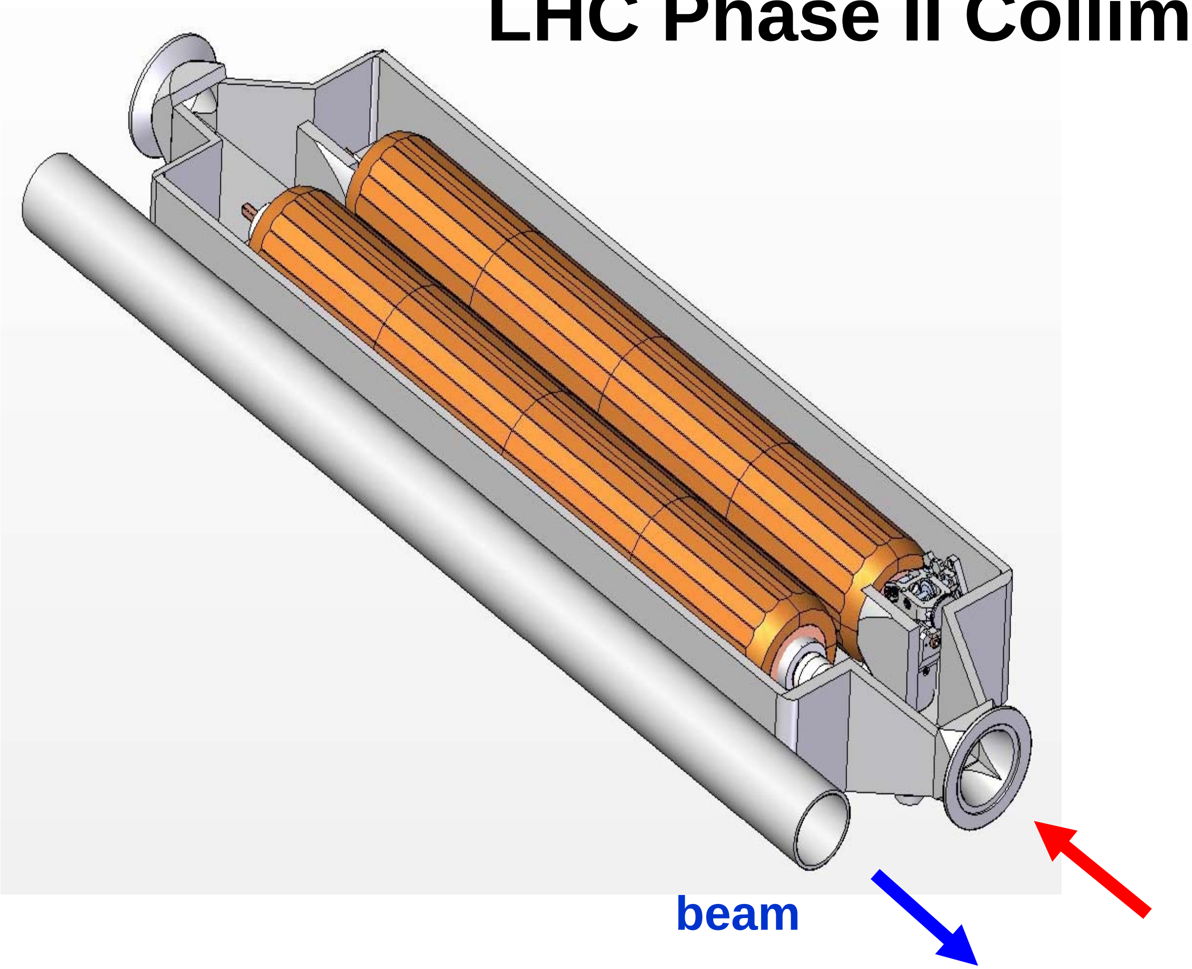
LARP

US LHC Accelerator Research Program

BNL - FNAL- LBNL - SLAC

LARP Contributions to LHC Phase II Collimation



01 October 2007

Beam'07 - CERN

Tom Markiewicz/SLAC

Three of Four LARP Collimation Program Tasks: Address Phase II Collimation

SLAC: Study, design, prototype and test a collimator design based on SLAC NLC "Rotatable" concept that can be dropped into 30 reserved lattice locations as a part of the "Phase II Collimation Upgrade" required if the LHC is to reach its nominal 1E34 luminosity

BNL (N. Simos et al): irradiate and then measure the properties of the materials that will be used for phase 2 collimator jaws

Fermilab (N. Mokhov et al): Activation of Phase II Collimators

LARP Collimator Tasks Also Address Phase I Collimation Issues:

- Fermilab: Understand and improve the design of the tertiary collimation system that protects the LHC final focusing magnets and experiments
- BNL: Studies of the properties of irradiated Phase I materials (C-C)
- BNL (A. Drees et. al): Use RHIC data to benchmark the code used to predict the cleaning efficiency of the LHC collimation system and develop and test algorithms for setting collimator gaps that can be applied at the LHC

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

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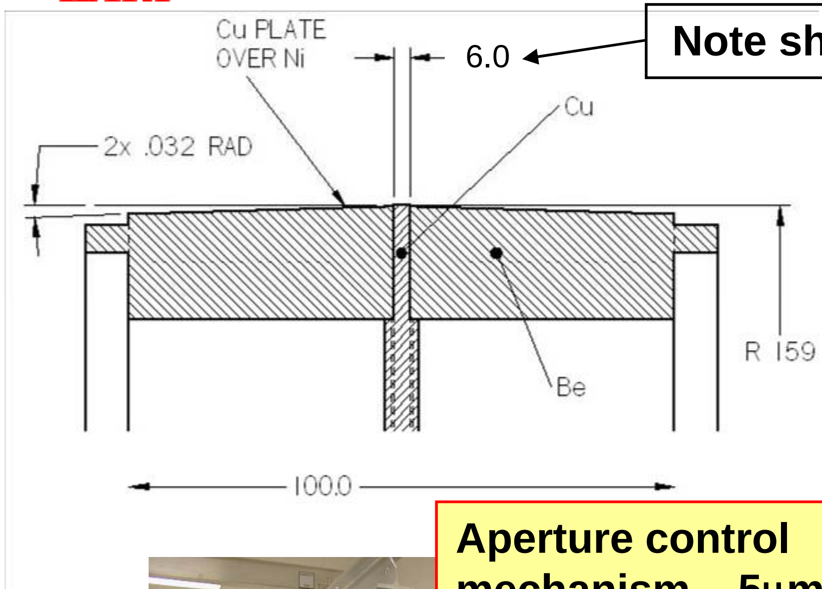
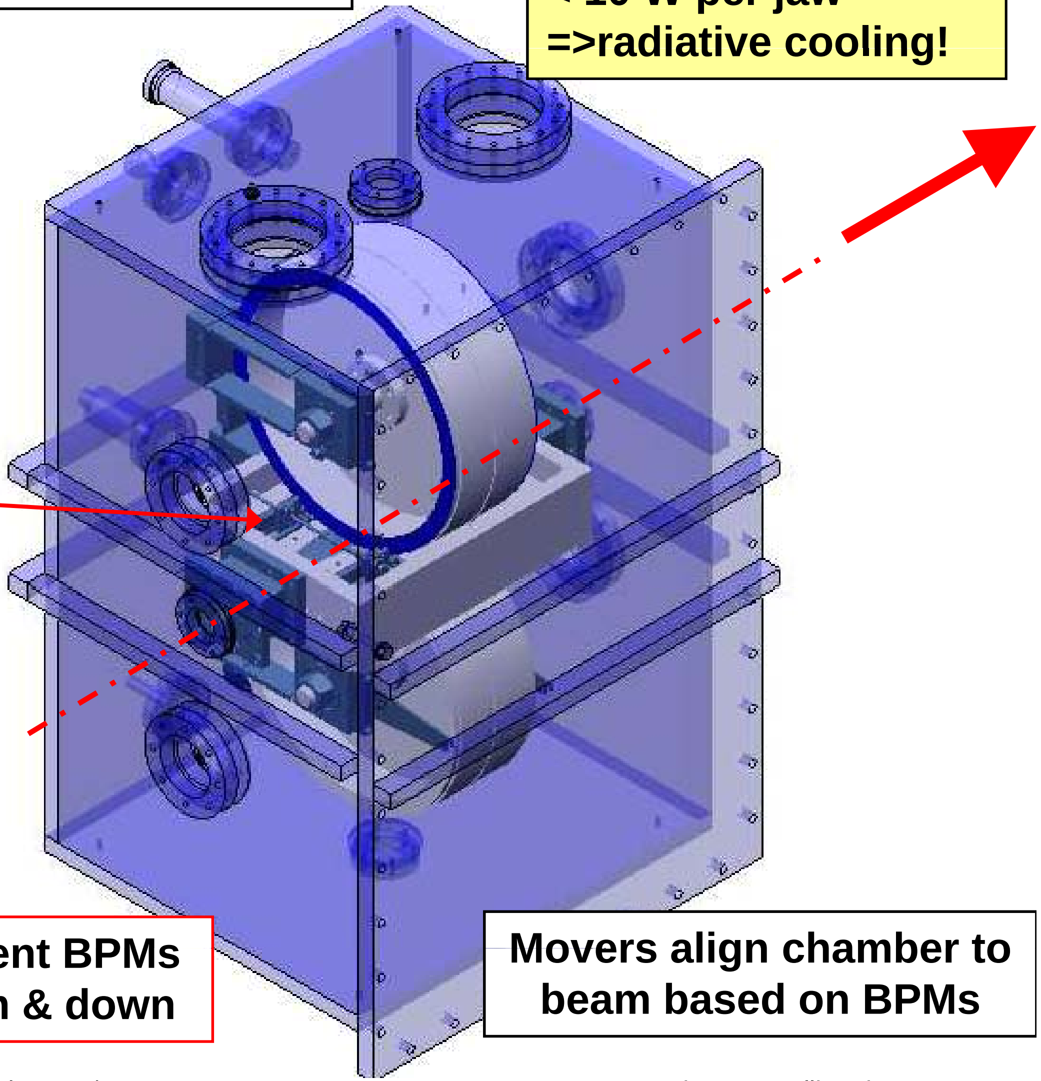
NLC Consumable Collimator

rotatable jaws – 500 to 1000 hits



Note short high-Z material.

Aperture control mechanism – 5μm accuracy & stability



< 10 W per jaw =>radiative cooling!

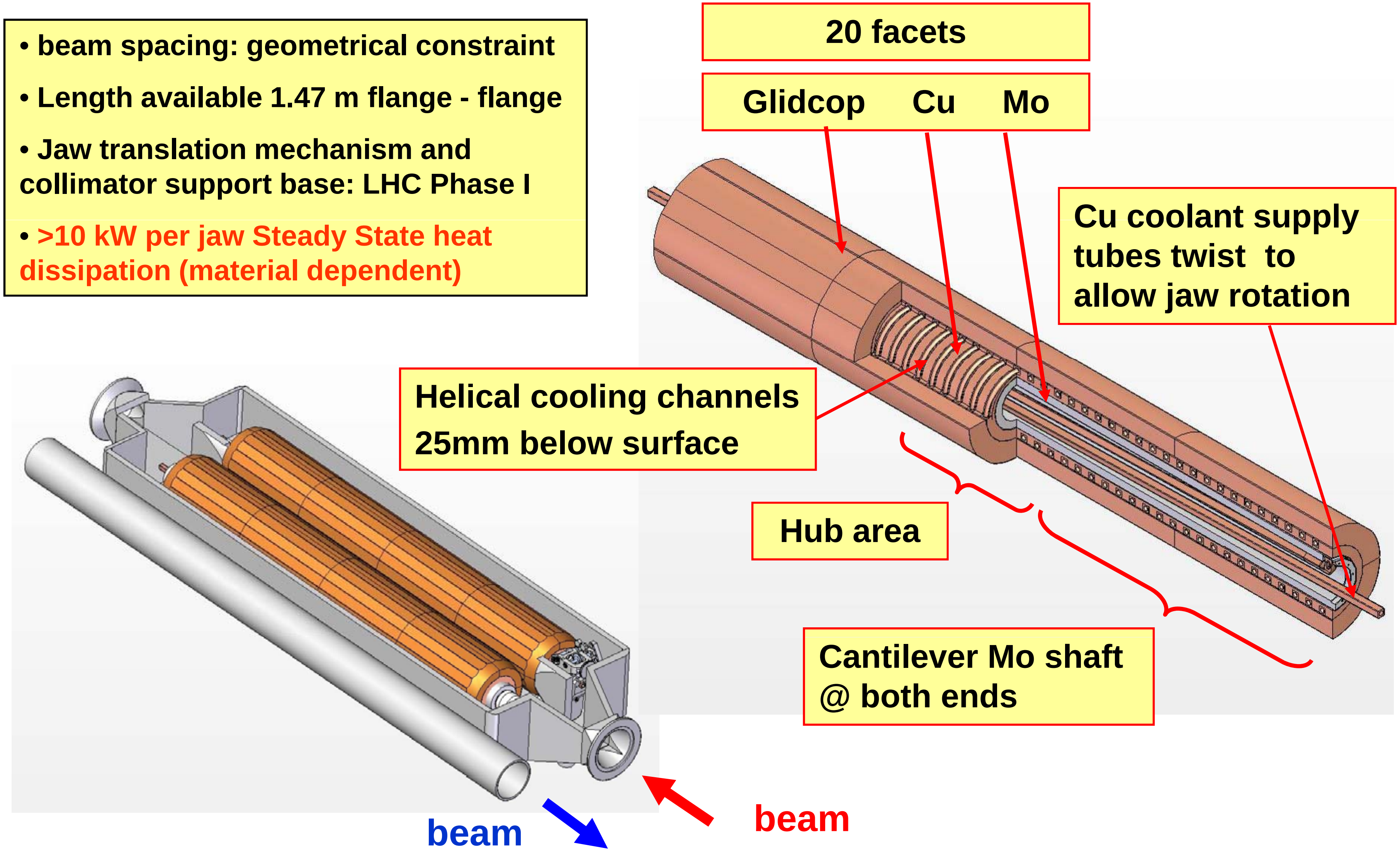
Alignment BPMs upbeam & down

Movers align chamber to beam based on BPMs

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 $\rightarrow$ 350 MJ
- Δt=25ns, σ~200μm (collisions)

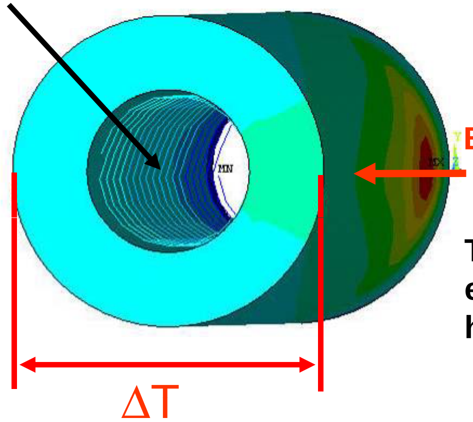
System Design Requirement:

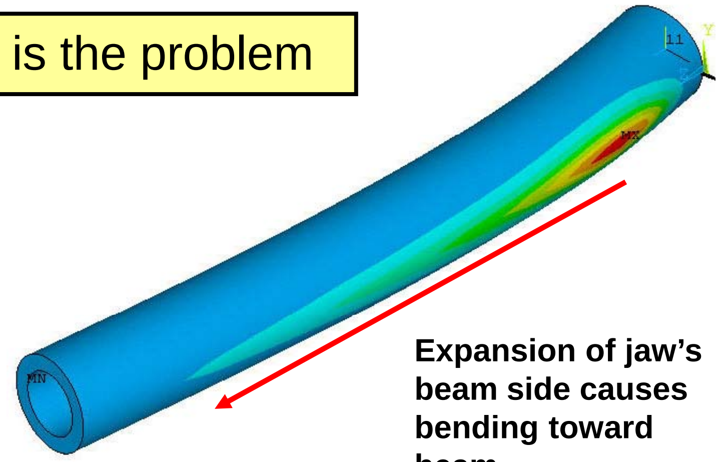
- Protect against quenches as beam is lost
  - "Steady state" collimator cooling for τ = 1 hour or 8E10 p/s or 90kW
  - "Transient" bursts of τ = 12 min or 4E11 p/s or 450kW
    - abort if lasts > 10 sec
- Accident Scenario : Beam abort system fires asynchronously with respect to abort gap - 8 full intensity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

Dominant collimator specifications

- 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 problem





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

SIXTRACK simulation

compare materials' collimation efficiency tradeoff with mechanical performance

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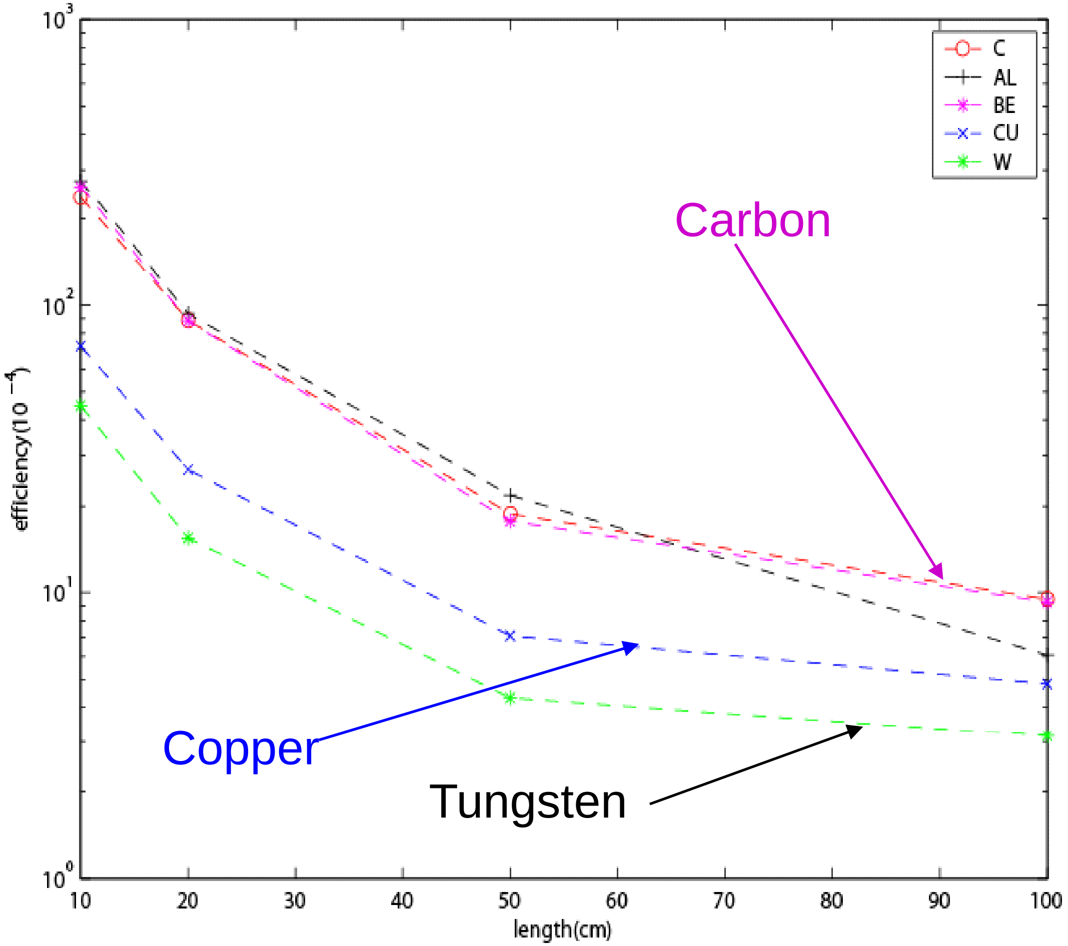
Yunhai Cai

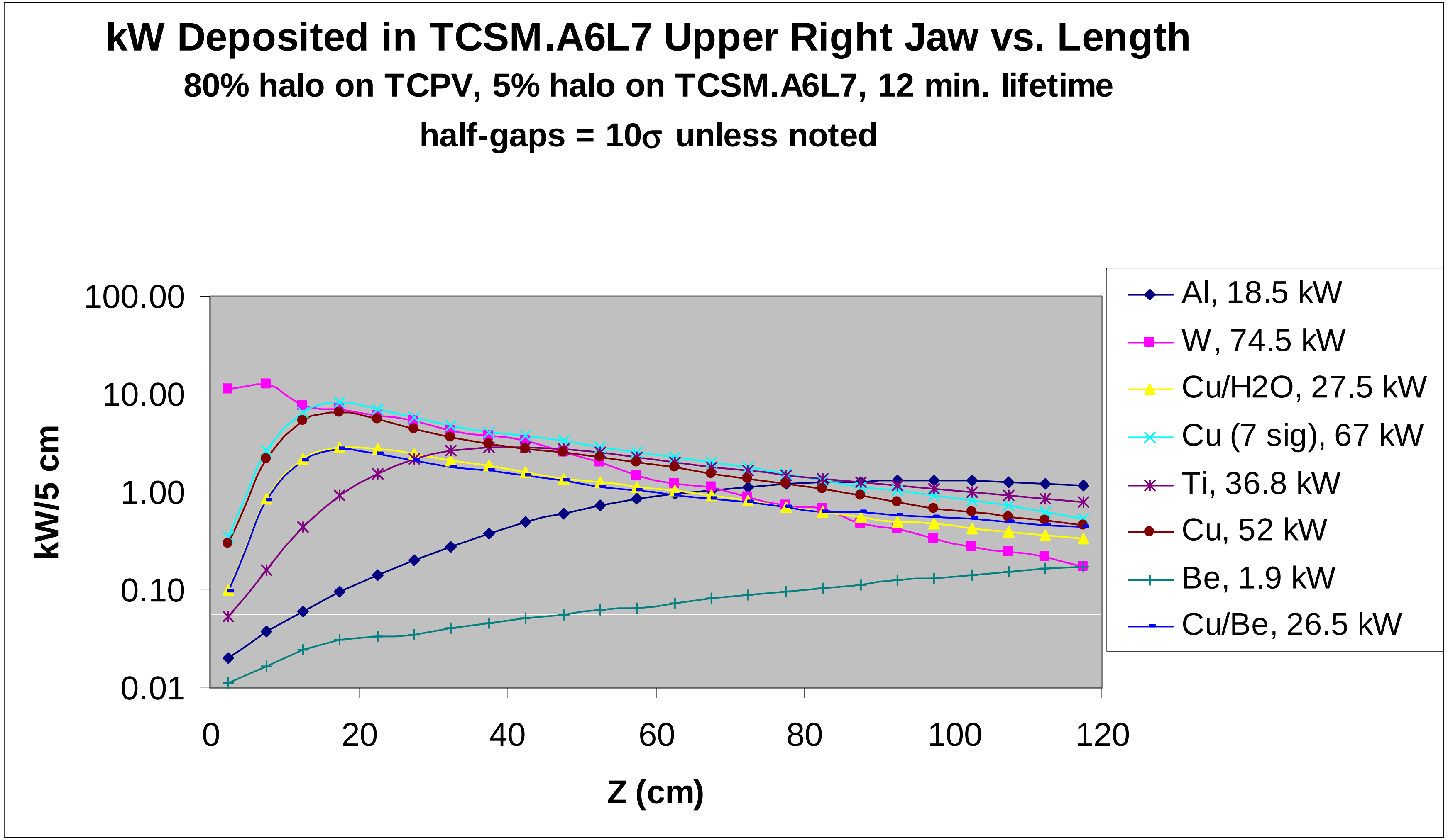


- High Z materials improve system efficiency but generate more heat
- Copper considered because its high thermal conductivity and ease of fabrication
- Available length for jaws is about 1 meter

