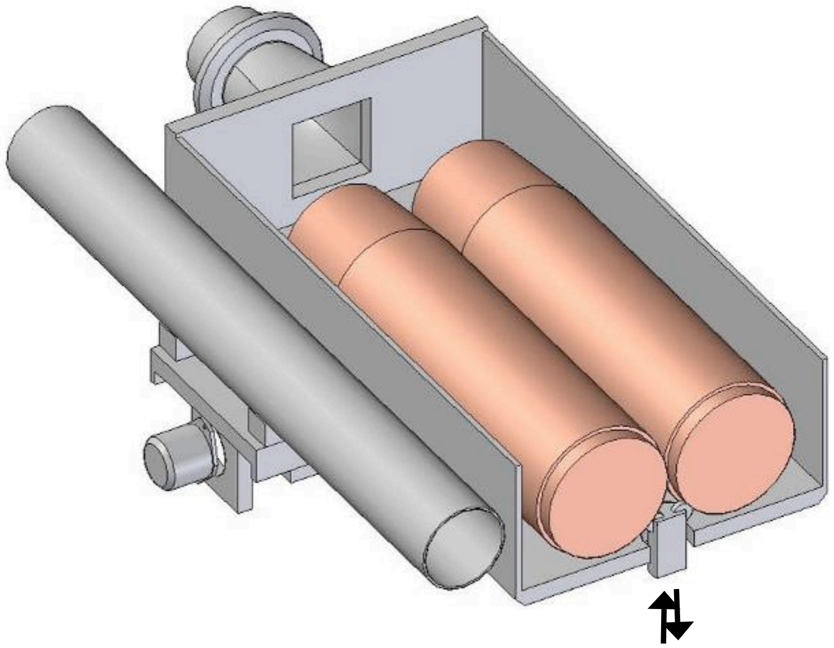
This side expands due to heating

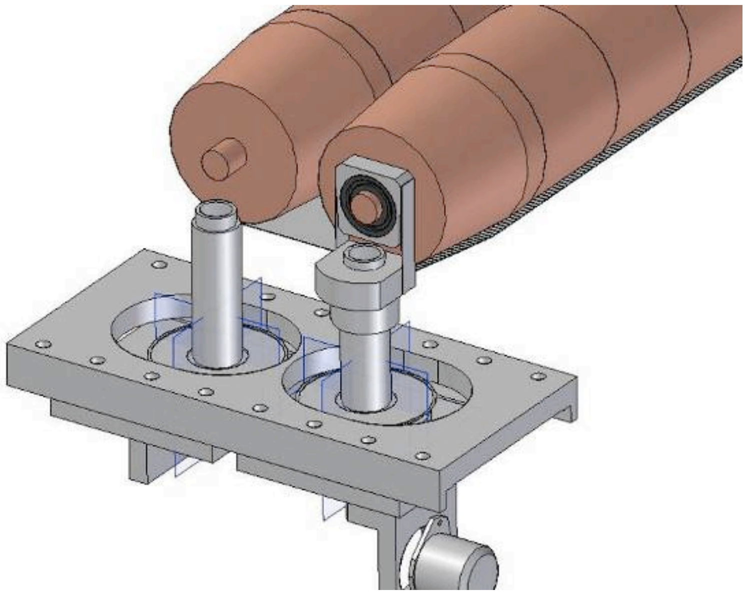


Expansion of jaw's beam side causes bending toward beam

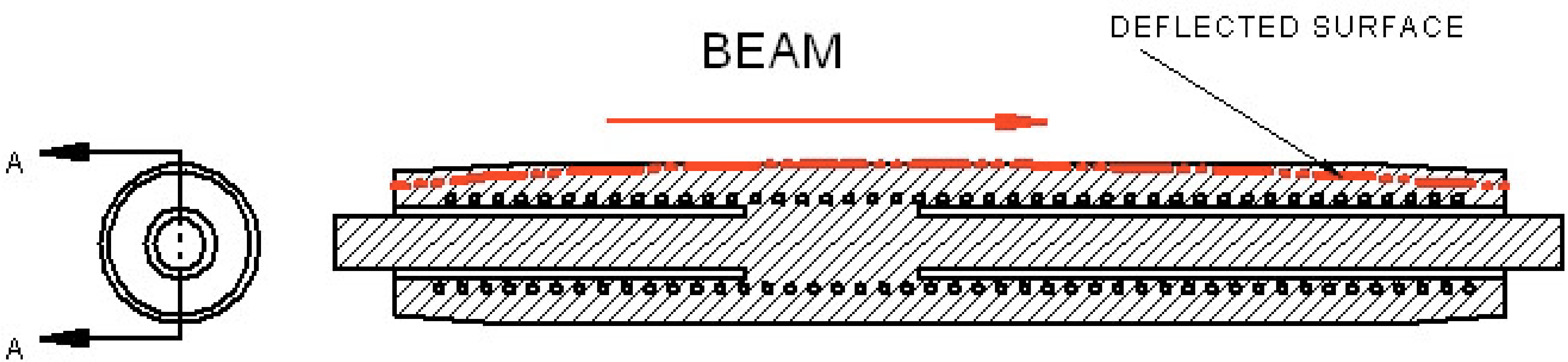
This effect is a function of material, jaw OD & ID, length, and cooling arrangement

June 2006
Introduce new **jaw-hub-shaft** design which eliminates central stop & flexible springs





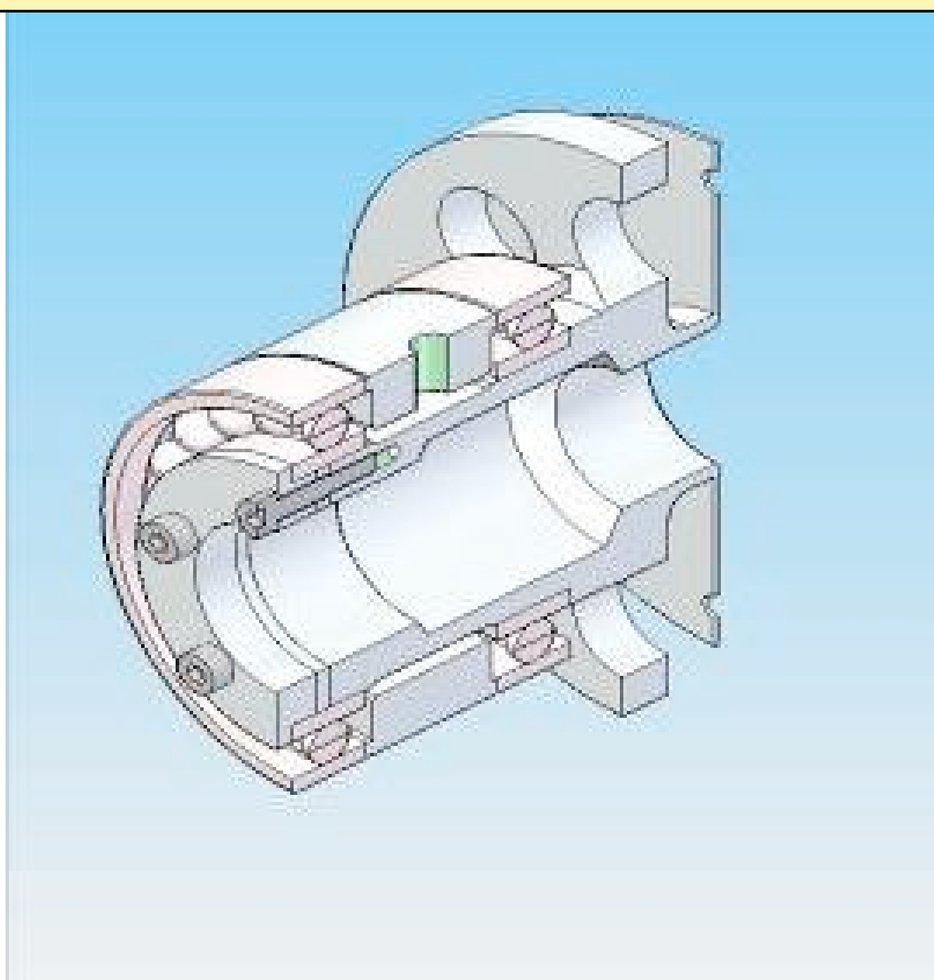
x5 improvement in thermal deformation
1260 um → 236 um (60kW/jaw, τ=12min)
426 um → 84 um (12kW/jaw, t=60min)

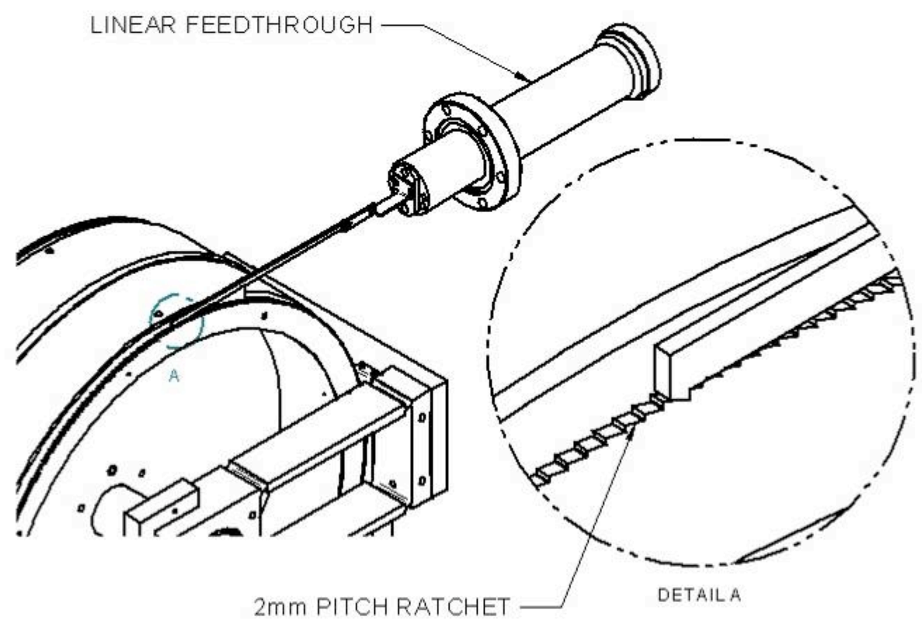


Introduce new **Internally actuated drive and jaw mount** for rotating after beam abort damages surface
Completed 27 May 2007

