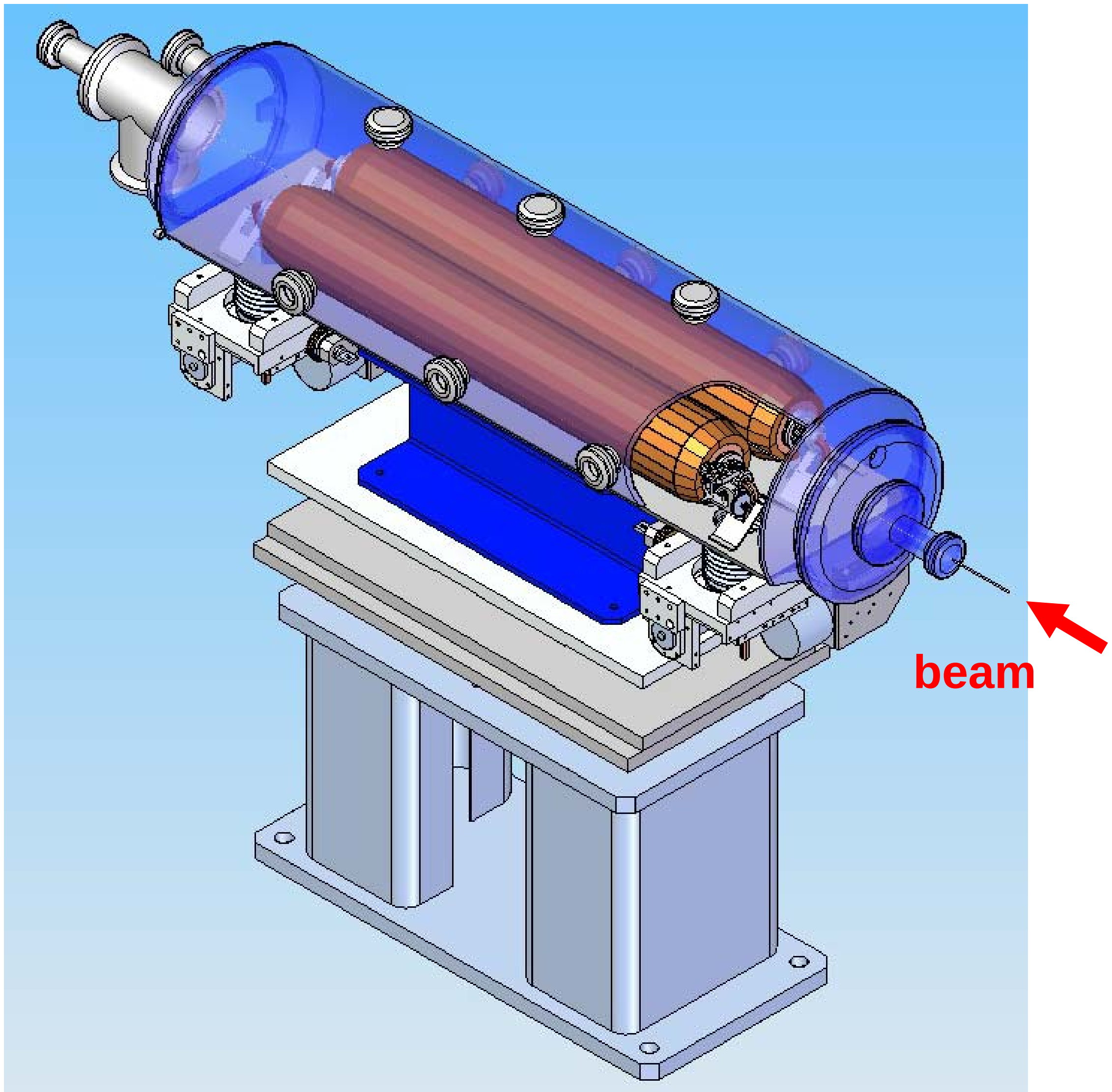
LARP

US LHC Accelerator Research Program

BNL - FNAL- LBNL - SLAC



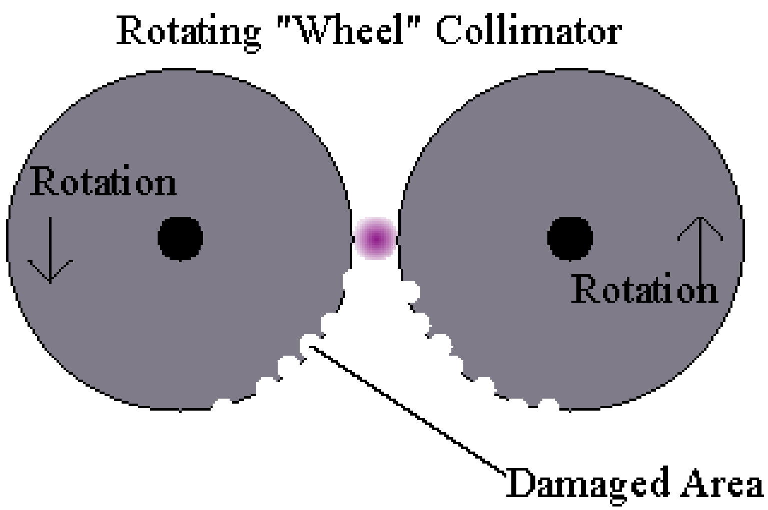
LARP Rotatable Collimator

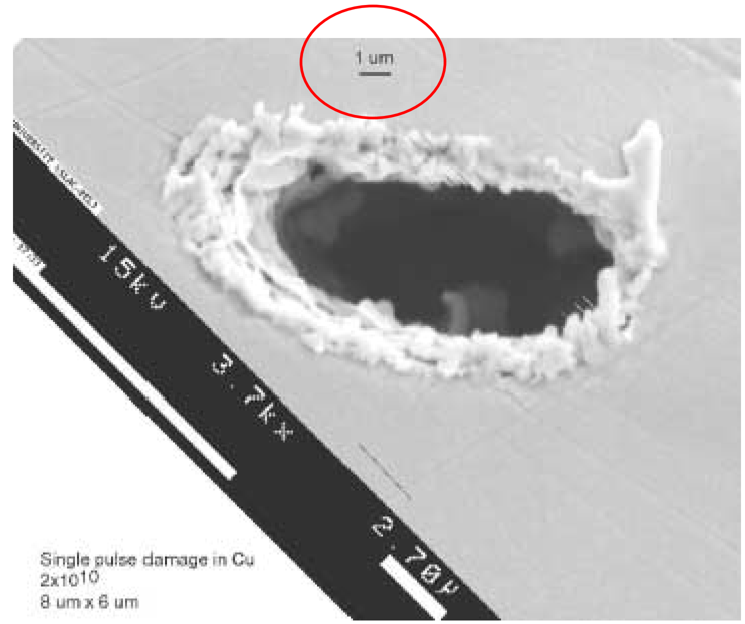
02 April 2009

Phase II Collimation Conceptual Review - CERN

Tom Markiewicz/SLAC

NLC Developed “Consumable” Collimator to Handle Infrequent e- Beam-Impact Events





In 2003 SLAC suggested to CERN & LARP that this concept might be the basis of an LHC Phase II Secondary Collimator

NLC Consumable Collimator Prototype

rotatable jaws – 500 to 1000 hits

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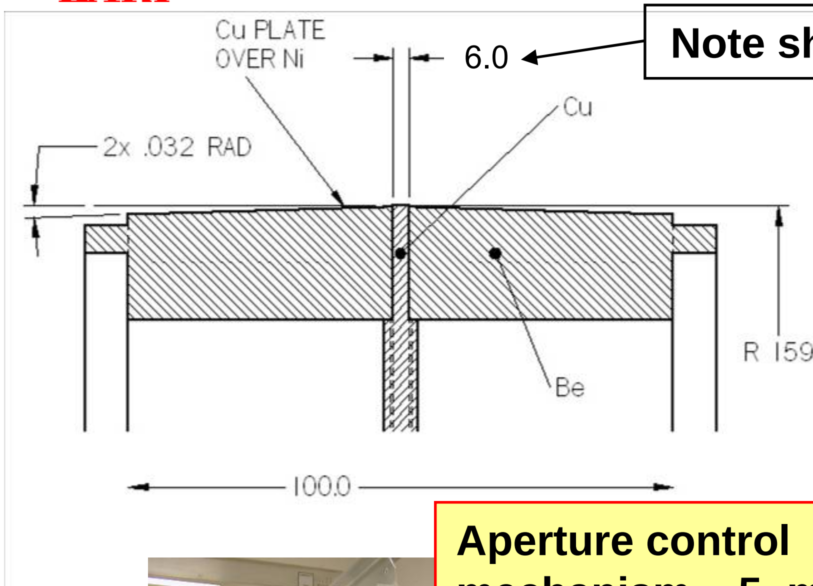
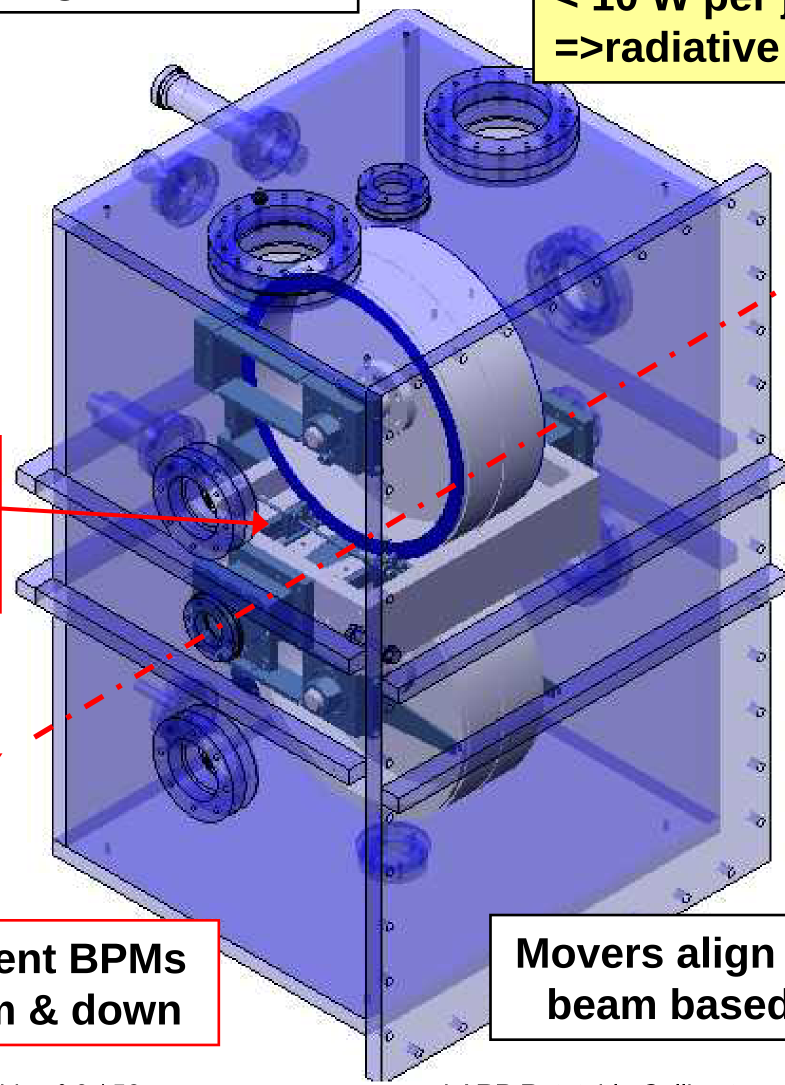


Note short high-Z material.

< 10 W per jaw
=>radiative cooling!

Aperture control mechanism – 5μm accuracy & stability



Alignment BPMs upbeam & down

Movers align chamber to beam based on BPMs

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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

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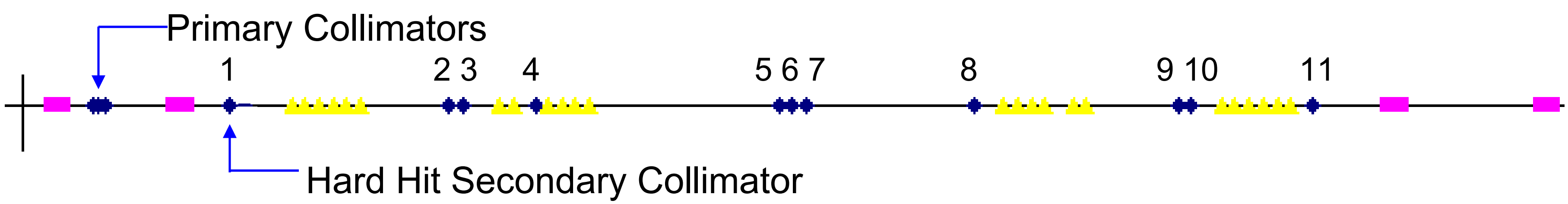
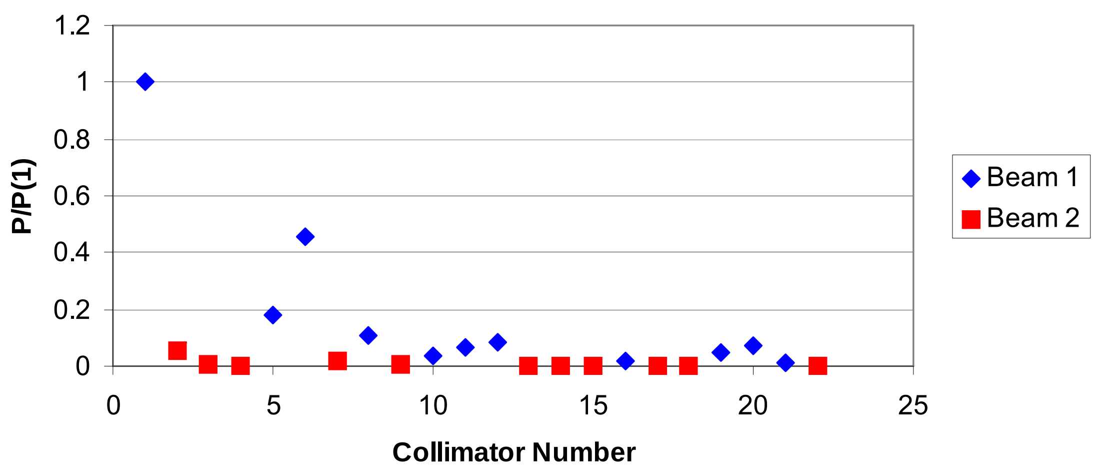
Secondary Collimator Design Specifications