Similar result was obtained by Ralph Aβmann

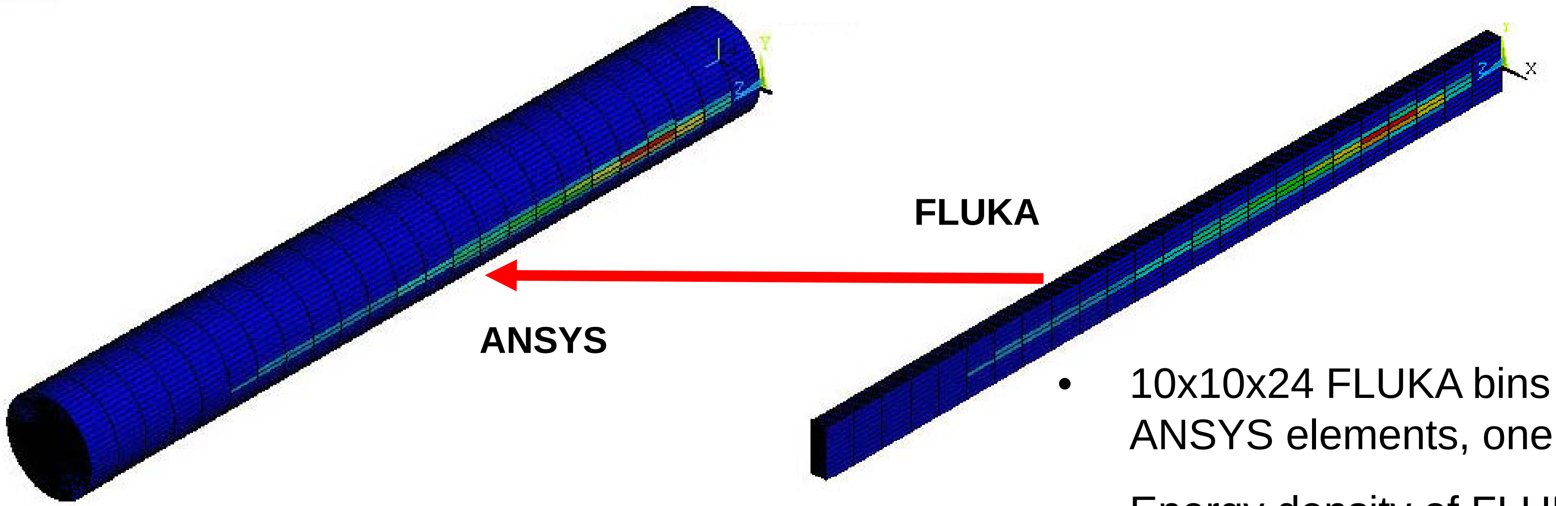
FLUKA Results - Power Deposited vs. Length

- Ist secondary collimator
- Various materials

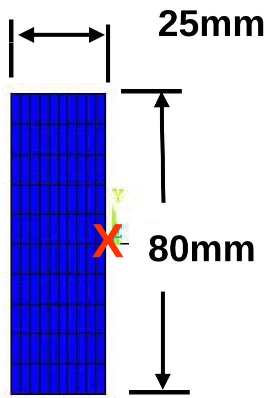


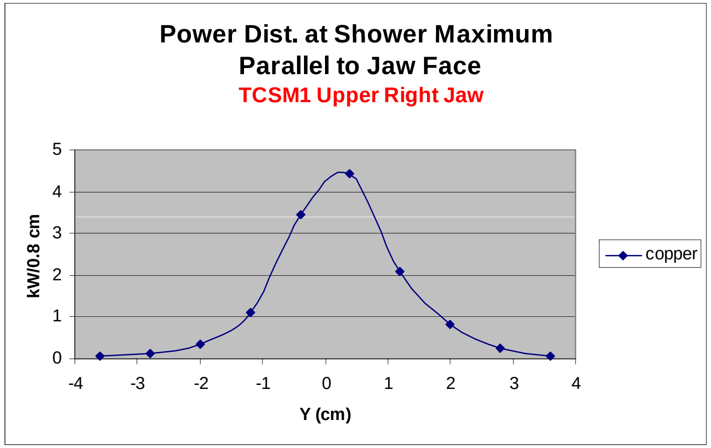
Basis for Design Choices

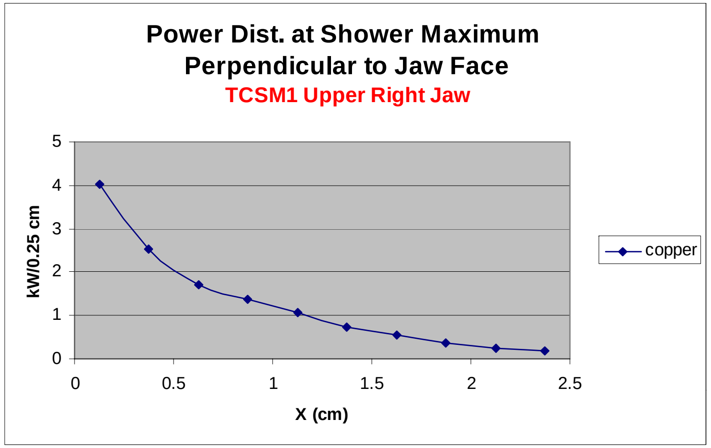
ANSYS Thermal/Mechanical simulations using FLUKA energy deposit



- 10x10x24 FLUKA bins mapped to ANSYS elements, one for one
- Energy density of FLUKA bin applied to ANSYS element







Material thermal performance

- Hollow Cylinder Model
- O.D = 150 mm, I.D. = 100 mm, L = 1.2 m
- NLC-type edge supports
- aperture 10σ

10σ, primary debris + 5% direct		SS @ 1 hour beam life					transient 10 sec @ 12 min beam				
material	cooling arc (deg)	power (kW) per jaw	Tmax (C)	defl (um)	Tmax water side(C)	max flux (W/m^2)	power (kW)	Tmax (C)	defl (um)	Tmax water side(C)	max flux (W/m^2)
Al	360	3.7	33	143			18.5	73	527		
2219 Al	360	4.6	34	149	26	7.1E+04	23	79	559	46	3.1E+05
BeCu (94:6)	360	0.85	24	20			4.3	41	95		
C R4550	360	0.6	25	5			3.0	41	20		
Cu	360	10.4	61	221	43	2.7E+05	52	195	829	117	1.2E+06
Cu - 5mm	360	4.5	42	117	39	2.3E+05	22.4	129	586	117	1.2E+06
Cu/Be (5mm/20mm)	360	5.3	53	161							
Super Invar	360	10.8	866	152 [1]	60						
Inconel 718	360	10.8	790	1039	66		54	1520	1509	85	
Titanium	360	7.4	214	591	42		36.8	534	1197	77	
Tungsten (.48 m L)	360	13.5	183	95	79		67.5	700	335	240 [2]	2.6E+06
Al - solid core	36	3.7	40.8	31			18.5	80	357		
2219 Al	36	4.6	43	31			23	89	492		
BeCu (94:6) *	36	0.85	27	2			4.3	46	101		
Cu	36	10.4	89	79	67	5.6E+05	52	228	739	139	1.4E+06
Cu - solid core	36	10.4	85	60	65	5.3E+05	52	213	542	120	1.2E+06

1. deflection not valid, super invar loses its low c.t.e. at 200C
2. pressure > 30 bar needed to suppress boiling

* **Promising but no practical implementation**

Cu chosen – balance of efficiency, deflection and manufacturability

Justification of Cu Choice

Material evaluations

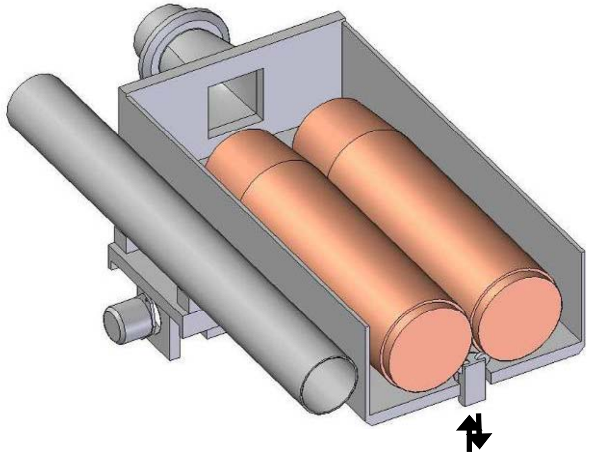
material	**reasons for rejection in favor of Cu**
Aluminum	relatively poor cleaning efficiency, water channel fabrication difficulty
BeCu (6% Cu-loaded Be)	(Note: an imaginary metal - unknown fabrication difficulties) Be is strongly discouraged by CERN policy; low cleaning efficiency.
Cu - 5mm wall	deflection only ~50% lower than 25mm Cu; loss of safety zone between the beam and water channels
Cu/Be (5mm/20mm bonded)	deflection only ~30% lower than 25mm Cu; Be prohibition; fabrication difficulty
Inconel 718	poor thermal conductivity => high temperature & very high deflection (1039um SS, 1509um transient)
Super Invar	poor thermal conductivity => high temperature 4X higher than temp at which low thermal expansion coefficient disappears.
Titanium	poor thermal conductivity => deflection 2.7 x Cu (591um, SS)
Tungsten	High temperature on water side (240C => ~30bar to suppress boiling); high power density - can't transfer heat without boiling; fab difficulty

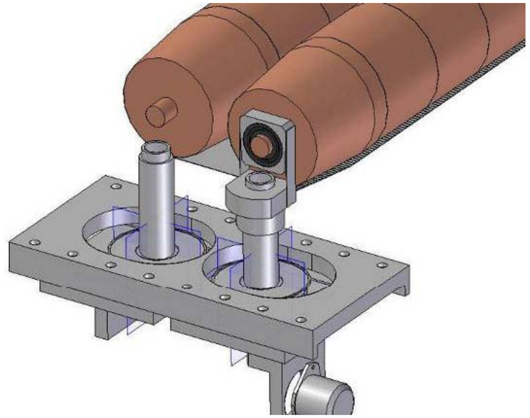
Cu chosen as best balance between collimation efficiency, thermal distortion & manufacturablity

June 2006

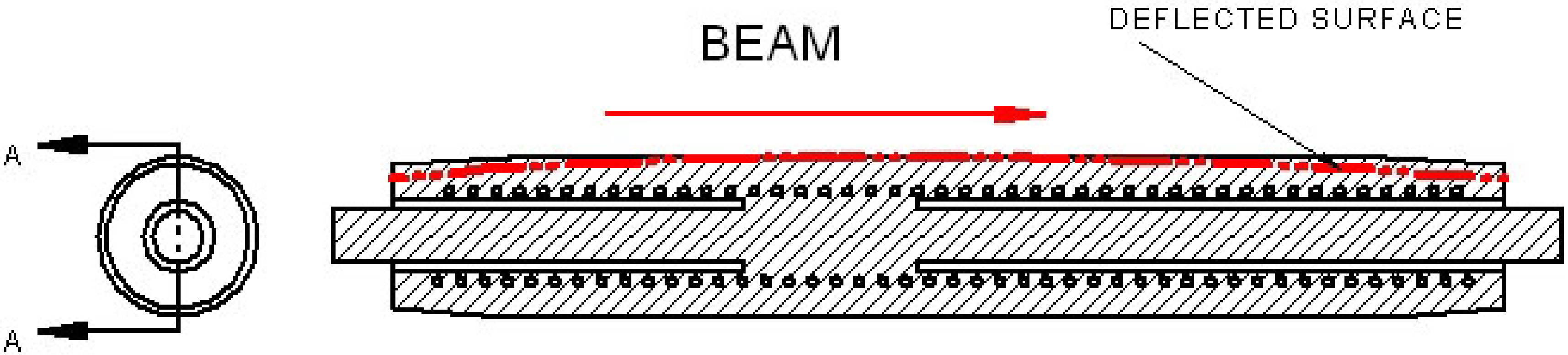
Introduce new **jaw-hub-shaft** design which

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)



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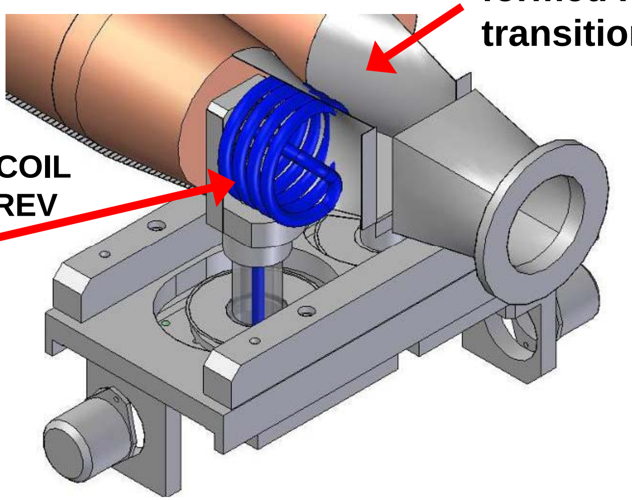
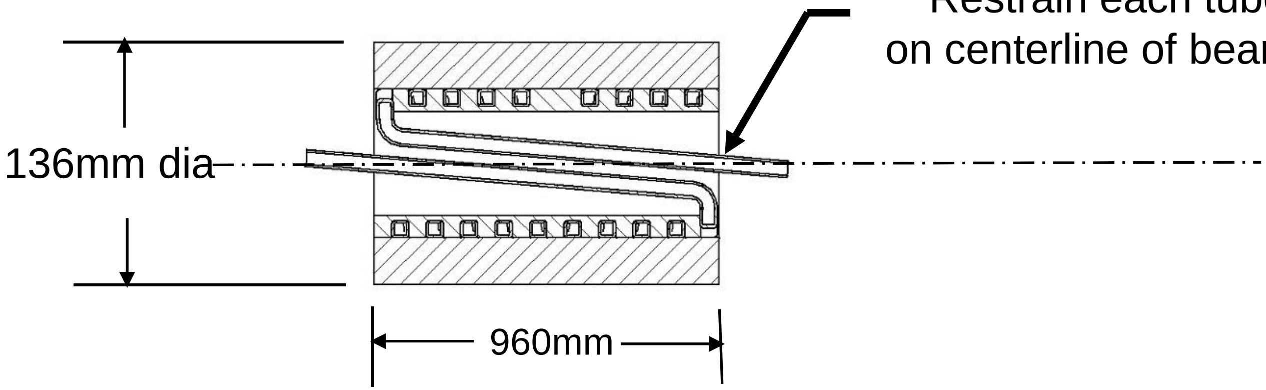
June 2006

Introduce new **reverse-bend winding concept** for the cooling coil which eliminates the 3 end loops, permitting longer jaws and freeing up valuable space for jaw supports, rotation mechanism and RF-features



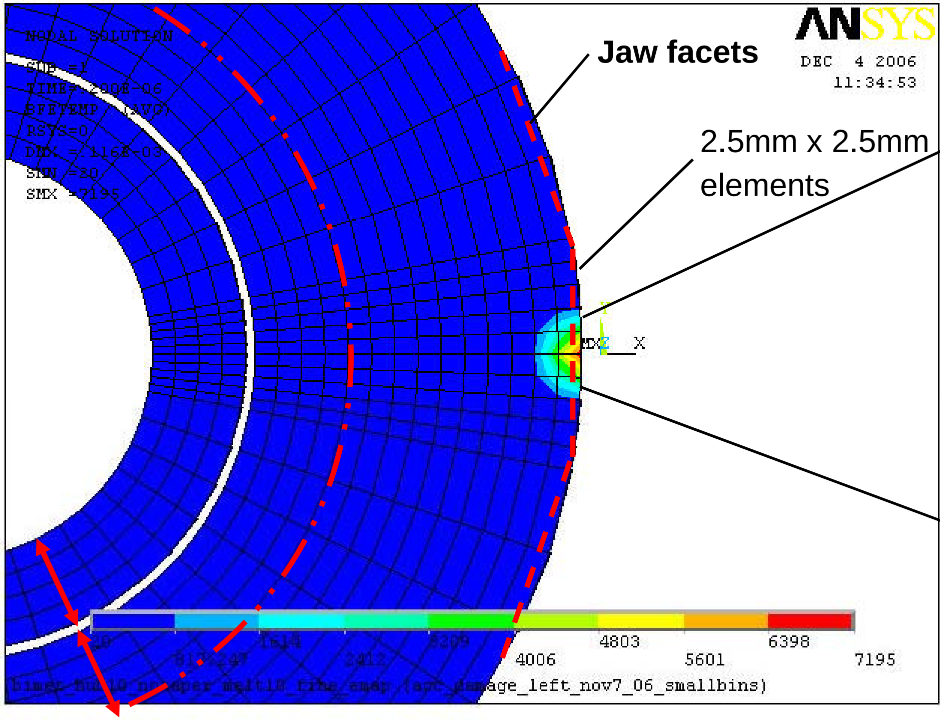
4-1/2 Turns without failure

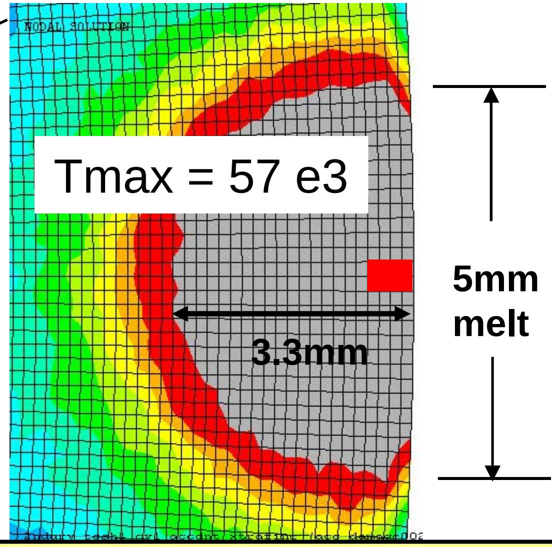


Comparison of Hollow Moly shaft and Solid Copper Shaft to same FLUKA secondaries: Improved deflections

	Solid Cu, 75cm tapered jaw, asymmetric hub		Tubular Moly, 95 cm straight jaw, symmetric hub	
	Steady State τ=1 hour	τ = 12 min for 10 sec	Steady State τ=1 hour	τ = 12 min for 10 sec
Gravity sag	200 um		67.5 um	
Power absorbed	11.7 kW	58.5 kW	12.9 kW	64.5 kW
Peak Temp.	66.3 °C	197 °C	66 °C	198 °C
Midjaw Δx	100 um	339 um	83.6 um	236 um
Effective Length	51 cm	25 cm	74 cm	39 cm
Sagitta	221 um	881 um	197 um	781 um

Accident Case





Shower max – extent of melted zone

Case: beam abort system fires asynchronously, **8 full intensity bunches into jaw**

Model: - increased resolution 3-D ANSYS & FLUKA models
- Thermal heating/cooling analysis followed by quasi-static stress analysis
- Jaw ends constrained in z during 200 ns, released for 60 sec cool-down
- 0.27 MJ deposited in 200 ns
- Molten material removed from model after 200 ns

Result: - 57e3 peak temperature (ultra fine model)
- **54 µm permanent deformation** (concave)

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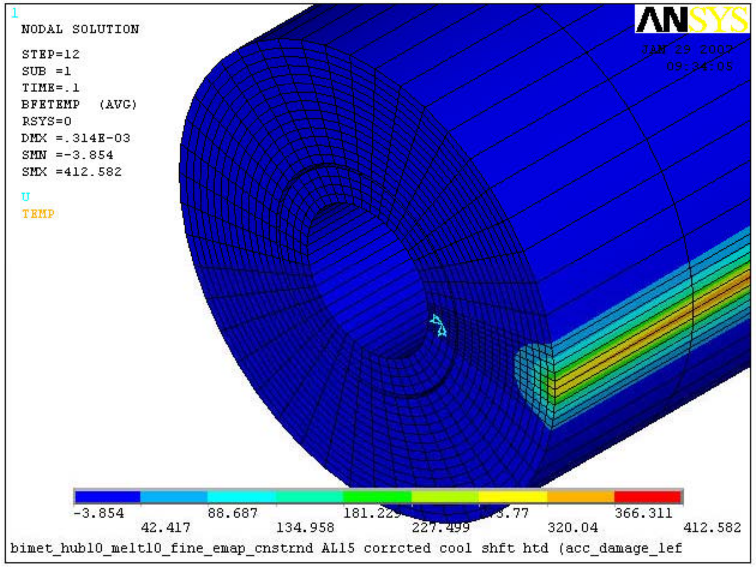
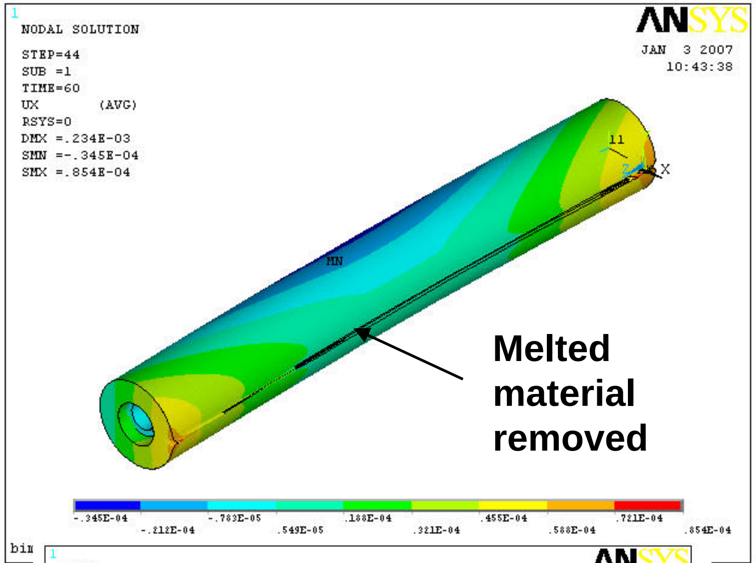
Accident Case

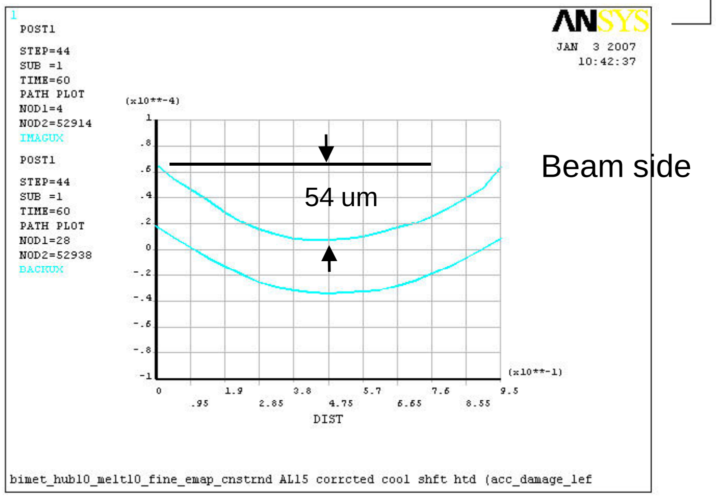
Permanent Jaw deflection, ux, after 60 sec cool-down



After energy deposit (200ns – 60 sec), z-constraints released. Original analysis used this constraint at all times.