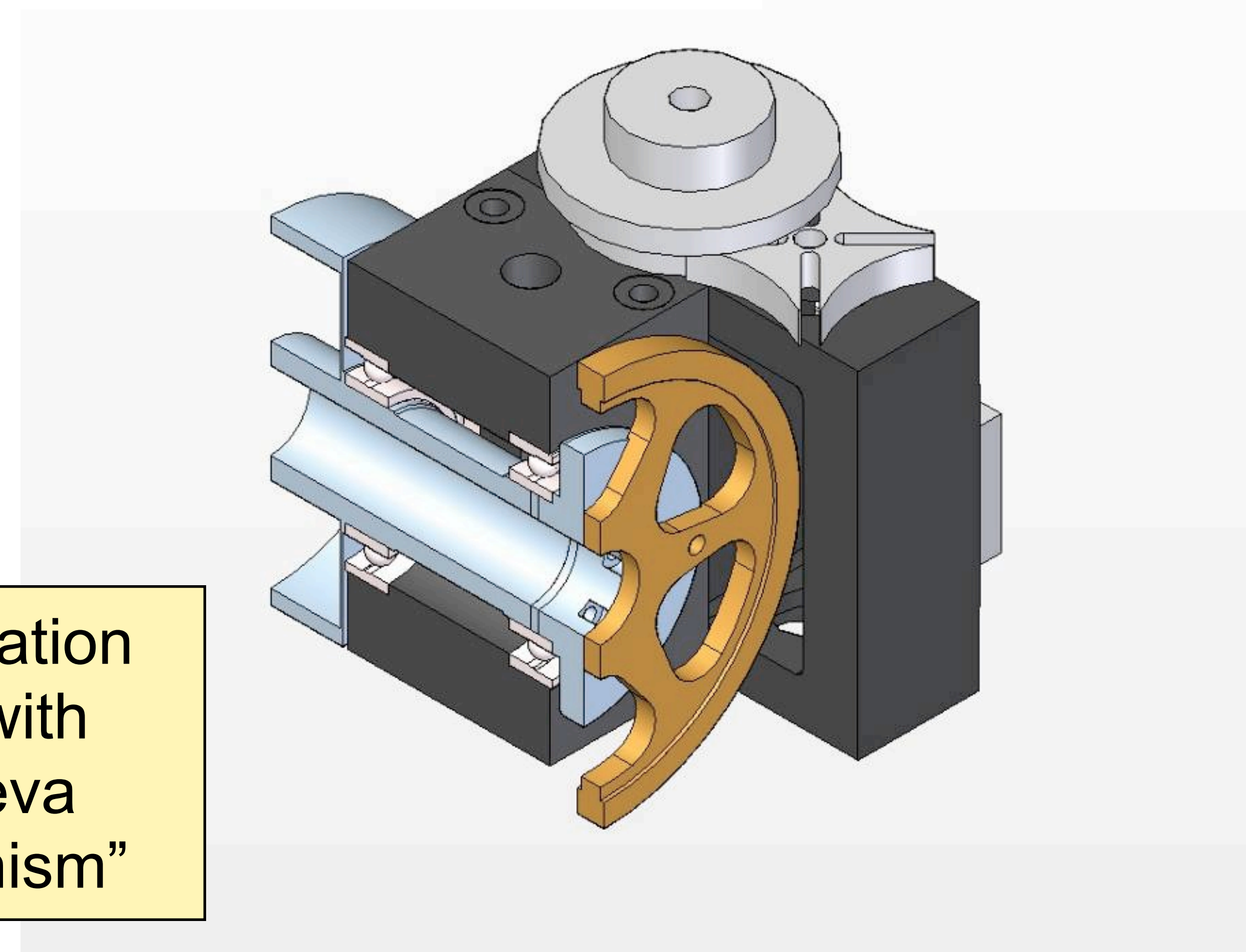
Universal Joint Drive Axle Assembly

- Thermal expansion
- Gravity sag
- Differential transverse displacement





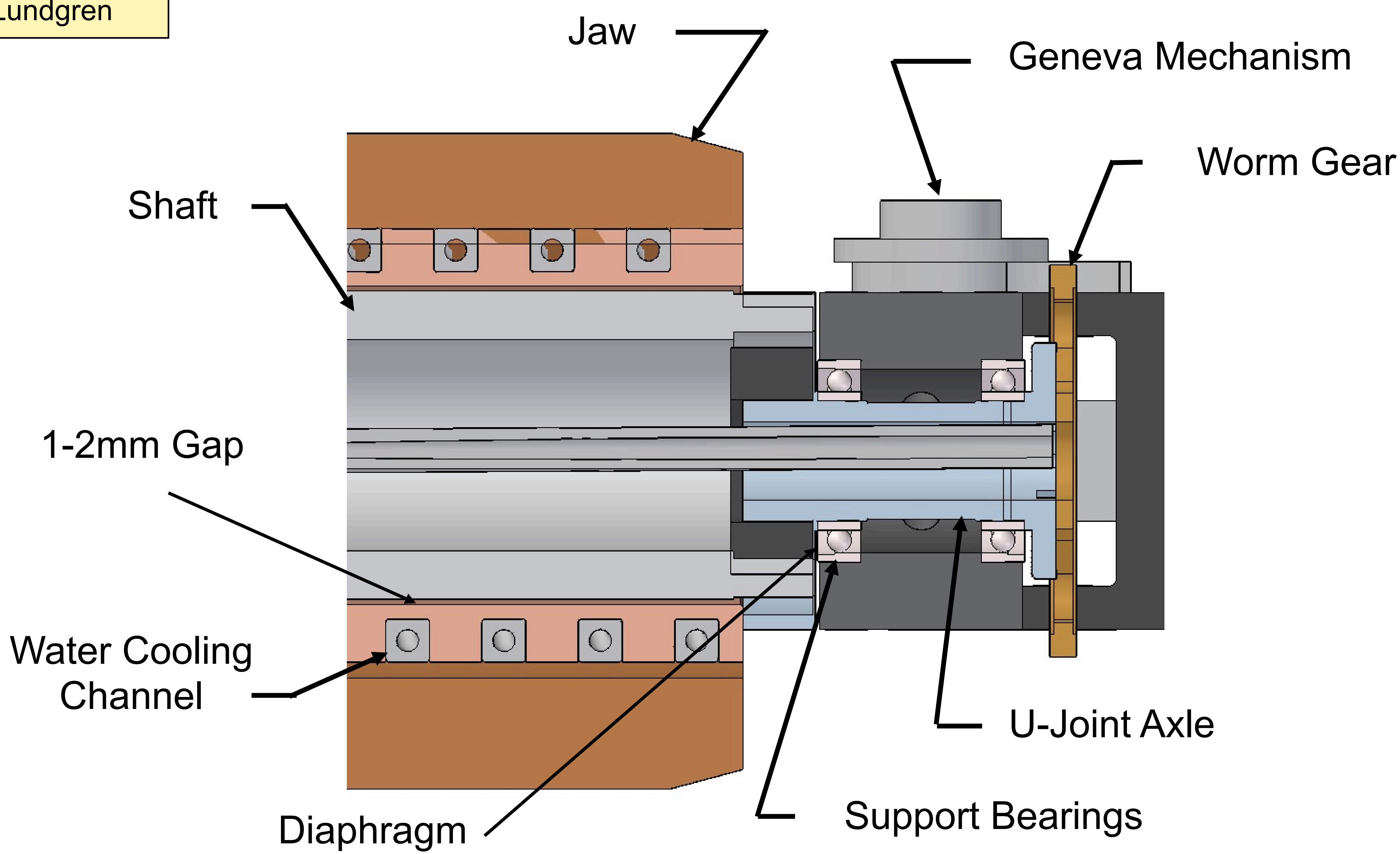
NLC Jaw Ratchet Mechanism



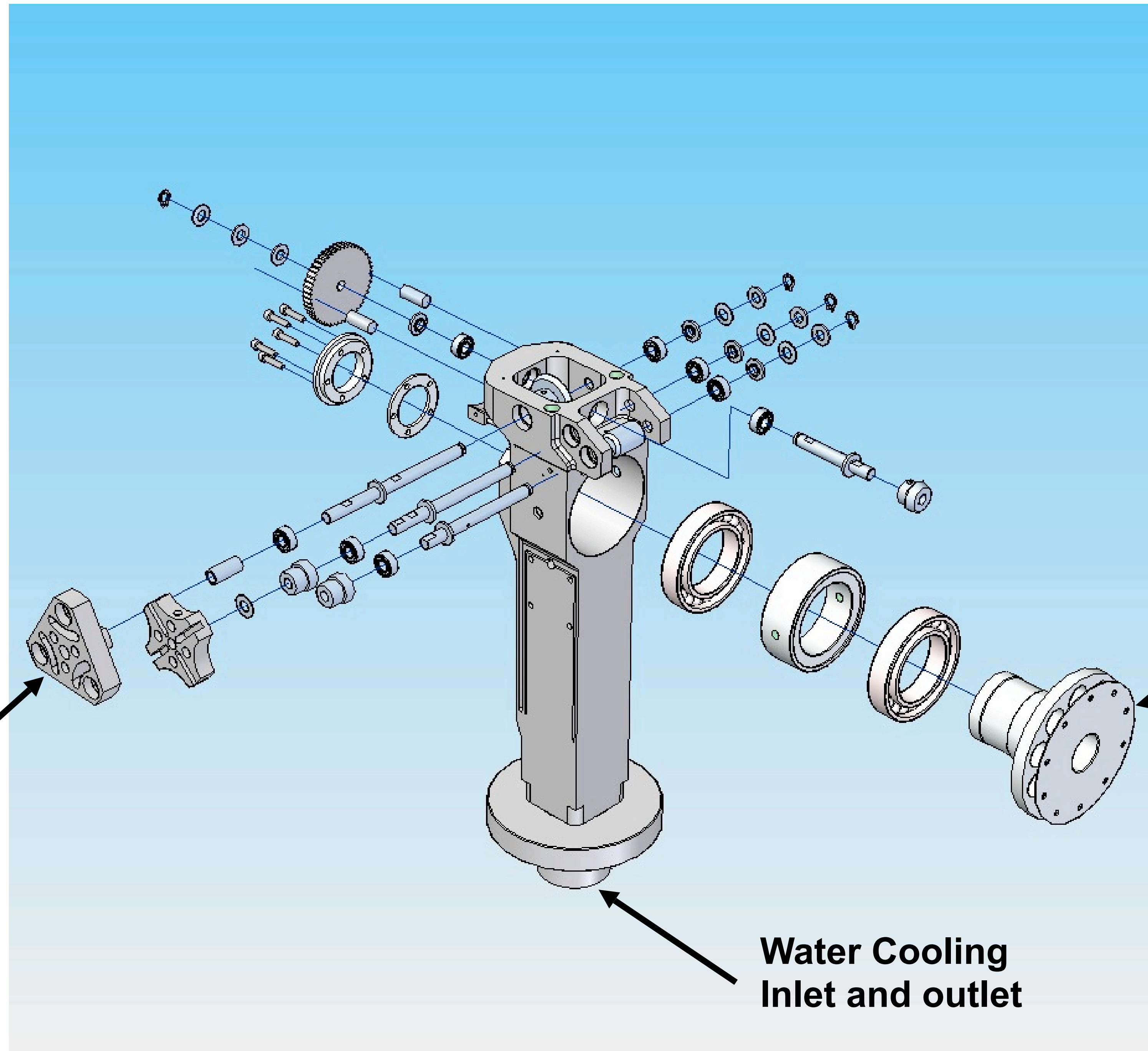
New rotation drive with “Geneva Mechanism”

Upstream end vertical section

Lundgren



Exploded view of CAD model of Flex Mount



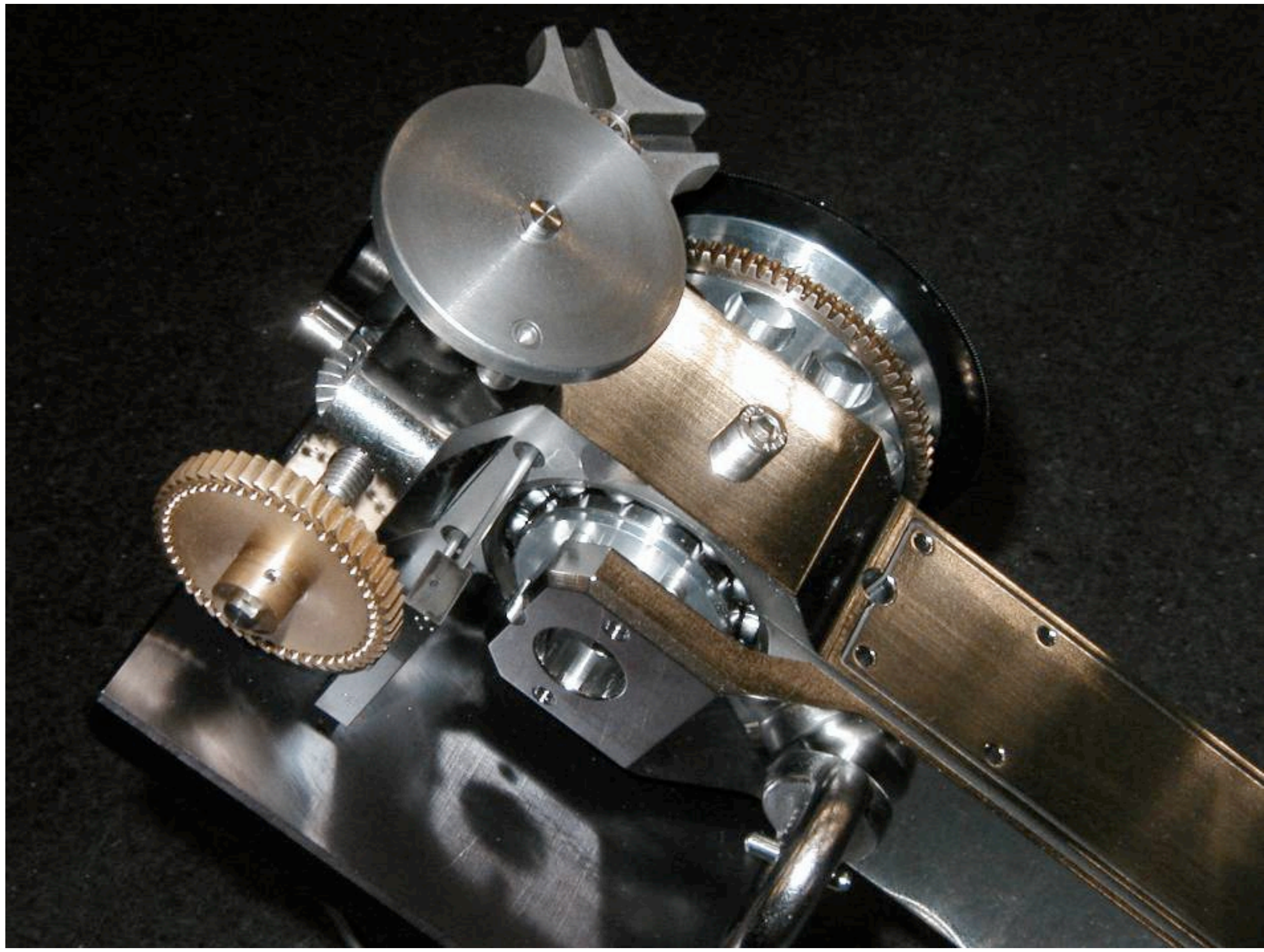
Triple Cog Geneva Drive Wheel required for 512 clicks per facet

Water Cooling Inlet and outlet

U-Joint Flexes for Shaft “sag” and “Slewing”

LARP

Up Beam Flex Mount Assembly showing Ratchet and Actuator



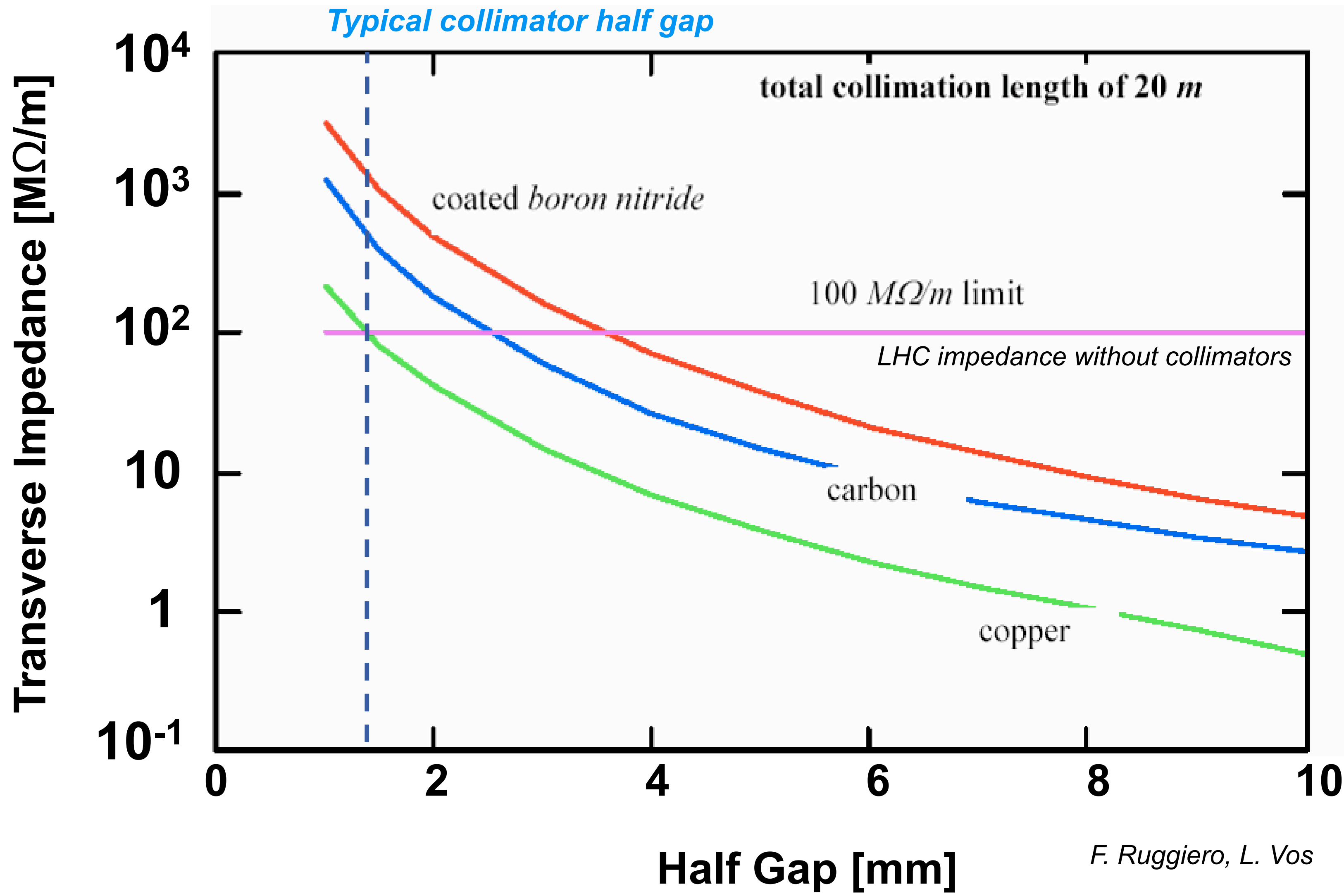
RF and Image Current Shielding

ONLY PART OF DESIGN THAT REMAINS TO BE FINALIZED

Copper Jaws lower resitive impedance considerably over Carbon Jaws (phase I design) nevertheless, LHC impedance still dominated by collimators

In Progress:

- Discussions with CERN and PeP-II experts
- MAFIA simulations
  - Geometric versus resistive contributions
  - trapped modes?
- Transverse impedance probably most critical



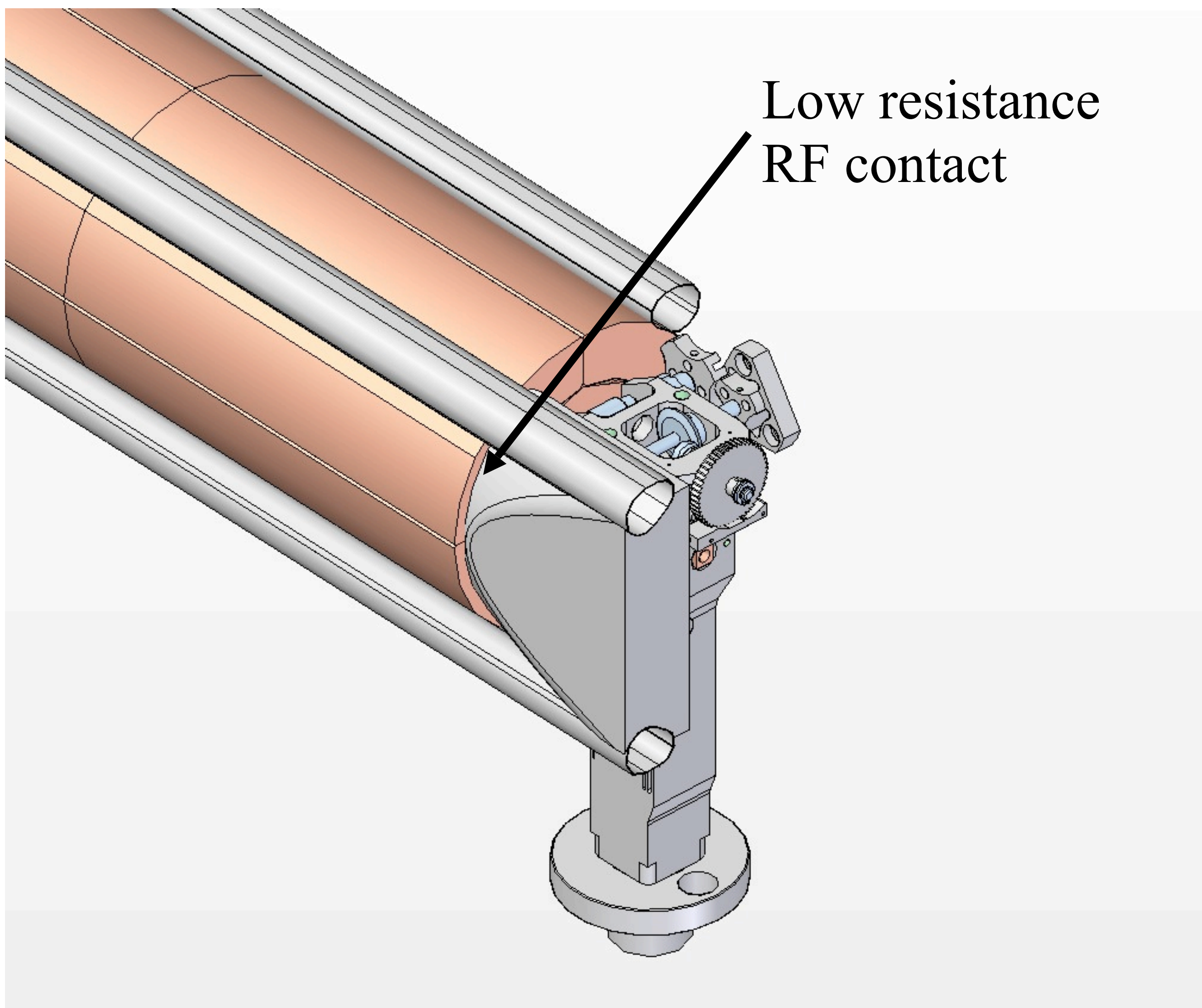
F. Ruggiero, L. Vos

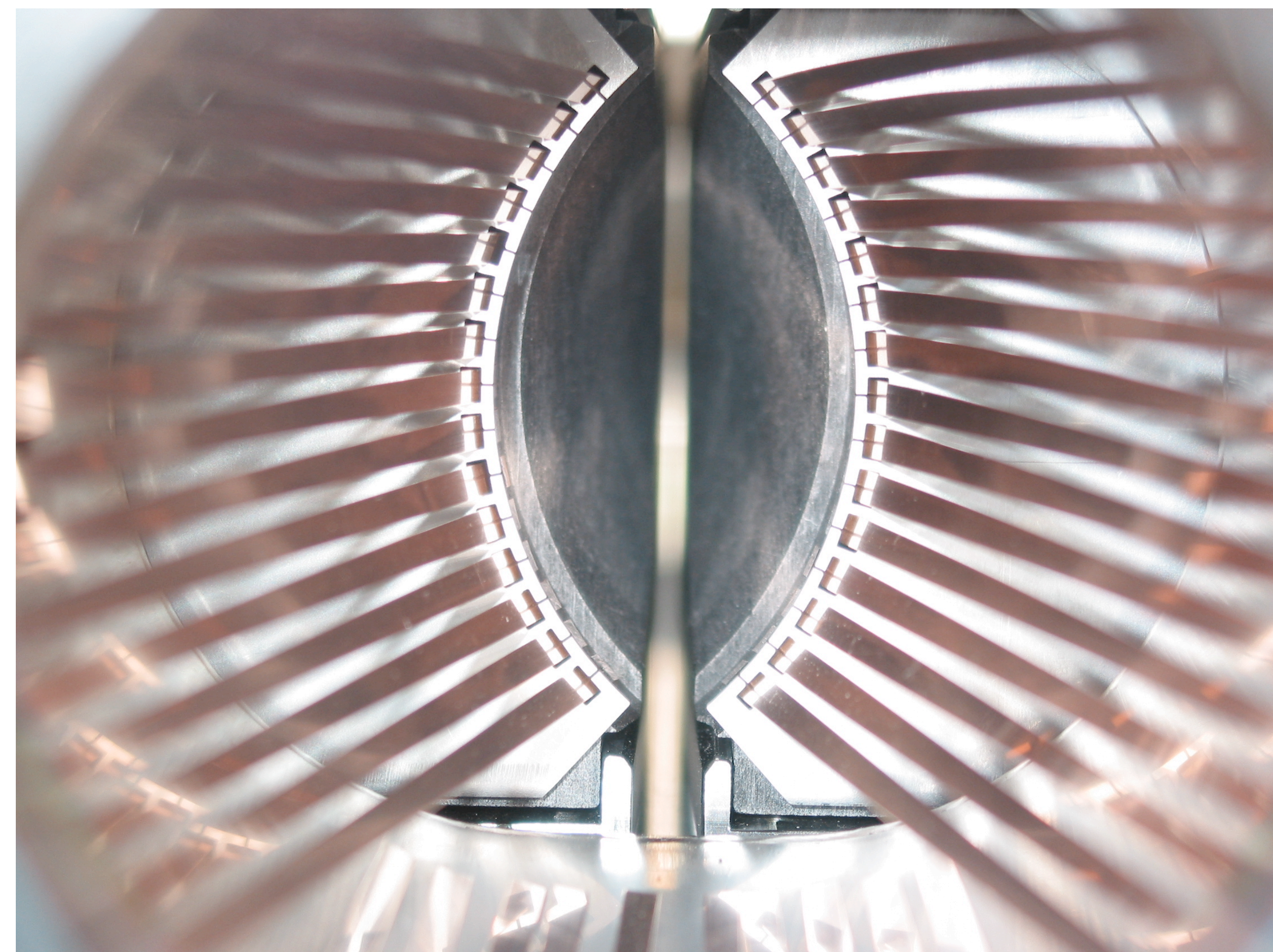
To be done:

- Bench top impedance measurements with stretched wire and network analyzer
- Contact resistance measurements

RF Contacts

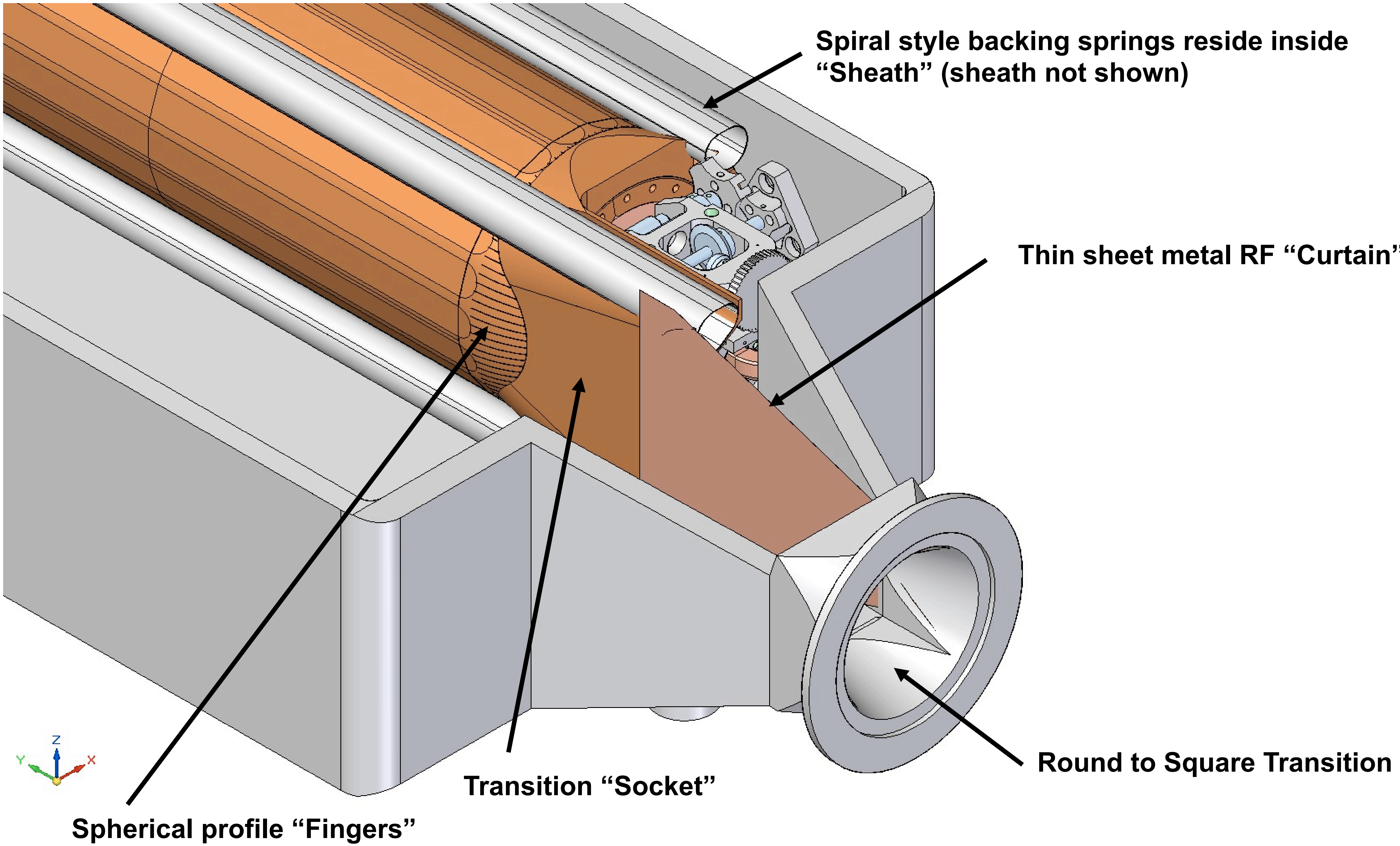
- Must have low impedance for RF contacts, especially Jaw/transition piece interface
  - Each RF bridge must have <0.1 mOhm low frequency resistance
  - What kind of electric contacts should be used here?
    - Silver plated? Rhodium? Is copper good enough? Cold welding copper?



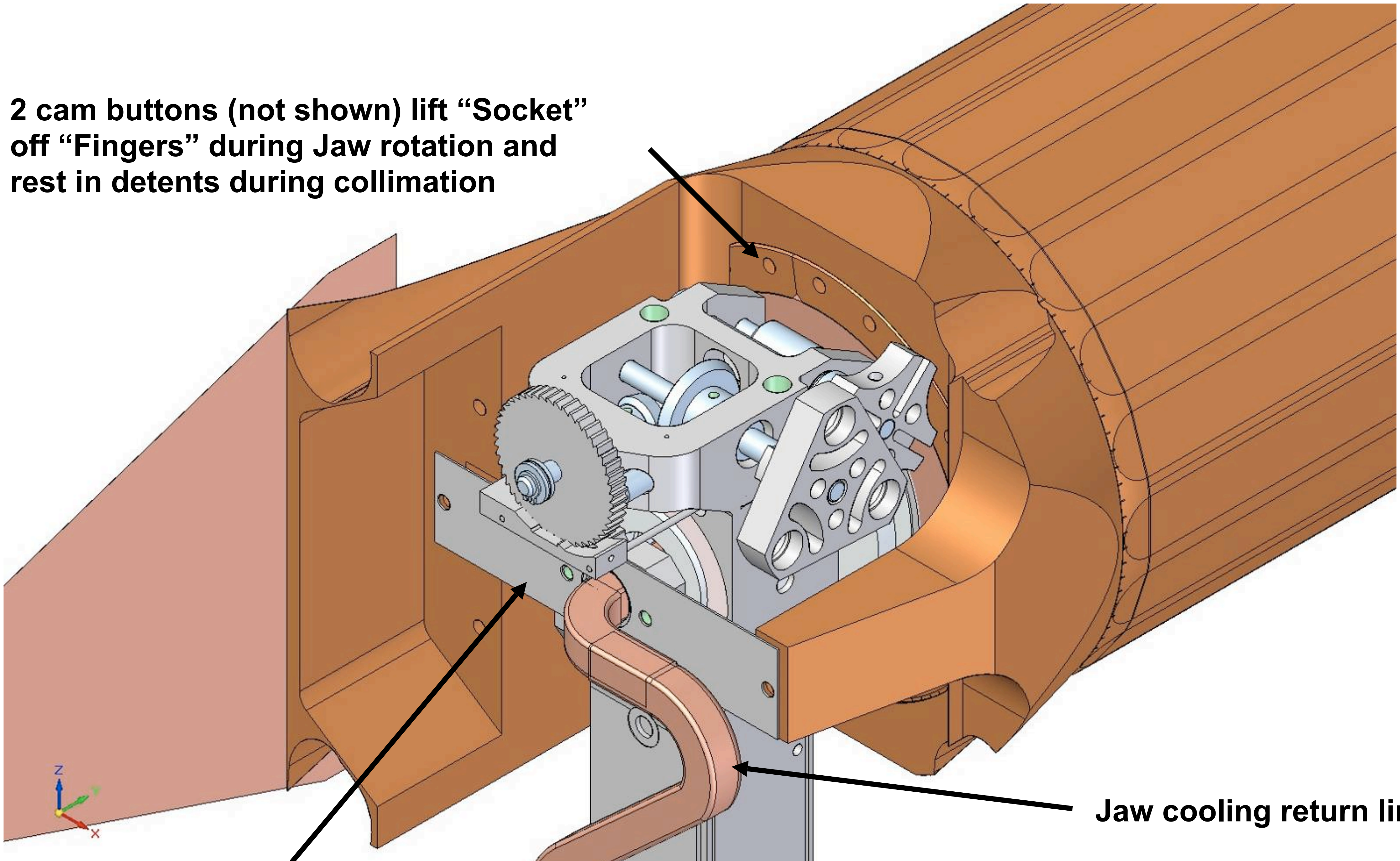


RF contacts in Phase 1 collimators

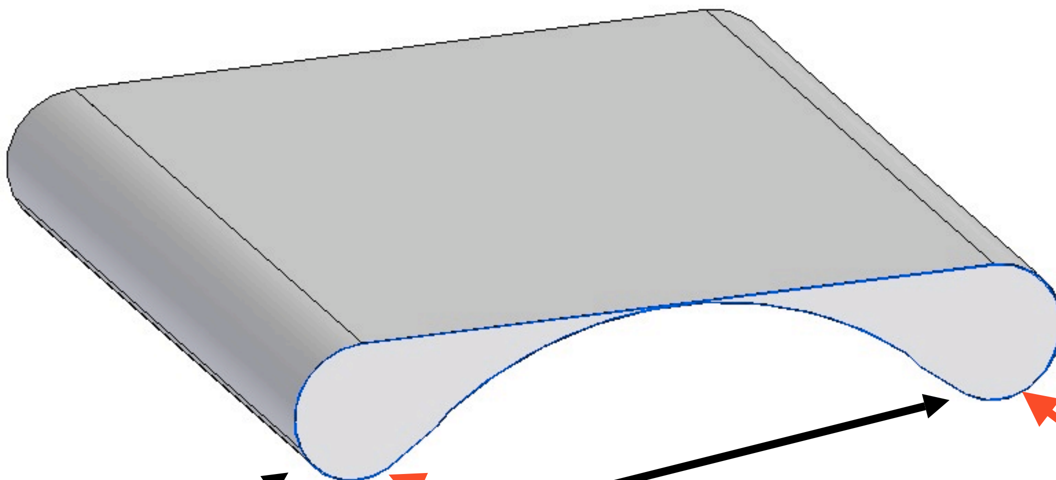
Up Beam end beam side view



Up Beam end detail view away from beam side

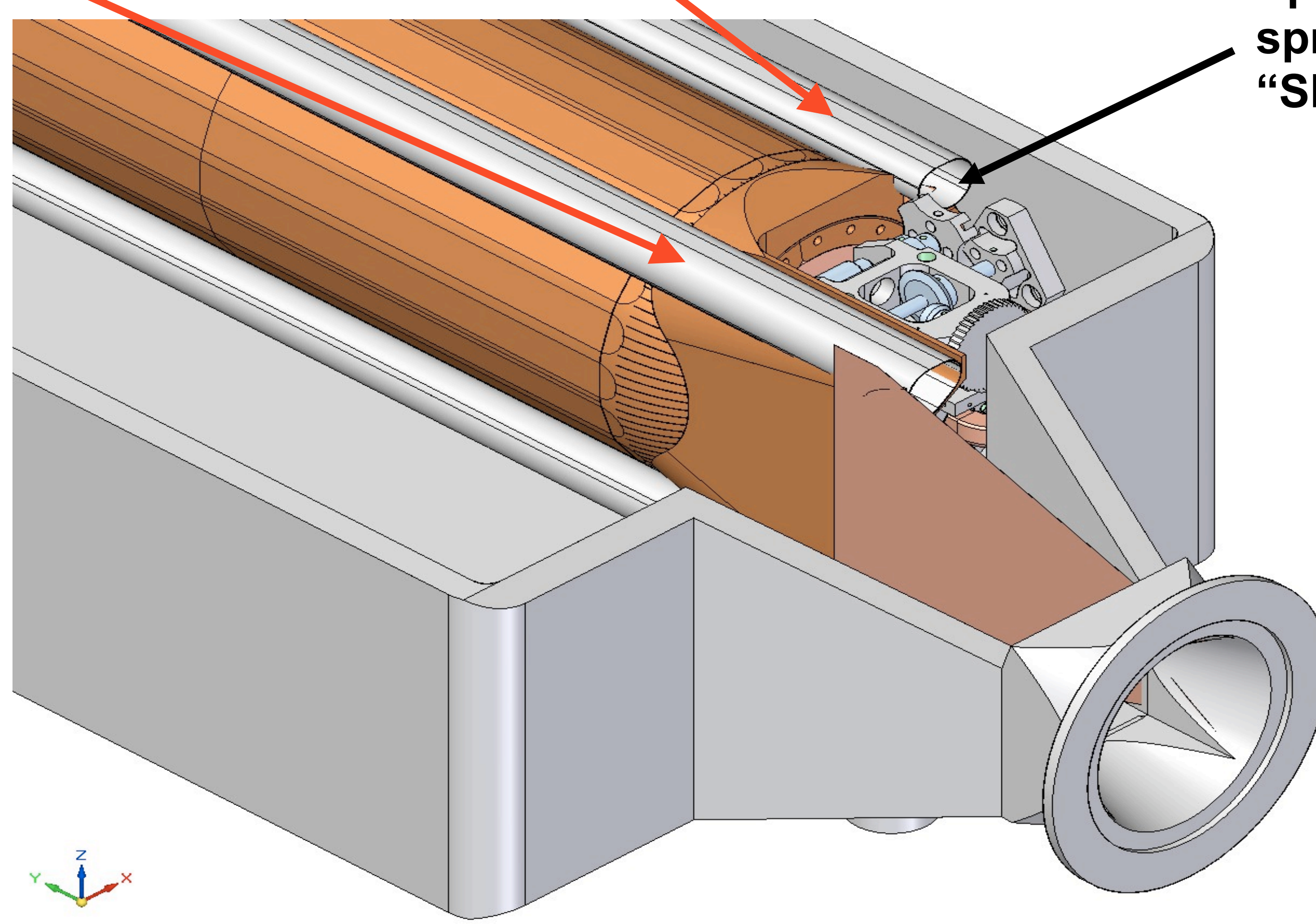


"Sheath" concept for transverse RF seal



Sheath may require slits at 3mm intervals along loop sides to prevent wrinkling

Paired spiral type RF Springs fit inside loop for balanced loading



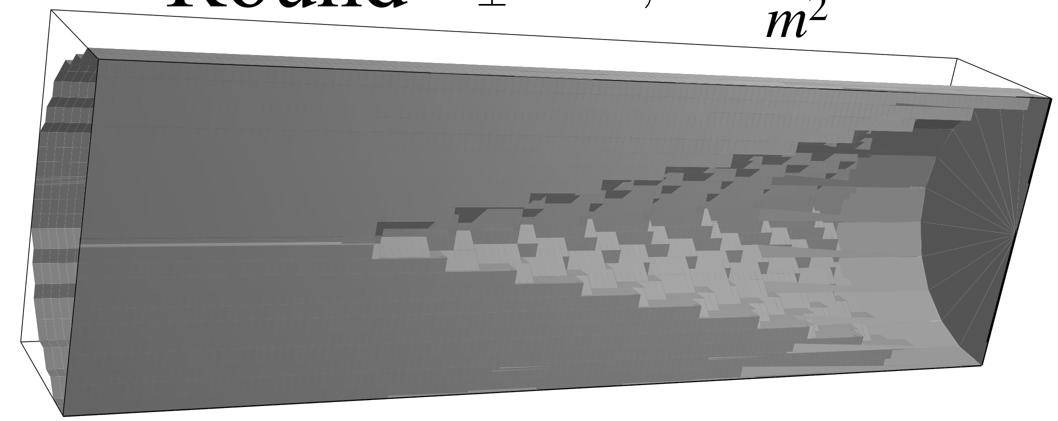
Spiral style backing springs reside inside "Sheath"