Space	Plug ready for 30 prepared Phase II locations & orientations Transverse dimensions to not interfere w/ other beampipe
Material	No Beryllium
Thermal performance	Thermal distortion under "Steady State" and "Transient" beam loss rates must not decrease collimation efficiency **Minimize thermal swelling & distortion from differential heating**
Vacuum	UHV, in situ bake-capable NO water-vacuum braze joints
Precision	25 um jaw flatness, 10um step size
Robustness	Radiation Hard **Survive beam abort accident and still be useable**
Impedance	Metal, with low contact resistance in joint that permits rotation
Time	Originally, prototypes were to be required in 2008 → "Shovel Ready" materials & technology "Best Effort" extension of NLC design to LHC application

First Secondary Sees Most Energy





Relative Energy Deposition in C-C Secondary Collimators in IR7 [P(1)=23kW at 4E11 p/s]

- Final configuration may have different designs, materials or gaps
- It is important to understand performance with, for example, "Cryo Collimators" in lattice

Not much difference

Inefficiency	1C-10Cu	All Cu
Horizontal	2.8×10^{-4}	3.7×10^{-4}
Vertical	3.6×10^{-4}	4.4×10^{-4}
Skew	4.6×10^{-4}	3.9×10^{-4}

SLAC Timeline for RC=Rotatable Collimator Prototype

J. Amann, **G. Anzalone**, Y. Cai, E. Doyle, L. Keller,
S. Lundgren, T. Markiewicz, H. Rogers, **J. Smith,** L. Xiao

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 postdoc
2008:	Thermal tests of 1st jaw, begin to fabricate 3 more jaws, rework jaw fabrication process, redesign RF transitions, redesign vacuum tank, jaw support
2009:	Fabricate & test full RC adequate for TT60 robustness tests; ship to CERN
2010:	Fabricate & test 2nd full RC adequate for tests in LHC; ship to CERN
2011:	TT60 and LHC tests (?); Collimator technology selection; final drawing package
2012:	Production support, as needed
2013:	Production & installation support
2014:	Commissioning support

Main Deliverables

- Thermal tests of single collimator jaw
- Construct and mechanically test full RC prototype for TT60
- Construct and mechanically test full RC prototype for LHC

FY	LARP (k$)
2004	110
2005	190
2006	350
2007	800
2008	950
2009	950
Total	3350

Evolution of Project: A serious and thorough effort

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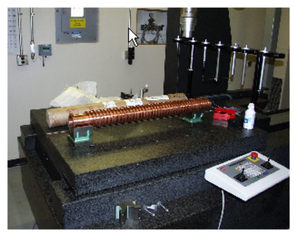
Too much for 20min talk: See web site and design report

- Materials: Copper, Glidcop, Molybdenum, CuNi
- Fabrication Process: Precision machining, brazing
- Mechanical Design: Ever evolving (how to stop it!):
  - >500 2-d drawing and 3-d solid models
- Test parts
- Test Fixtures
- Tooling
- Metallurgy
- Vacuum tests
- Metrology
- Radiation testing
- Lab development
- Instrumentation
- DAQ
- ANSYS, FLUKA, SixTrack, OMEGA3P

The Rotatable Collimator Program

The RC is one of several designs under consideration as a Phase II Secondary Collimators for the LHC



Management

Meetings

Status

- Drawing Tree with links to existing pdfs & jpegs and Summary of weekly status meetings
- Status of Mechanical Drawing Process

Photos

Talks

Files

Mechanical Design

Documentation

LHC Phase II Rotatable Collimator - RC1 Conceptual Design Report

J. Amann, G. Anzalone, R. Assmann, C. Bracco, Y. Cai, E. Doyle, L. Keller, L. Lari, S. Lundgren, T. Markiewicz, T. Raubenheimer, R. Rogers, J. Smith, Th. Weiler, L. Xiao,

1. Introduction
2. Beam Line Layout and Operating Scenarios
3. LHC Constraints and Specifications
4. Design Evolution and Rotatable Collimator Concept
5. Current Design
6. Prot[illegible]nstr[illegible]
7. Pro[illegible]pe[illegible]in[illegible]

References

Appendix A. Efficiency Simulations
Appendix B. Energy Deposition Simulations
Appendix C. Accident Simulations
Appendix D. Impedance Calculations and Measurements
Appendix E. Evolution of ANSYS Simulations

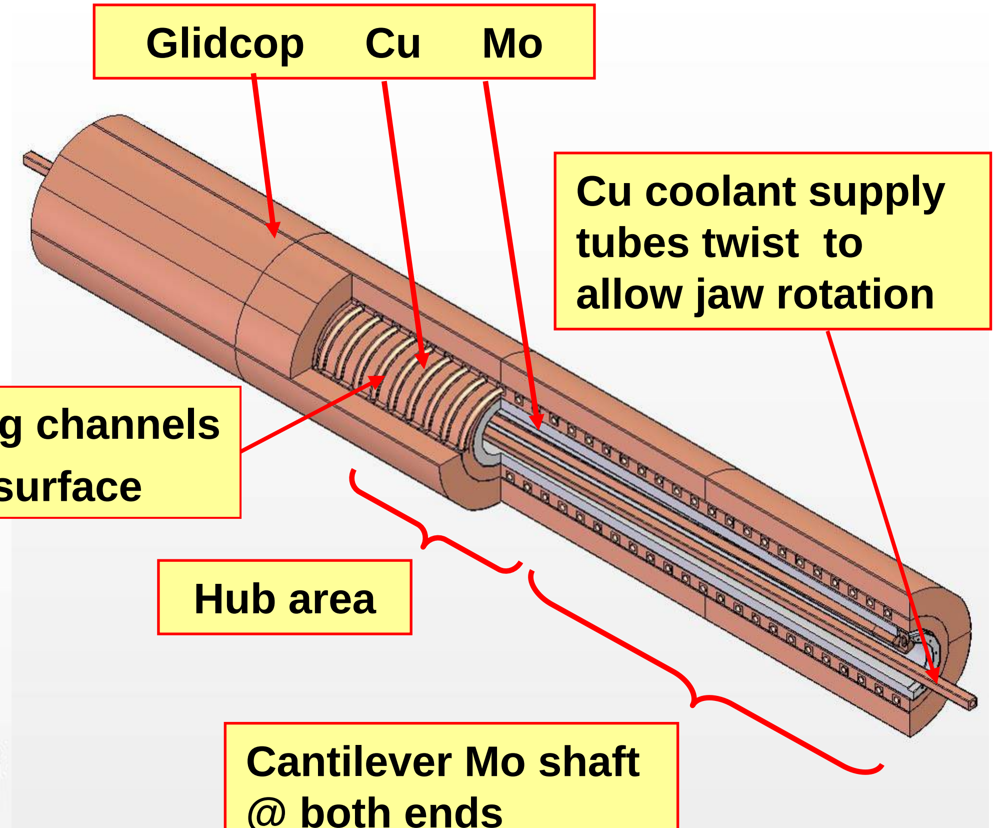
DRAFT

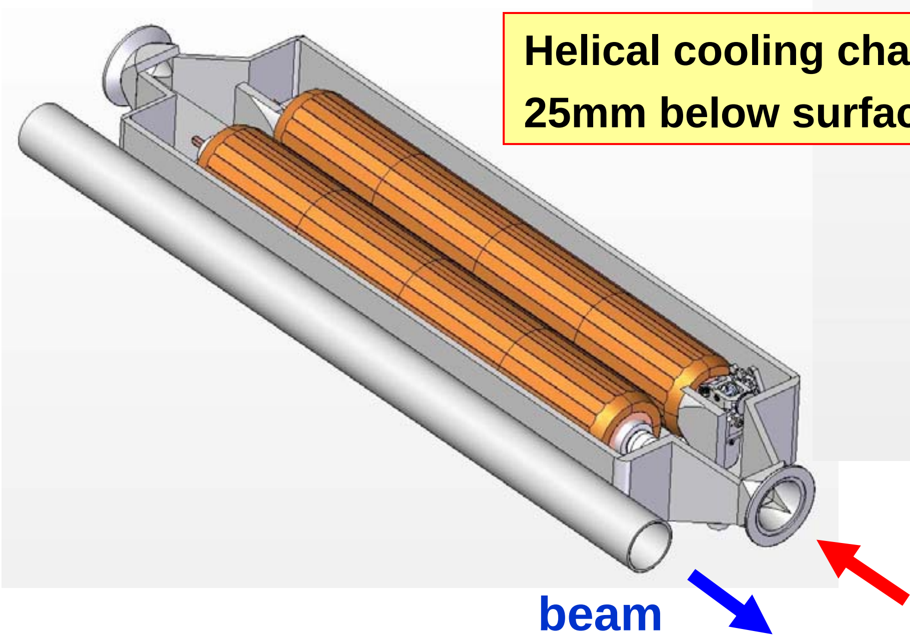
http://www-project.slac.stanford.edu/ilc/larp/rc/

LHC Phase II Base Concept

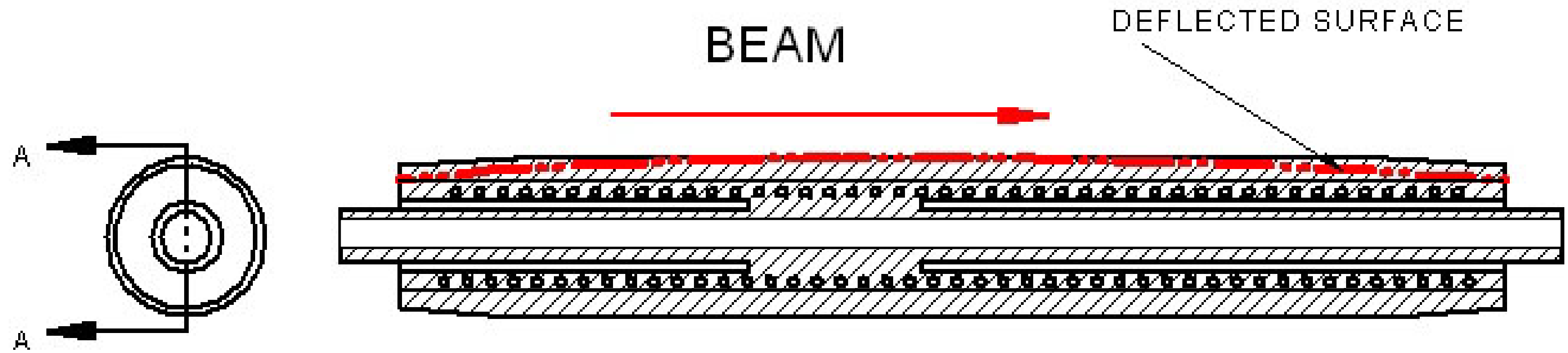
physical constraints
current jaw design

- 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)



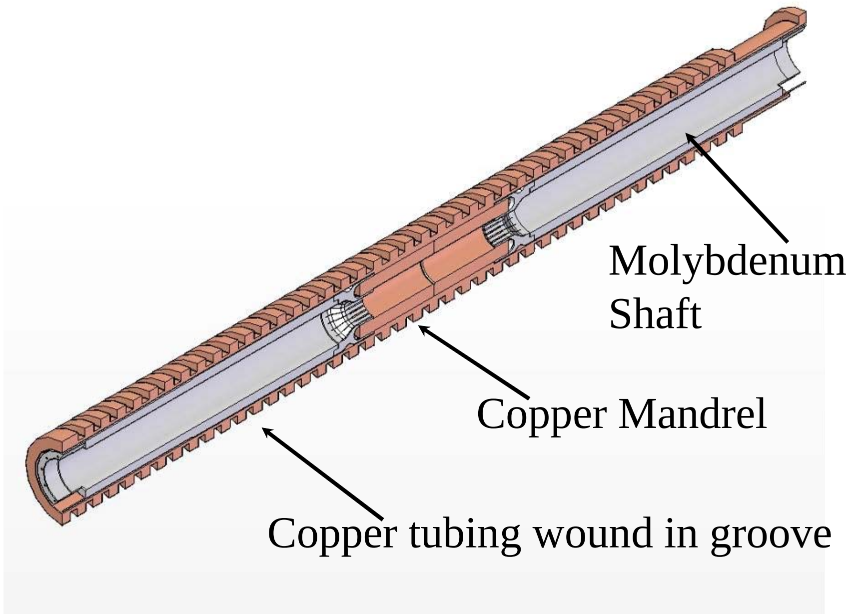


Glidcop Jaw – Cu Mandrel – Cu Hub - Molybdenum Shaft Design



2mm shaft-jaw gap gives x5 improvement in thermal deformation over solid shaft-jaw design
1260 μm → 236 μm (60kW/jaw, τ=12min)
426 μm → 84 μm (12kW/jaw, τ=60min)

Rather than Cu, Moly shaft improves Gravity sag x3:
200 μm → 67 μm
Thermal bulge 30%:
339 μm → 236 μm



Design and Performance Summary

Grooved Copper Mandrel with center bore is wound with 16m 10mm x 10mm x 1.5mm wall CuNi tube provides cooling