- What happens to vaporized/melted material?
- How to use deformed jaw?





In-plane permanent deflection

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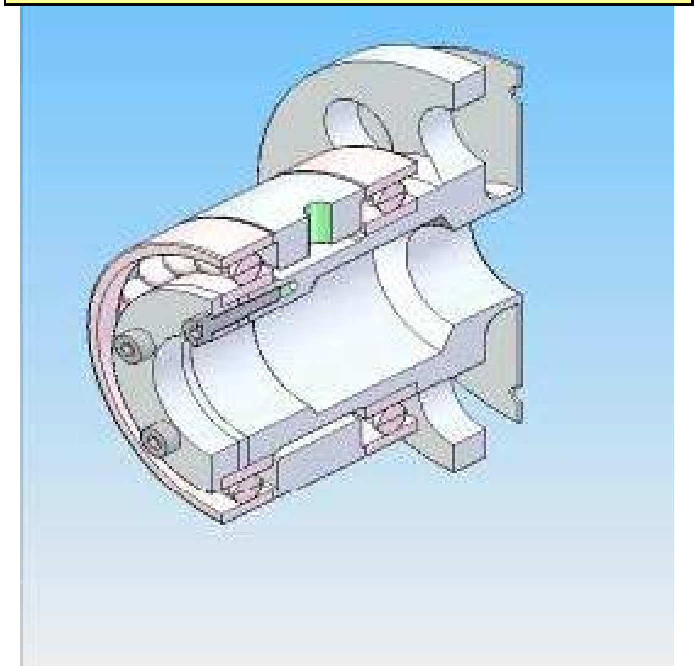
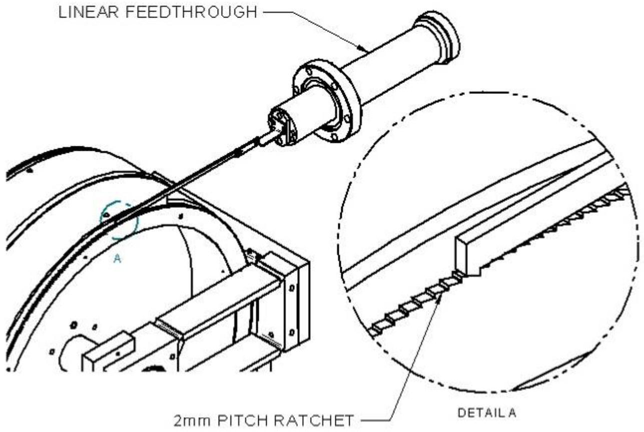
Introduce new **Internally actuated drive and jaw mount** for rotating after beam abort damages surface

Completed 27 May 2007

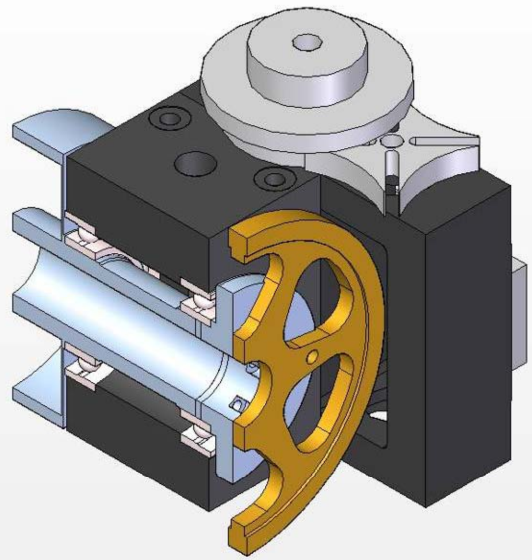
Universal Joint Drive Axle Assembly

- Thermal expansion
- Gravity sag
- Differential transverse displacement





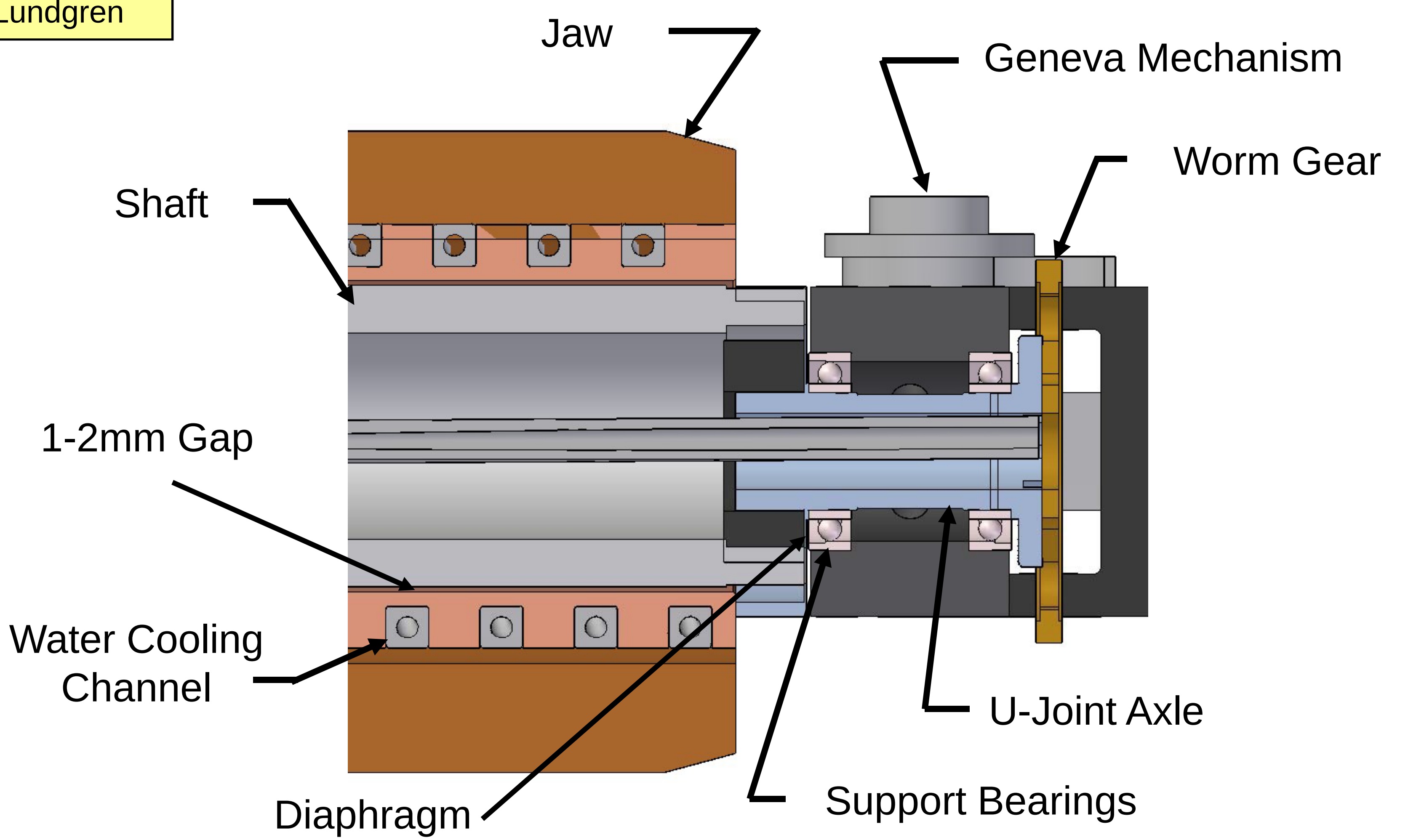
NLC Jaw Ratchet Mechanism



New rotation drive with "Geneva Mechanism"

Upstream end vertical section

Lundgren



RF and Image Current Shielding

ONLY PART OF DESIGN THAT REMAINS TO BE FINALIZED

Current Concept:

- Transition from round beam pipe id to 58mm square geometry is built into tank ends.
- A thin sheet metal “curtain” bridges to the “Transition Socket”.
- The “Transition Socket” mates with the Jaw’s flexible spherical end.
- Paired spiral style RF springs balance the loading on the RF “Sheath”.

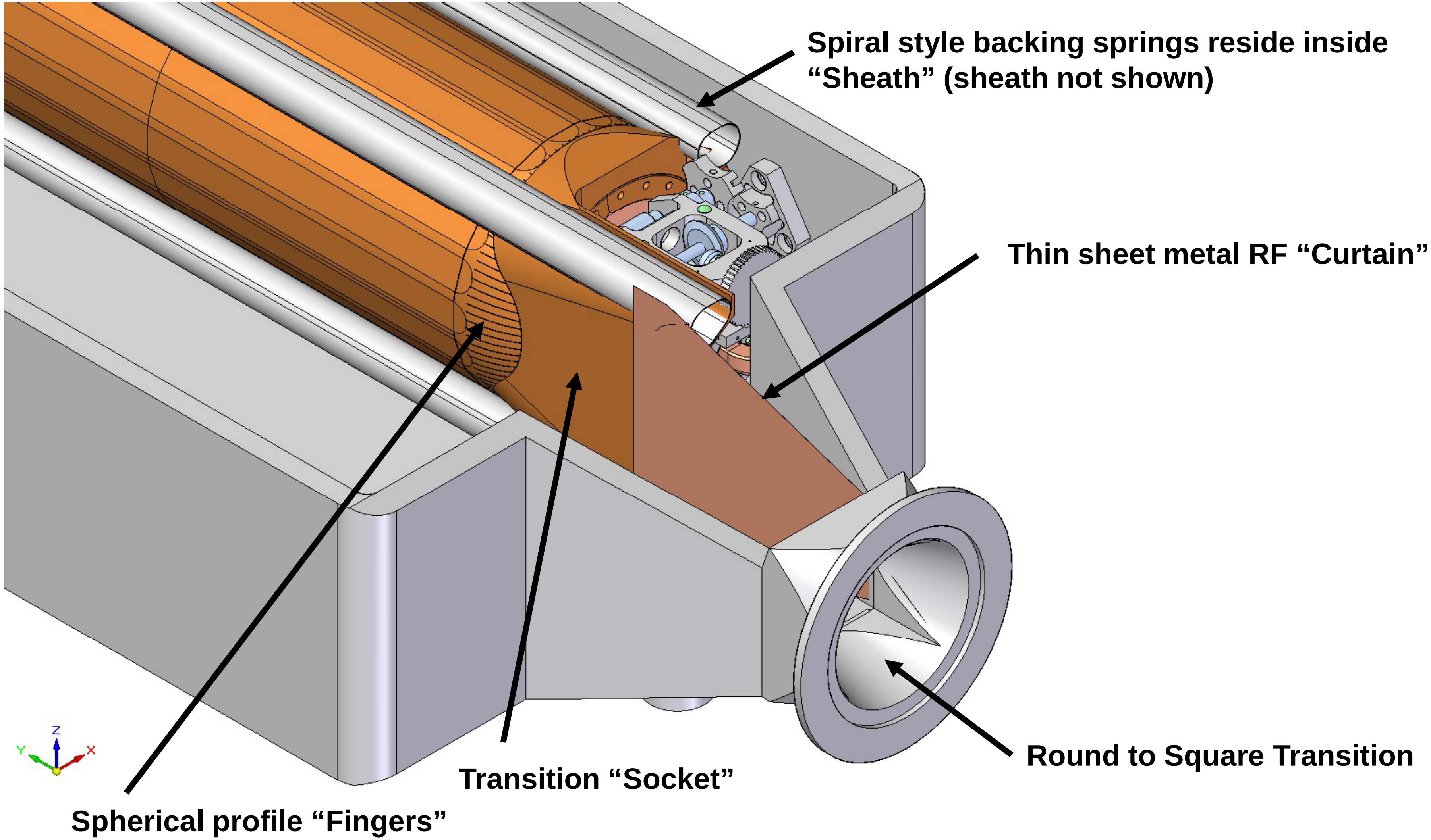
In Progress (Jeff Smith):

- Discussions with CERN and PeP-II experts
- MAFIA simulations
  - Geometric versus resistive contributions

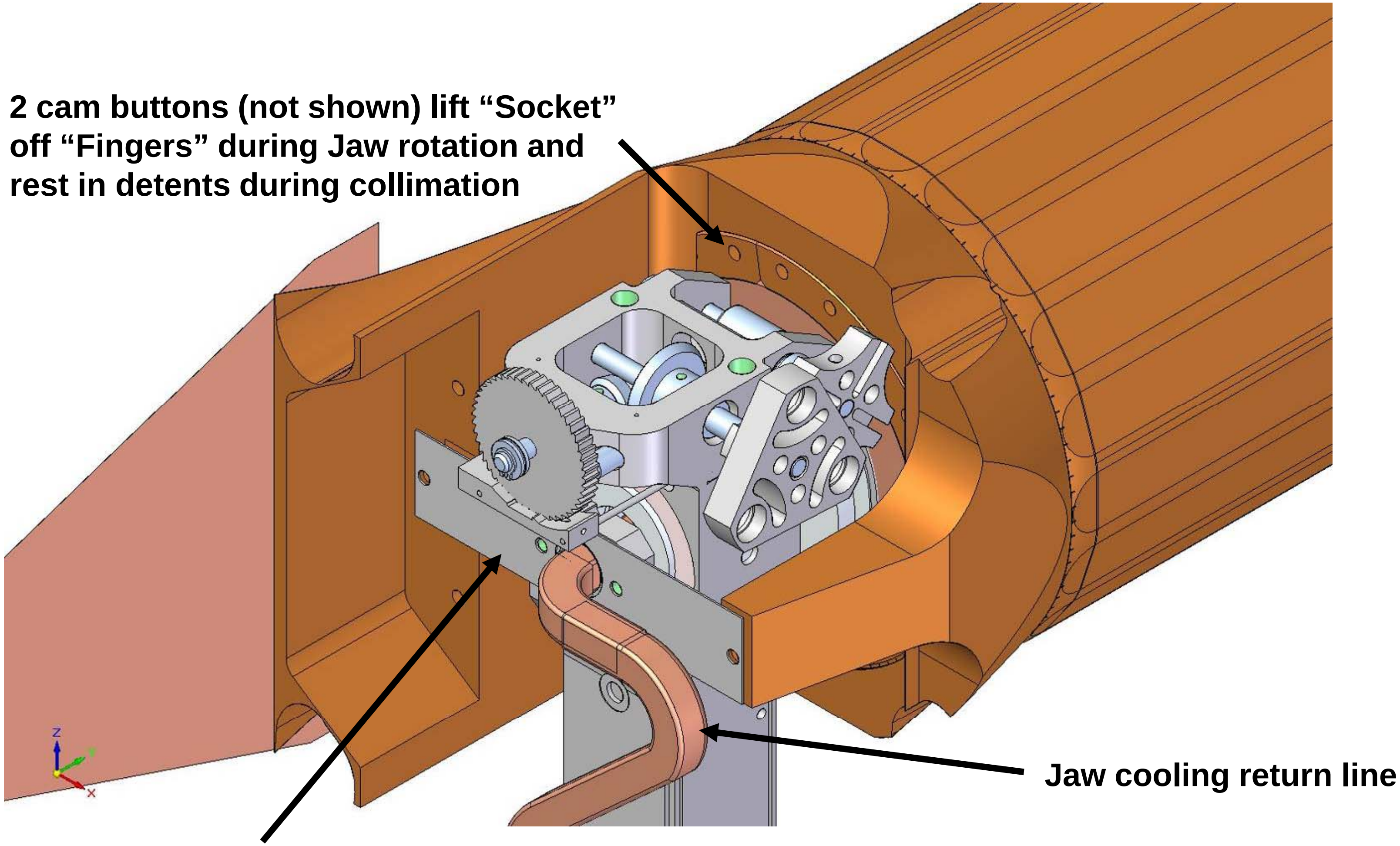
To be done:

- Impedance measurements with network analyzer
- Contact resistance measurements

Up Beam end beam side view

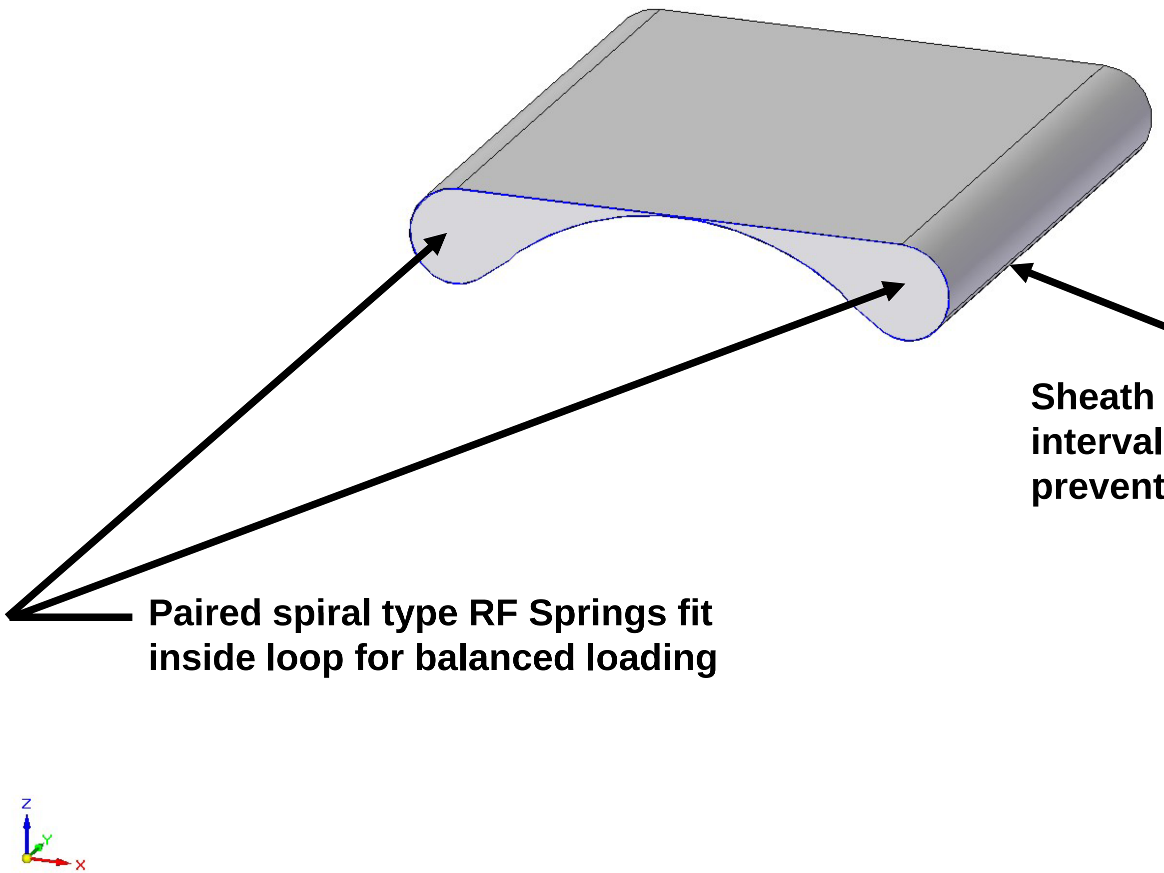


Up Beam end detail view away from beam side



Spring flexes to maintain contact force on “Fingers” for longitudinal and lateral displacements of the Jaw ends

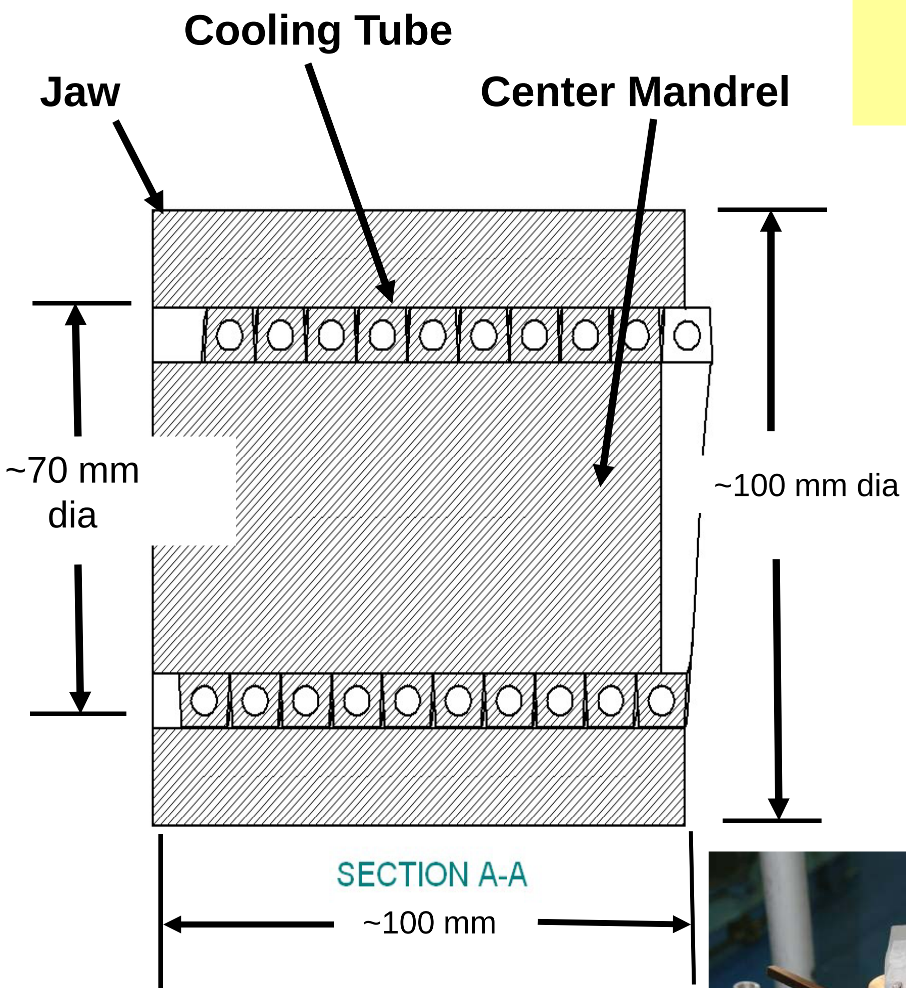
“Sheath” concept for transverse RF seal

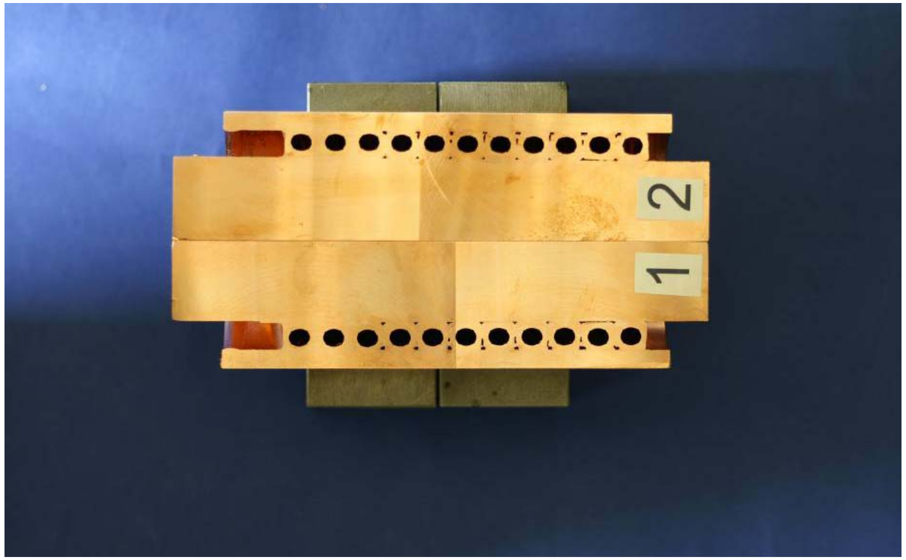


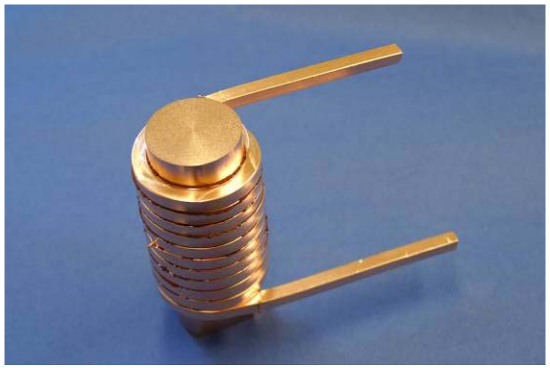
Sheath may require slits at 3mm intervals along loop sides to prevent wrinkling