MAFIA Simulations

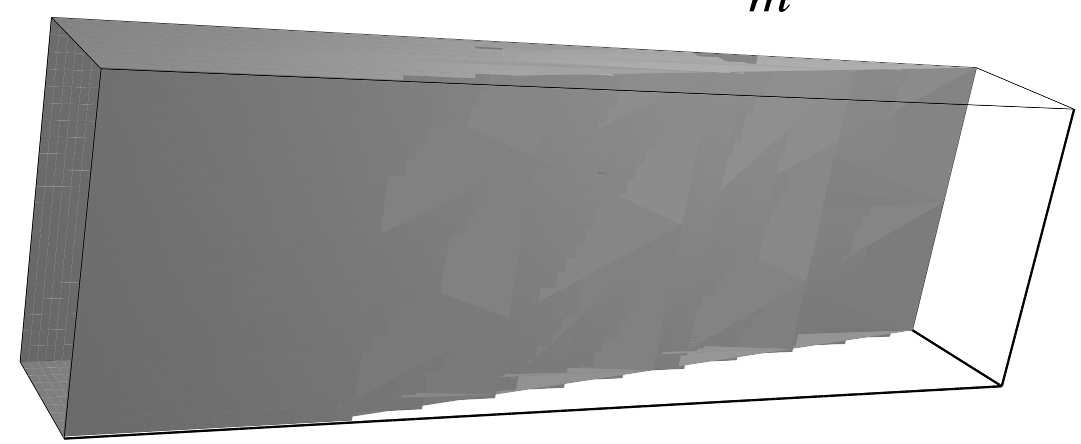
Have begun basic comparative studies between different collimator geometries and our current design

- ★Studies so far suggest round jaws with conic ends result in about a factor of two larger transverse wakefield than flat jaws
- ★Transverse kickfactor shown at right

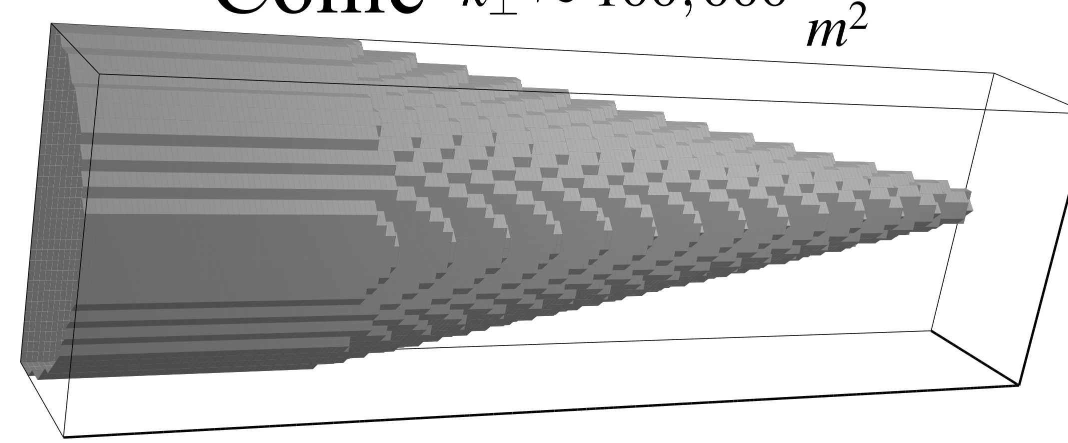
Round $k_{\perp} \approx 33{,}000 \, \frac{1}{m^2}$



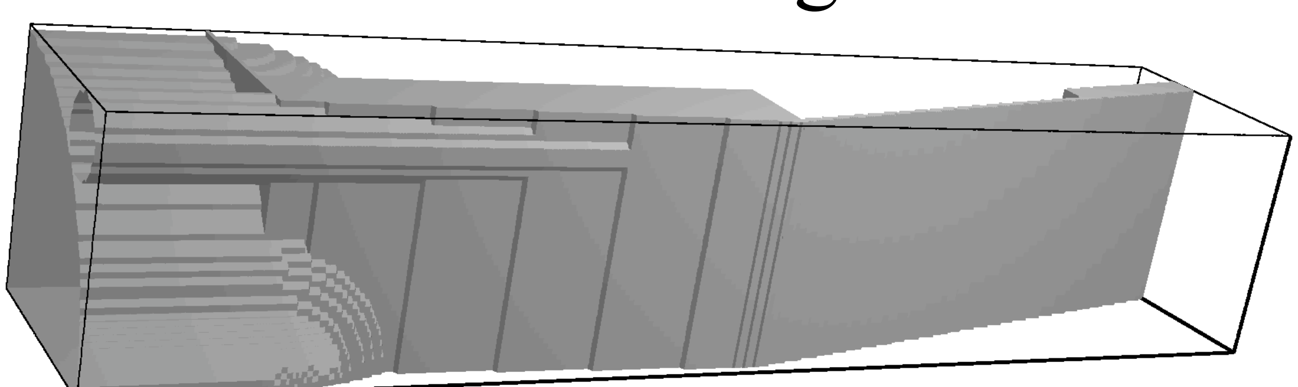
Flat $k_{\perp} \approx 50{,}000 \, \frac{1}{m^2}$



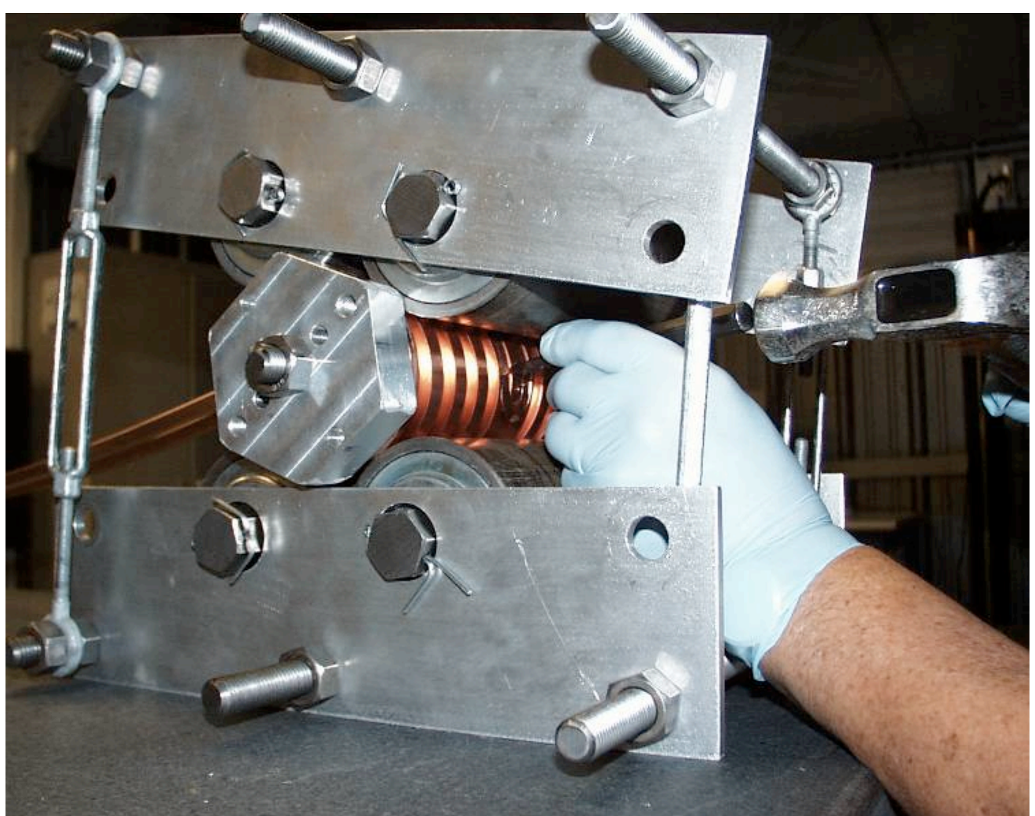
Conic $k_{\perp} \approx 100{,}000 \, \frac{1}{m^2}$



Current realistic design $k_{\perp} \approx \text{TBD}$

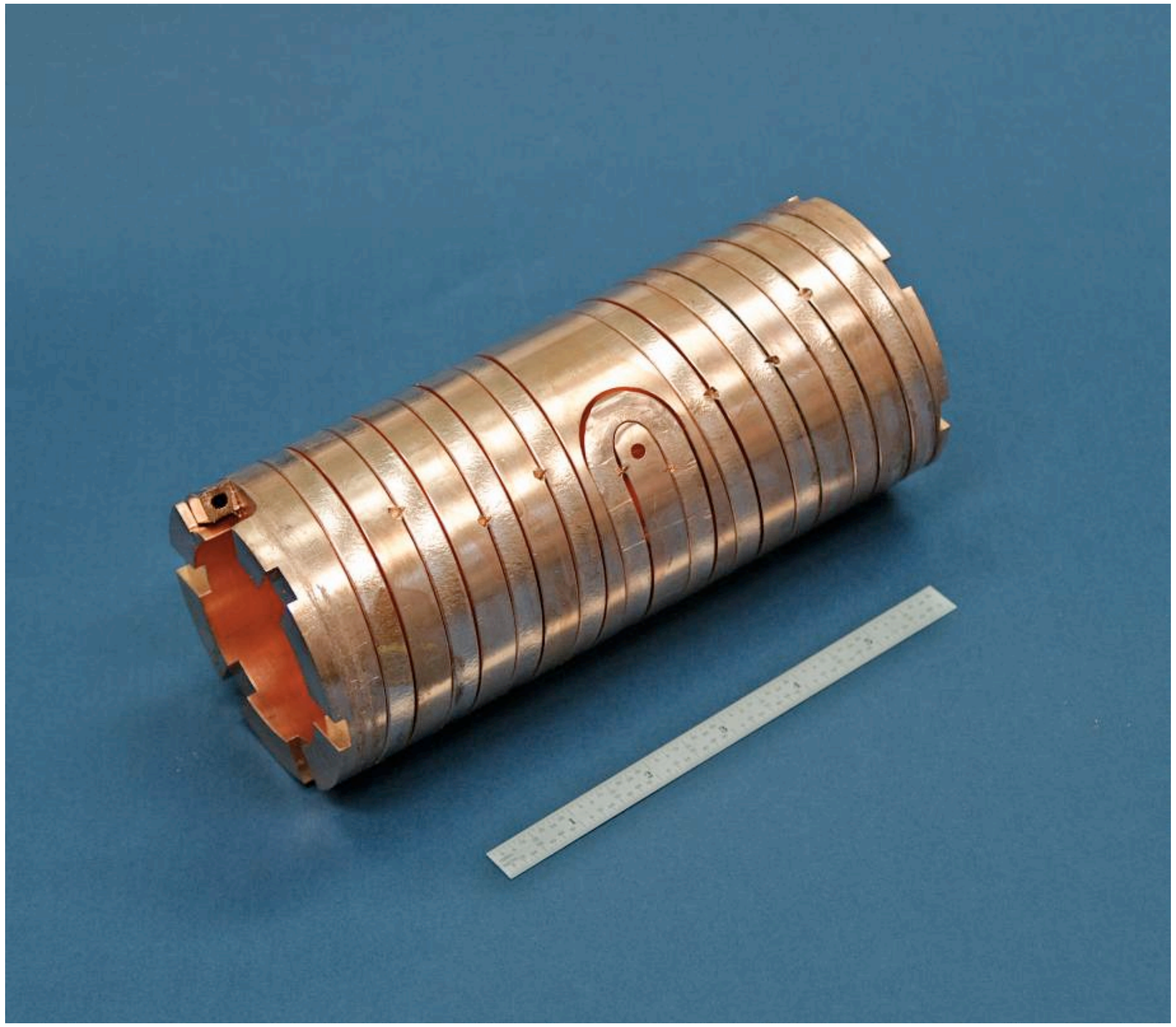


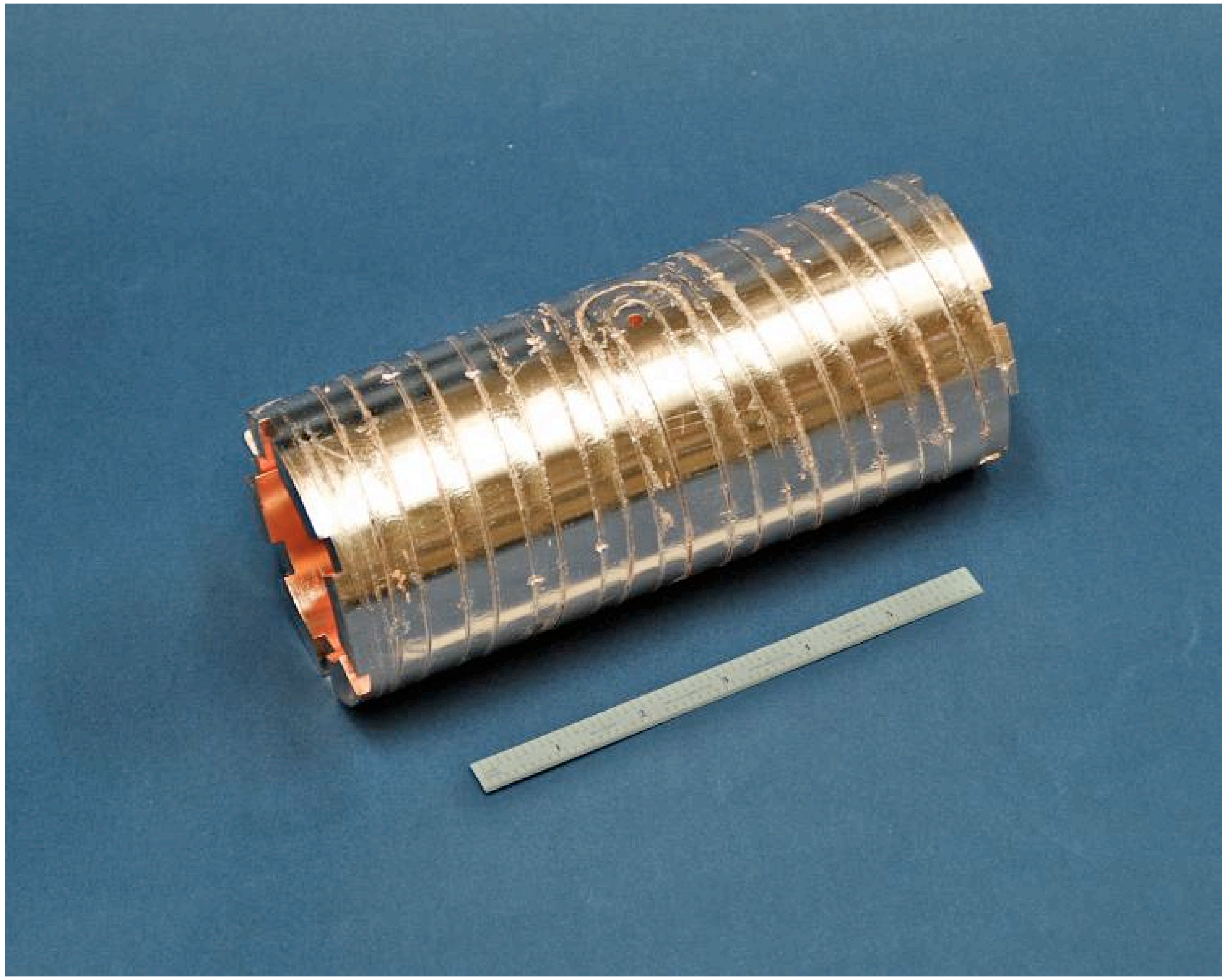
Final Wind of First 200mm Copper Mandrel



First 200mm Prototype
Before-After Brazing Coil to Mandrel

LARP



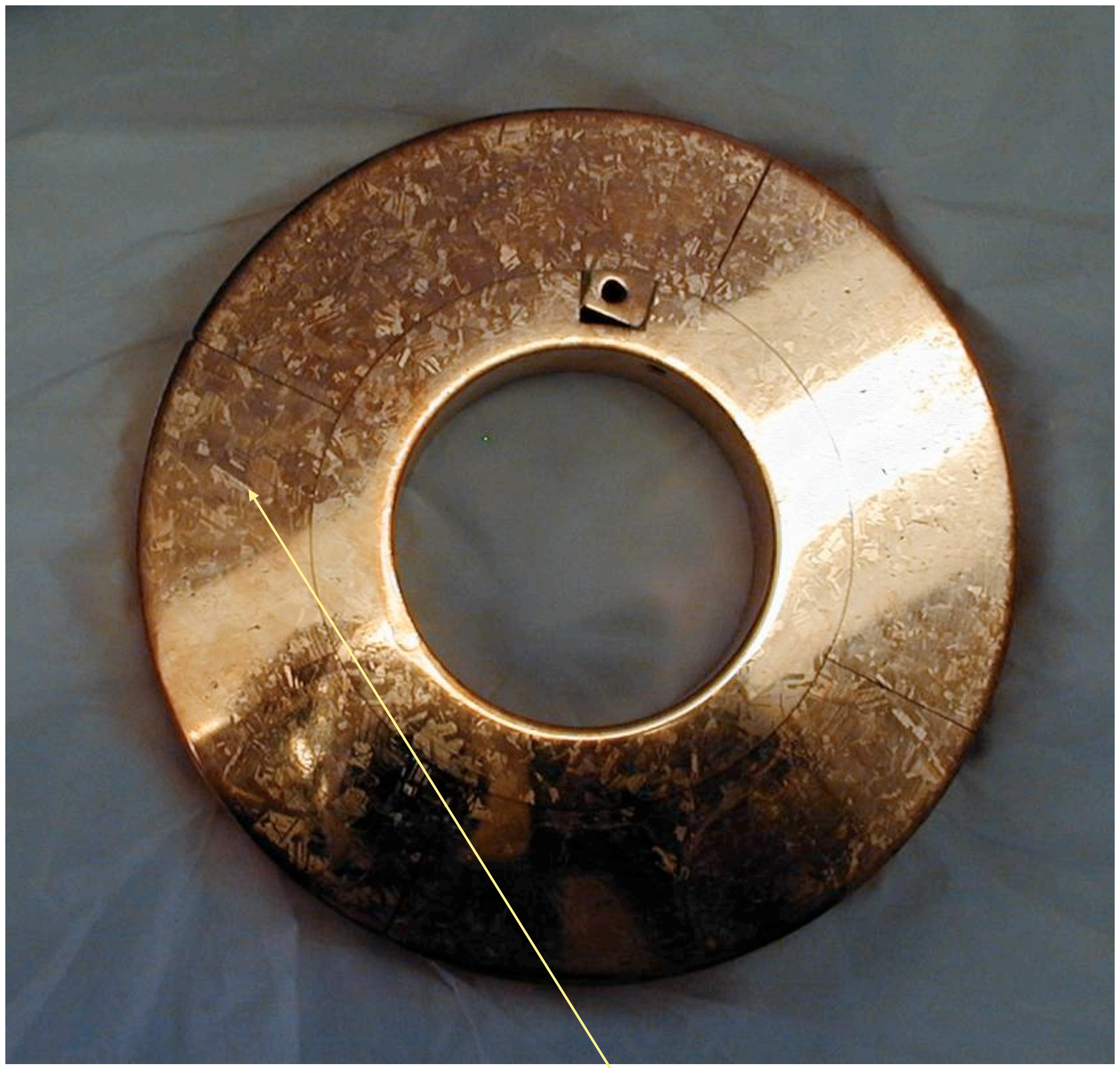


Pre-Coil-Braze

4 braze cycles were required before part deemed good enough to do jaw braze
Learned a lot about required tolerances of cooling coil and mandrel grooves