Glidcop Jaws with 20 facets, brazed to OD of mandrel, provide collimation surface

Hollow Molybdenum half-shafts, brazed to a central hub, in turn brazed to ID of mandrel, supports mandrel & jaw assembly at center, providing a 2mm gap so that when hot beam-side of collimator expands, assembly bends away from beam

Ends of CuNi tube reverse wound back through center of hollow shaft and twist to permit rotation

Simple Molybdenum vane supports shaft and Geneva-Gear rotation drive and permits jaw expansion

RF transition piece to vacuum tank ends runs on jaw end on 25μm gold plated ball bearings & permits jaw to open for injection

Bench-marked ANSYS calculations predict 84μm, 236μm for t = 1hr, 12min beam lifetimes

For 1 MJ beam abort accident ANSYS calculations predict 50μm permanent deformation and 1°C temperature rise in cooling water (4 bar). Risks to be tested in TT60 include:

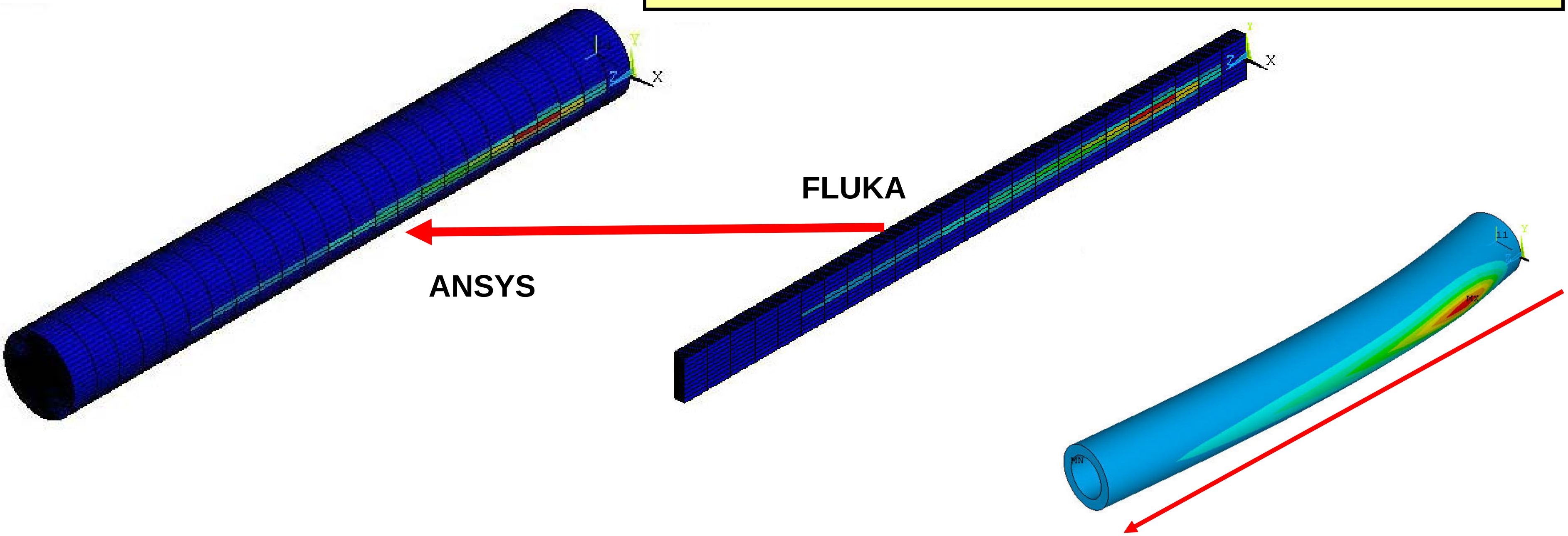
- Damage to Glidcop surface that extends over "too much" of circumference
- Cu vapor gumming rotation mechanism
- Welding opposite jaws together

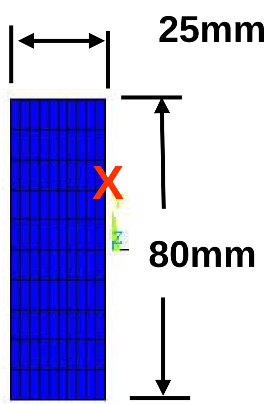
See other talks for efficiency & impedance expectations

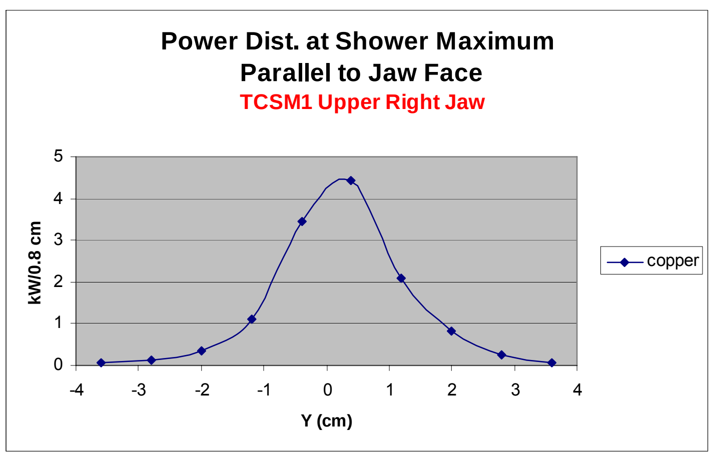
Basis for Design Choices

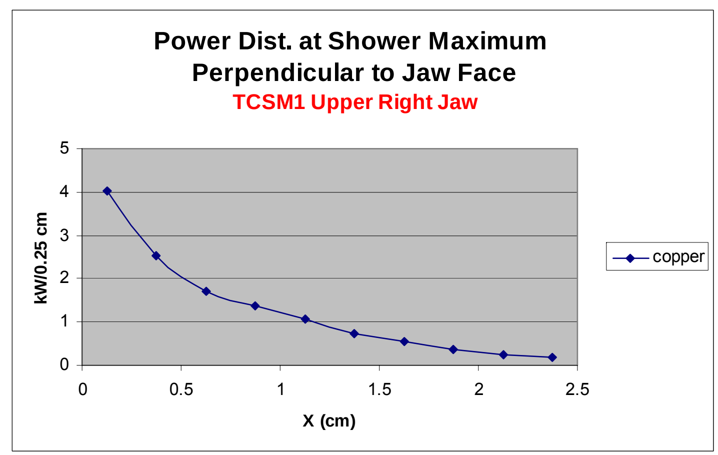
ANSYS Thermal/Mechanical simulations using FLUKA energy deposit

Thermal distortion is a function of material, jaw OD & ID, length, and cooling arrangement









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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

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

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

Brazing Each Moly Shaft End to a Central Copper Hub

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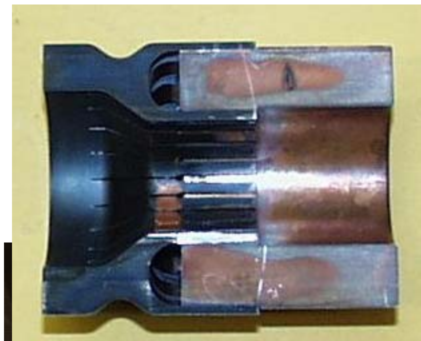
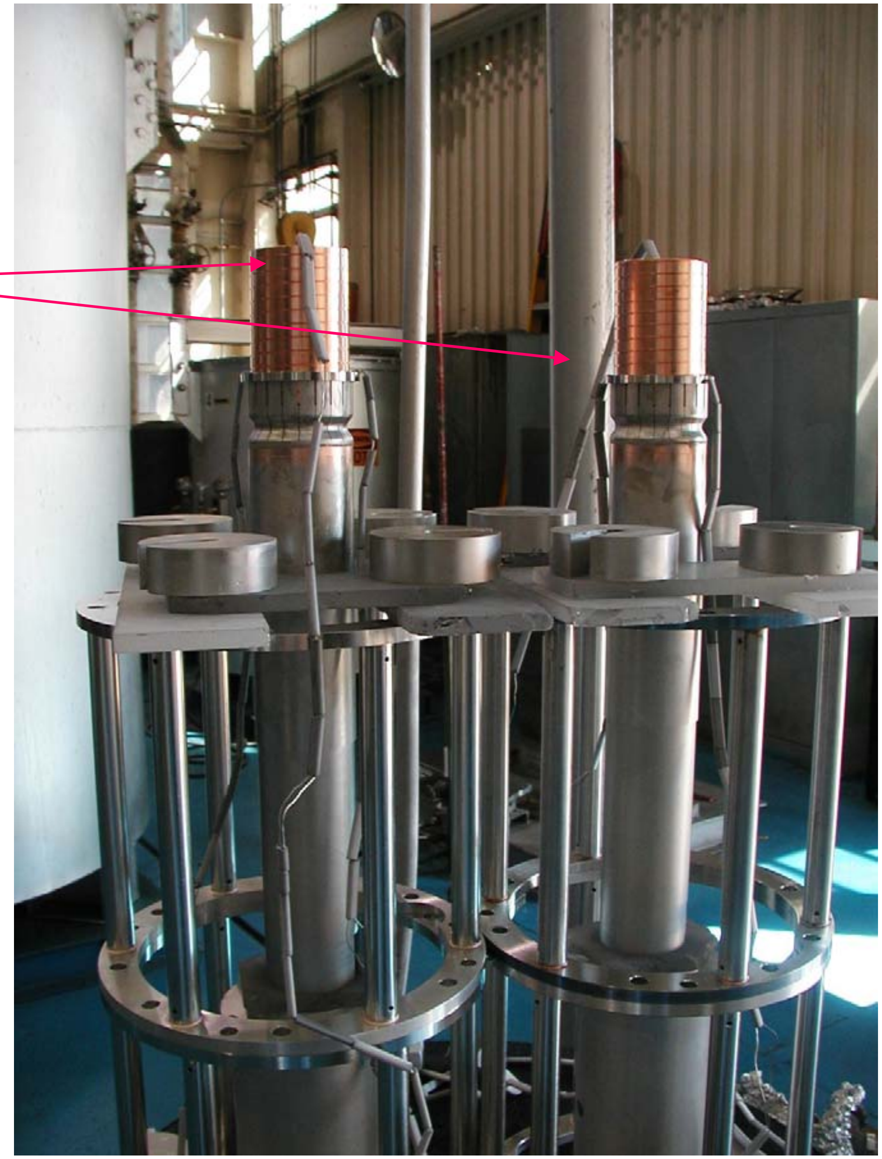
After **much** R&D, developed method to braze Molybdenum to Copper for inner shaft



Shaft halves



Inserting Molybdenum Shaft Ends into Mandrel then Wind Coil Around Mandrel with Ends of Coil Protruding Out Each End

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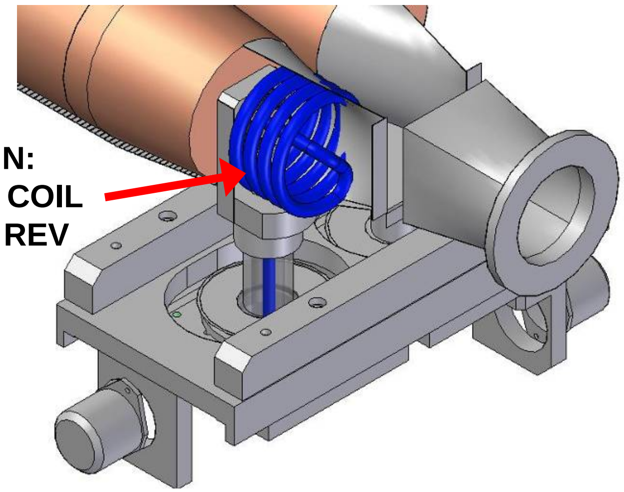
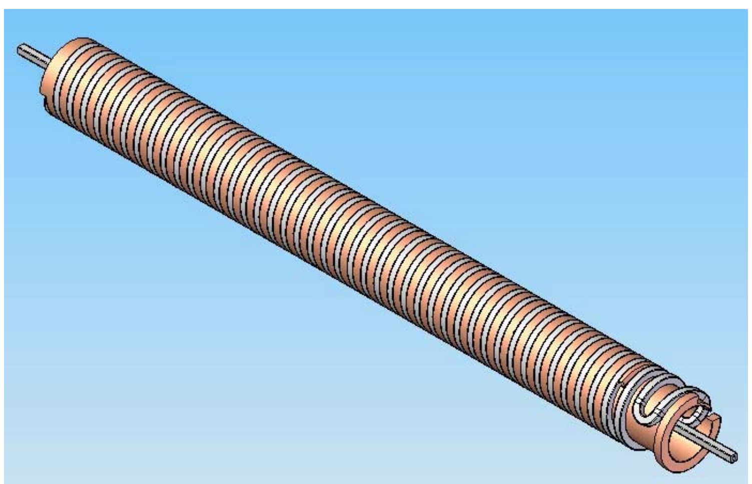
Reverse-bend and Twisted Cooling Coil

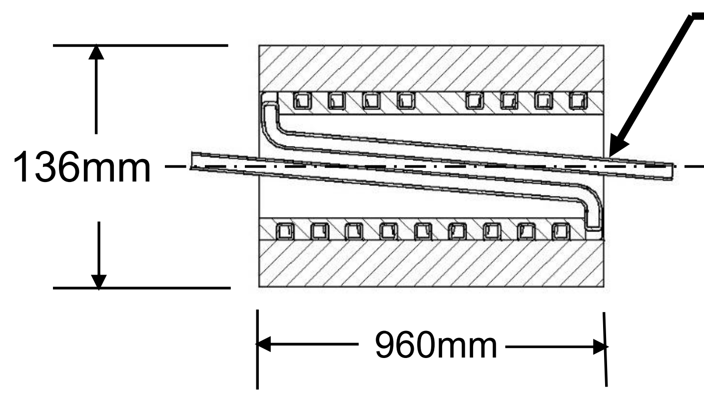
permits longer jaws and frees up length for jaw supports, rotation mechanism and RF-features