Paired spiral type RF Springs fit inside loop for balanced loading

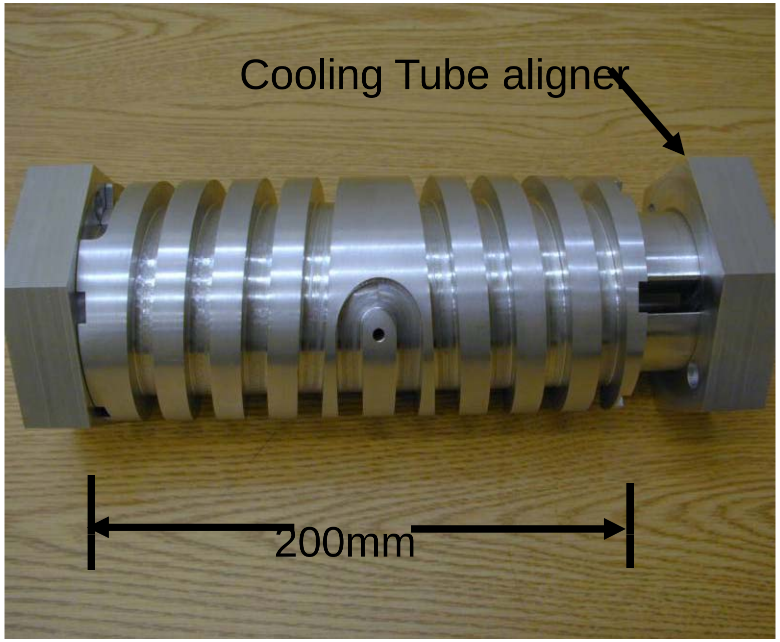
BrazeTest #1 (May 2006)





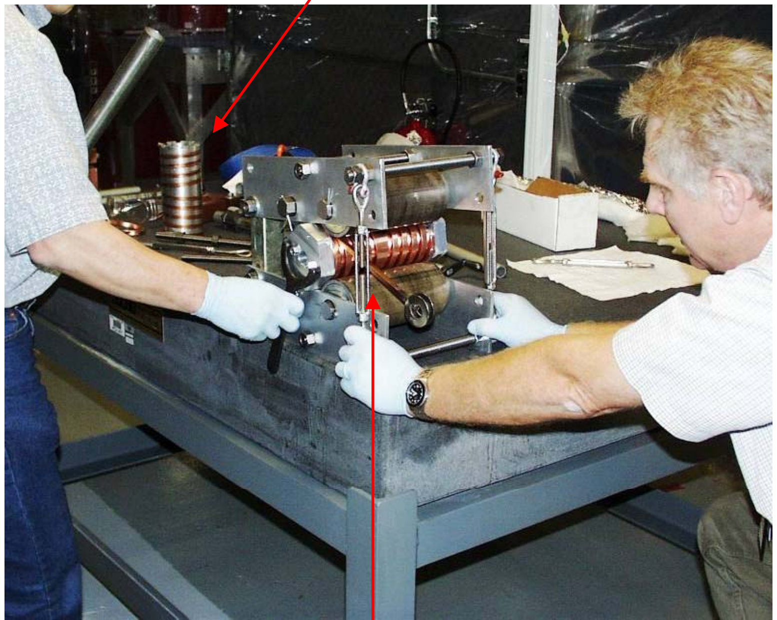


Development of Winding Tooling



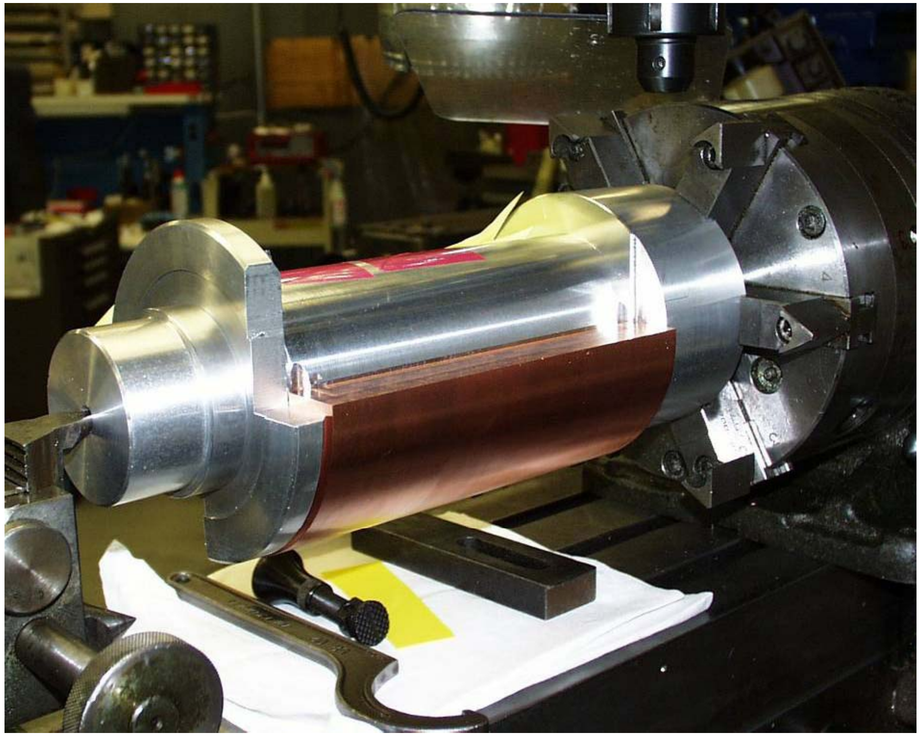
Aluminum Mandrel for Coil Winding Test and to test 3-axis CNC Mill before cutting 200mm and 950mm Copper Mandrels

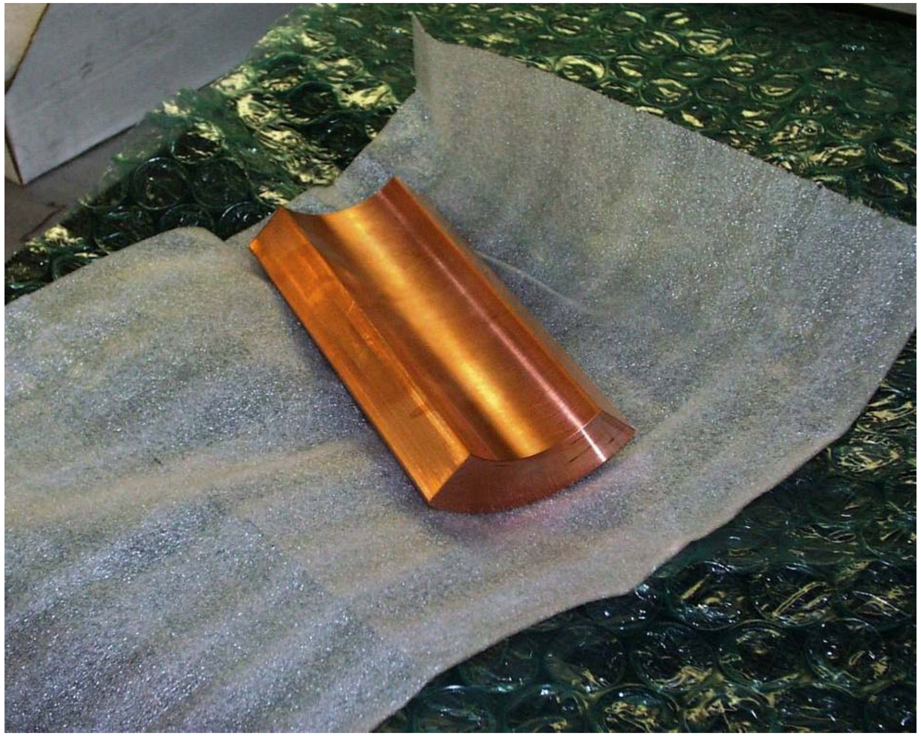
Aluminum Mandrel with Coil Wound



Roller-Type Coil Winding Tool used to test wind the 200mm Copper Mandrel

Fabrication of Quarter Jaws for 2nd Braze Test





Final Wind of First 200mm Copper Mandrel

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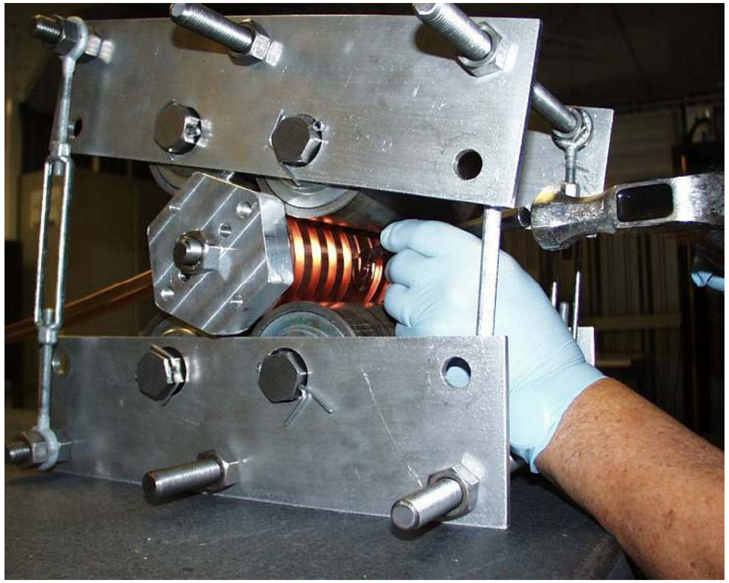
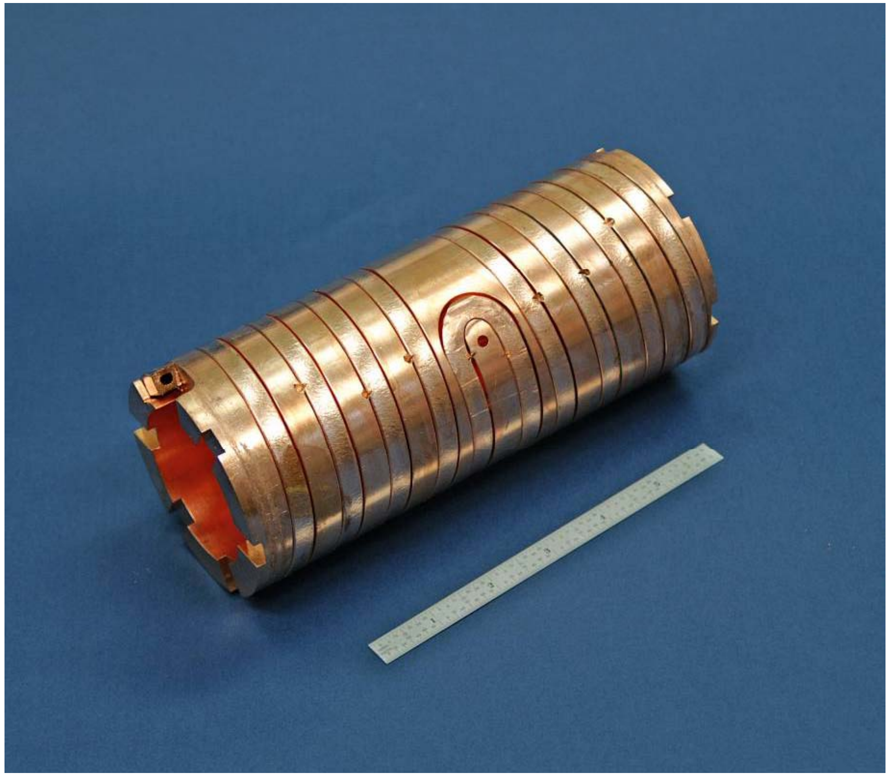
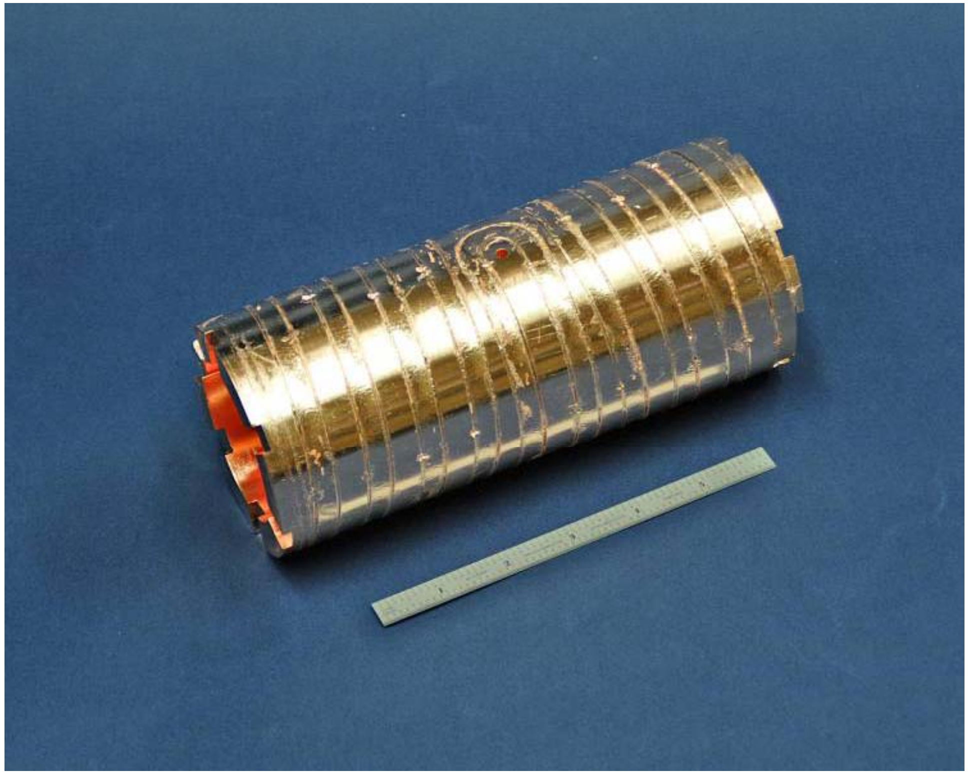


First 200mm Prototype
Before-After Brazing Coil to Mandrel





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

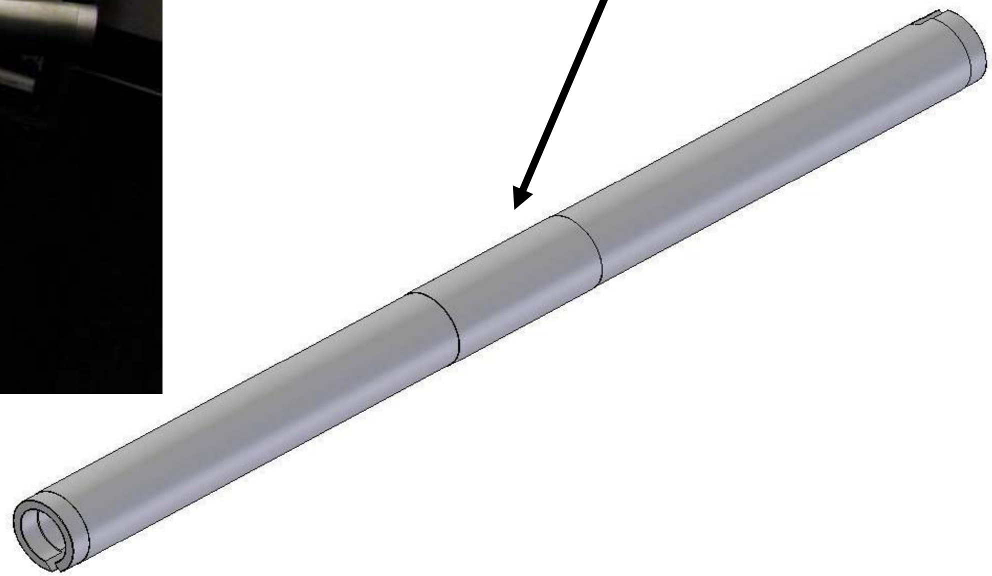
More Winding Tooling Developed

1m winding tooling for full length jaw

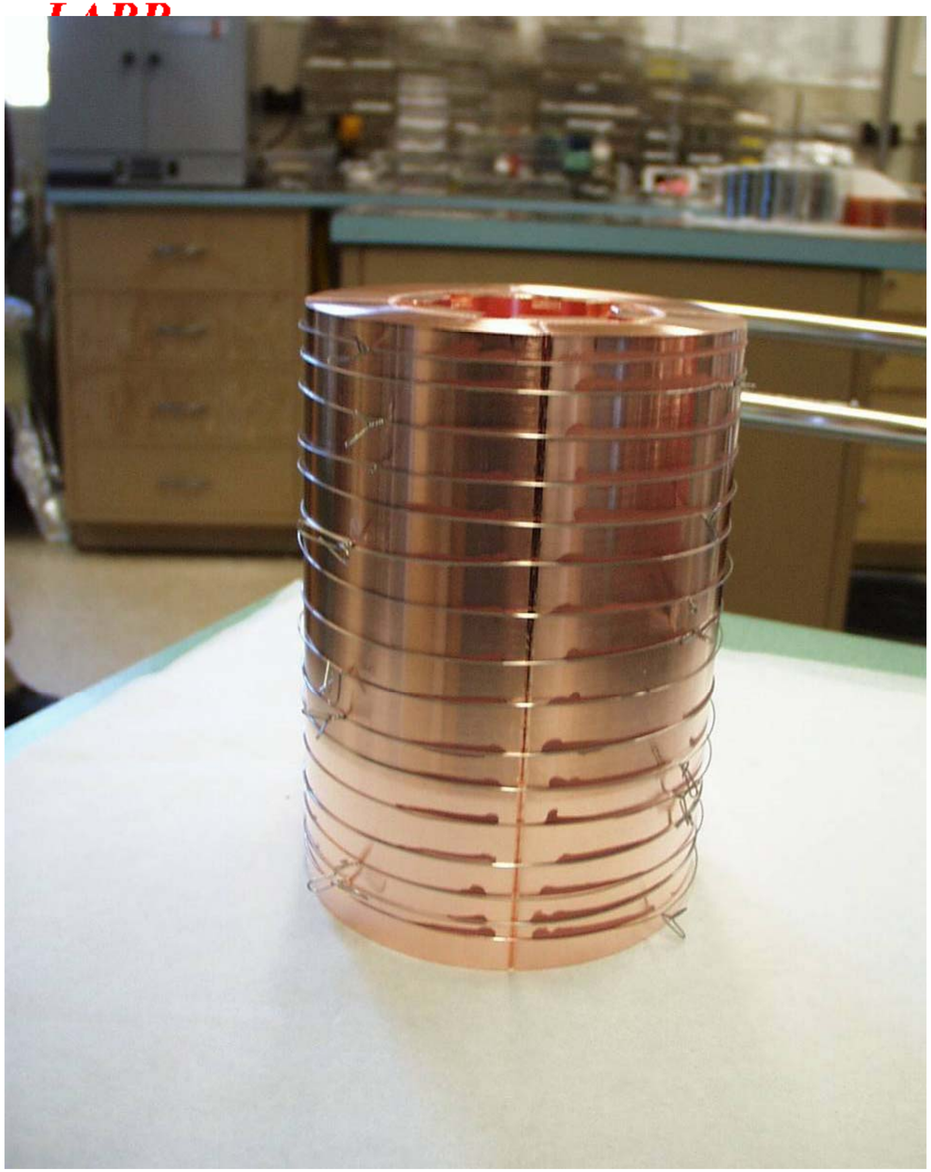
Mill vise as precision bender

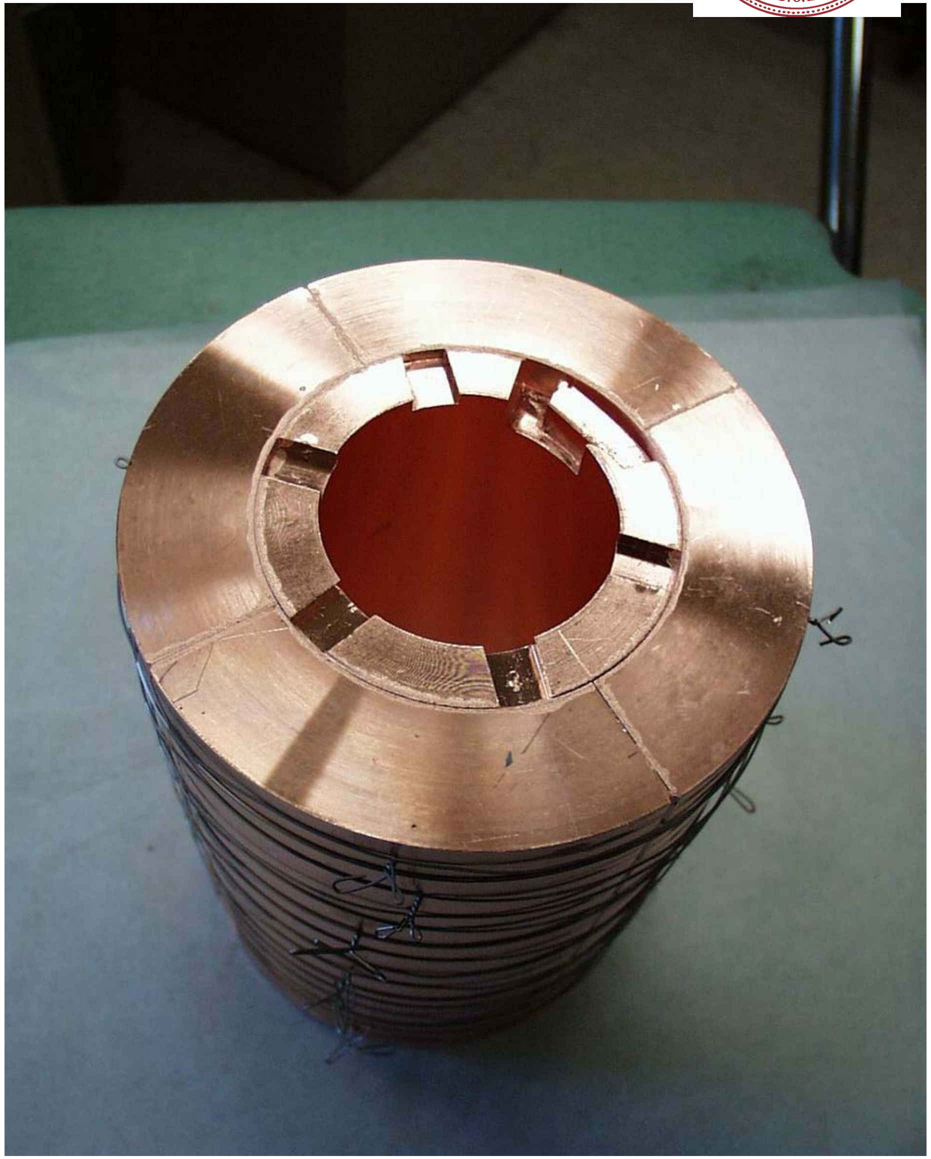
Full Length Molybdenum Shaft
(final design calls for half-length Moly shaft attached to central Copper Hub so ensure good braze)

1mm raised shoulder (Hub) at center to produce “expansion gap”



Braze Test#2 Delivered 19 Dec 2006





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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.