6/25/07-7/2/07 Slice & Dice Braze Test#2

Interior slice: polished & etched



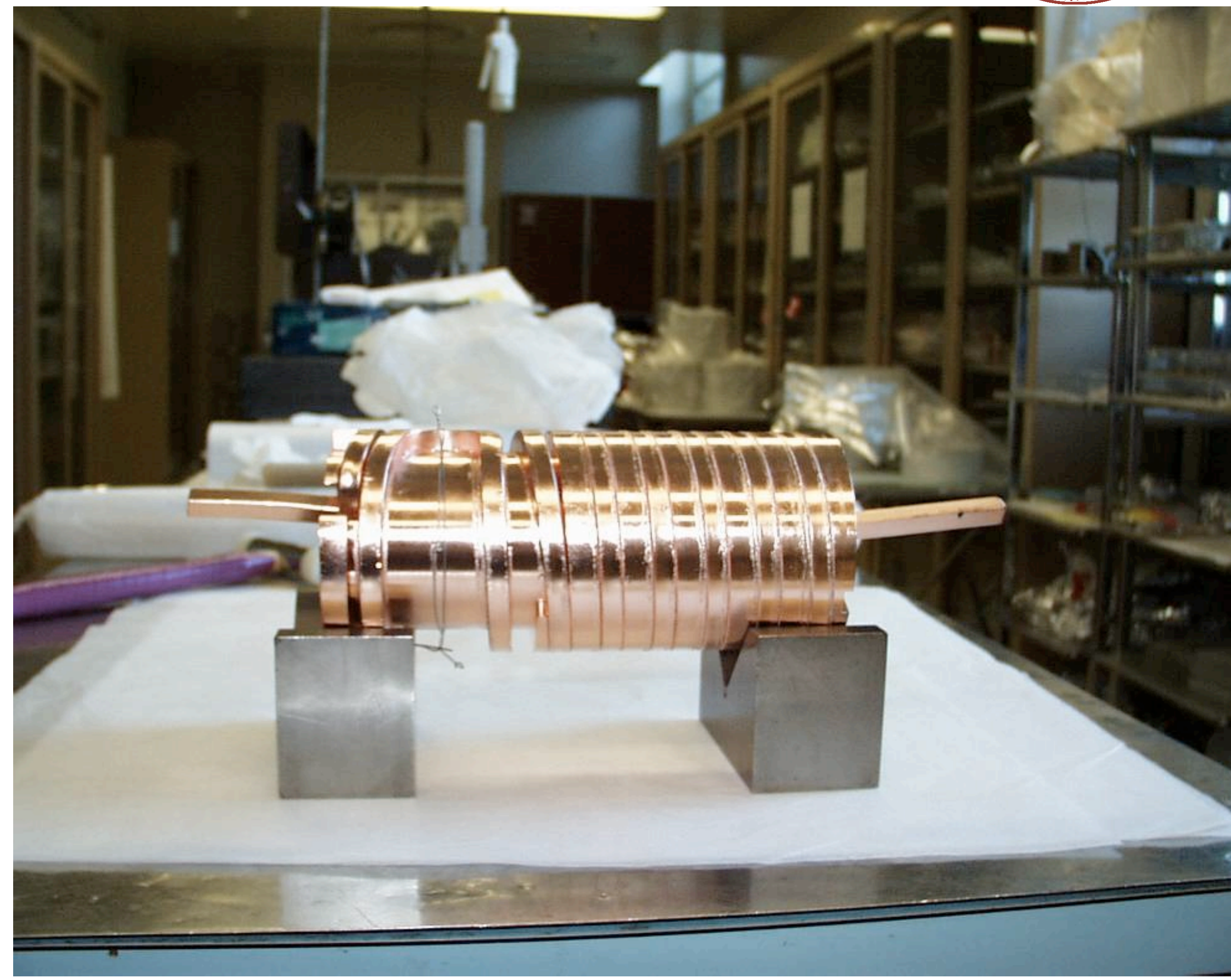
· Evidence of fracturing along grain boundaries presumed due to too-rapid cooldown after braze
  - areas near ends and OD look better
· Braze of jaws to hub GOOD
· 3 of 4 jaw-jaw brazes GOOD

Longitudinal slice

· Same fracturing patterns as in other slice
· Braze of cooling coils to jaw ID good
· Braze of cooling coil bottom to mandrel so-so

Braze Test #3:
Coil-to-mandrel braze

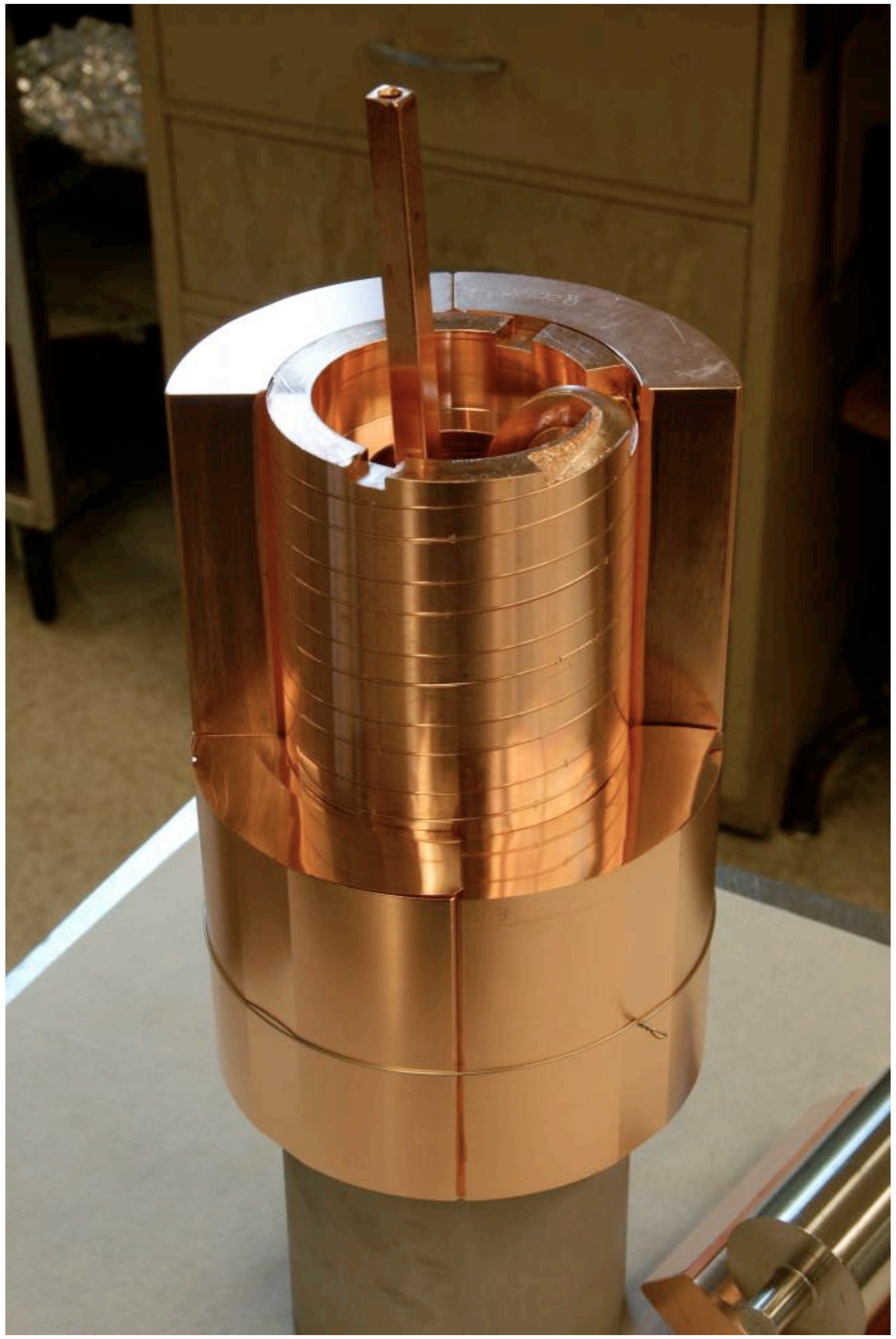
13 Apr 07: Prepped for 1st coil-mandrel braze



23 Apr 07: After 2 braze cycles, OD & braze wire grooves machined

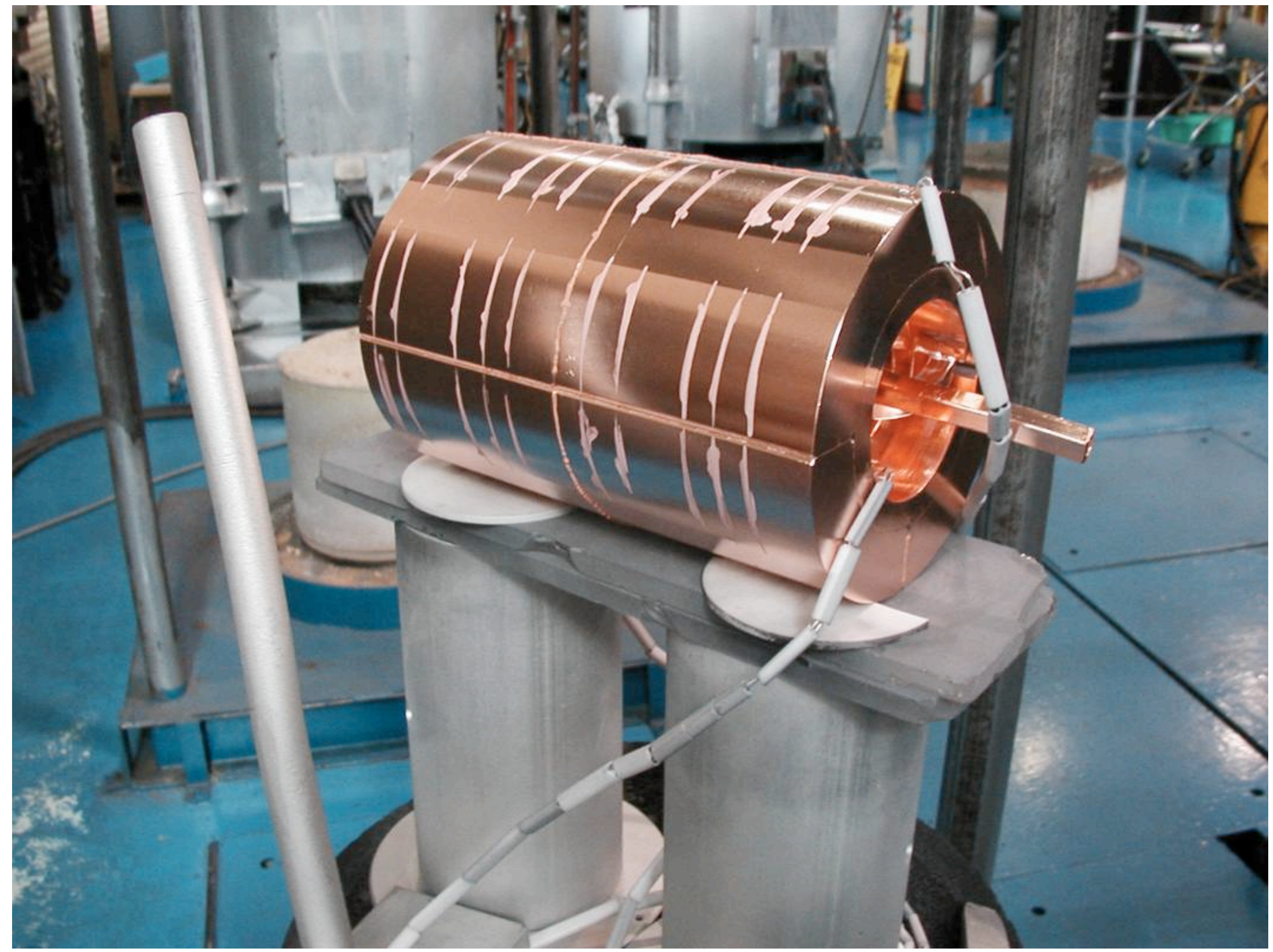
Braze Test #3:
8 ¼-round jaws to mandrel/coil

LARP



14 June 2007: Jaw Fit Up

19 June 2007: After 1st Jaw Braze
Prepped for 2nd Braze to fillup jaw-jaw joints



Next steps:
- **-Vacuum test (July 15)**
- **-Section & examine braze quality**

Vacuum Bake of Braze Test#2 Results: 4/1/07
~3x over LHC Spec

1st Jaw Braze Test Assembly has been vacuum baked at 300 degrees C for 32 hours.

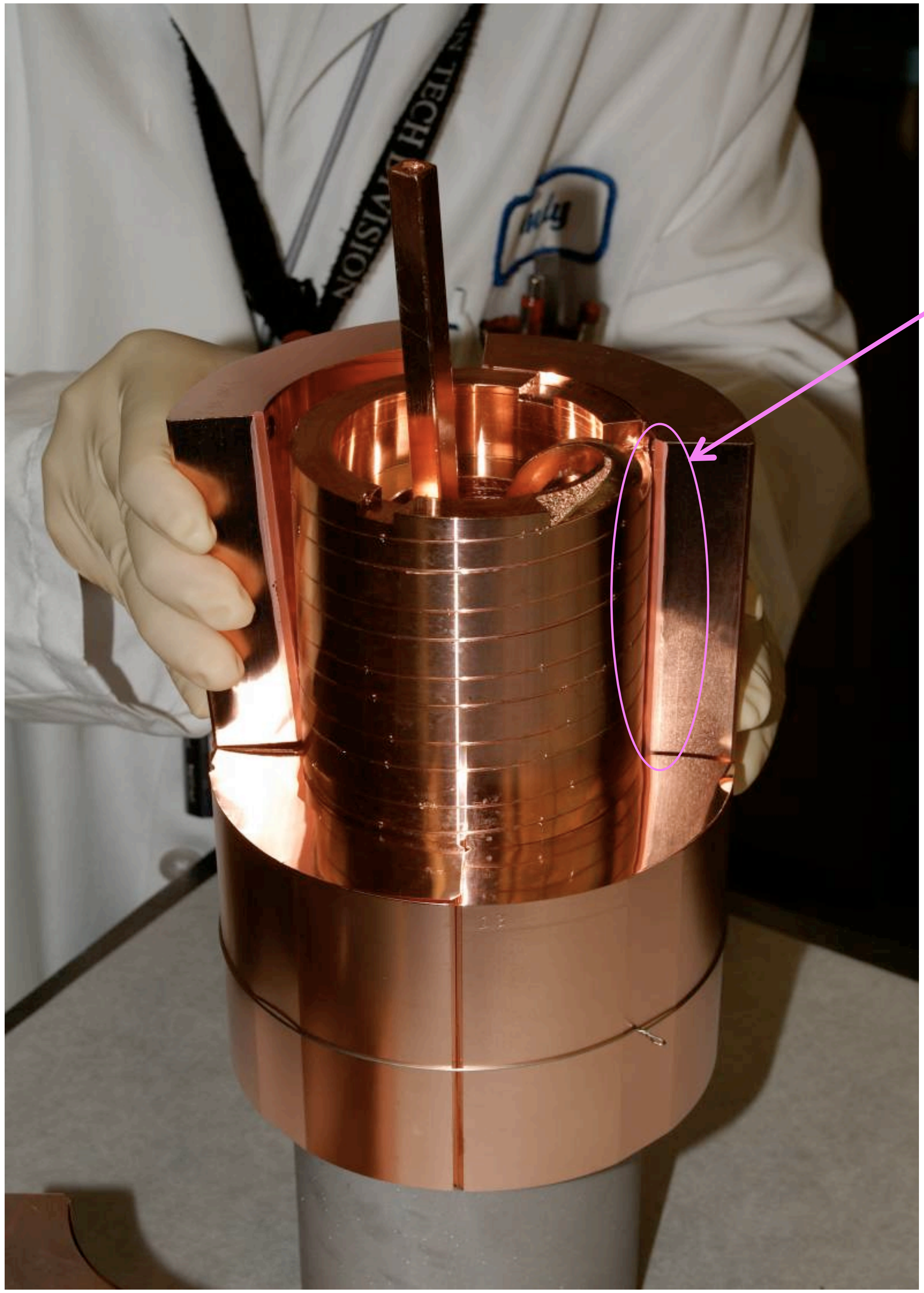
- LHC Requirement = 1E-7 Pa = 7.5E-10 Torr
- Baseline pressure of Vacuum Test Chamber:
  4.3E-7 Pa (3.2E-9 Torr)
- Pressure w/ 200mm Jaw Assy. in Test Chamber:
  4.9E-7 Pa (3.7E-9 Torr)
- Presumed pressure of 200mm lg. Jaw Assy.:
  6.0E-8 Pa (4.5E-10 Torr)
- Note: above readings were from gauges in the foreline, closer to the pump than to the Test Chamber. Pressures at the part could be higher.