**OLD DESIGN:
EXTERNAL COIL
PERMITS 1 REV
OF JAW**



4-1/2 Turns without failure



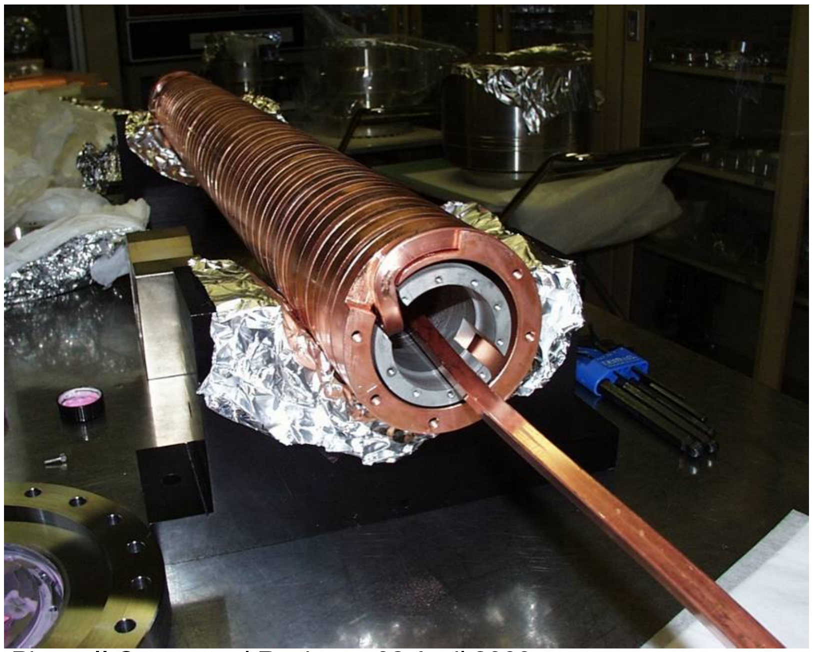


Restrain each tube on centerline of bearing

Braze Step#1 Shaft Assembly & Coil to Mandrel

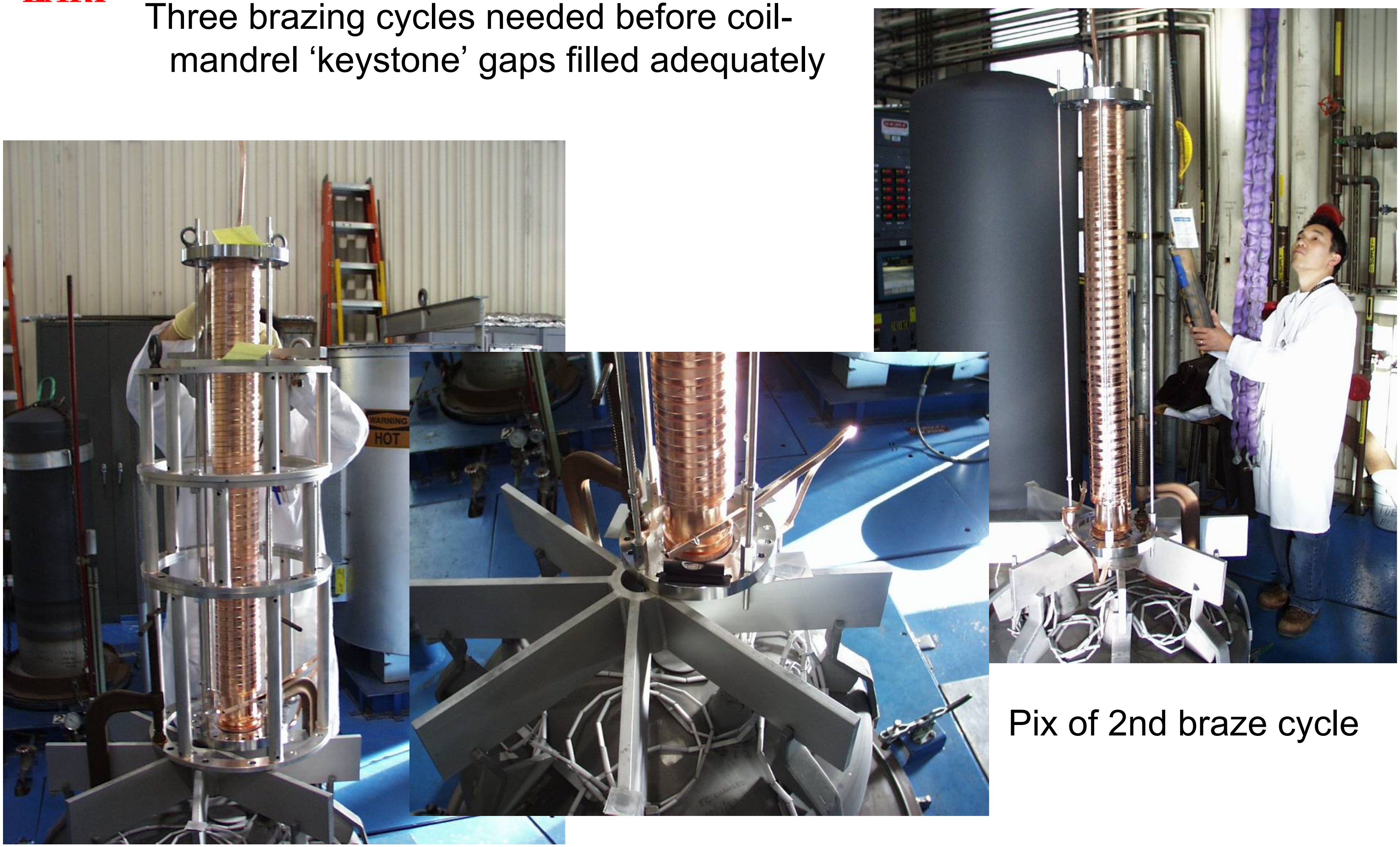
On support stand and ready for insertion in baking oven

- Carbon block used to hold thermally expanding copper against central hub and shaft (moly and copper)
- Next time may use carbon block full length of mandrel



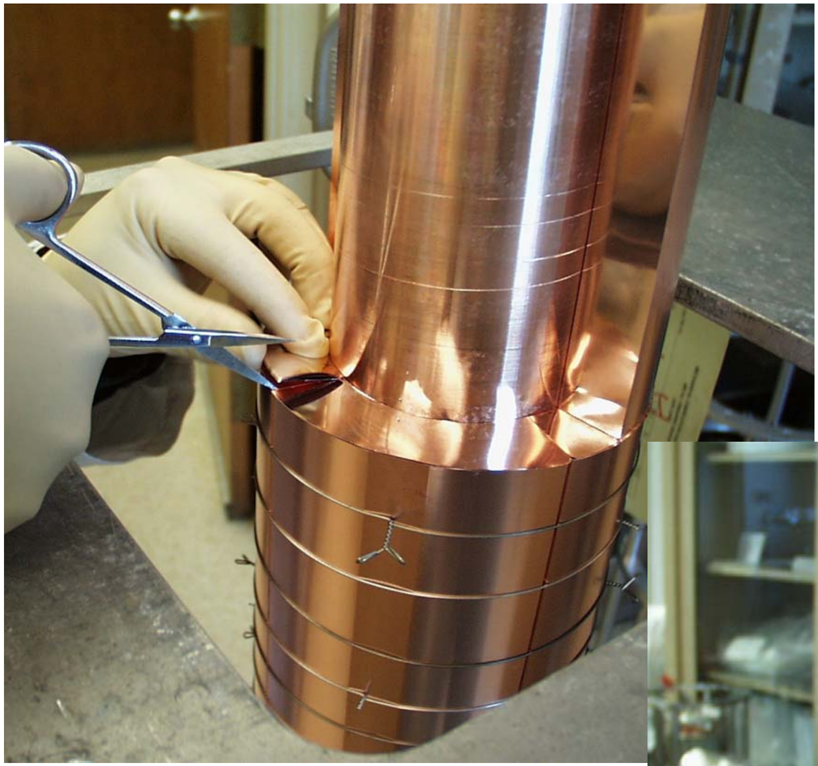
Filling Coil-Mandrel Keystone Gaps

Three brazing cycles needed before coil-mandrel ‘keystone’ gaps filled adequately



Pix of 2nd braze cycle

Measure & Machine Quadrants to Mandrel. Assemble & Braze



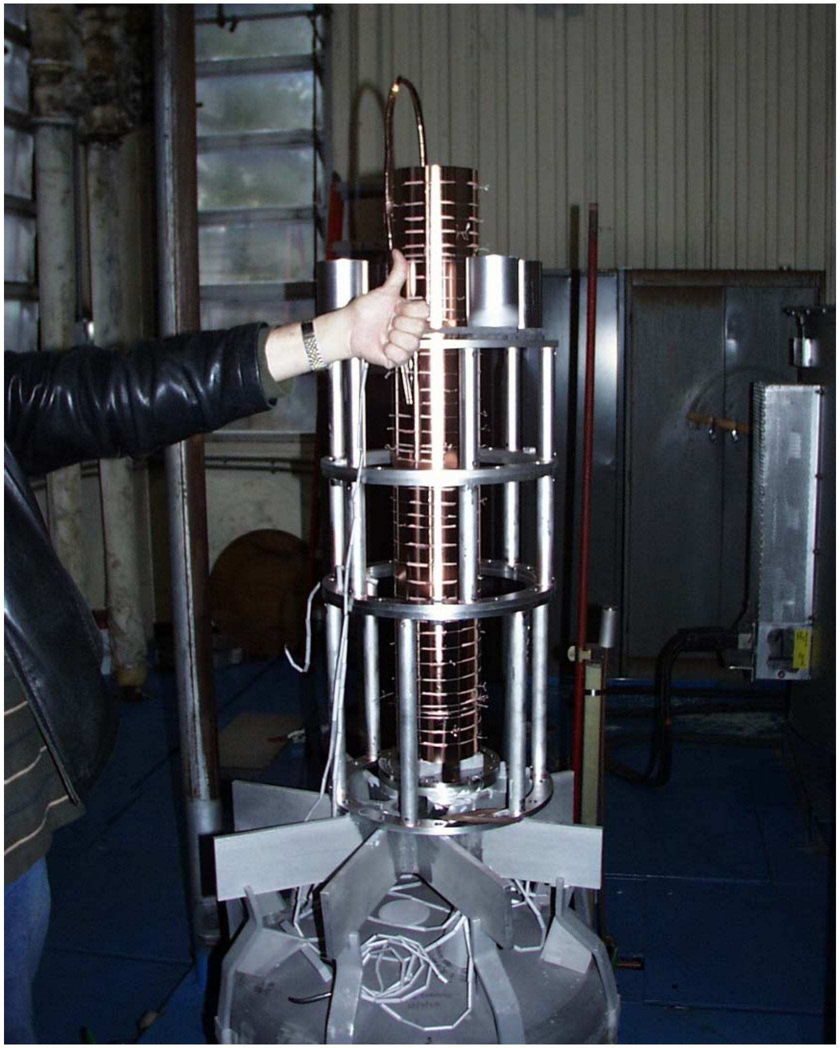
Using 50-50 Au-Cu brazing material ($$)

Results of Jaw Brazing 22 April 2008

Looks good!

For next 3 jaws plan to:

- Use full round jaw segments
- Over-size parts & cut down to proper radius



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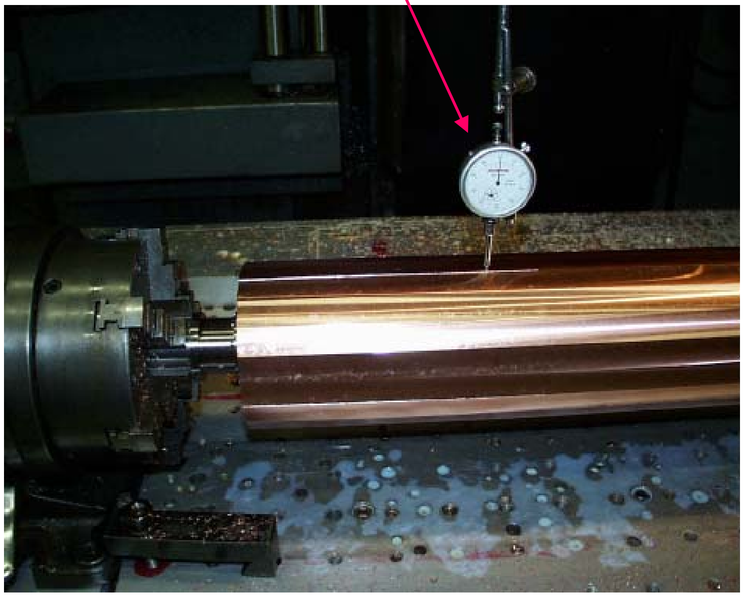
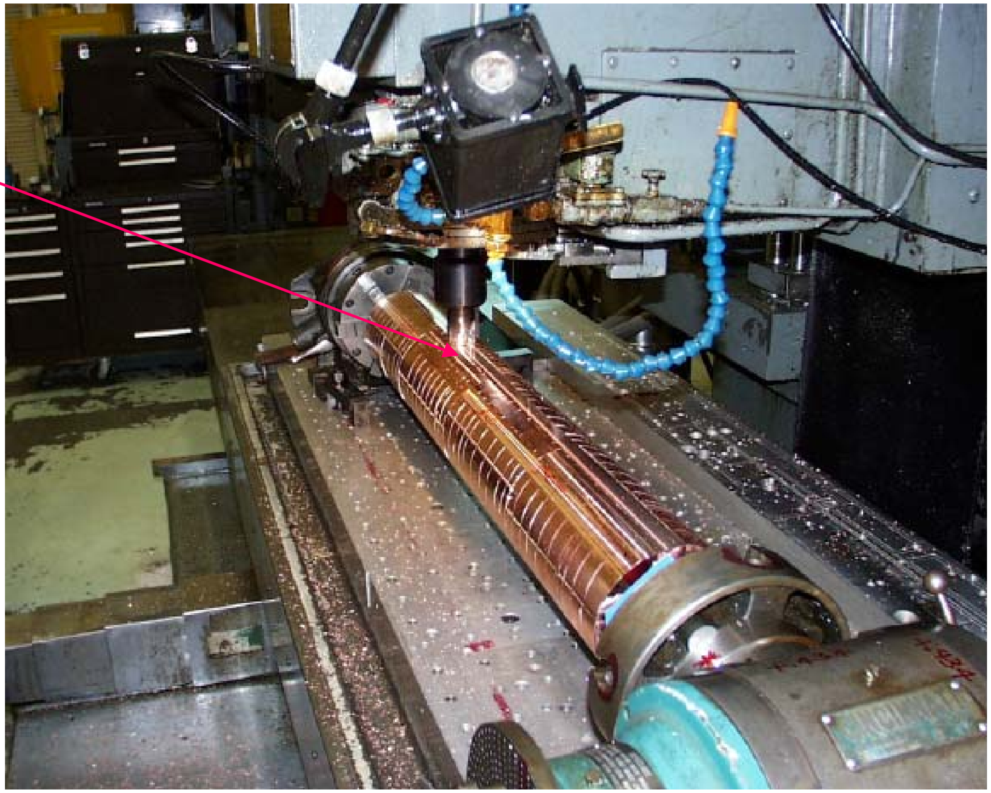
Machine Flat Facets and Groove for Heater Test

Final brazing was a success!