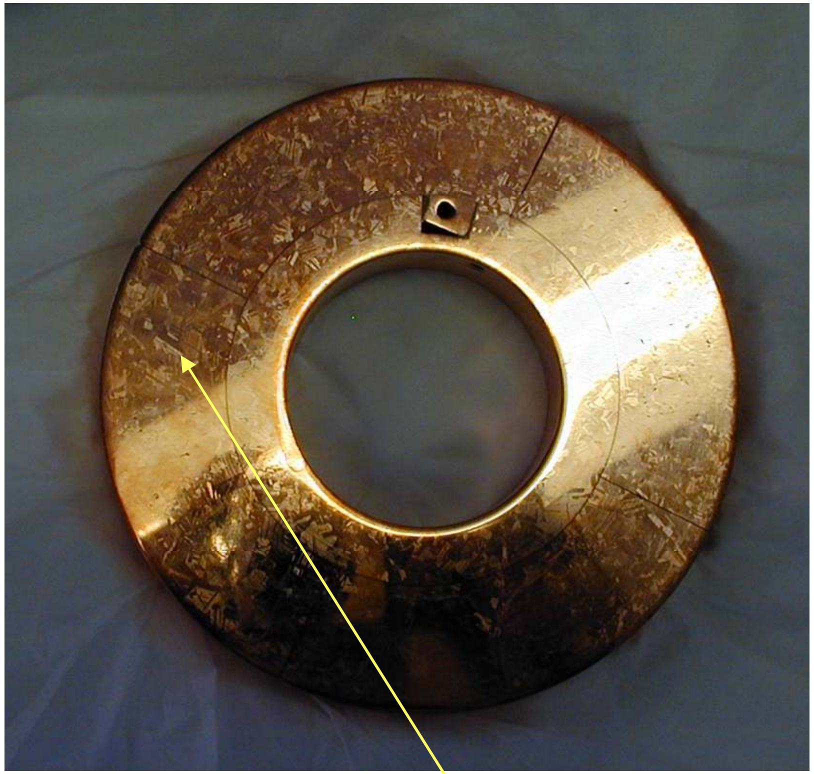
Outcome:

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

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

LARP

Interior slice: polished & etched

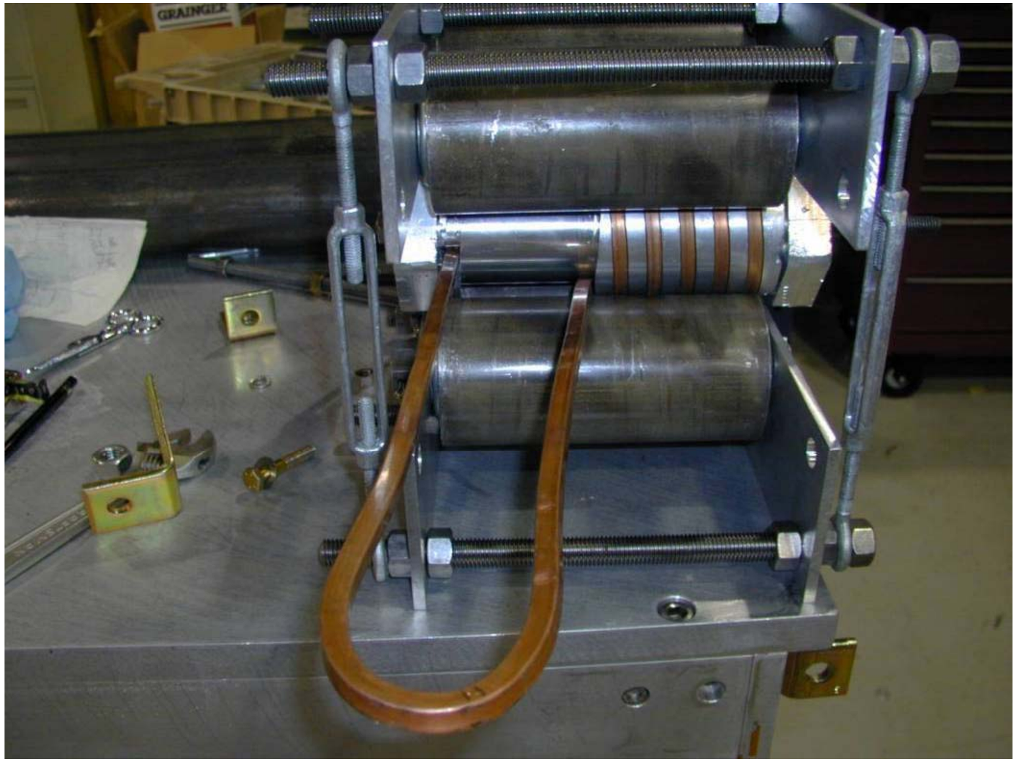


· Evidence of fracturing along grain boundaries presumed due to too-rapid cooldown after braze
    - areas near ends and OD look better
· Braze of jaws to hub GOOD
· 3 of 4 jaw-jaw brazes GOOD

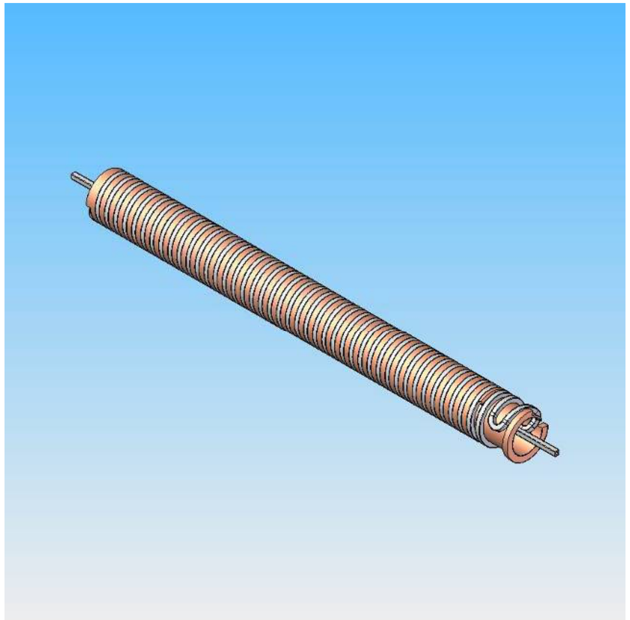
Longitudinal slice

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

Aluminum Test Mandrel with 80mm Gap for Downstream U-Bend (11/17/06)



Model showing 42.5 winds of coil on Mandrel with 80mm wide space for U-Bend at downstream end



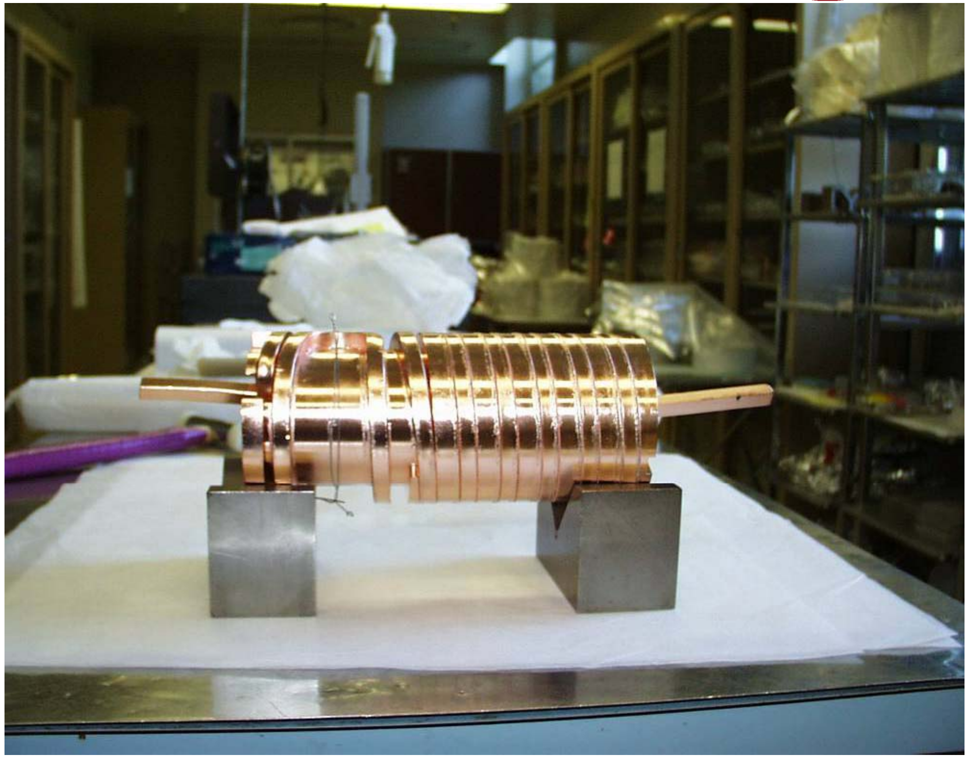
Braze Test #3: 200mm mandrel with U-Bend

Upstream end of Mandrel

Tubing Wound and Tack Welded to Mandrel at the U-Bend

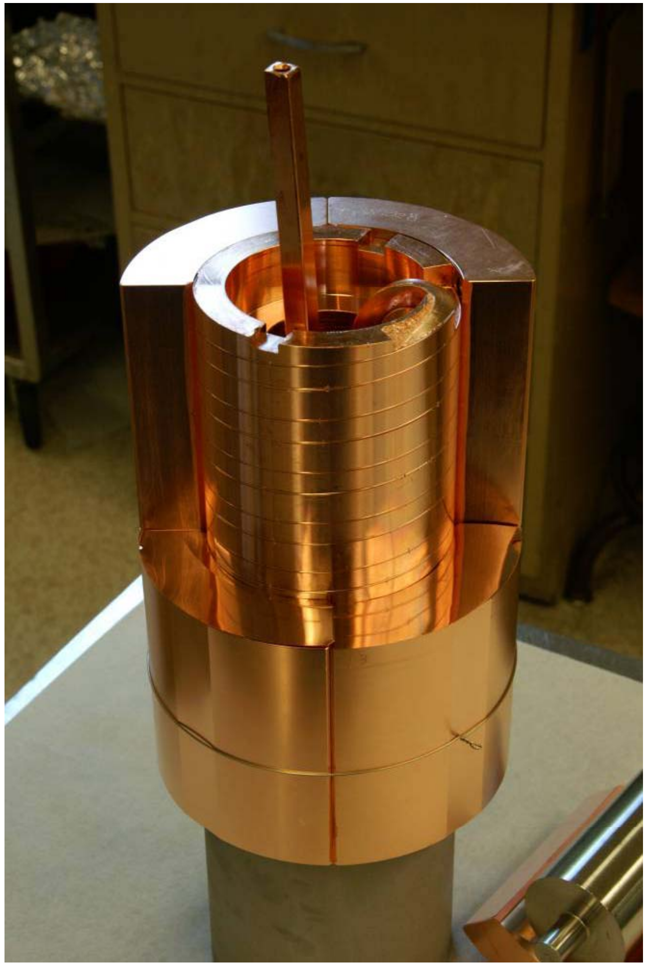
Braze Test #3:
Coil-to-mandrel braze

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



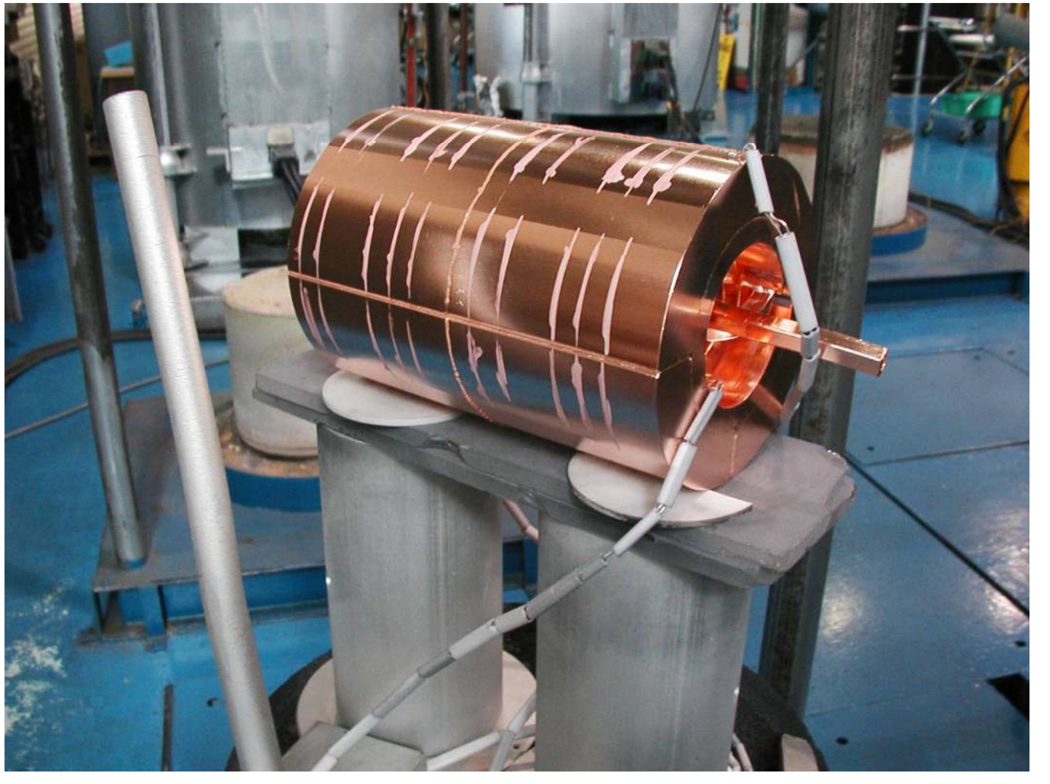
23 Apr 07: After 2 braze cycles, OD & braze wire grooves machined

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



14 June 2007: Jaw Fit Up

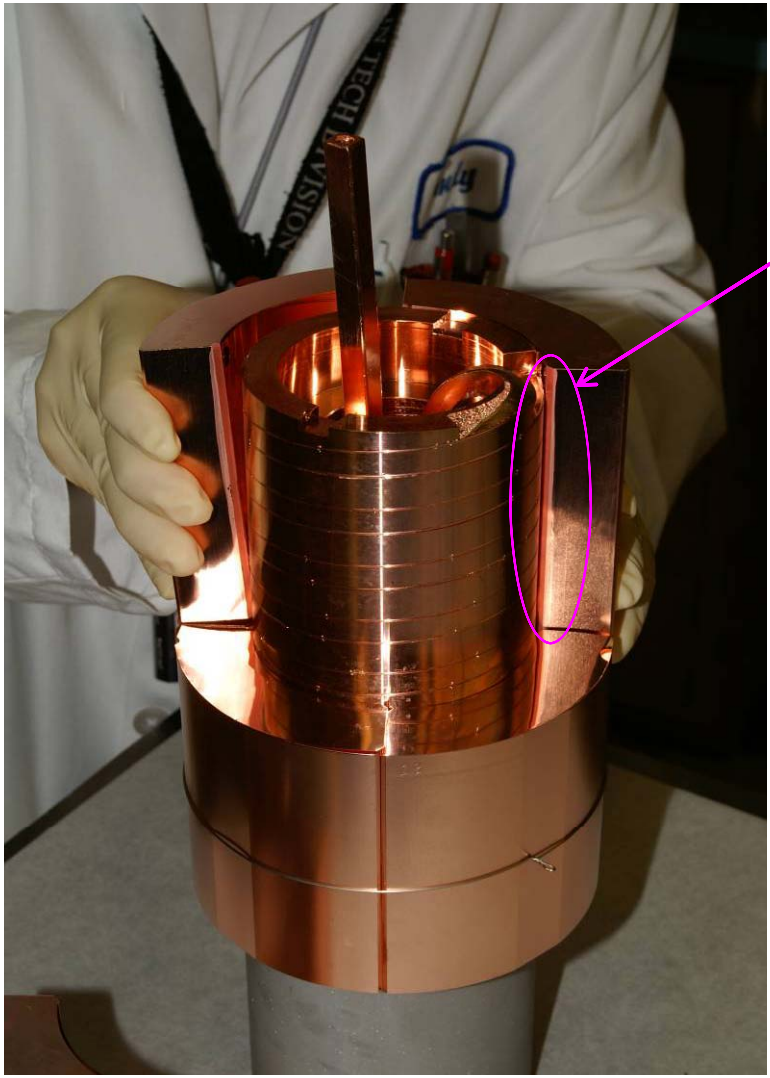
19 June 2007: After 1st Jaw Braze
Prepped for 2nd Braze to fillup jaw-jaw joints



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

Braze Test #3: Vacuum tests

LARP

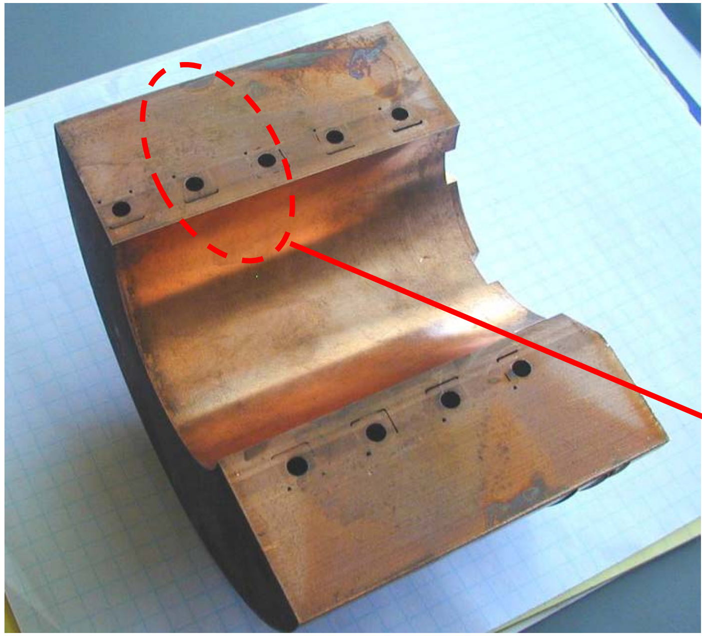


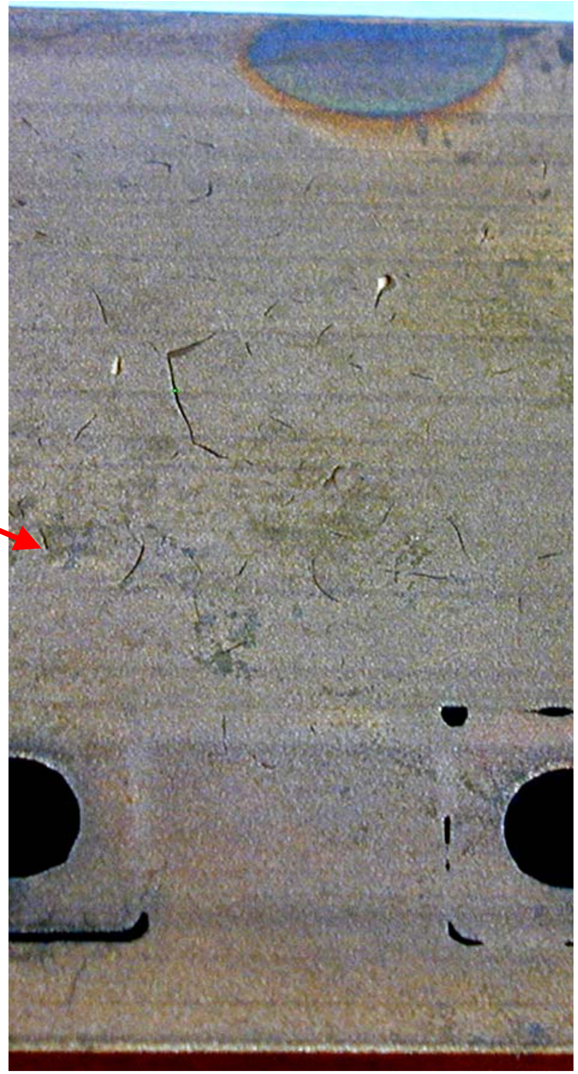
- 3rd Jaw Braze Test Assembly has been vacuum baked at 300 degrees C for 32 hours. Results in slightly lower pressure.
- Inclusion of longitudinal grooves in the inner length of jaws for better outgasing
- Test Chamber setup similar to previous test.