Outcome:

SLAC vacuum group has suggested longitudinal grooves be incorporated into the inner length of jaws; incorporated into next prototype

LARP

Braze Test #3: Vacuum tests

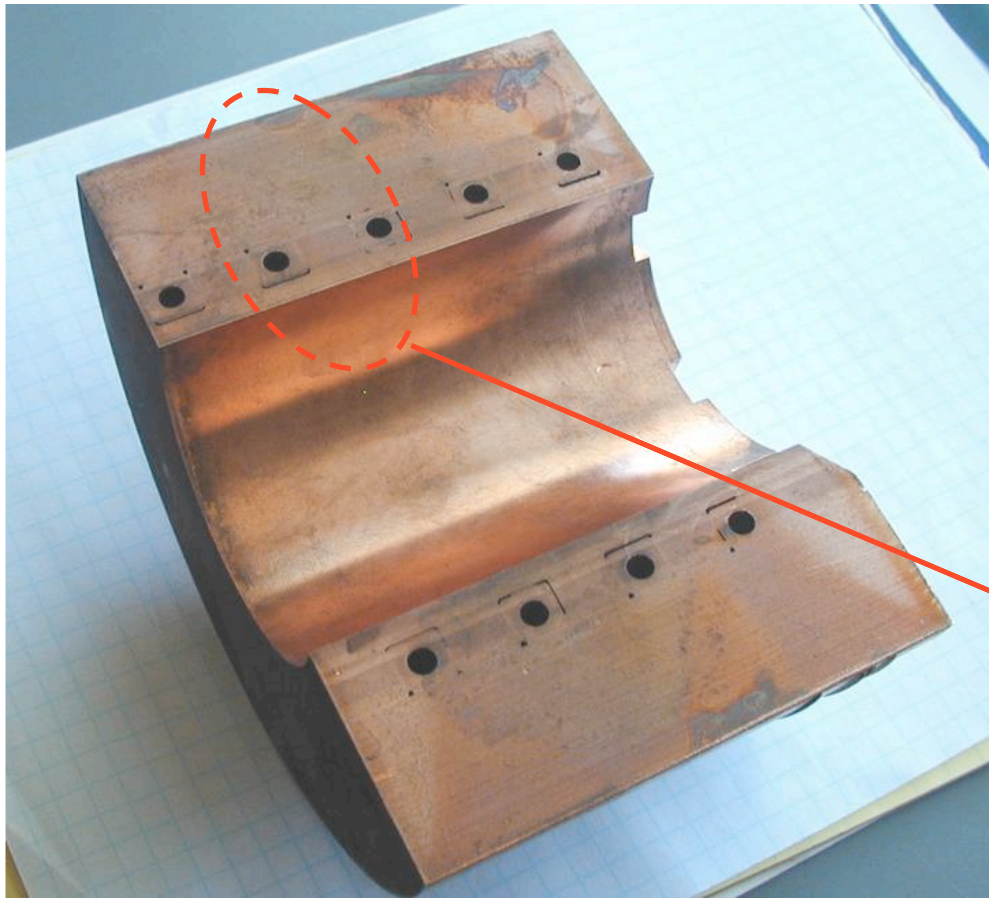


- 3rd Jaw Braze Test Assembly has been vacuum baked at 300 degrees C for 32 hours. Results in slightly lower pressure.
- Inclusion of longitudinal grooves in the inner length of jaws for better outgasing
- Test Chamber setup similar to previous test.

	Old	New
Baseline	3.2E-9 Torr	2.4E-9 Torr??
w/ jaw assy.	3.7E-9 Torr	3.4E-9 Torr
Presumed jaw assy. pressure	4.5E-10 Torr	10E-10 Torr??
LHC requirement	7.5E-10 Torr	7.5E-10 Torr

Under Investigation…

Braze Test #3: Sectioning & Examination
Cu grain boundary cracking during brazing



Specimen 140mm OD x 60mm ID x 200mm L (¼ section shown)

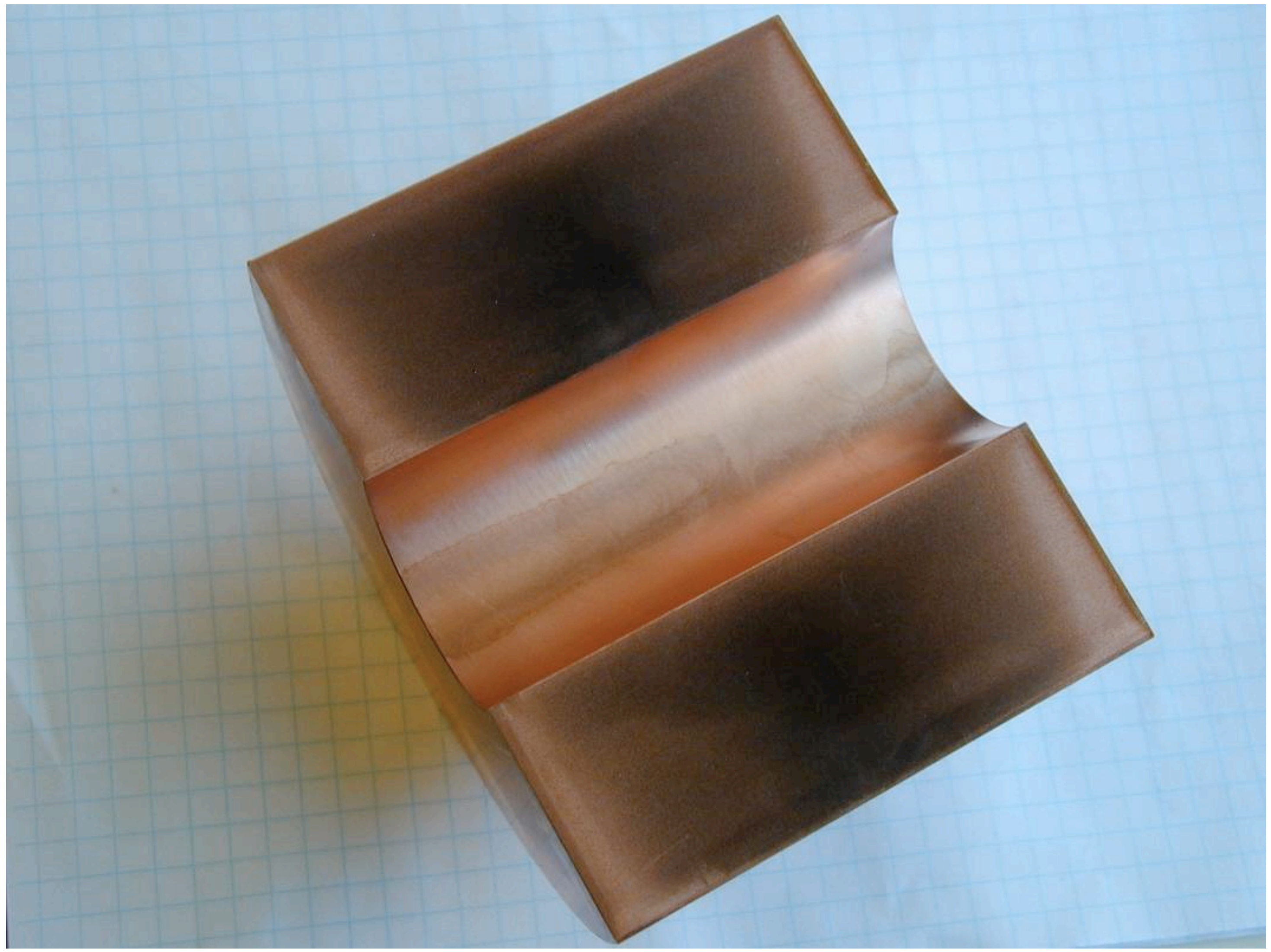
- one braze cycle in the 900 C range
- grain boundary cracks located in interior regions
- believed due to excessive heating rate
- Glidcop to be tested

Concerns

- Effect on performance
- What happens in accident case?

Glidcop Al-15 Heat sample

While 1st jaw used to test thermal mechanical issues is Copper first full 2 jaw prototype will use Glidcop



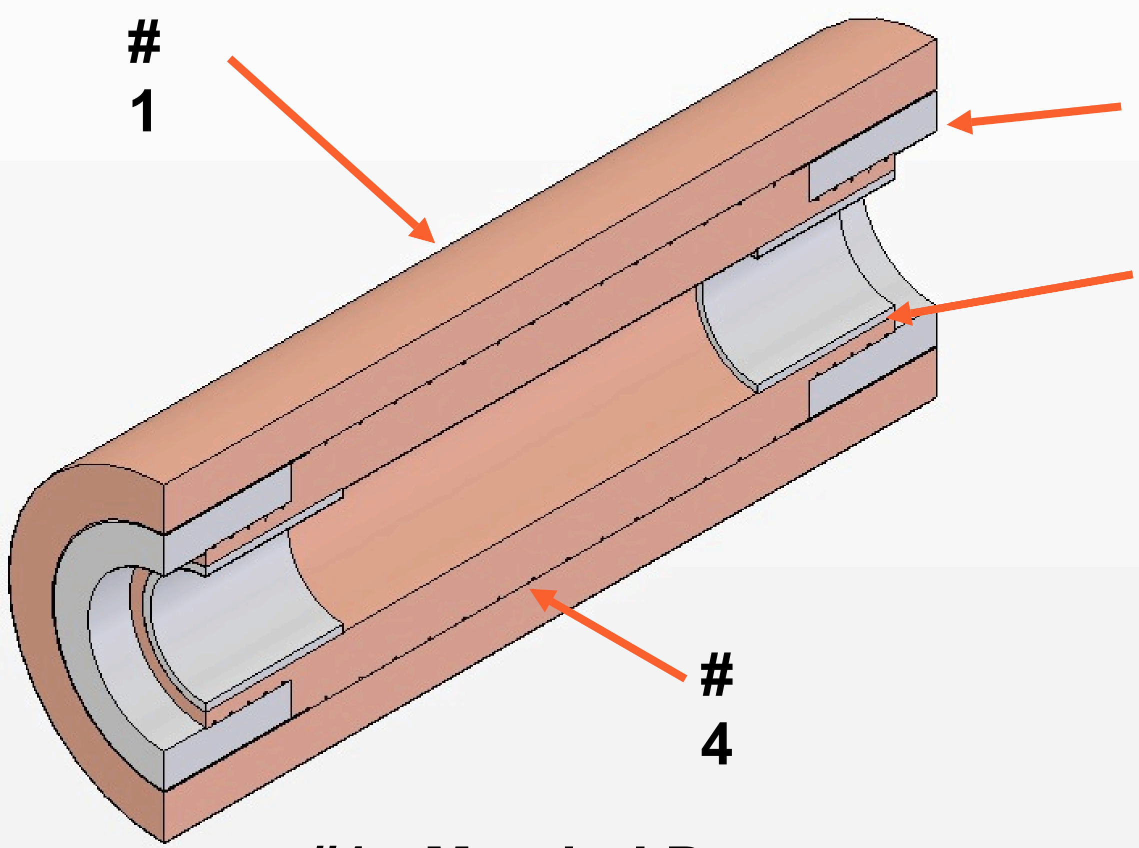
2 Heats (at Jaw brazing temperature)

No grain boundary cracking is apparent

Metallographic samples are being prepared for microscopic inspection

Fear of Copper-Moly Shaft-to-Mandrel Braze Joint Leads to Mini R&D Cycle Devoted to Issue

LARP



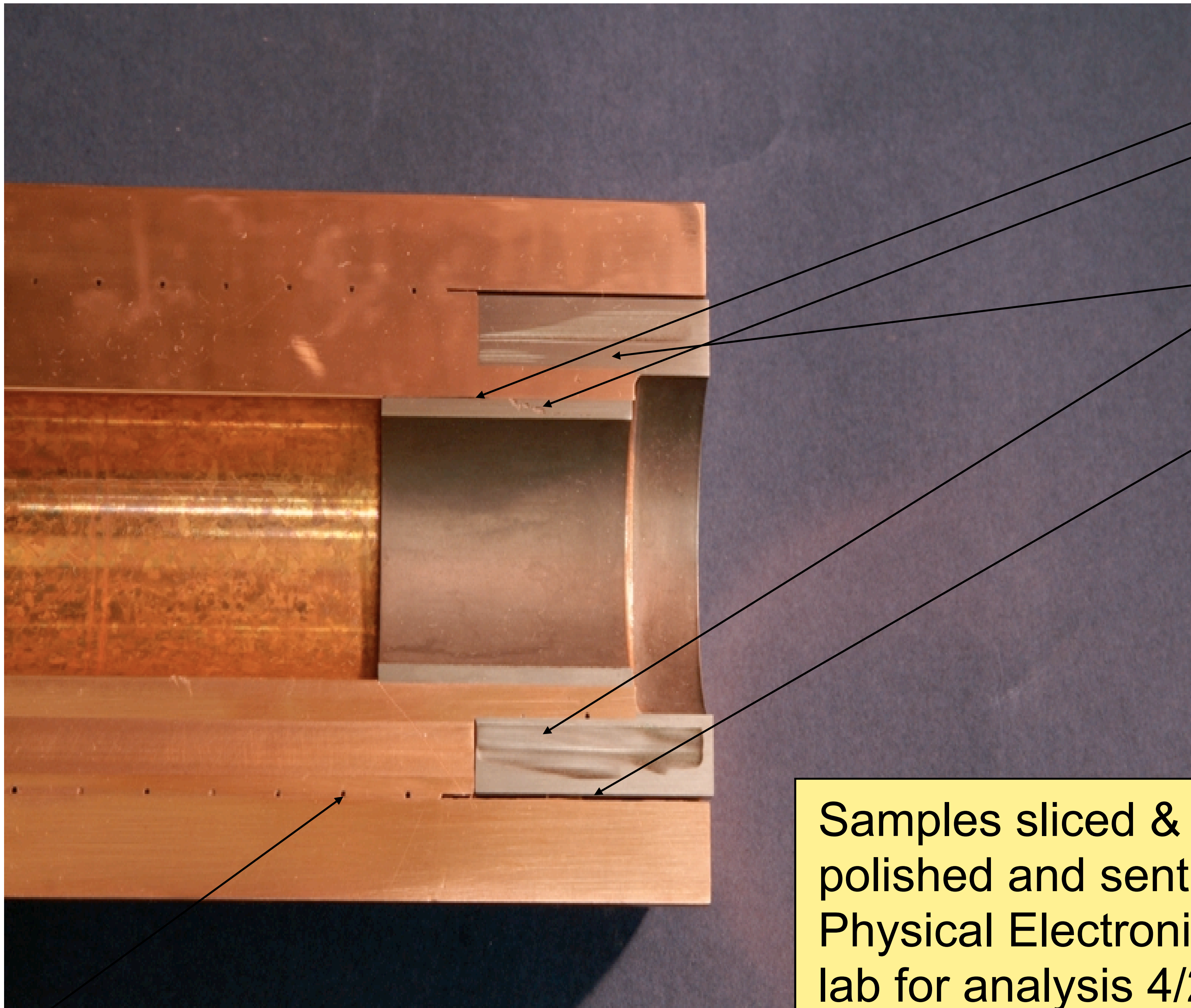
#1 - Mandrel Dummy
#2 - Mo Shaft Dummy
#3 - Mo Backing Ring
#4 - Cu Hub with braze wire grooves

Initial plan to braze one long Mo shaft with raised hub to inner radius of Cu mandrel deemed unworkable

Brazing HALF-LENGTH shafts to a COPPER hub piece and THEN brazing the Cu hub to the Cu mandrel deemed possible

First test if Mo “backing ring” sufficient to keep Mo and Cu in good enough contact for a strong braze joint

Apr 6: Cu-Mo Hub Braze Test Assembly after 3 additional heat cycles (to mimic full assembly procedure) then sectioned. Cu "finger" fractured



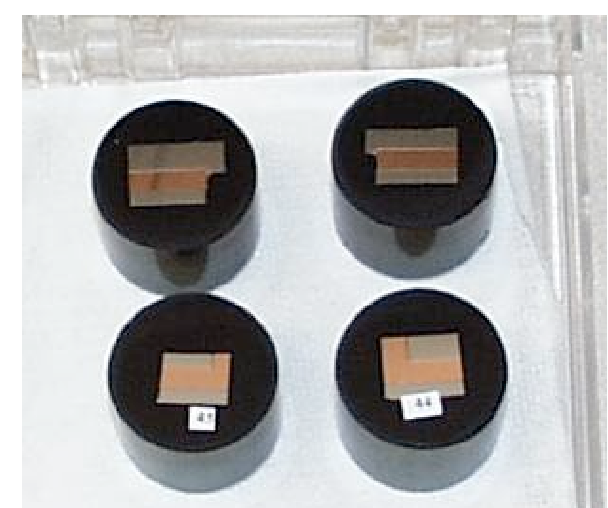
- Grain boundary issues?
- Possible fracturing?