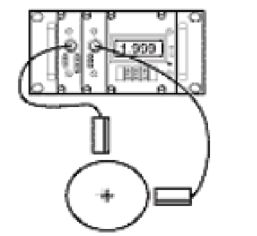
- Flat facets and grooves for heater tests and thermocouple holes have been machined.
- Within 25 micron tolerance along facet surface.



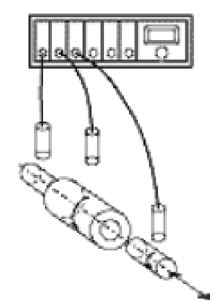


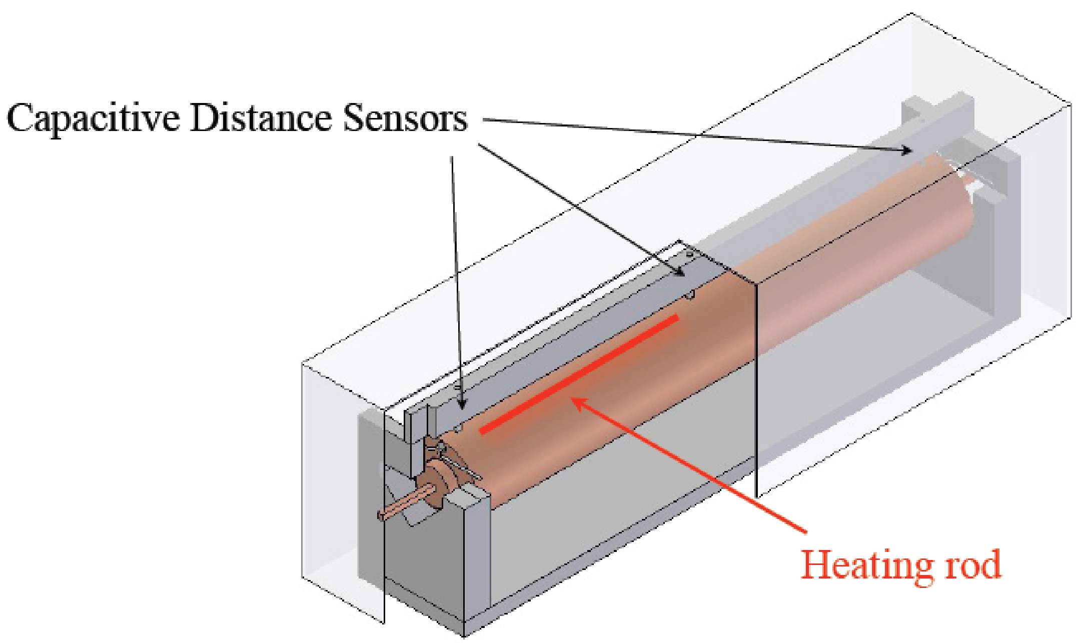
First Full Length Jaw Thermal Tests

- Use two 5 kW heaters placed along jaw surface (simulating steady state beam heating)
- Sensors measure thermal deflection to confirm ANSYS simulations.
- Deflection toward beam during beam heating must be minimized.



Images from www.capacitec.com





Thermal test setup

Jaw in support stand

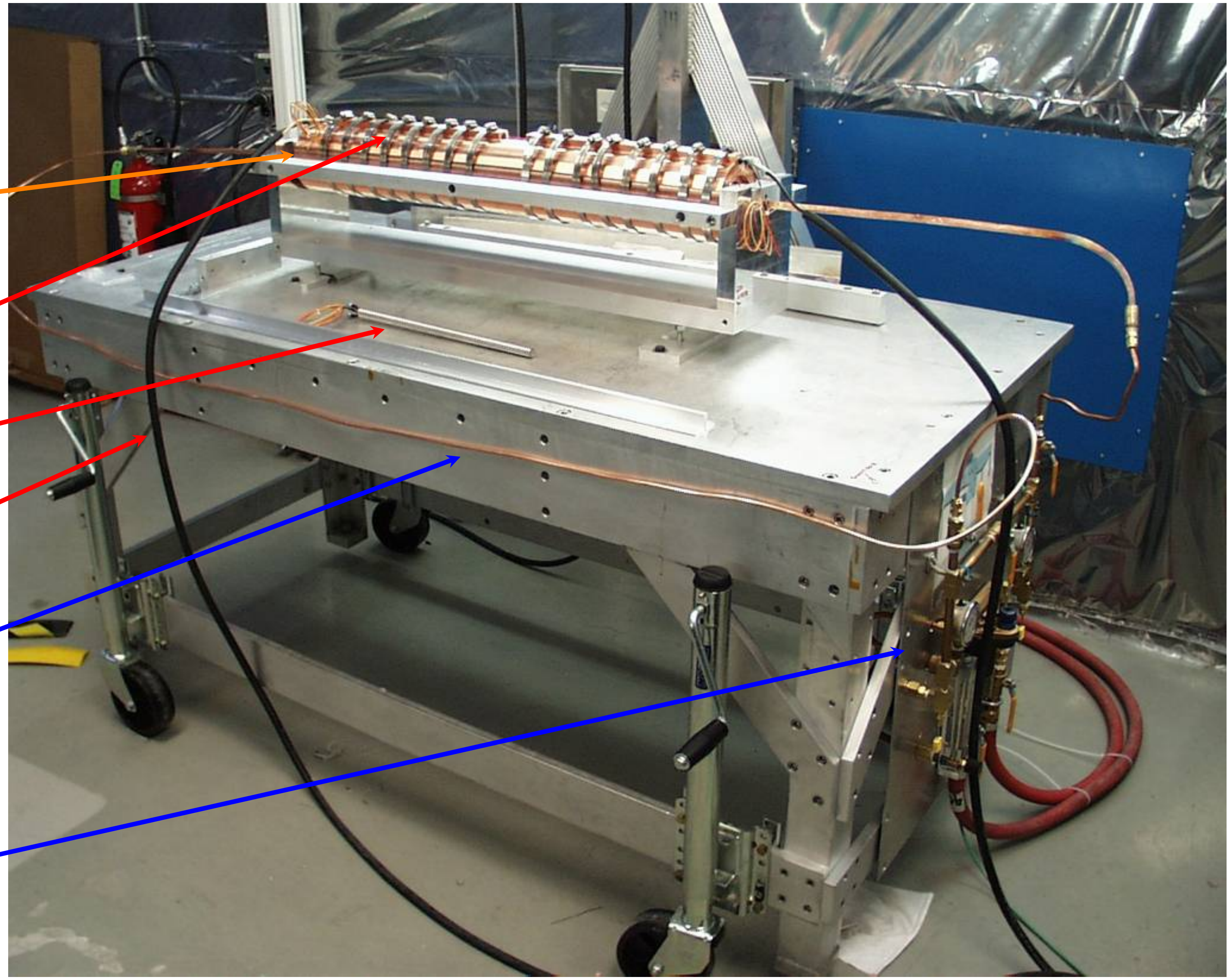
Heaters strapped on jaw

Extra heater

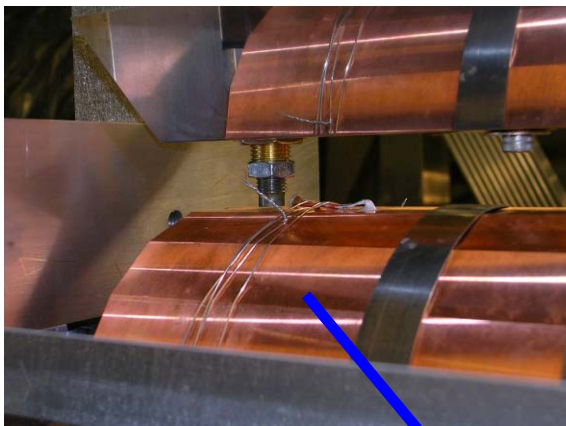
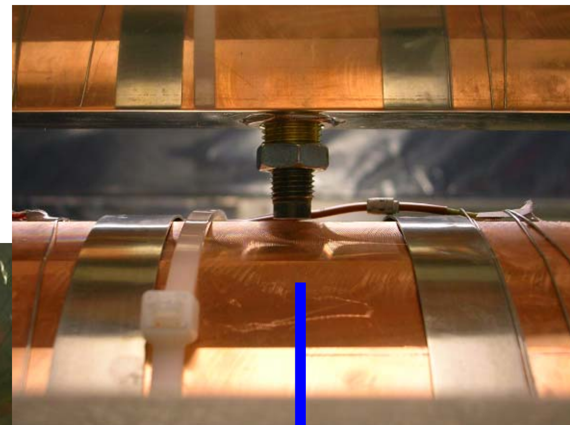
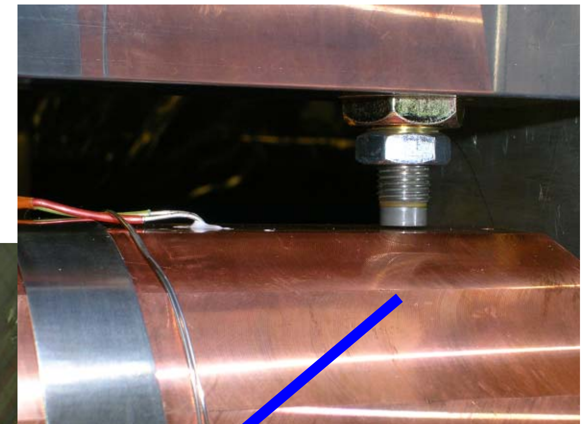
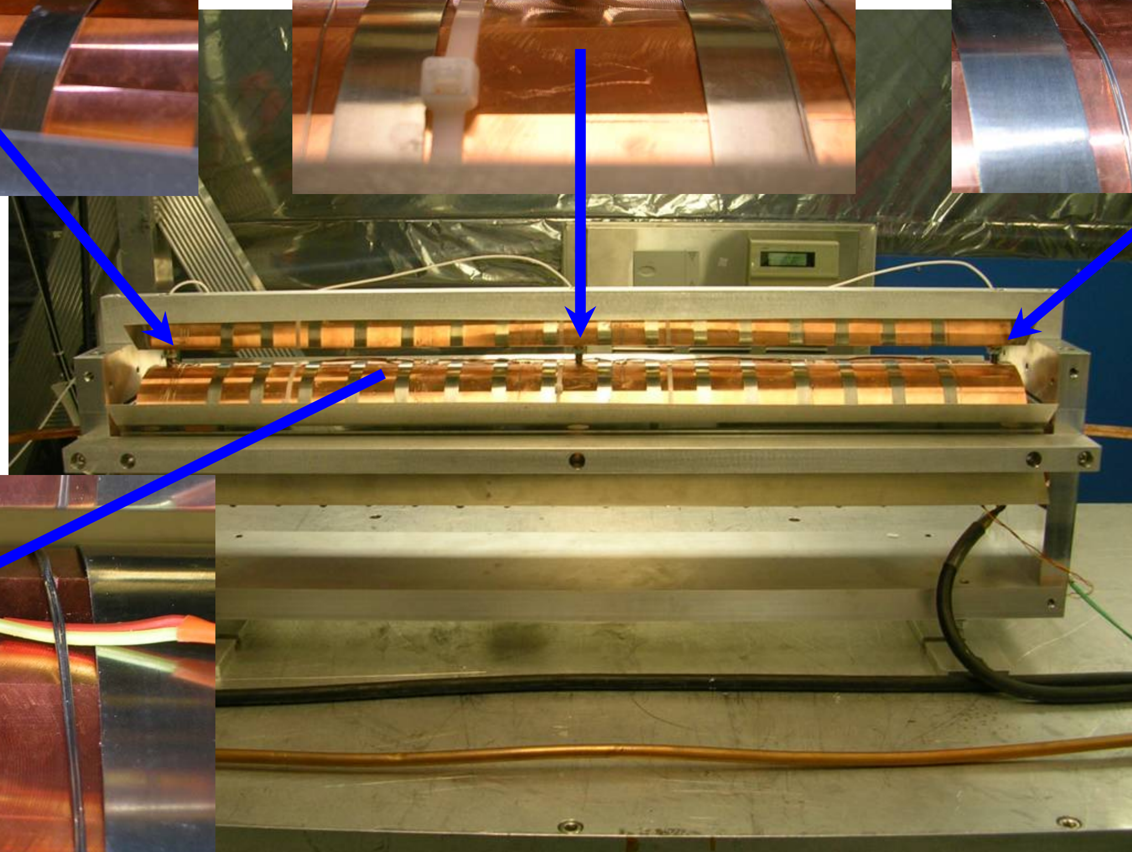
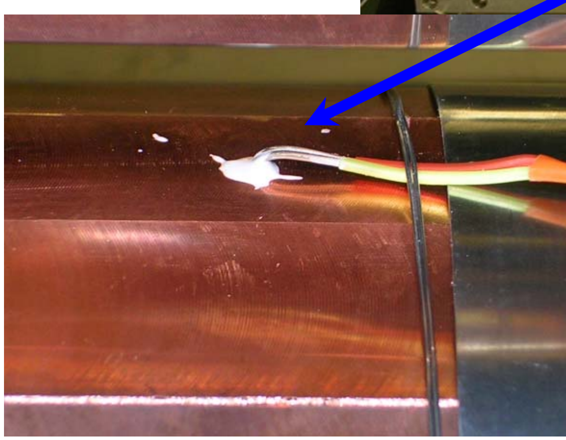
Heater cable