	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)

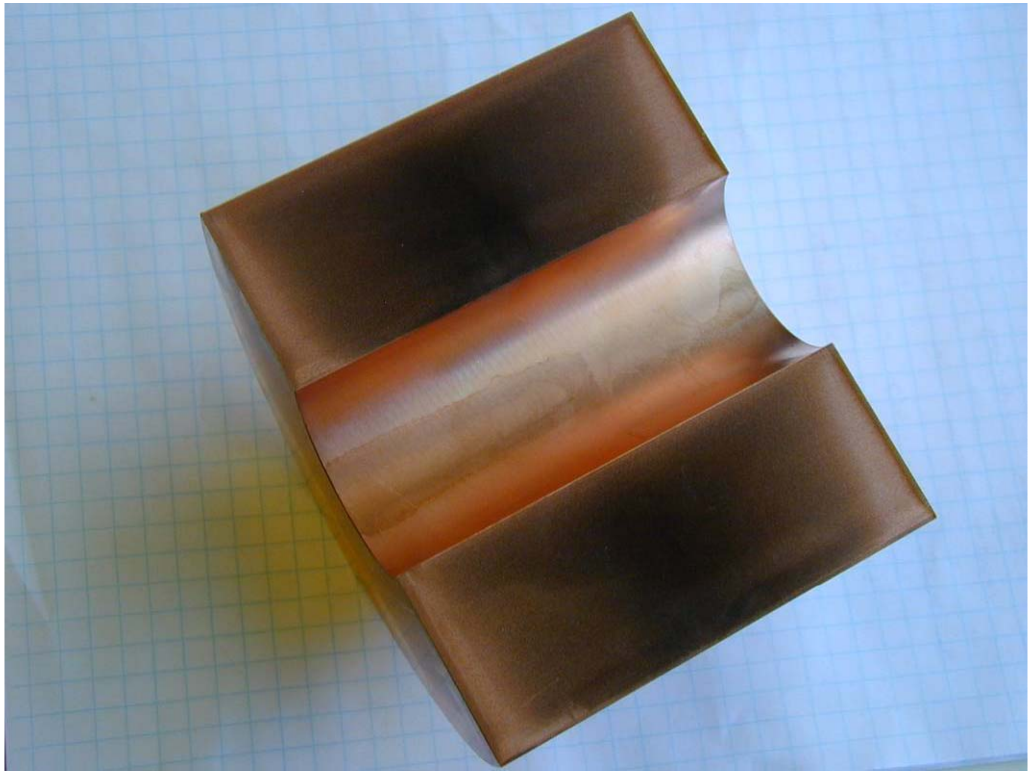
- **one braze cycle in the 900 C range**
- **grain boundary cracks located in interior regions**
- **believed due to excessive heating rate**
- **Glidcop to be tested**

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

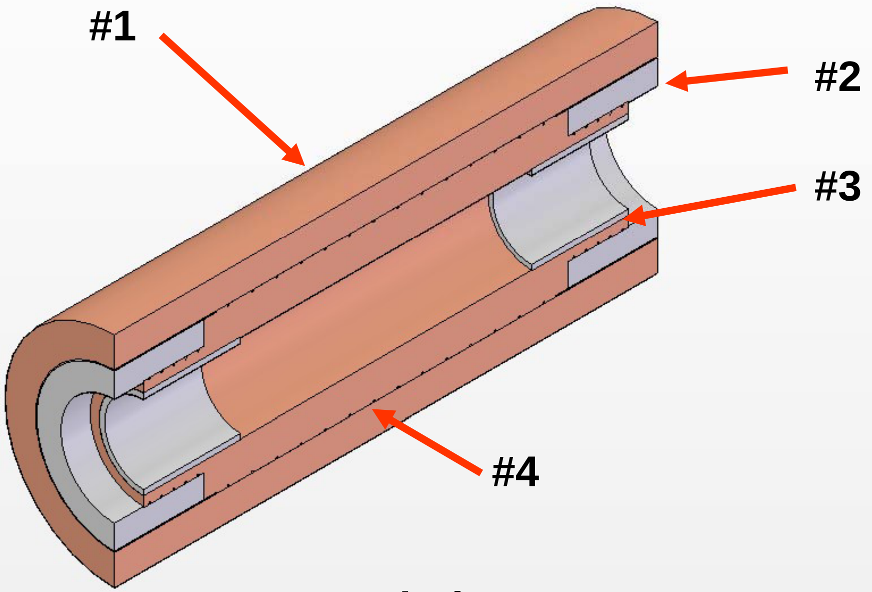


2 Heats (at Jaw brazing temperature)

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



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

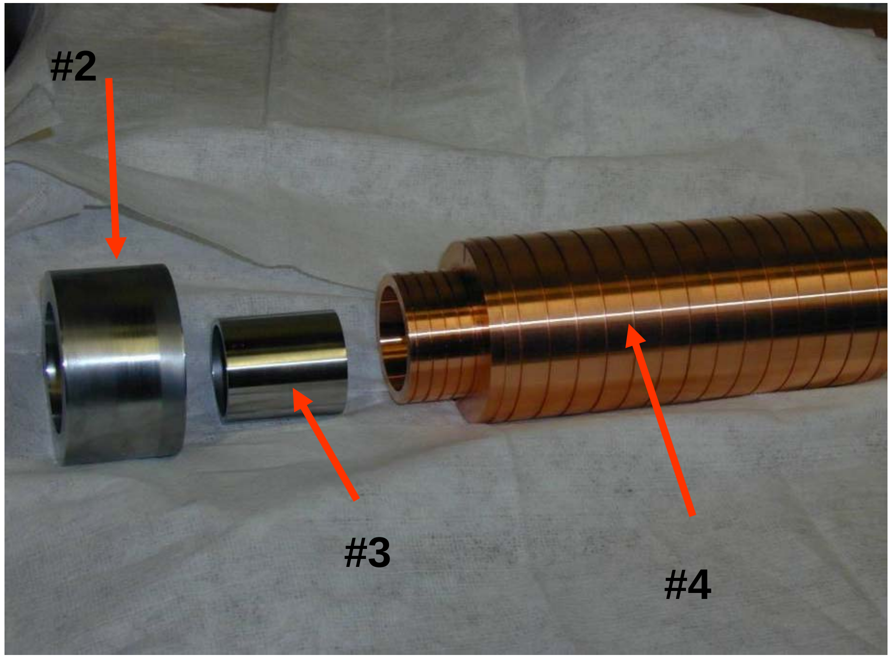
Initial plan to braze one long Mo shaft with raised hub to inner radius of Cu mandrel deemed unworkable

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

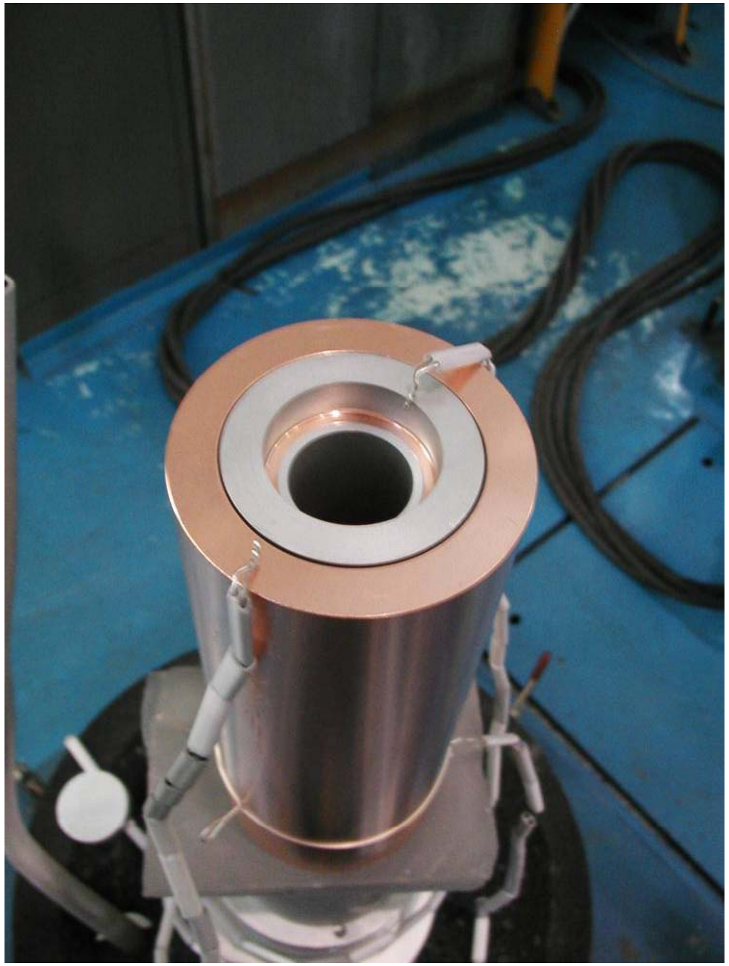
First test if Mo “backing ring” sufficient to keep Mo and Cu in good enough contact for a strong braze joint

Cu-Mo Hub Braze Test parts

28 Feb 2007: Cu-Mo Braze Test Parts

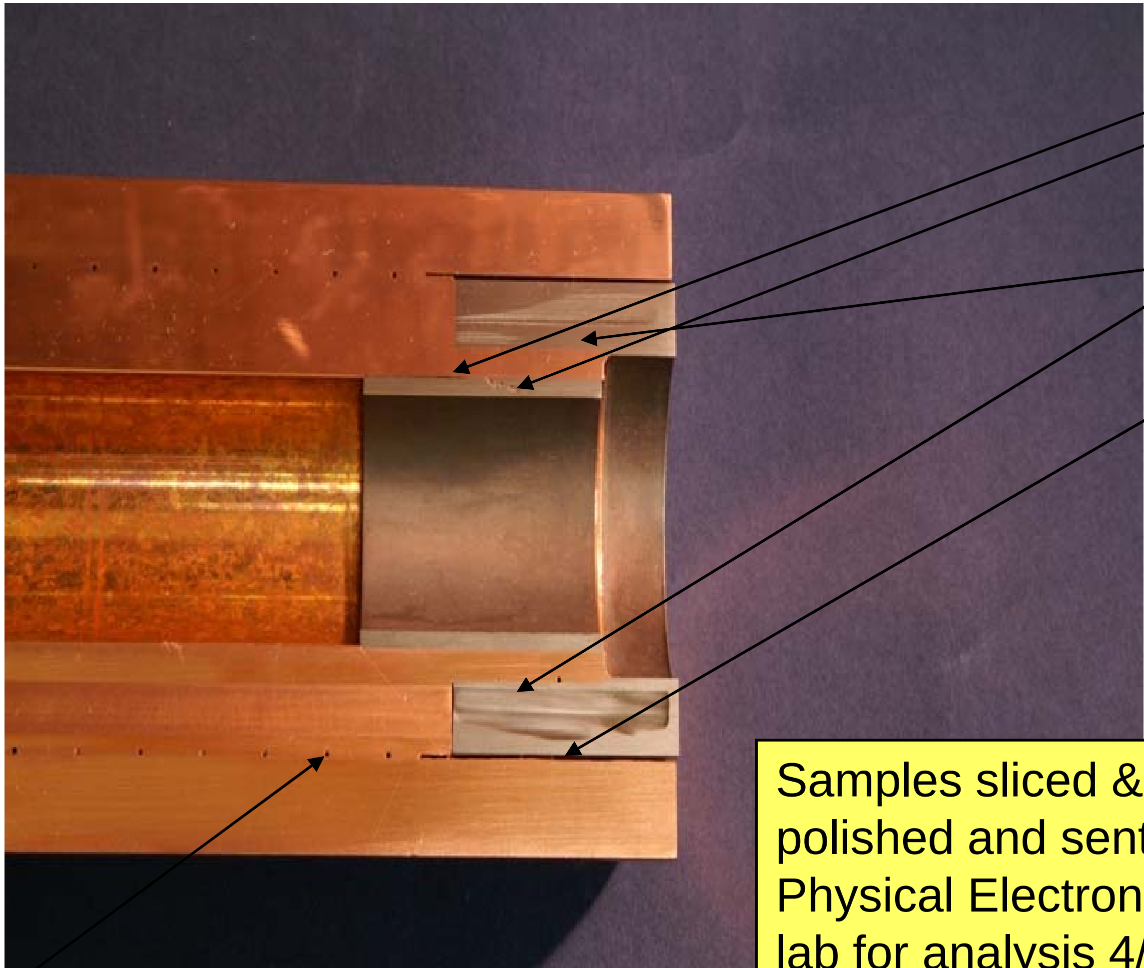


#1 - Mandrel Dummy (not shown)
#2 - Mo Shaft Dummy
#3 - Mo Backing Ring
#4 - Cu Hub with braze wire grooves



27 Mar 2007: Cu-Mo Braze In Oven

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



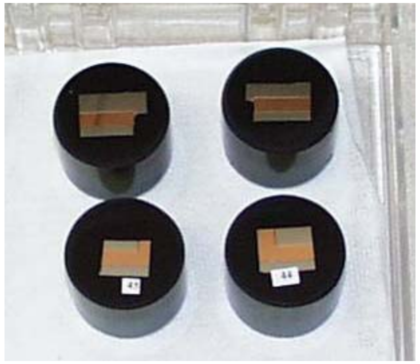
•Grain boundary issues?
•Possible fracturing?

Cu-Mo joints we care about

1mm expansion gap

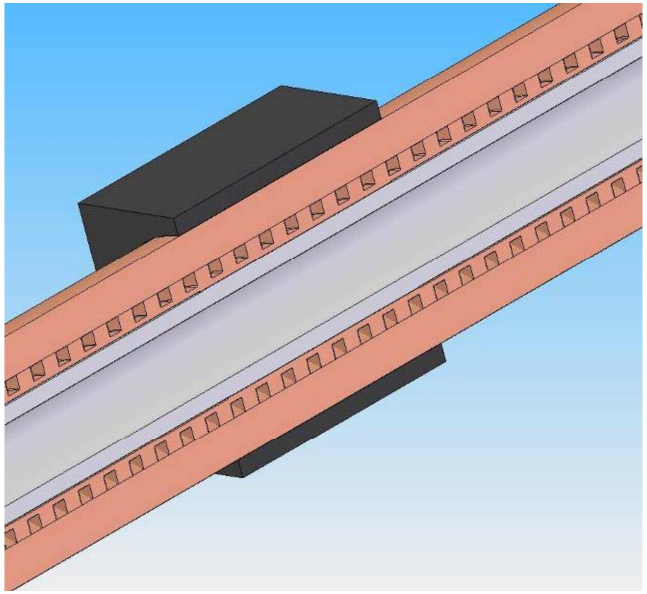
Small holes held braze wire

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



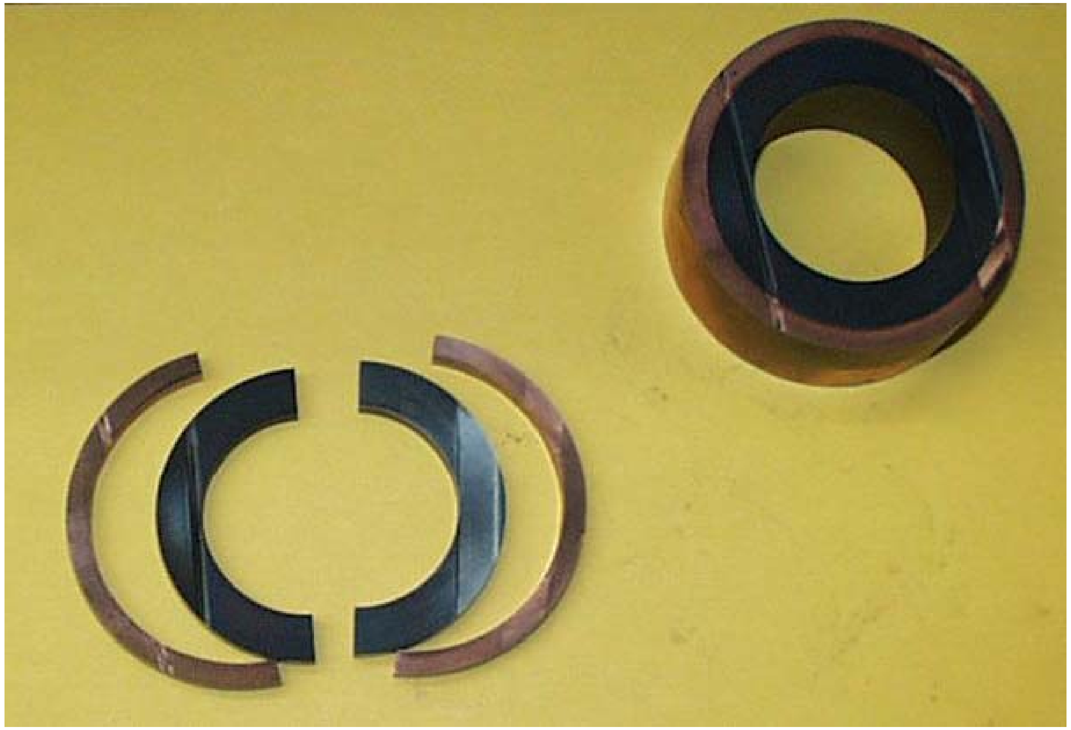
Compression fit for Cu-Mo joint

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



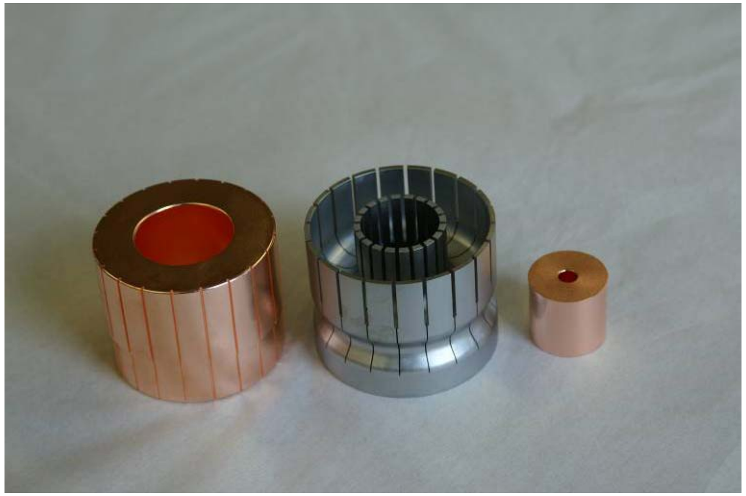
Copper Jaw is constrained on the outside diameter with Carbon and when heated to ~ 900 degrees C is forced to yield so that upon cooling to ~ 500 degrees C the inner diameter begins to shrink onto the Mo Shaft resulting a substantial interference fit.

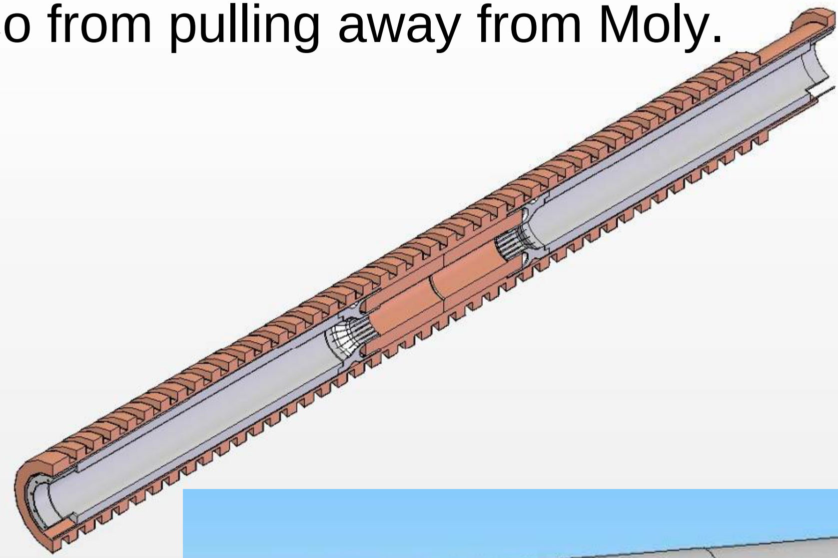
Test hub fell apart once we made a slice!

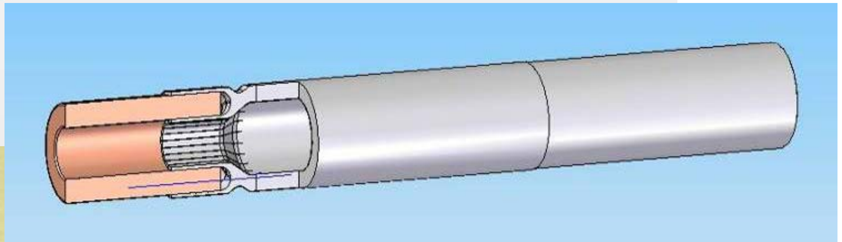


Cu-Mo joint: Segmented Moly for expansion

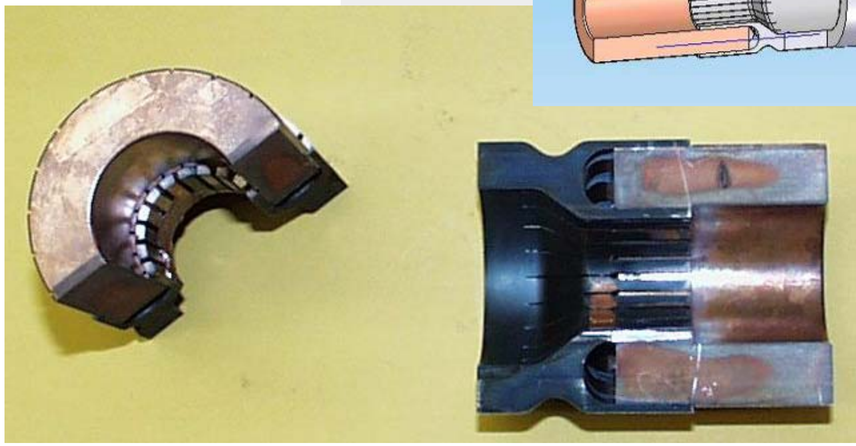
- Another option is to use a segmented flexible molybdenum end to prevent fractures and prevent Co from pulling away from Moly.