Cu-Mo joints we care about

1mm expansion gap

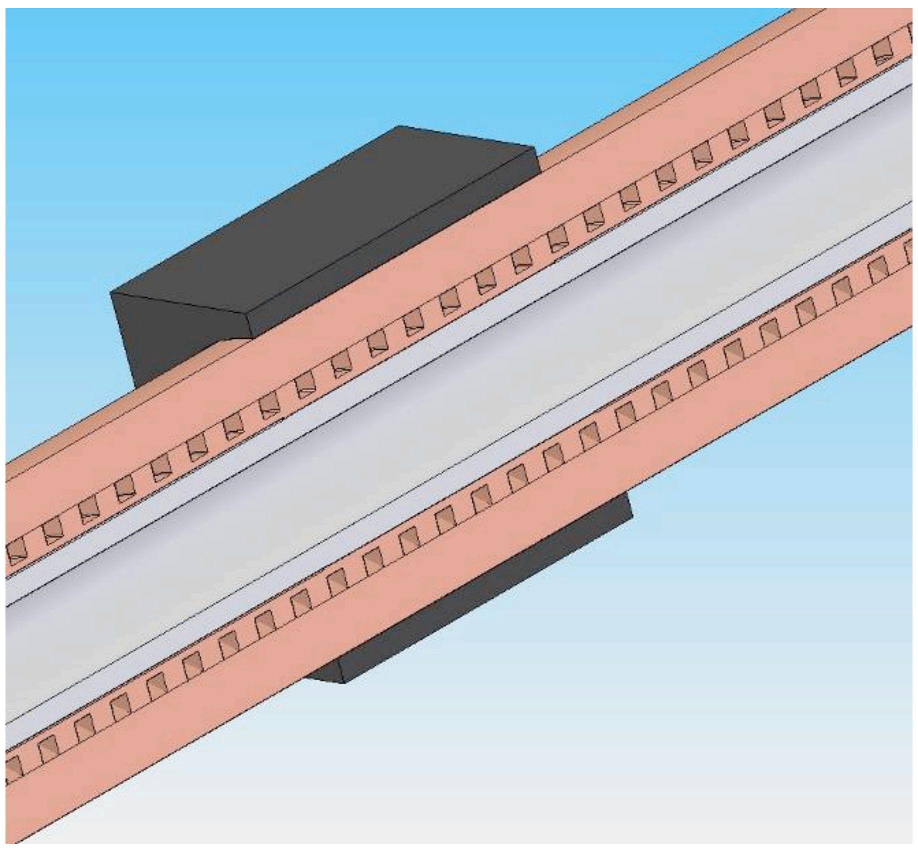
Small holes held braze wire

Samples sliced & polished and sent to Physical Electronics lab for analysis 4/23: **Fractures evident**



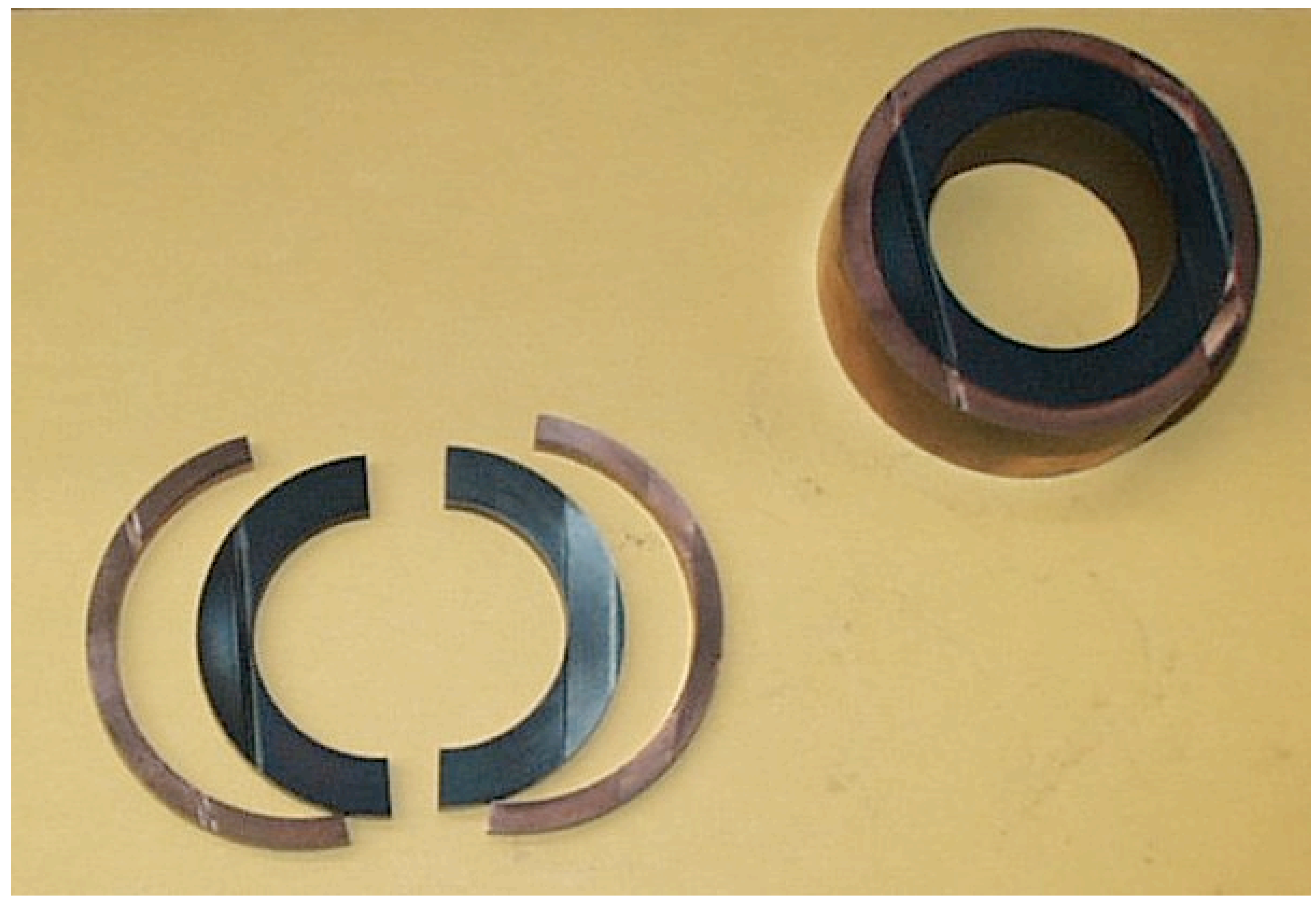
Compression fit for Cu-Mo joint

- Another option is to use a compression fit and diffusion bonding.



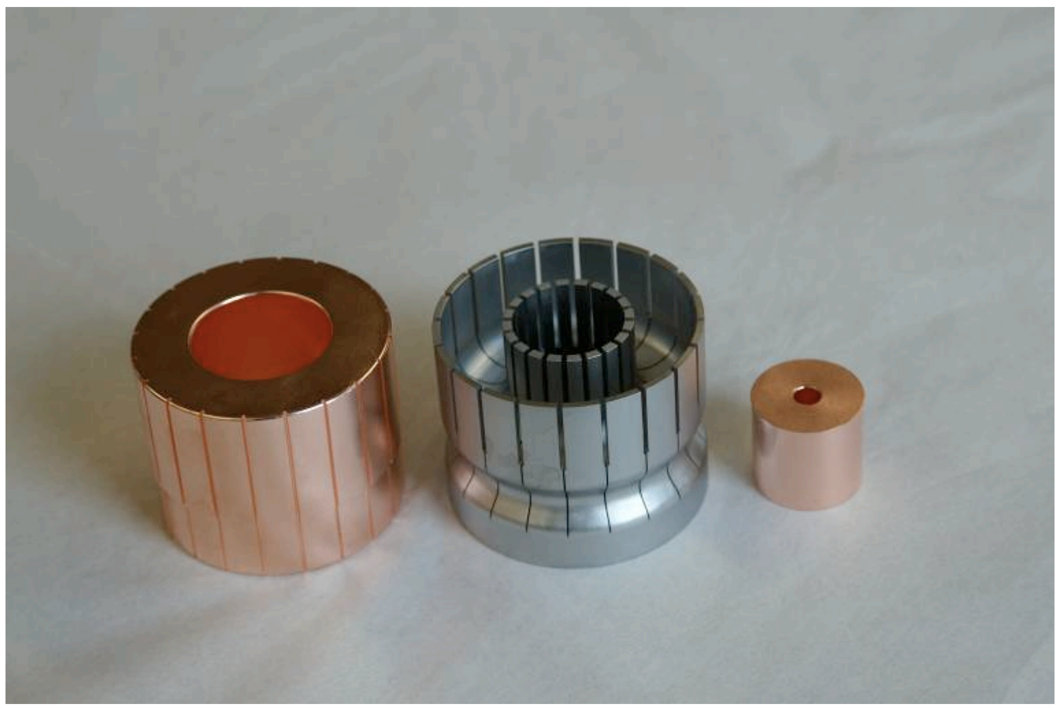
Copper Jaw is constrained on the outside diameter with Carbon and when heated to ~ 900 degrees C is forced to yield so that upon cooling to ~ 500 degrees C the inner diameter begins to shrink onto the Mo Shaft resulting a substantial interference fit.

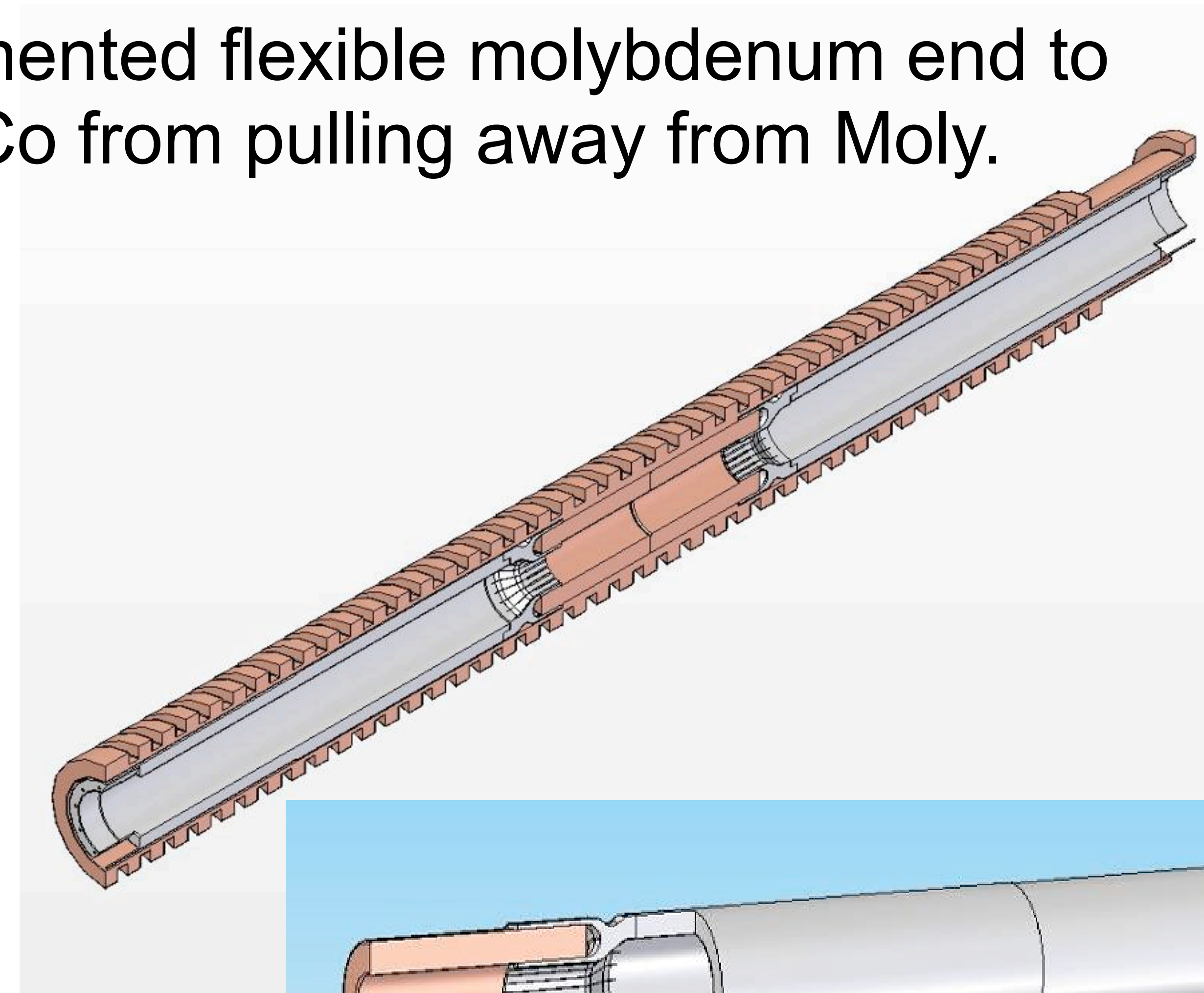
Test hub fell apart once we made a slice!

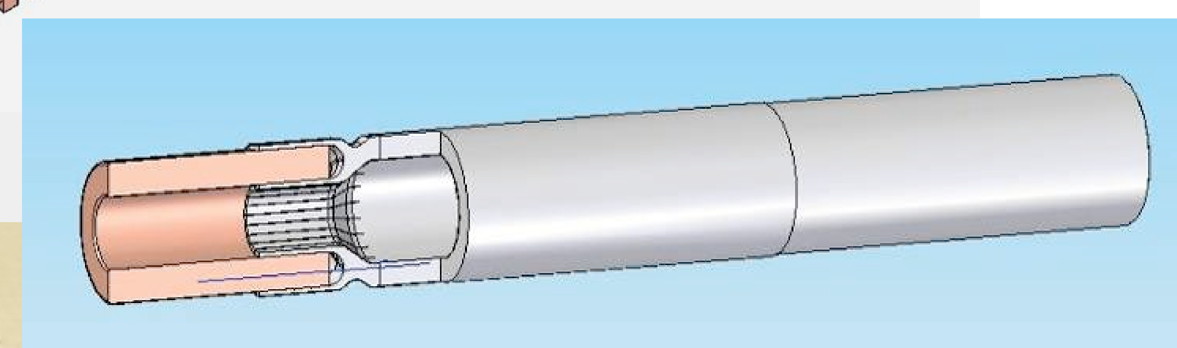


Cu-Mo joint: Segmented Moly for expansion

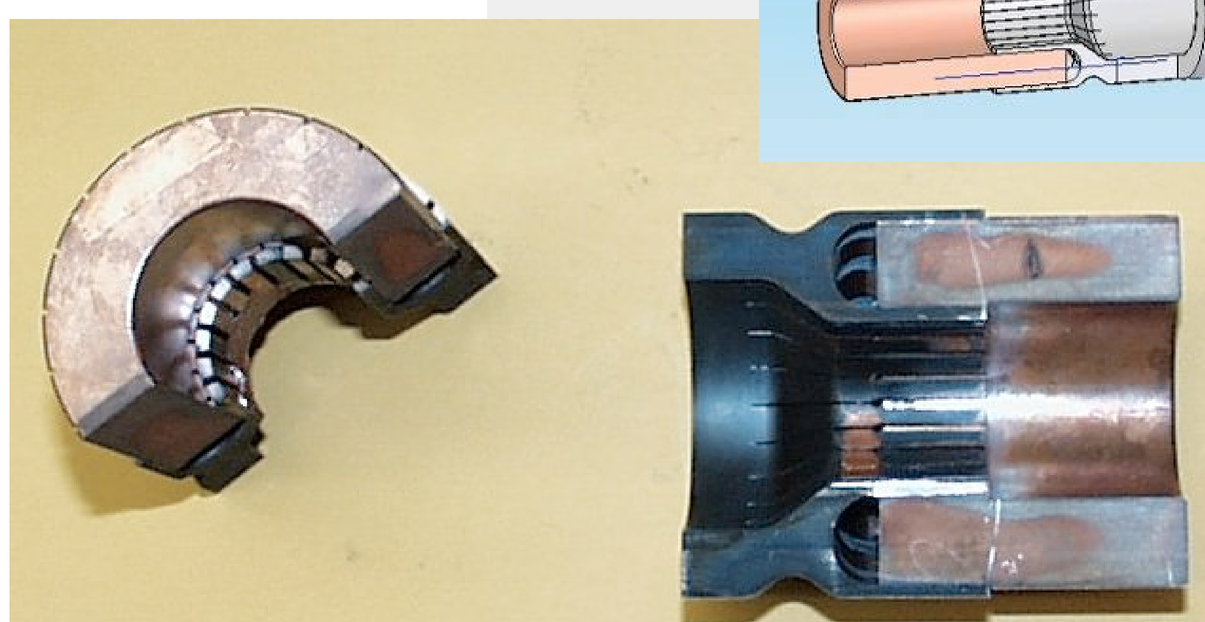
- Another option is to use a segmented flexible molybdenum end to prevent fractures and prevent Co from pulling away from Moly.