Water flow tube

Water flow control



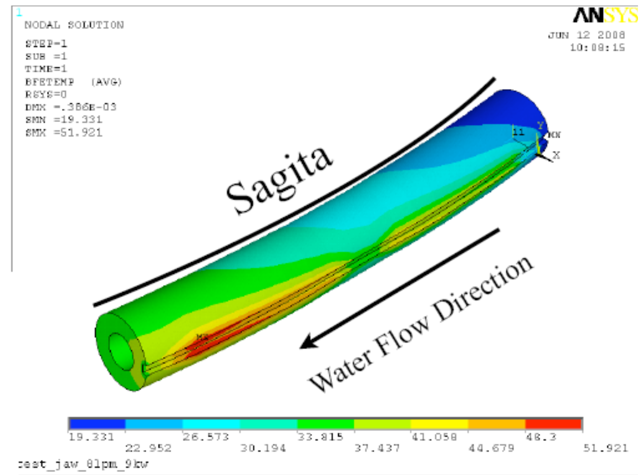
Measure jaw thermal expansion

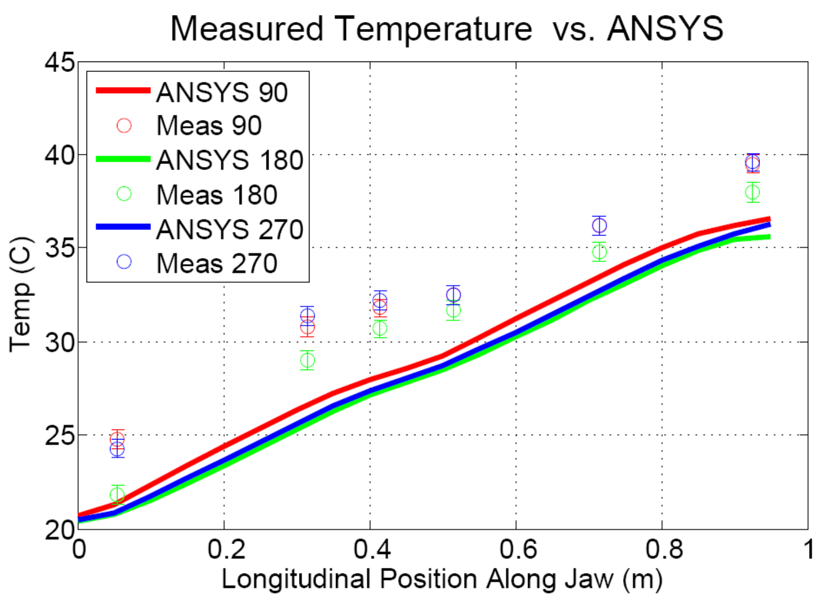






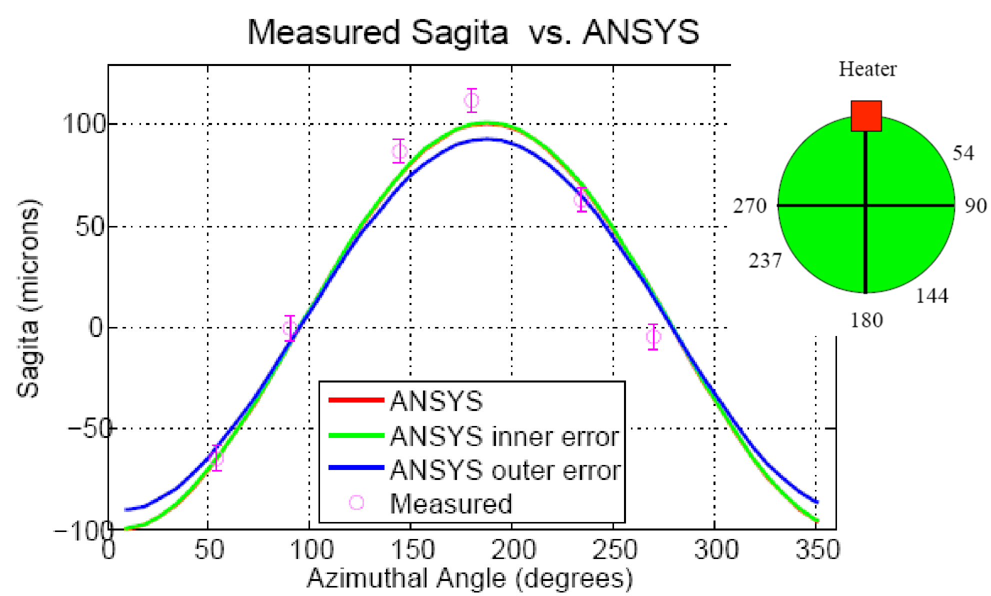
Heaters attached on bottom (jaw rotated 180 degrees from previous slide

Comparison of Sagitta & Temperature with ANSYS as a function of angle wit respect to heater

- Jaw with two 5 kW heaters modeled
- Includes accurate representation of
    - Water flow/temp change
    - Material properties
    - Thermal expansion
    - Heat flow / thermal conductivity
- Data ~10% larger than ANSYS



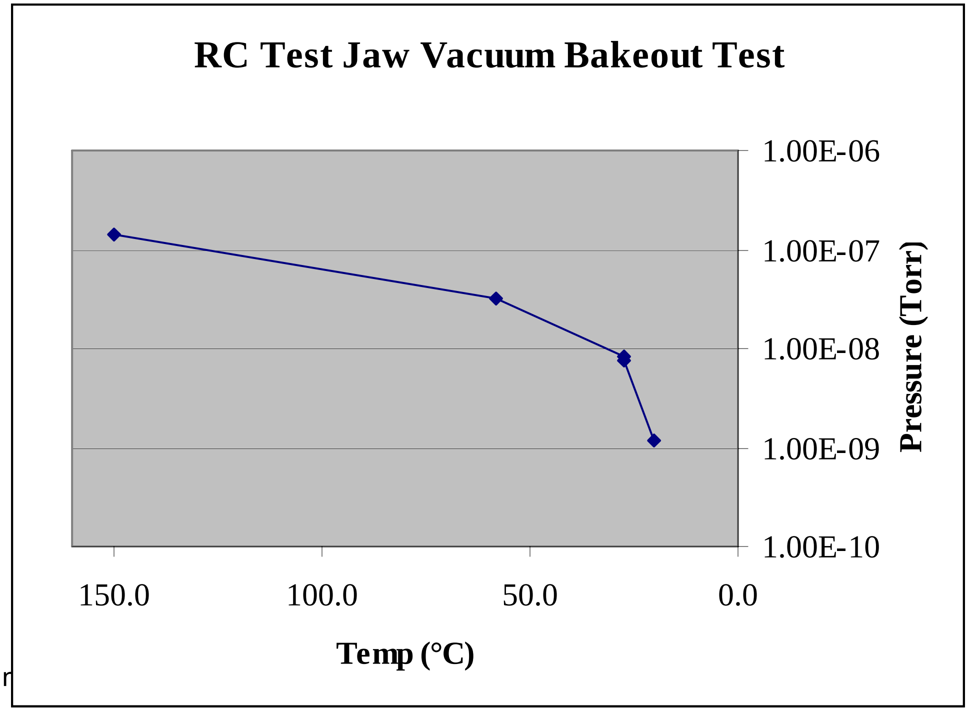




Results of Bake-Out test: 1.2E-09 torr for 1 jaw in a vacuum vessel

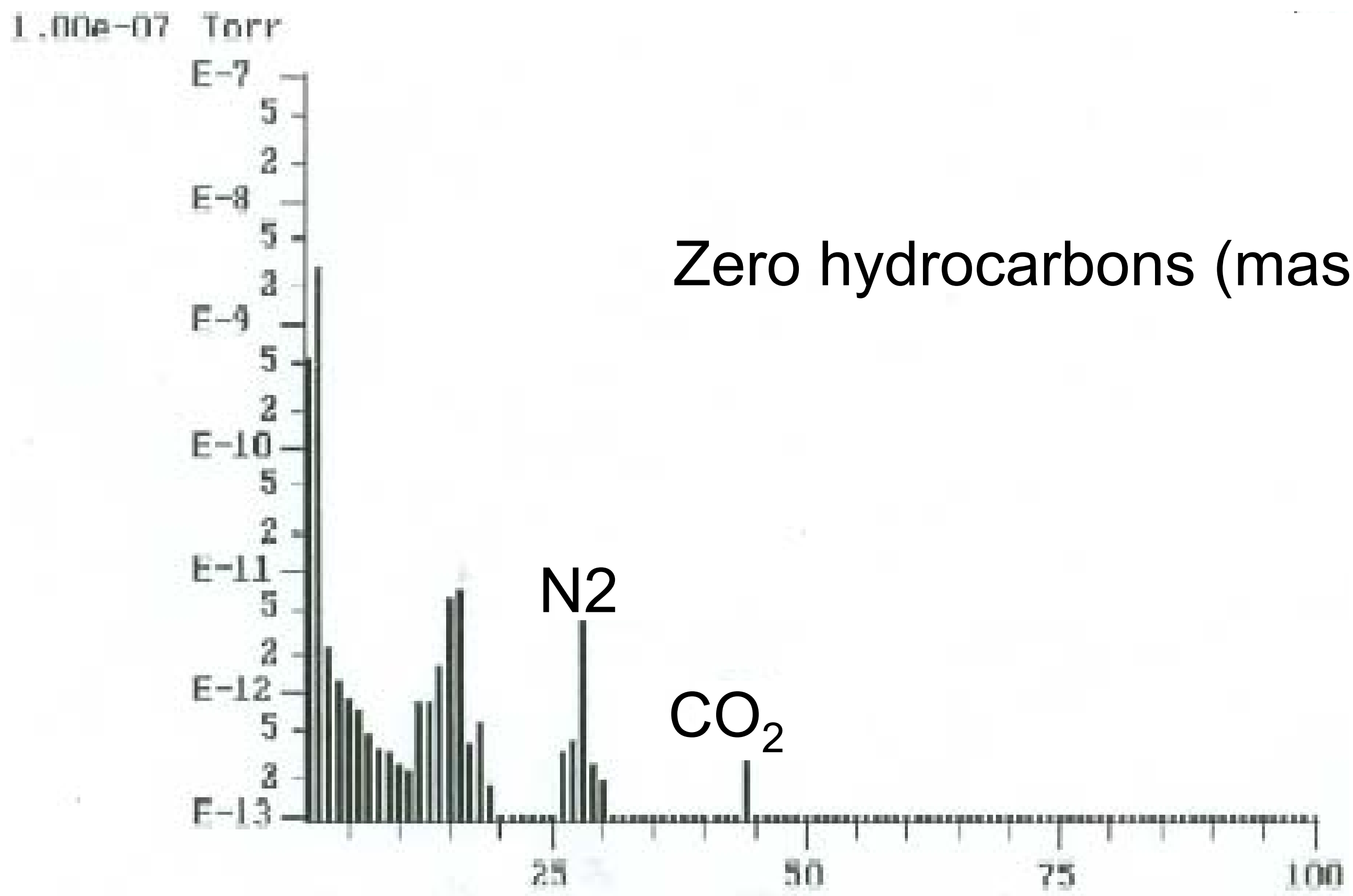
Process:

- "Standard" PEP-II Beamline bake-out sequence:
- Vacuum vessel separately baked 200°C for several days
  - 3.7E-9 torr
- Jaw H fired at 850°C before bake to accelerate bake-out process
- Bake 200°C several days with 24 hour excursion to 300°C
  - paranoia