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



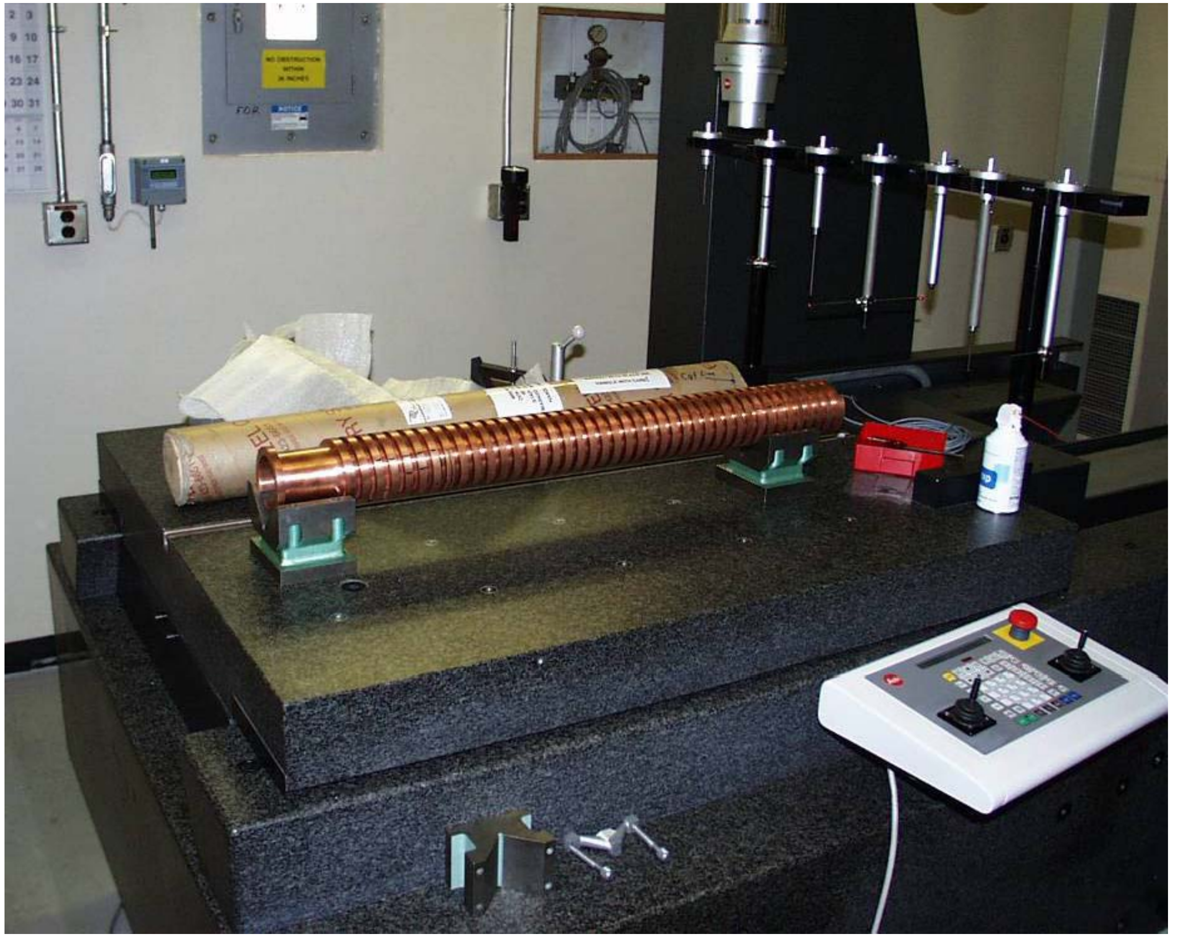
Molybdenum Half Shafts & Copper Hub Halves braze preparations

Retainer Ring

Expander Plug

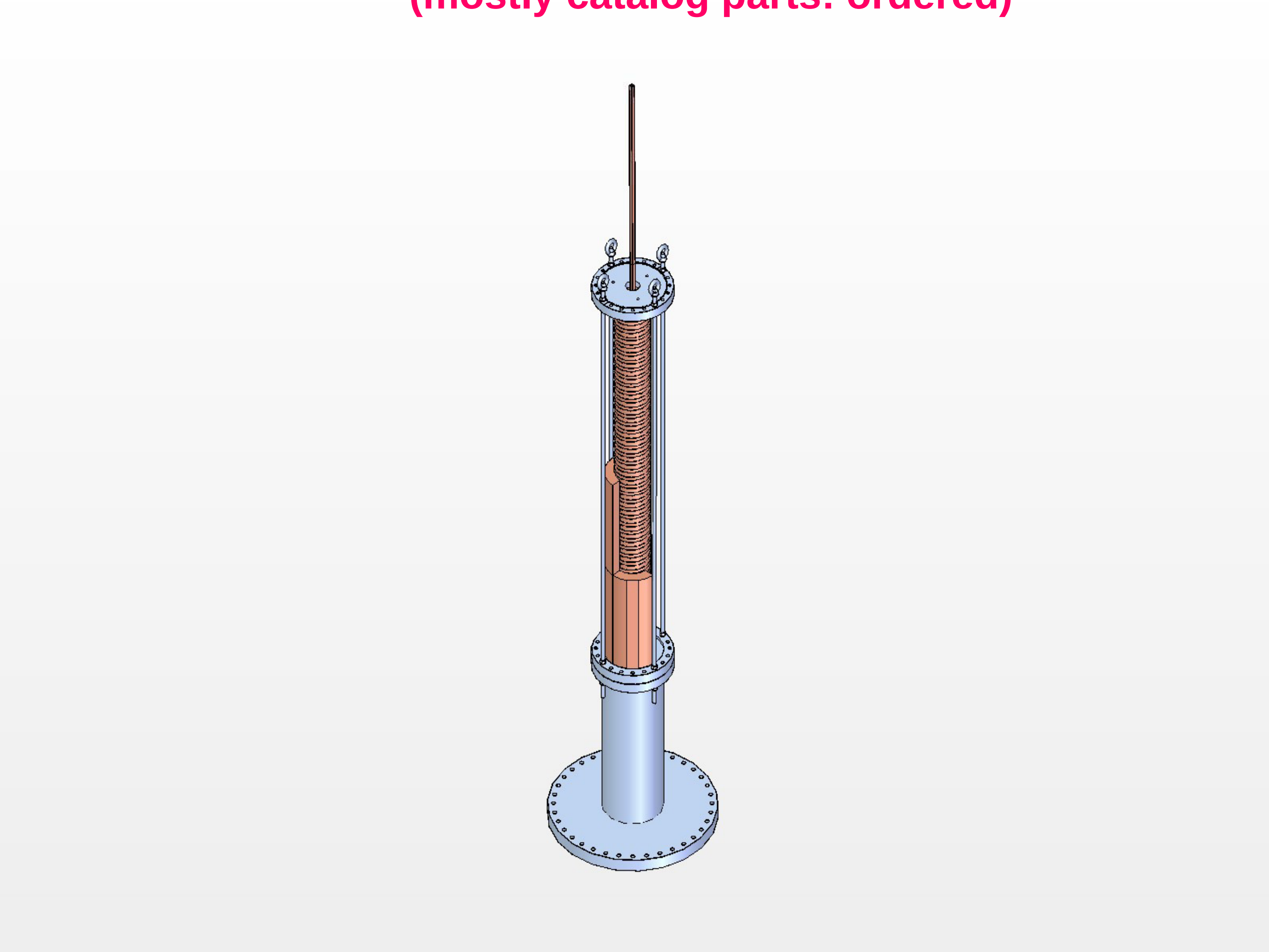
21 Mar 2007: Full length Mandrel: In-House & Inspected

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

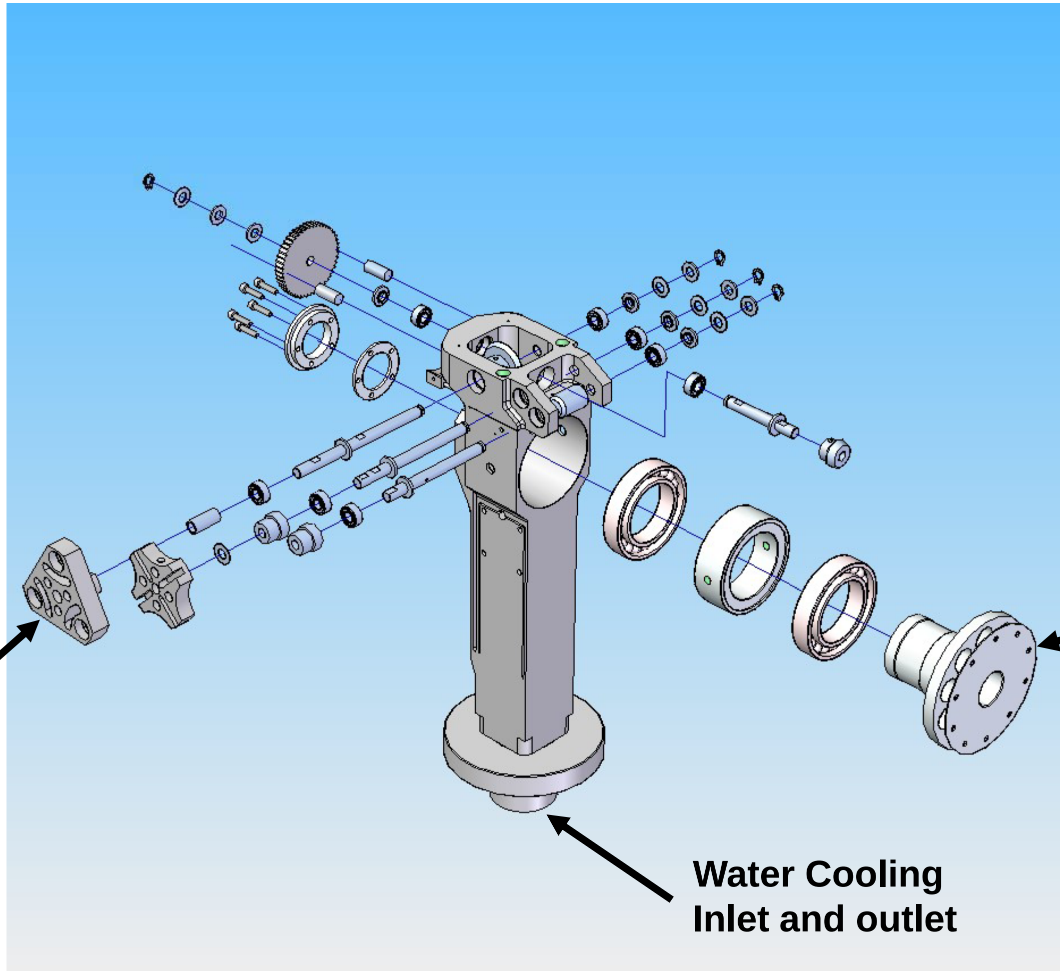


Fixture for stacking 16 24cm-long quarter round jaws on full 960mm cooling coil wrapped mandrel

(mostly catalog parts: ordered)



Exploded view of CAD model of Flex Mount

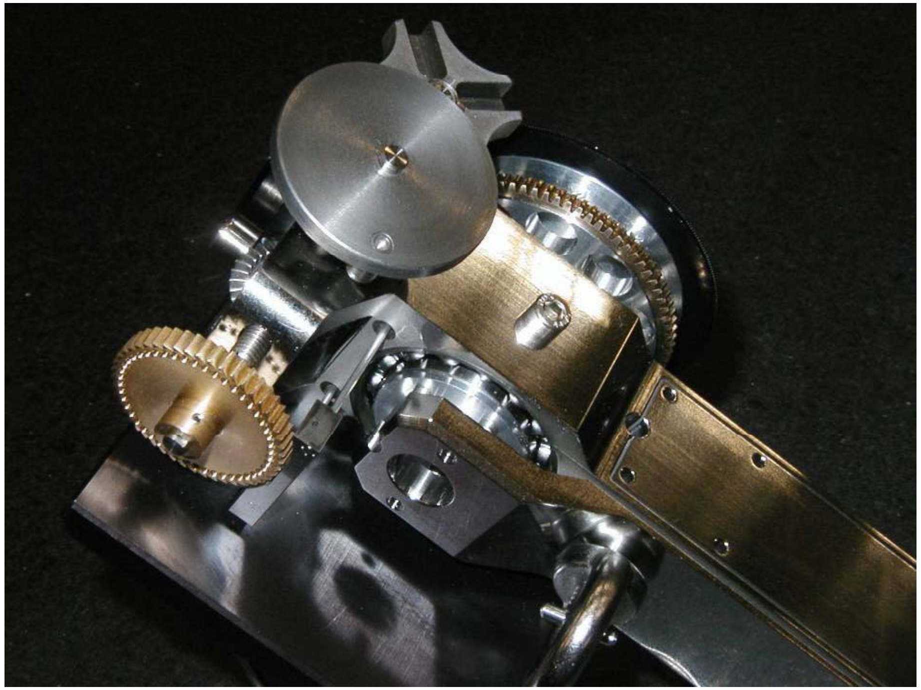


Triple Cog Geneva Drive Wheel required for 512 clicks per facet

Water Cooling Inlet and outlet

U-Joint Flexes for Shaft "sag" and "Slewing"

Up Beam Flex Mount Assembly showing Ratchet and Actuator



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
  - ✓ Rudimentary software tests only
- ✓ 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 (!!!)

Adjacent 16.5 kW Chiller

Heater Power Supplies staged for installation in rack

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

LARP

- 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 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
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

Conclusions

In a limited time with a relatively few people LARP team has

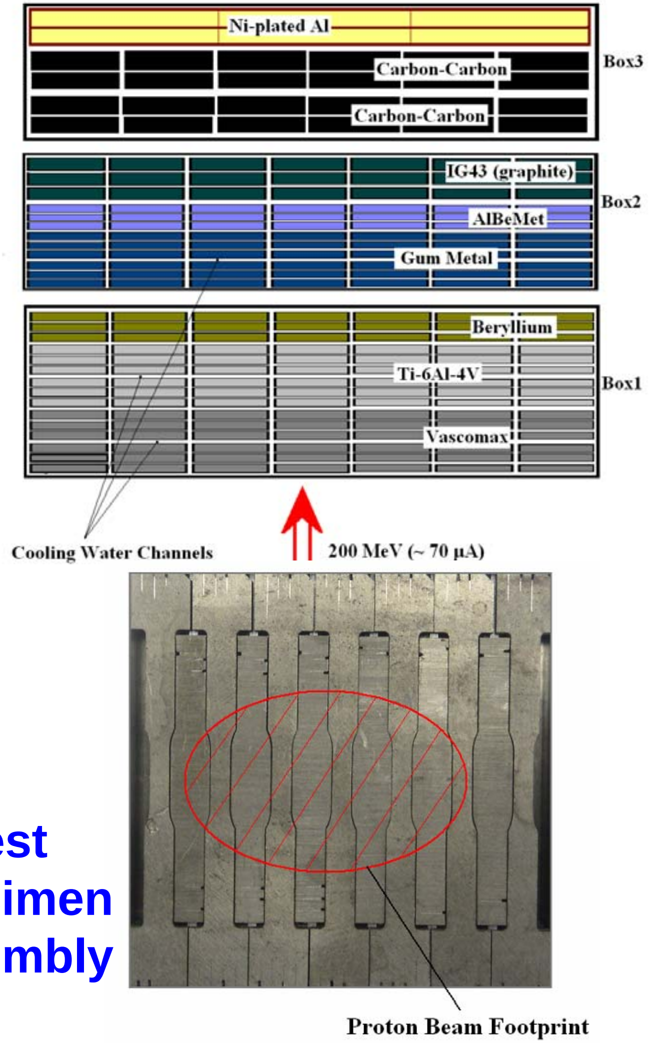
- Finalized a workable design (modulo rf design) and produced most full length mechanical fabrication drawings and models
- Finished all pretests, tooling and examinations that also required many fabrication drawing
- Is on track (?) to deliver full length operational prototypes on time
- Expected performance
  - 230 um flatness under 60kW/jaw/10 sec 12 minute beam lifetime
- Major uncertainties left have to due with 1 MJ “accident” case
  - Beam test
  - Advanced calculations (cf: Sept 2007 Collimator Materials Workshop)

Bonus Slides

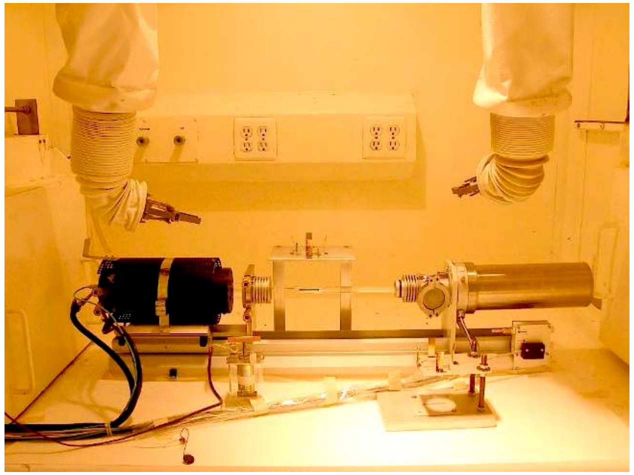
BNL Irradiation (BLIP) and Post-Irradiation Testing Facilities and Set-Up

LARP

Layout of multi-material irradiation matrix at BNL BLIP



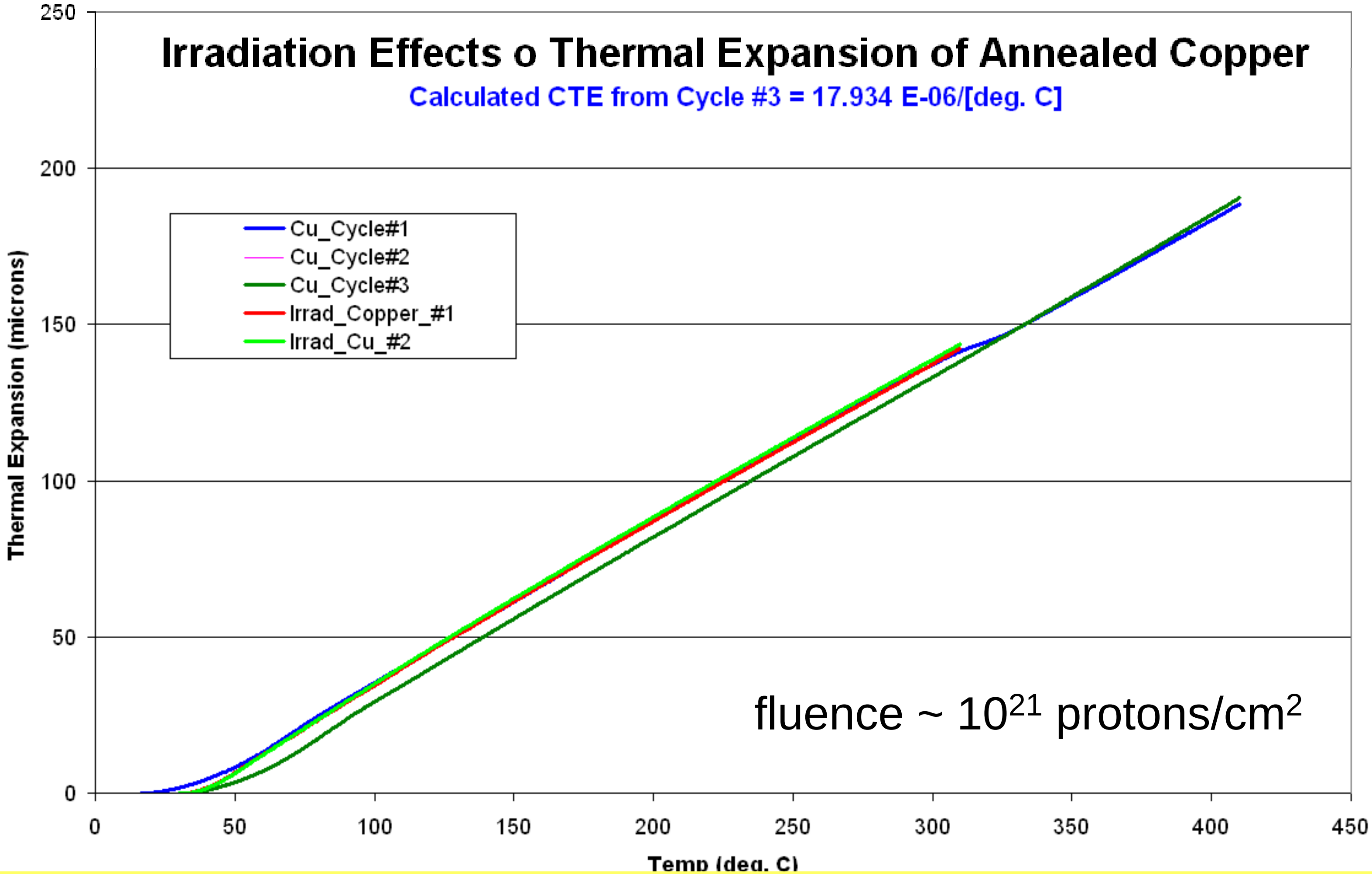
Test Specimen Assembly



Dilatometer Set-up In Hot Cell #1

Remotely-operated tensile testing system in Hot Cell #2

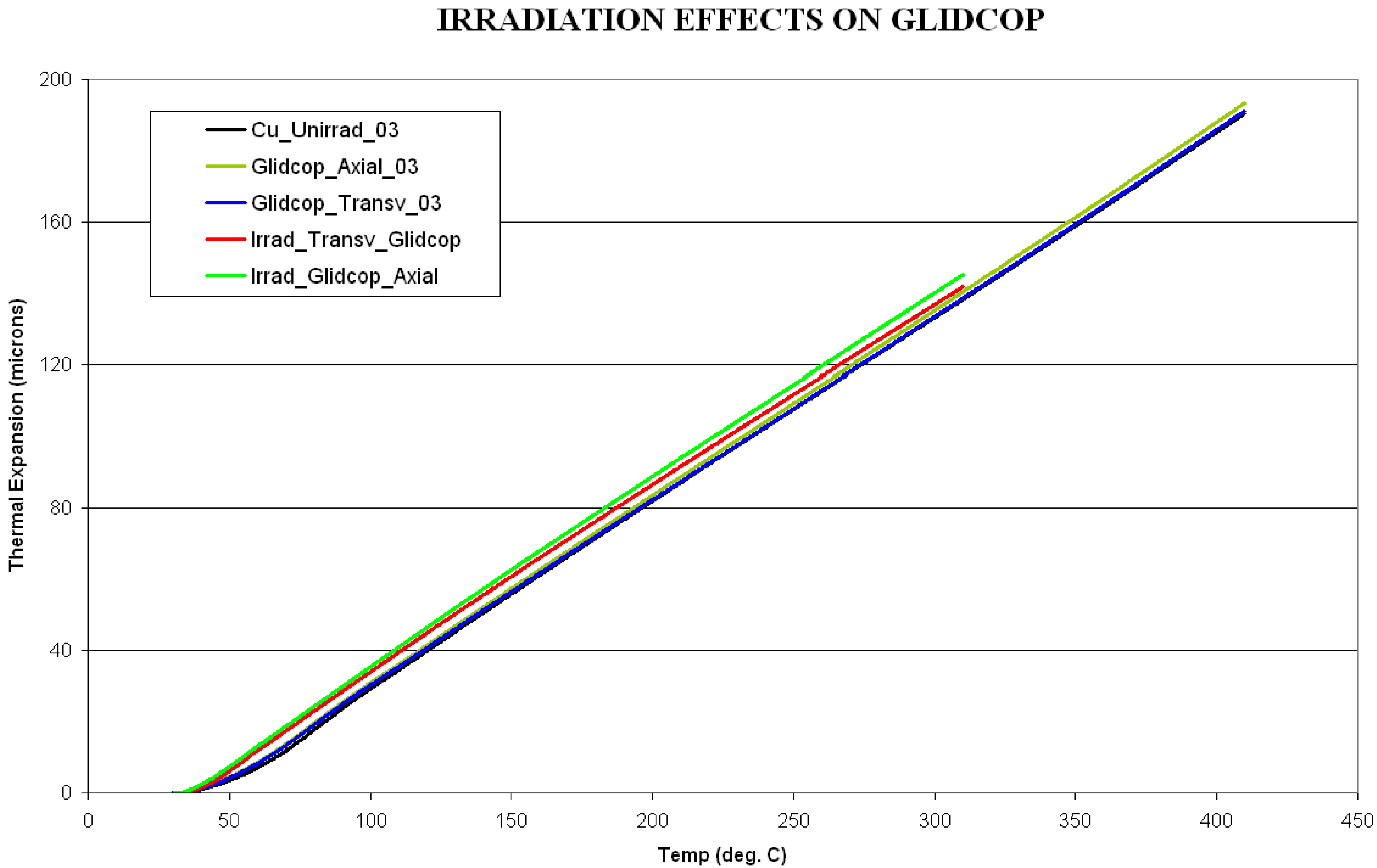
CTE Measurements of Irradiated Copper



fluence ~ 10^{21} protons/cm^2

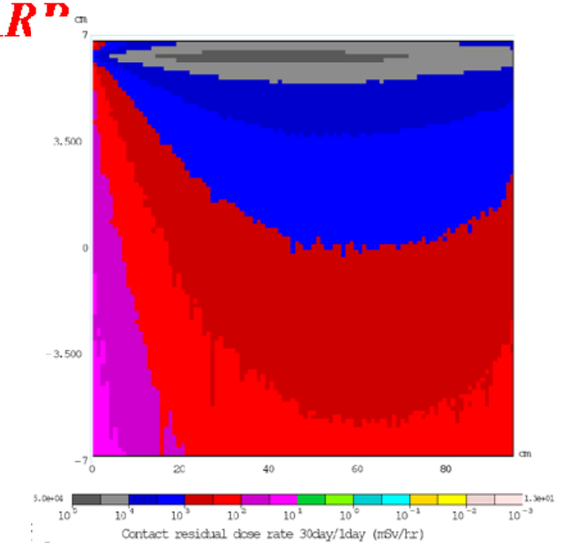
To Do: Measurements of Thermal Conductivity & Mechanical Properties