Will be cutting small samples for metallurgy tests. May make slight modifications for better braze joint



Molybdenum Half Shafts & Copper Hub Halves braze preparations

Expander Plug

Retainer Ring

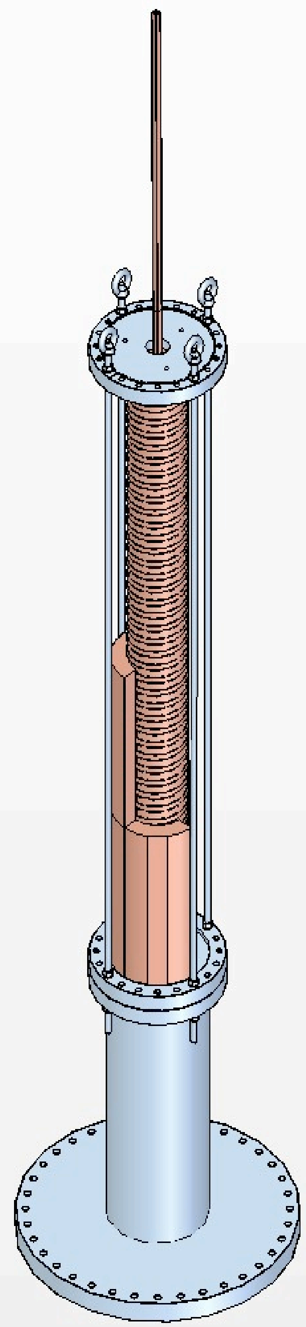
21 Mar 2007: Full length Mandrel: In-House & Inspected

LARP

– Now that shaft design complete, order to bore central hole made
– Will wind with in-house copper tubing

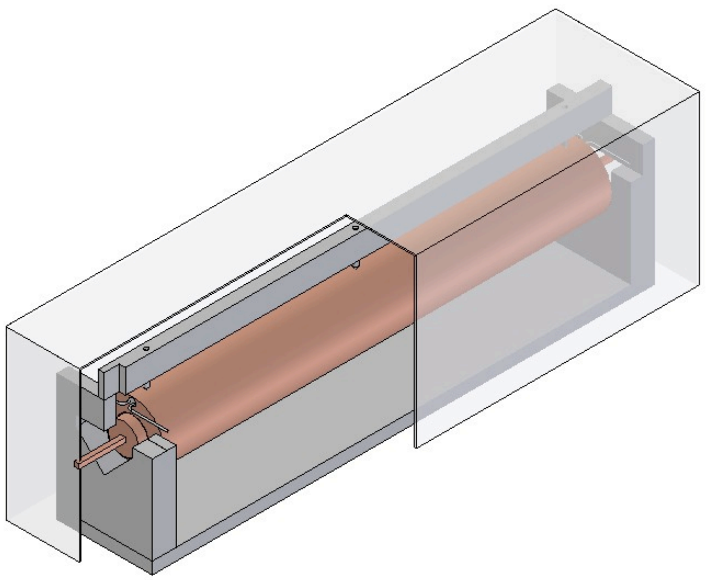
Fixture for stacking 16 24cm-long quarter round jaws on full 960mm cooling coil wrapped mandrel

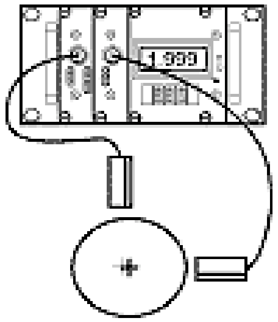
(mostly catalog parts: ordered)



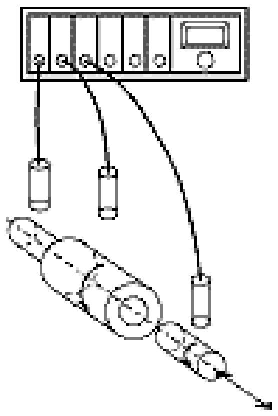
Test Lab Preparation ~Finished

- ✓ Clean space with gantry access
- ✓ Basic equipment: Granite table, racks, hand tools
- ✓ Power supplies to drive heaters
- ✓ Chiller & plumbed LCW to cool jaw
- ✓ 480V wiring for heater power supplies
  - required engineering review, safety review, and multiple bids (?!)
- ✓ Acquire Heaters
  - 5kW resistive heaters from OMEGA
- ✓ PC & Labview
- ✓ National Instruments DAQ with ADCs
  - Data Acquisition and Control Module
  - 32-Channel Isothermal Terminal Block
  - 32-Channel Amplifier
- ✓ Thermocouples
- ✓ Capacitive Sensors
- – Vacuum or Nitrogen (?)
- – Safety Authorization (!!!)





Images from www.capacitec.com



Steps still needed for a full length jaw assembly for thermal testing

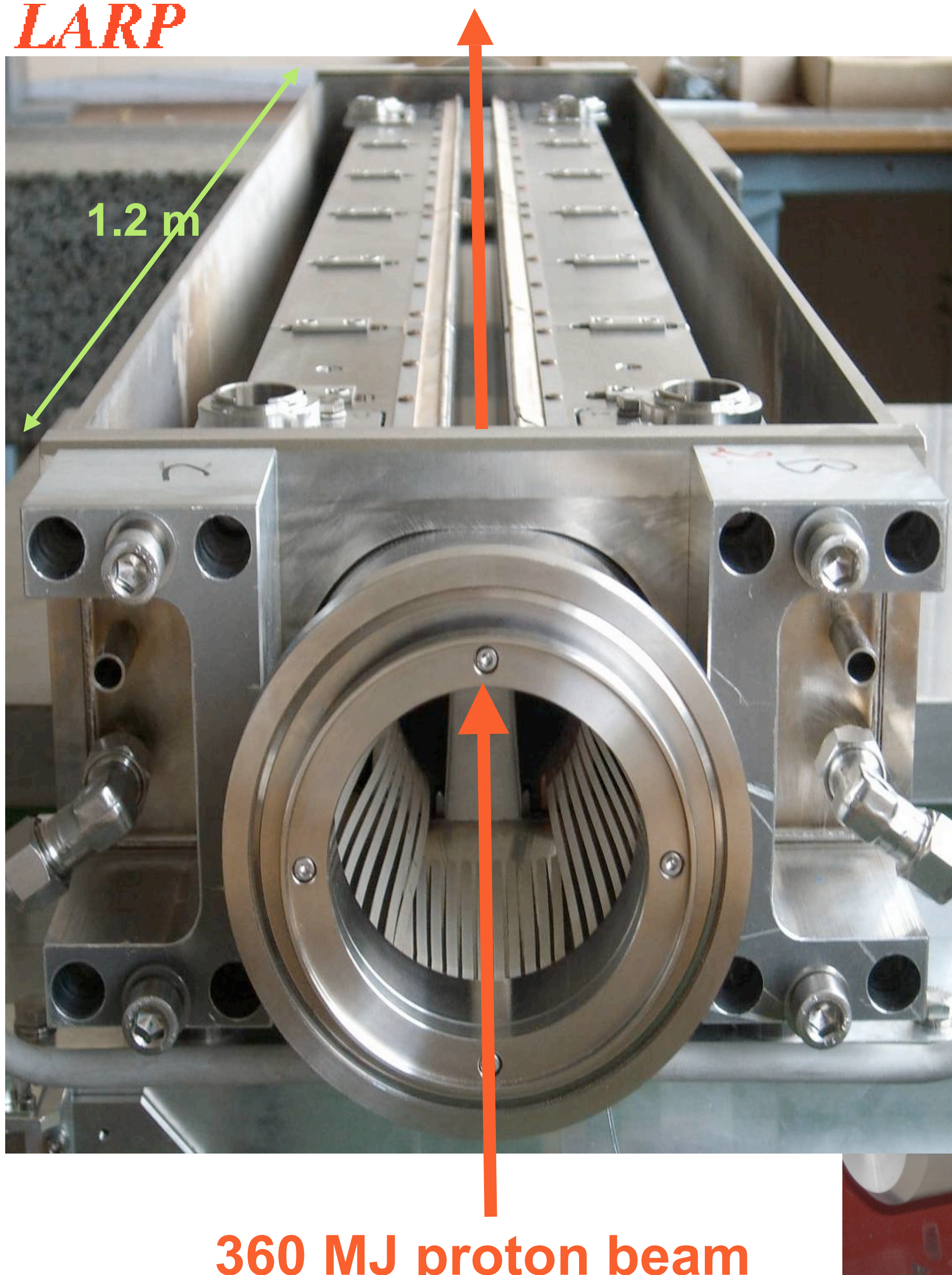
- ✓ After 200mm Jaw tests Completed Satisfactorily Freeze brazing protocol
- Drill Cu mandrel for Moly Shaft (out at vendor)
- ✓ Cut Moly shaft into two pieces, fab parts for hub assembly
- Braze shaft to bored out mandrel
- Wind coil using in-house SLAC Copper,
  - Need to order more (Finland 20 week delivery) OFE 10mm x 10mm or use CERN order of Ni-Cu alloy, anneal & wind mandrel
- Jaw 1/4 sections (16 needed of 24 now at SLAC) require slight modifications for braze gap requirements.
- Several braze Cycles
- Drill jaw to accept resistive heater or attach with thermal grease
  - Understand (ANSYS) any change to expected performance

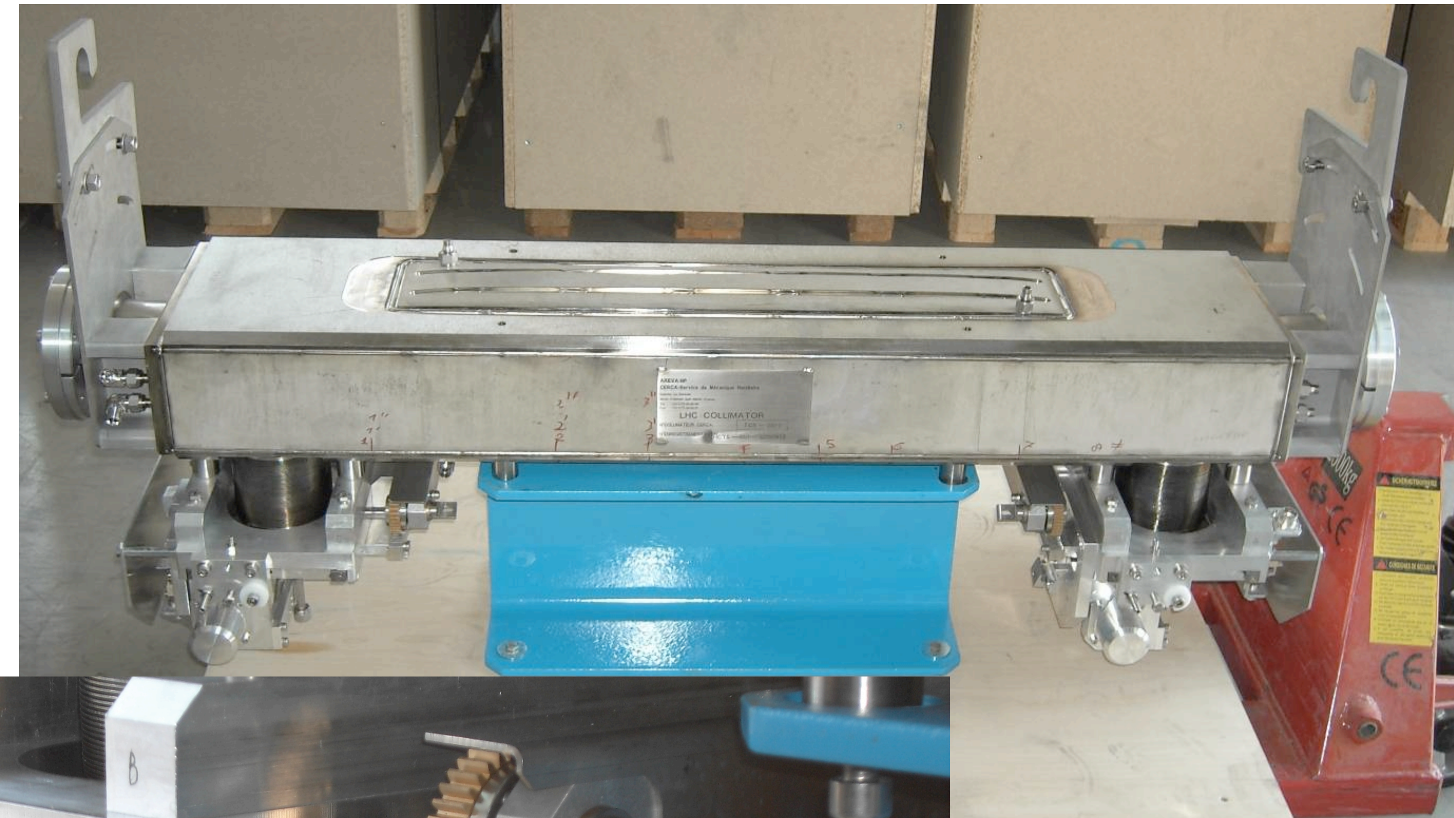
Steps needed for a complete mechanical (="RC1") prototype

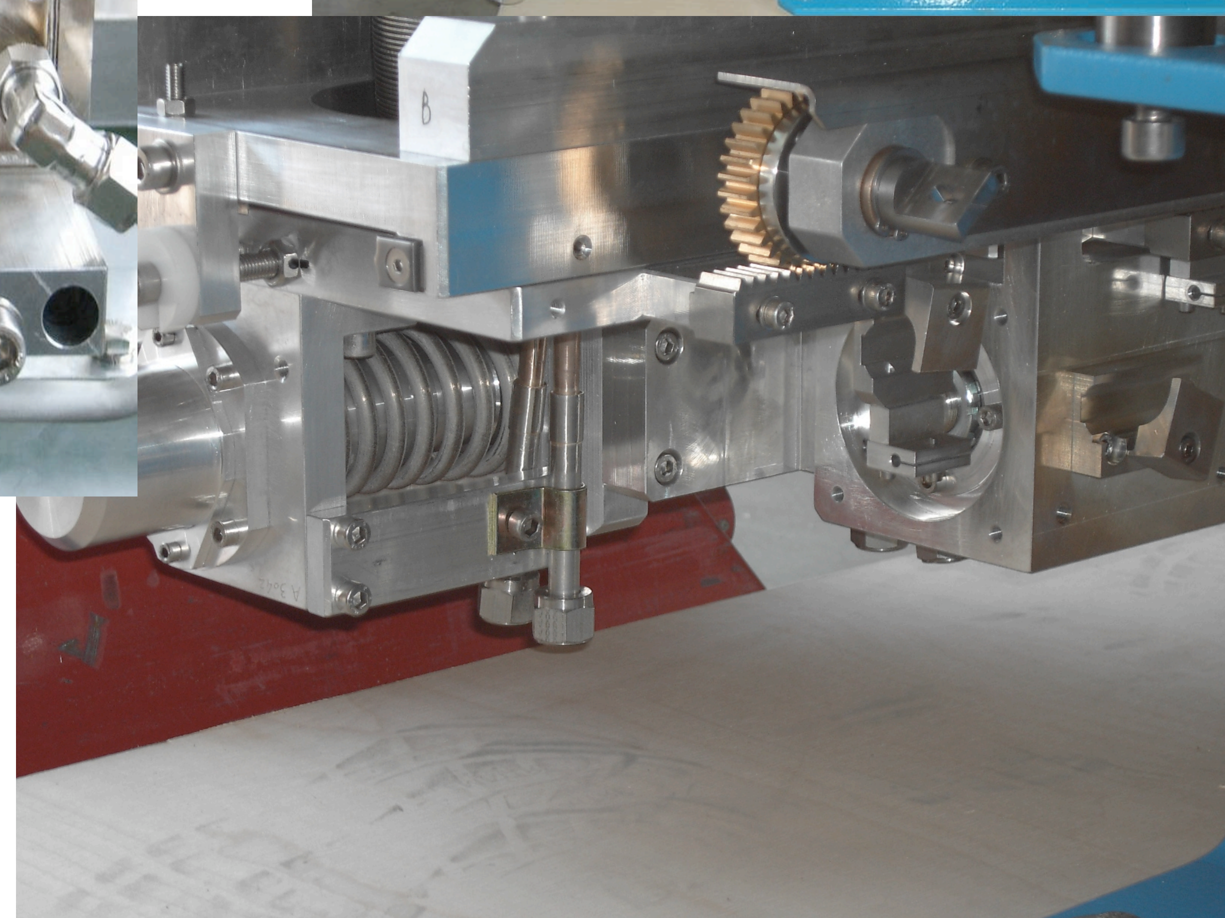
- Successful thermal performance of first full length jaw
- Complete the design of RC1 RF features
- Fit-up and initial tests of support/rotation mechanism on 1st full length jaw
- Complete fabrication of second and third jaws (Glidcop, Moly?) with full support assembly on the four corners
- Acquisition of Phase I support & mover assemblies
  - 18 APR 07 proposal to sell SLAC a non-functional CERN TCS collimator with damaged tank & bellows
- Remodeling of CERN parts for interface to US parts
  - An enlarged vacuum tank has been modeled and some CERN support stand modifications have been identified
    - No fabrication drawings have been done as yet
- Acquire motors, LDVTs,etc.. Not part of CERN TCS purchase

Agreement in Progress to Buy a damaged “TCS1” collimator and stand from CERN

LARP







LARP Collimator Delivery Schedule

Done	Braze test #1 (short piece) & coil winding procedures/hardware Prep heaters, chillers, measurement sensors & fixtures, DAQ & lab Section Braze test #2 (200mm Cu) and examine –apply lessons Braze test #3 (200mm Cu) – apply lessons learned
	Fab/braze 930mm shaft, mandrel, coil & jaw pieces
2008-01-01	1st full length jaw ready for thermal tests
	Fab 4 shaft supports with bearings & rotation mechanism Fab 2nd 930mm jaw as above with final materials (Glidcop) and equip with rf features, cooling features, motors, etc. Modify 1st jaw or fab a 3rd jaw identical to 2nd jaw, as above Mount 2 jaws in vacuum vessel with external alignment features Perform bench-top stretched wire impedance measurements in parallel
2008-09-01	2 full length jaws with full motion control in vacuum tank available for mechanical & vacuum tests in all orientations ("RC1")
	Modify RC1 as required to meet requirements
2009-01-01	Final prototype ("RC2") fully operational with final materials, LHC control system-compatible, prototype shipped to CERN to beam test