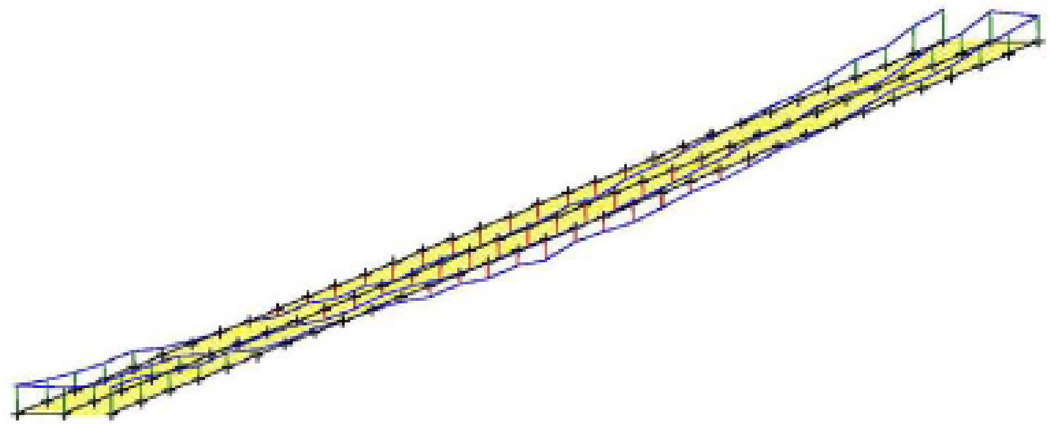
Slide r

RGA Scan



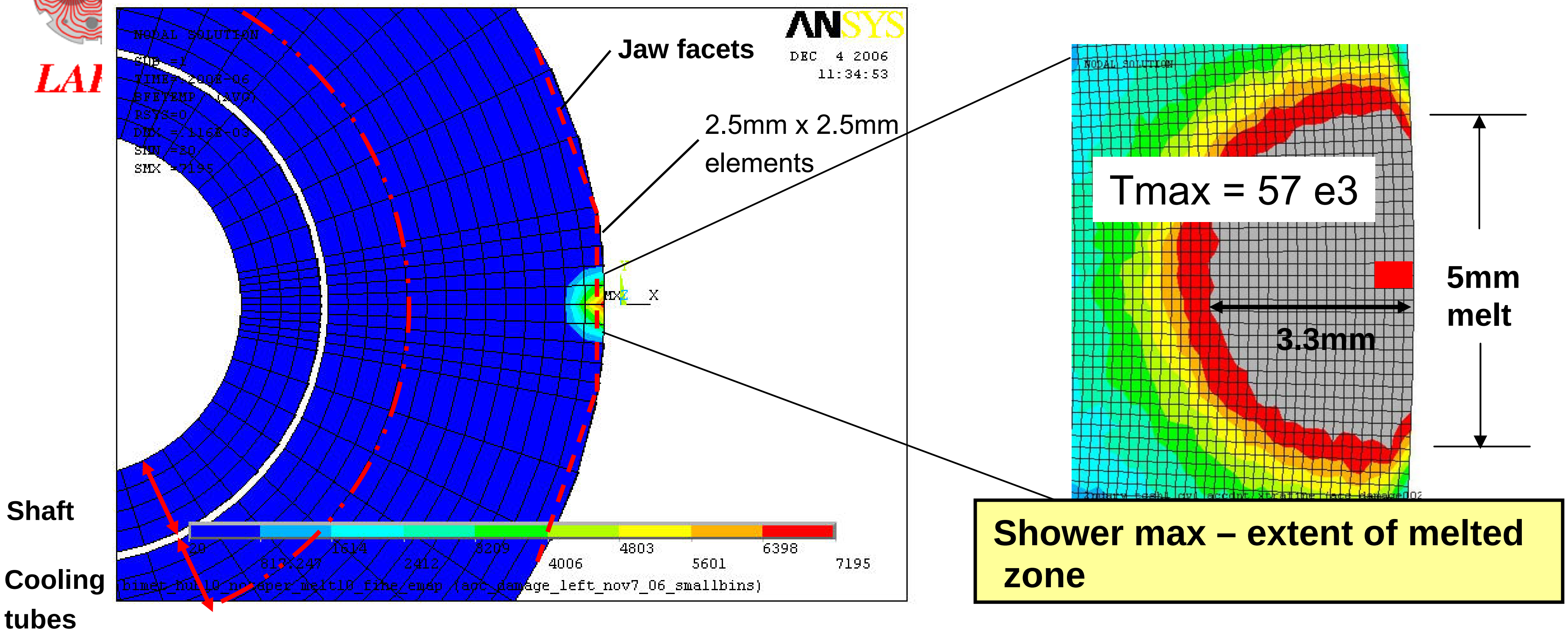
Zero hydrocarbons (mass >40)

RC0 CMM Survey After Vacuum Bakeout



facet	max negative deviation (mil)	max positive deviation (mil)	total deviation (mil)
1	-0.6	1.0	1.7
5	-0.5	0.7	1.3
8	-0.5	0.5	1.0
13	-0.7	0.6	1.3
16	-0.5	0.8	1.3

Accident Case



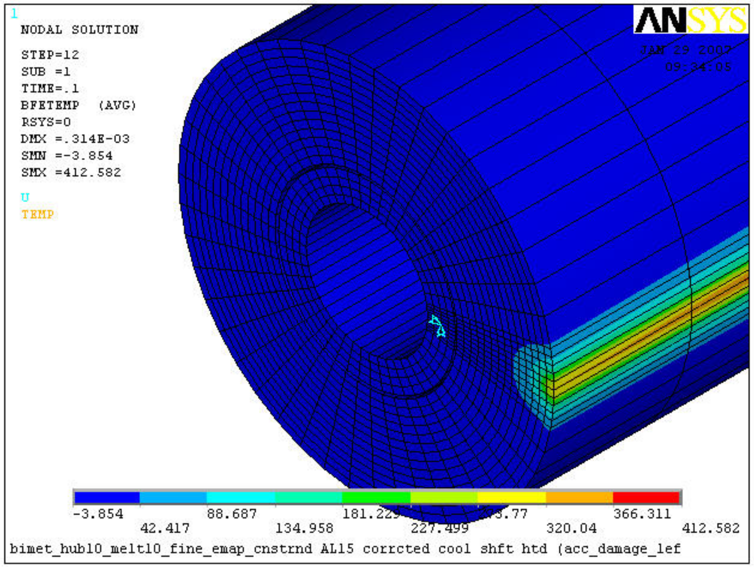
Case: beam abort system fires asynchronously, **8 full intensity bunches into jaw**

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)

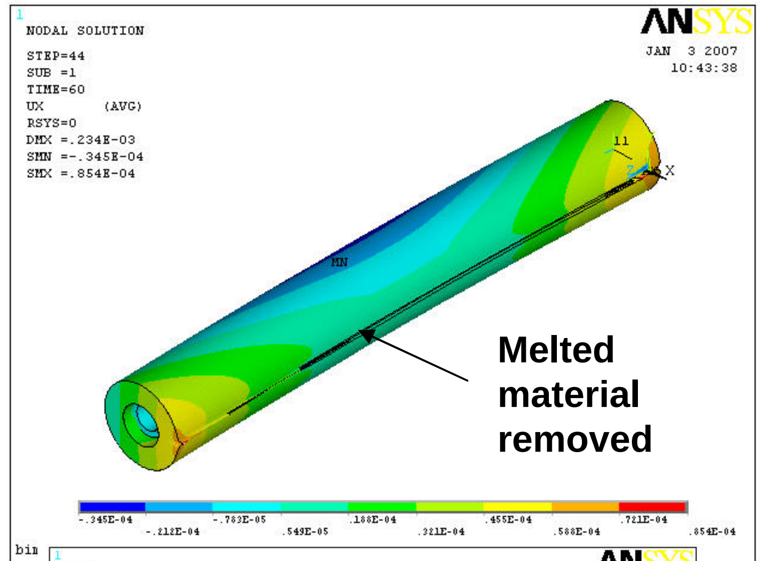
Accident Case

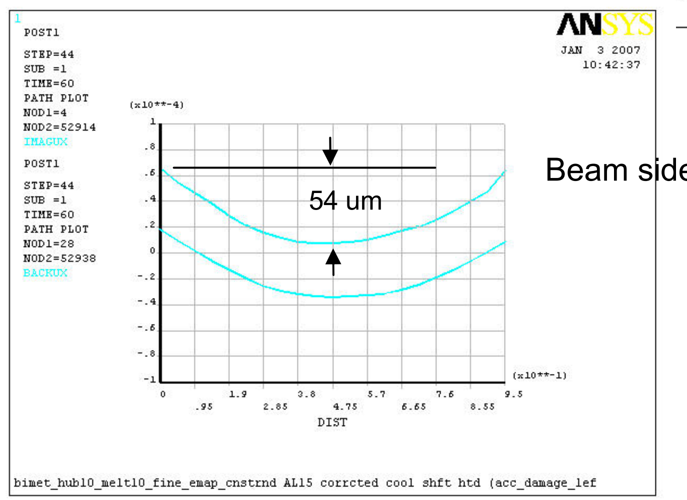
Permanent Jaw deflection, ux, after 60 sec cool-down



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

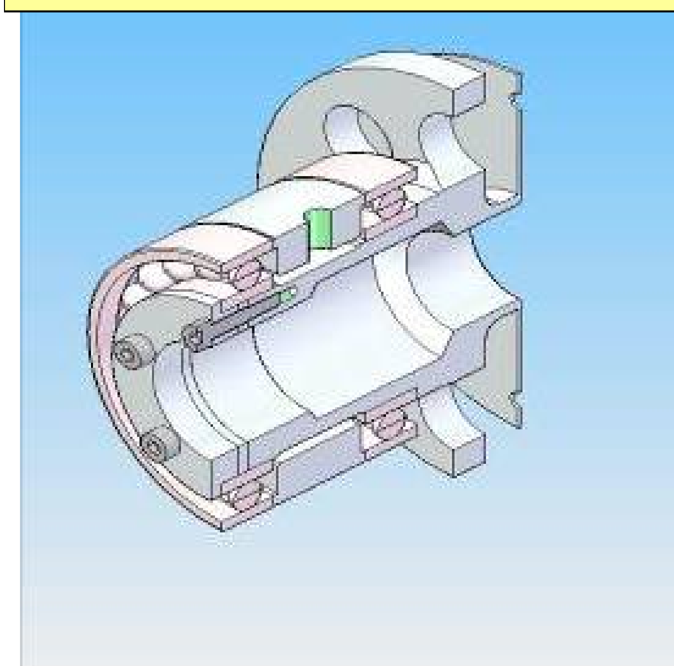
LARP

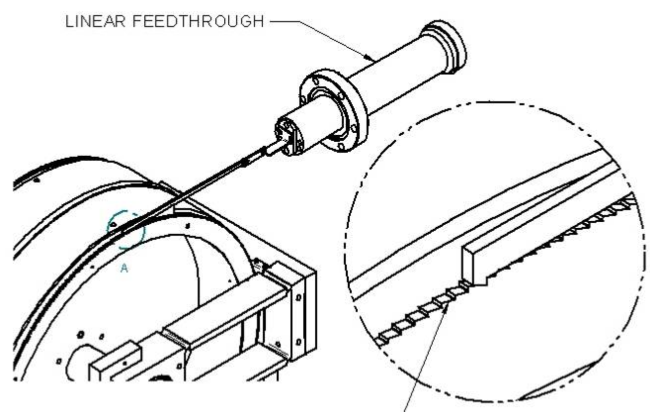
Introduce new **Internally actuated drive and jaw mount** for rotating after beam abort damages surface

Completed 27 May 2007

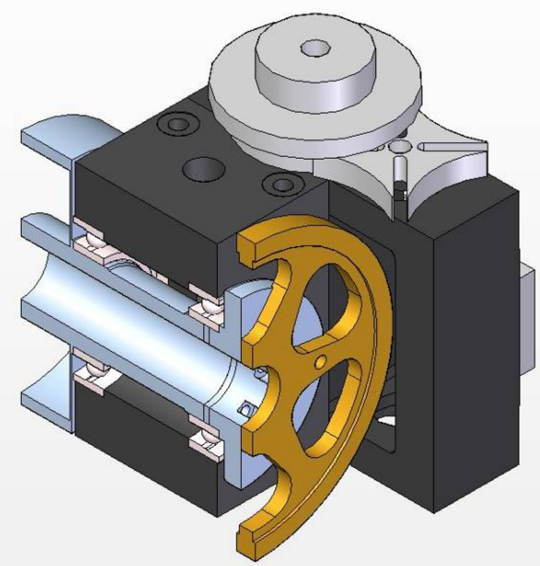
Universal Joint Drive Axle Assembly

- Thermal expansion
- Gravity sag
- Differential transverse displacement



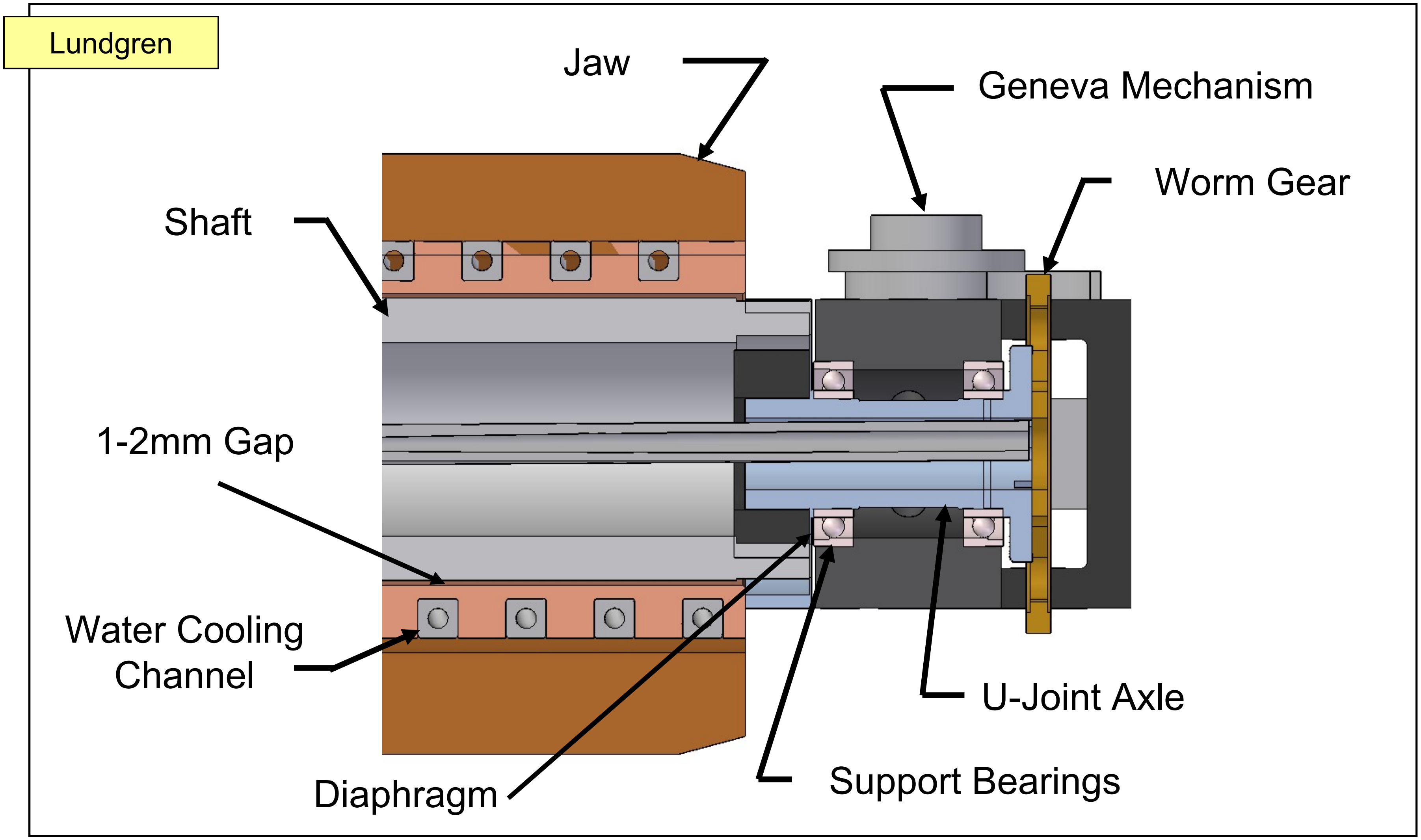


NLC Jaw Ratchet Mechanism



New rotation drive with “Geneva Mechanism”