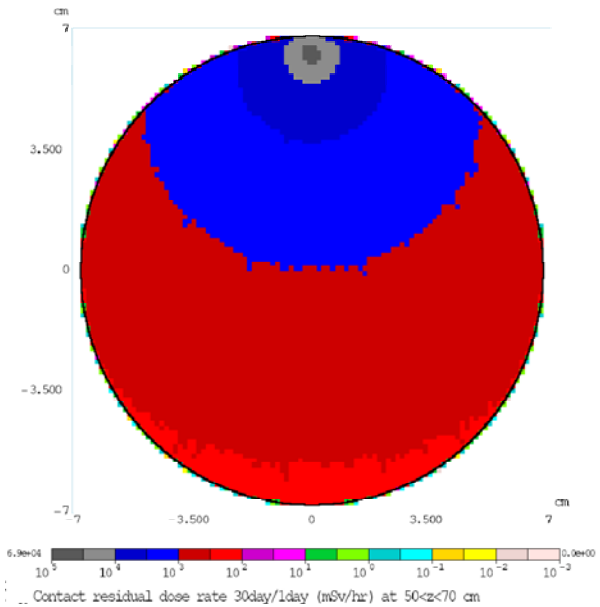
CTE Measurements of Irradiated GlidCop

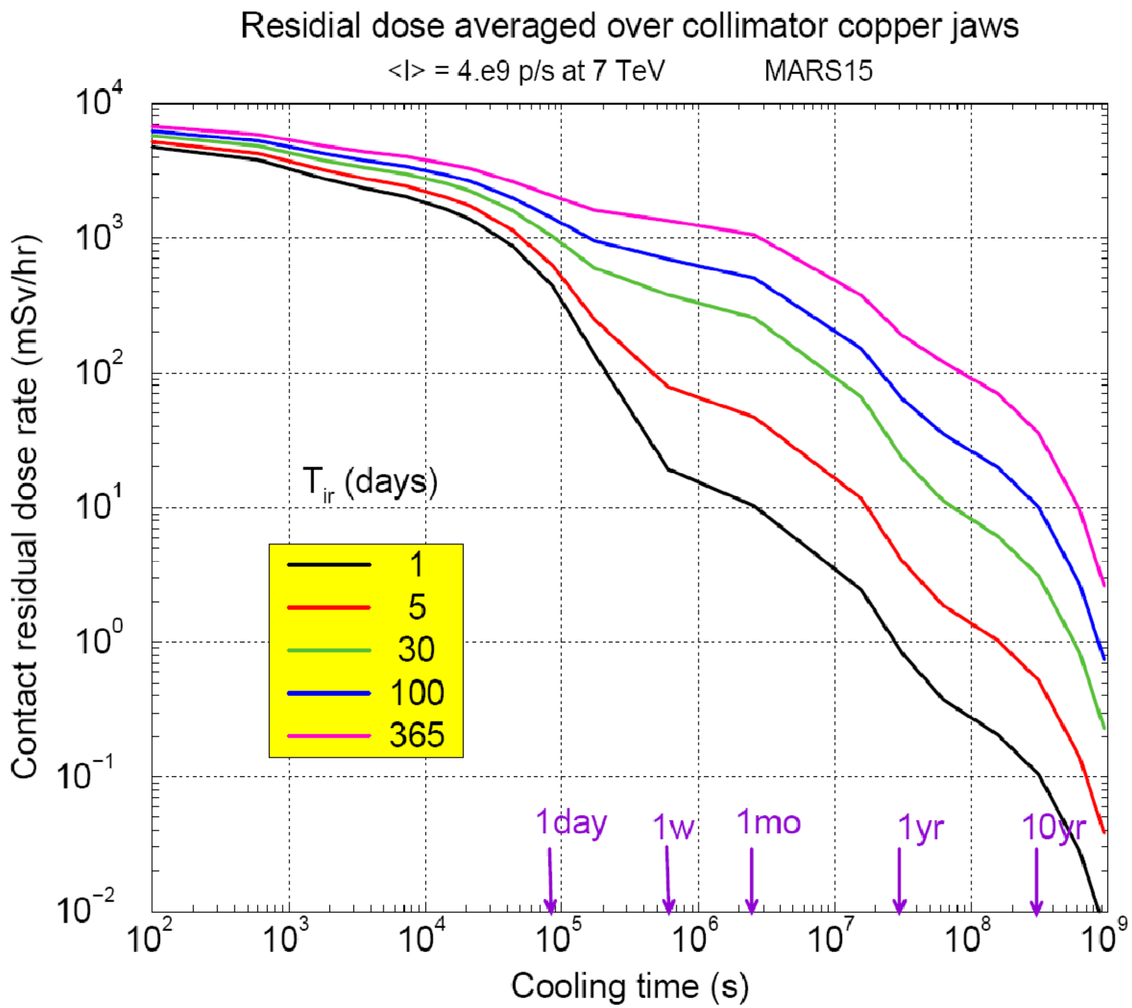


fluence ~ 10^{21} protons/cm^2

Rotatable Collimator Activation & Handling







Need dose rate at ~1m; Mokhov et al

Inter-Lab Collaboration

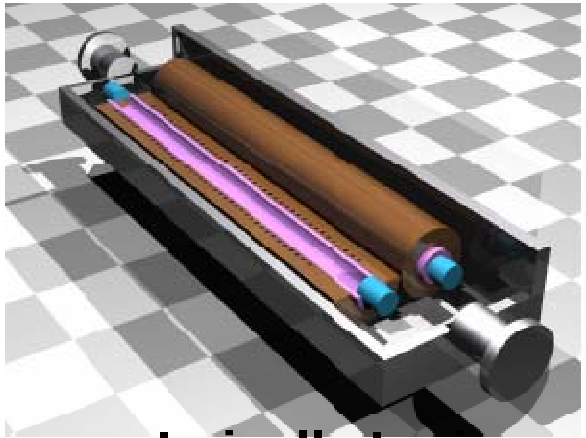
Good will & cooperation limited only by busy work loads

- Regular ~monthly video meetings
- Many technical exchanges via email
- CERN FLUKA team modeling Rotatable Collimator
- CERN Engineering team looking at SLAC solid-model of RC and independently doing ANSYS calculations of thermal shock
- CERN physicists
  - investigating effects of Cu jaws at various settings on collimation efficiency
  - Participating in discussion of RF shielding design
- SLAC Participation in upcoming CERN Phase II brainstorming meeting

Examples of CERN Collaboration on SLAC Phase II Design

LARP

Phase II – TCSM fluka model



Luisella Lari

3/8/2007 L.Lari - AB/ATB/EET 1

LARP Collimator Video Meeting

4 questions to answer (3/3)

In conclusion

⟹ SIMULATIONS should be performed for the slots etc... (geometric part)

⟹ MEASUREMENTS should be performed for the contact resistance

Elias Metral Addressing RF Concerns

The LHC Collimation project

LHC Collimators - Phase II

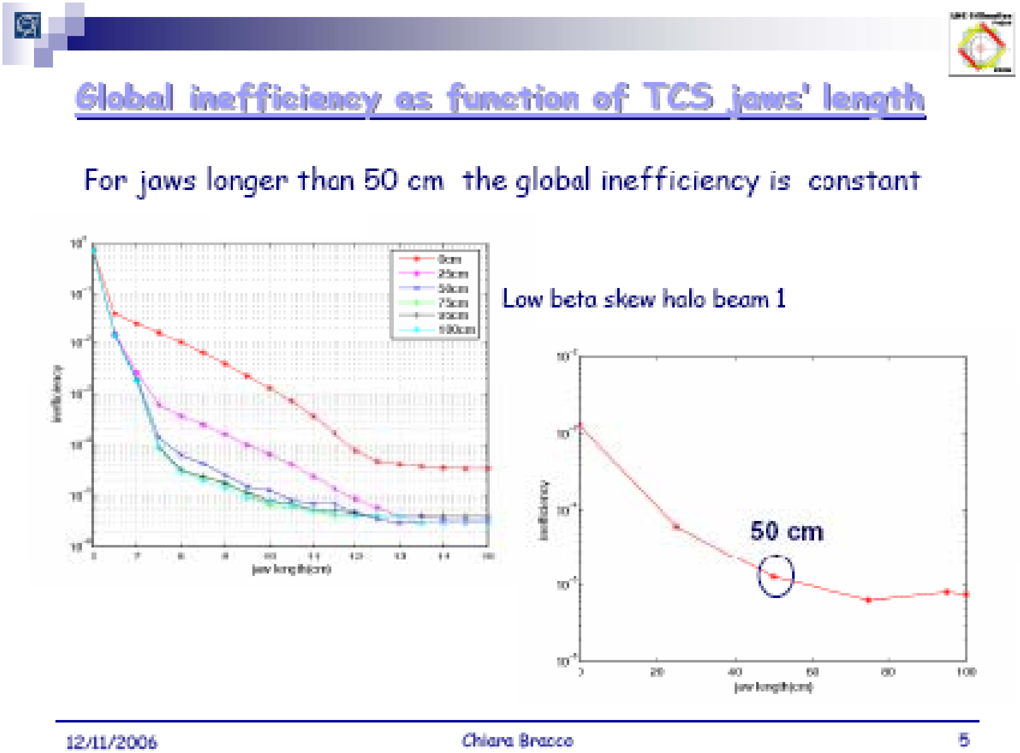
Accident case – simplified elastic-plastic analysis of SLAC Rotatable Jaw

Alessandro Bertarelli
Alessandro Dallocchio
Pawel Smas

Monthly LARP Collimator Video Meeting
2007-03-07

Collaboration on ANSYS

Collaboration on Tracking Efficiency Studies
Chiara Bracco - CERN



- Phase II collimators should provide x 2.5 improvement in global inefficiency
- Beam intensity limitations are due to losses in the dispersion suppressor above the quench limit. These losses are not improved by metallic secondary collimators
- Solutions must be found to improve performance of primary collimators

Specification Changes Relative to April 2006 Design

		RC1 Report 12/12/05	Current
	spec	**value**	**value**
jaw	Length	95cm including 10cm end tapers	93cm with 1cm end tapers
	Diameter	136mm	20 facets, tangent to ϕ136mm
	Material	Copper	Glidcop AL-15
	cooling	Embedded helical channel	Reduced helix depth, Helix pitch reversal
	Special features	Circumferential slots to reduce thermal-induced bending, if no RF problems	eliminated
	deformation	<25um toward beam; <325mm away in steady state; <750um away in 10 sec transient	Inward: 84um SS, 236um Trans – 1st coll to be set at 8.5 σ for clearance
	Range of motion	25mm per jaw, including +/- 5mm beam location drift	27.5 mm per jaw including +/- 5mm
Aperture stop	Range of motion	Controls aperture from 5-15 sigma (2-6mm full aperture), must float +/- 5mm as jaws are moved to follow beam drift	eliminated
Heat load	Steady state	11.3 kW	12.9kW
	Transient	56.5 kW	64.5kW
RF contacts	configuration	Sheet metal parts subject to CERN approval	New geometry

Heat deposited in major components (W/m^3) in 1 hr beam lifetime operation

Component	Units	Upbeam	Downbeam
Stub shaft, aluminum	W/m^3	6.5e3	52e3
Bearing, Si3N4	W/m^3	8.3e3	66.4e3
Image current bridge, aluminum	W/m^3	150e3	400e3
Mo shaft (~const in z, concentrated in $\phi=120^o$)	W	520	
Jaw, Glidcop AL-15 (heat highly variable in z and ϕ)	kW	12.8	

Major jaw dimensions and calculated cooling performance

Component	dimension	units
Jaw OD tangent to 20-faceted surface	136	mm
Jaw OD to facet vertices	137.7	mm
Jaw ID	66	mm
Jaw length, including 10mm (in z) x 15^{o} taper on each end	930	mm
Mo Shaft OD	64	mm
Mo Shaft ID	44	mm
Hub length (centered)	150	mm
Cooling tube OD x ID (square x square)	10 x 7	mm
Embedded helix – center radius	80	mm
Helix – number of turns	~47	-
Cooling tube length – helix + entry + exit from vac tank	~16	m
Flow per jaw	9	l/min
Velocity	3	m/s
Water temperature rise (SS 12.8 kW per jaw)	20.3	C
Pressure drop	2.4	bar

One Year Later…

At June 2006 DOE Review we introduced

- New **jaw-hub-shaft** design which eliminates central stop & flexible springs
- New **reverse-bend winding concept** for the cooling coil which eliminates the 3 end loops, permitting longer jaws and freeing up valuable space for jaw supports, rotation mechanism and RF-features
- **Internally actuated drive** for rotating after beam abort damages surface

Main accomplishments in the last year

- Many test pieces manufactured and examined, tooling developed, and, especially, brazing protocols worked out
- Hundreds of 3-D concept & 2-D manufacturing drawings made
- Rotation & support mechanism fully designed and manufactured
- All parts for first full length jaw assembly manufactured & in-house
- Test lab fully wired, plumbed and equipped

BUT…

- – Still have not brazed nor thermally tested a full length jaw assembly
- – Still do not have a complete mechanical (="RC1") prototype

Summary of New Baseline Configuration

Jaw consists of a tubular jaw with embedded cooling tubes, a concentric inner shaft joined by a hub located at mid-jaw

- Major thermal jaw deformation away from beam
- No centrally located aperture-defining stop
- No spring-mounted jaw end supports

Jaw is a 930mm long faceted, 20 sided polygon of Glidcop

Shorter end taper: 10mm L at 15^o (effective length 910mm)

Cooling tube is square 10mm Cu w/ 7mm square aperture at depth = 24.5 mm

Jaw is supported in holder

- jaw rotate-able within holder
- jaw/holder is plug-in replacement for Phase I jaw

Nominal aperture setting of FIRST COLLIMATOR as low as 8.5 **σ**

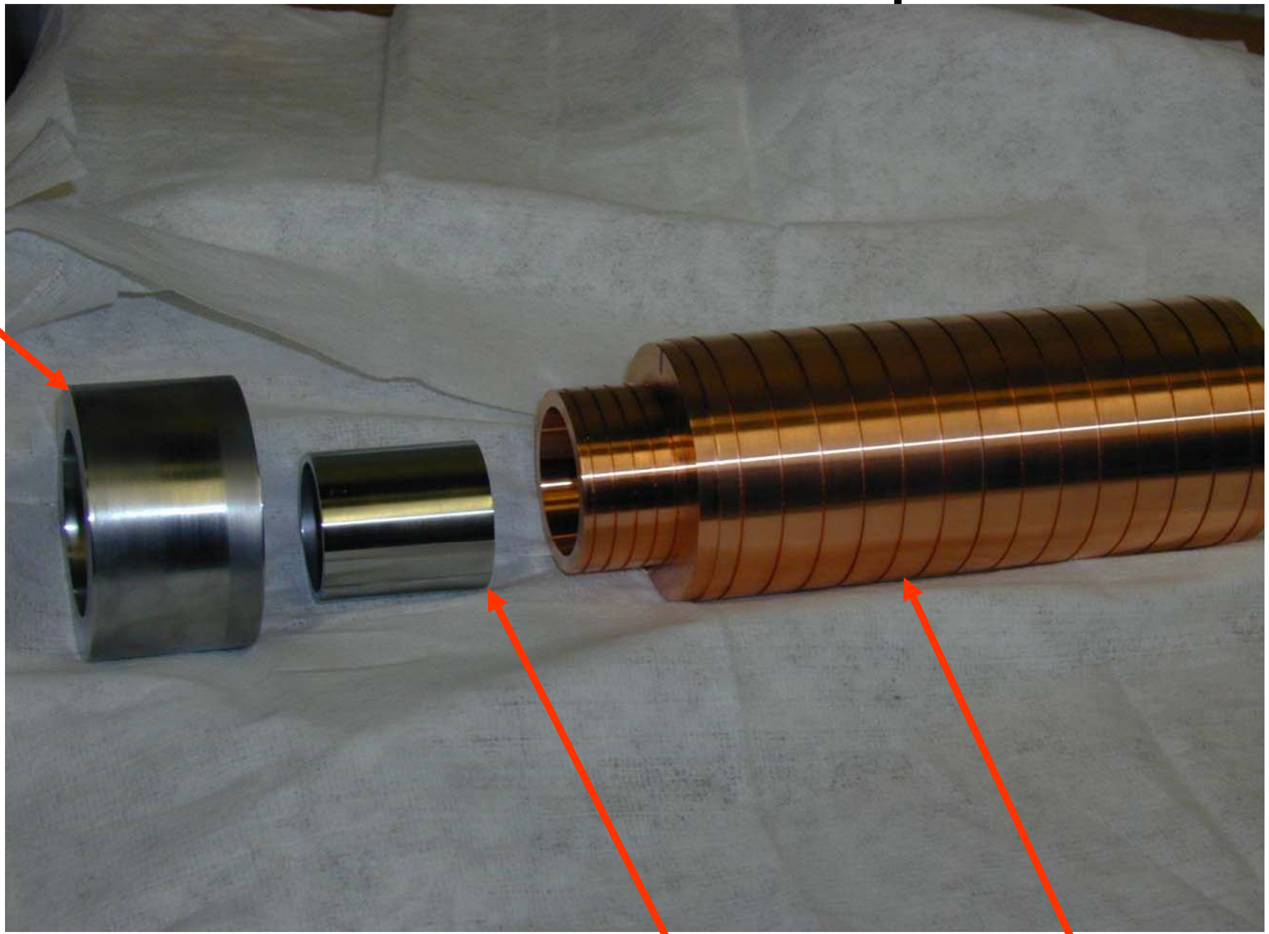
- Results in minimum aperture > 7σ in transient 12 min beam lifetime event (interactions with first carbon primary TCPV)
- Absorbed power relatively insensitive to aperture: for 950mm long jaw p=12.7kW (7σ), p=12.4kW (8.23σ)

Auto-retraction not available for some jaw orientations

Jaw rotation by means of worm gear/ratchet mechanism → "Geneva Mechanism"

Cu-Mo Hub Braze Test parts

#2



#3

#4

#1 - Mandrel Dummy (not shown)
#2 - Mo Shaft Dummy
#3 - Mo Backing Ring
#4 - Cu Hub with braze wire grooves

Up Beam Flex Mount – Rotation Assembly Complete

Design features that may not be apparent in the photos include:

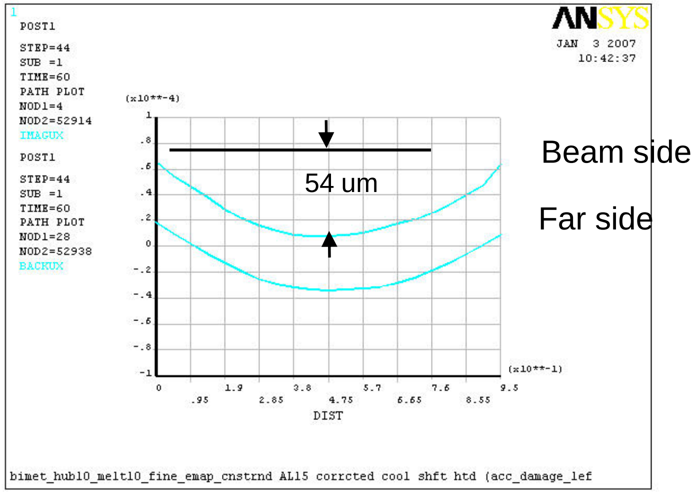
- Integral water cooling channel.
- Flexibility for length increase of the Collimator Shaft (proton load).
- Compensation for Shaft (in-plane) end angle rotation (sag).
- Flexibility for the +/- 1.5mm offsets required during “slewing”.
- Does not require an extra drive and control (uses existing systems).
- 2.5mm motions advance the ratchet 1 “click”.
- 512 “clicks” advance the Collimator to the next facet.
- Facet advancing is ~5% of the lifting load for Vertical Collimator

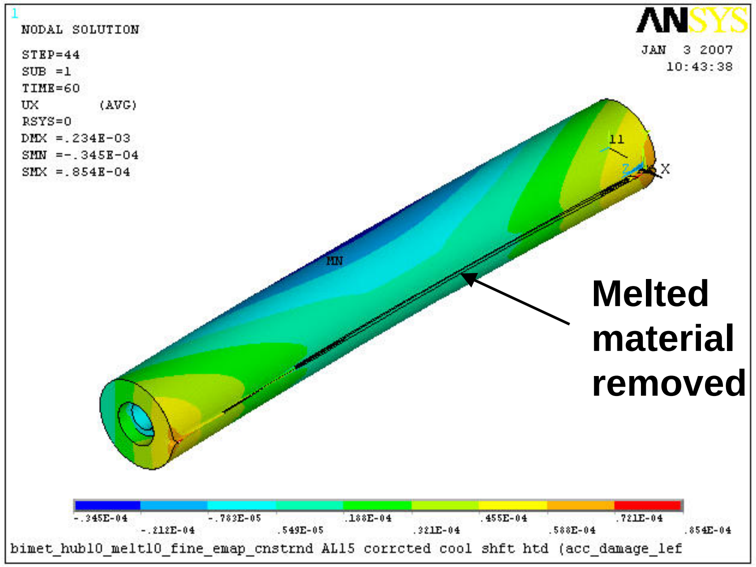
PLASTIC DEFORMATION of ENTIRE JAW after a BEAM ABORT ACCIDENT?

Doyle

PRELIMINARY RESULT:

- 0.27 MJ dumped in 200 ns into ANSYS model
- Quasi steady state temperature dependent stress-strain
  - bilinear isotropic hardening
- Result:
  - plastic deformation of 208 um after cooling, sagitta ~130um
    - Jaw ends deflect toward beam
  - Jaw surfaces at 90 to beam im





Impedance studies for Phase II collimators

Designing RF contacts for transition pieces.

- What are the critical problem areas or design concerns?
- What is the maximum taper angle? Can we use greater than 15 degrees over short distances?
- Are trapped modes/heating a concern?

MAFIA simulations

- Compare geometric impedance between Phase I and Phase II collimators. Our odd geometry increases/decreases geometric wakes by how much?
- Include resistive wall surfaces and contacts to look at surface resistance contribution to impedance.

Impedance measurement test stand

- Similar studies as performed at CERN for Phase I.
- Measure RF contact resistance for our transition piece.

RF geometry at beam mid-plane

Offset position is 5mm beyond beam centerline

Angles are sphere end tangents at 10mm and 2.5mm from beam