Upstream end vertical section



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".

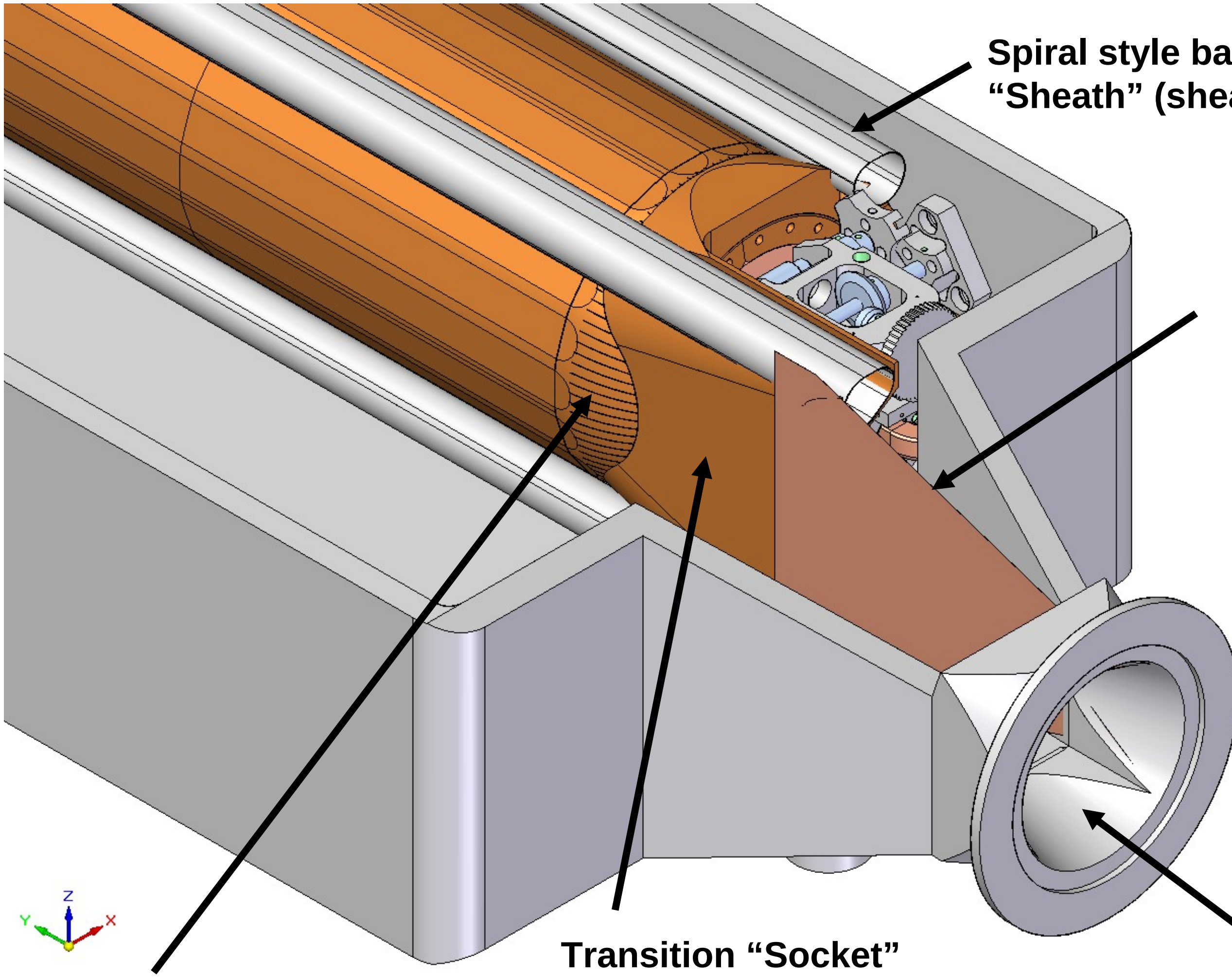
In Progress (Jeff Smith):

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

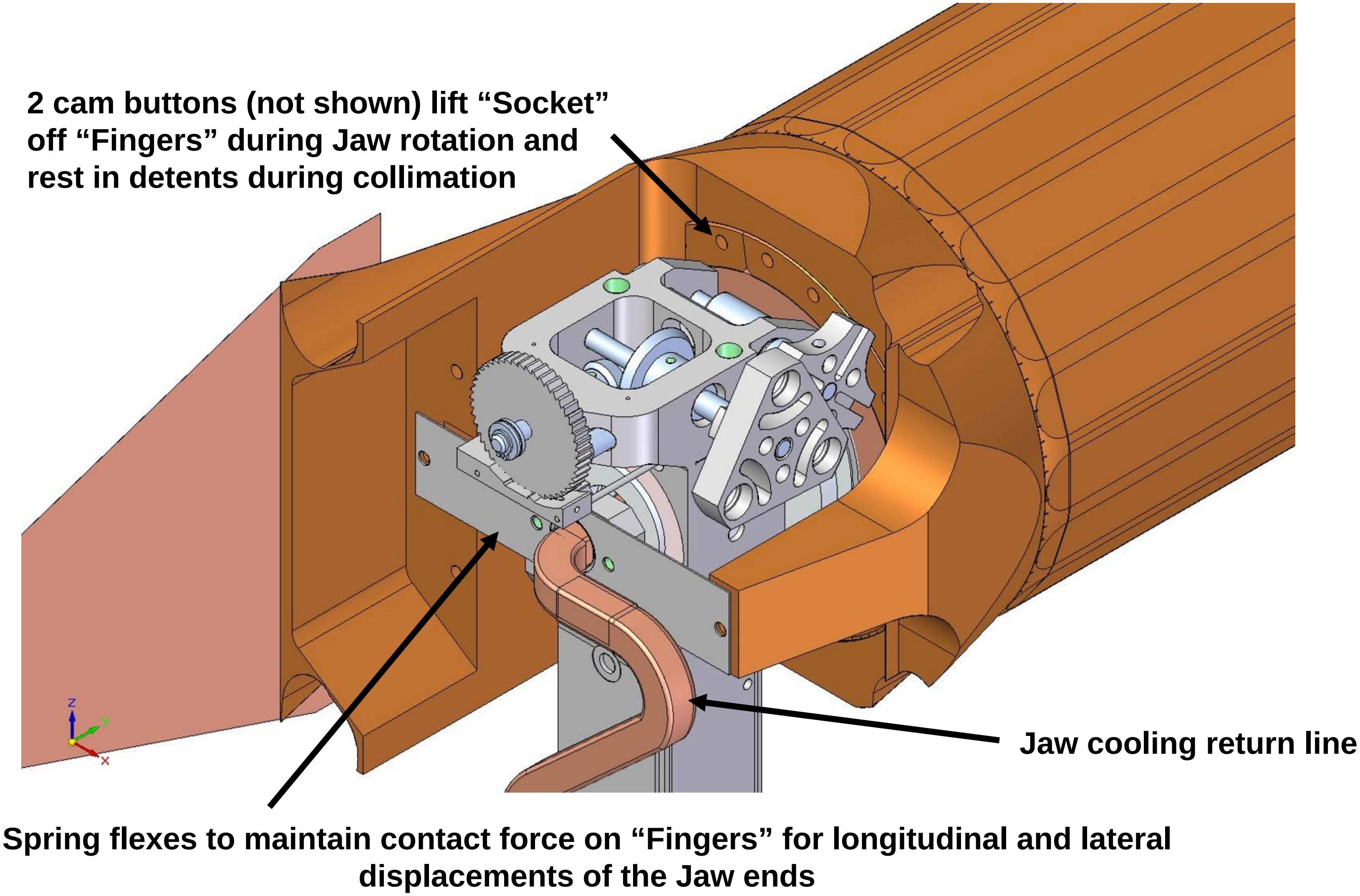
To be done:

- Impedance measurements with network analyzer
- Contact resistance measurements

Up Beam end beam side view

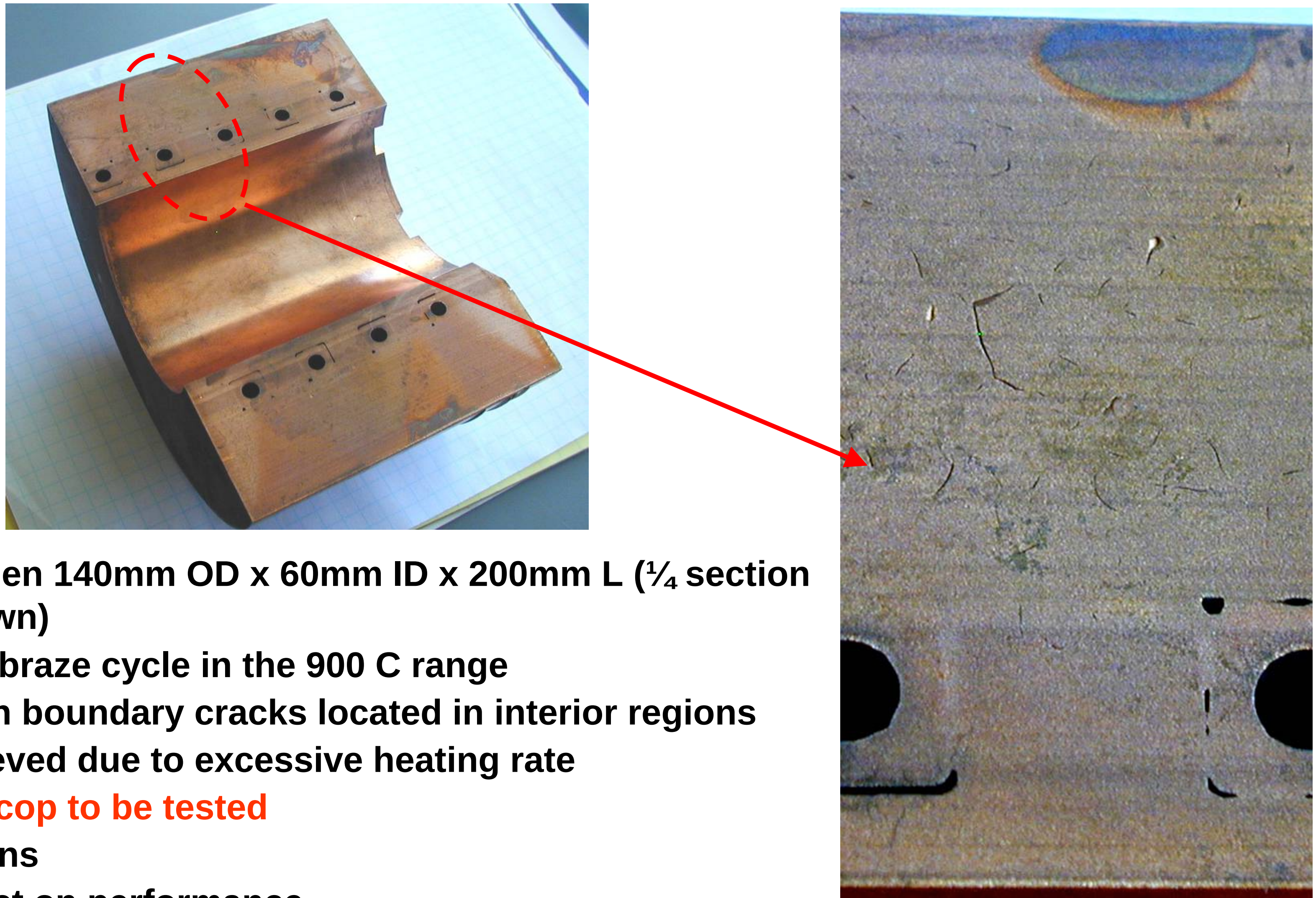


Up Beam end detail view away from beam side



Braze Test #3: Sectioning & Examination

Cu grain boundary cracking during brazing



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

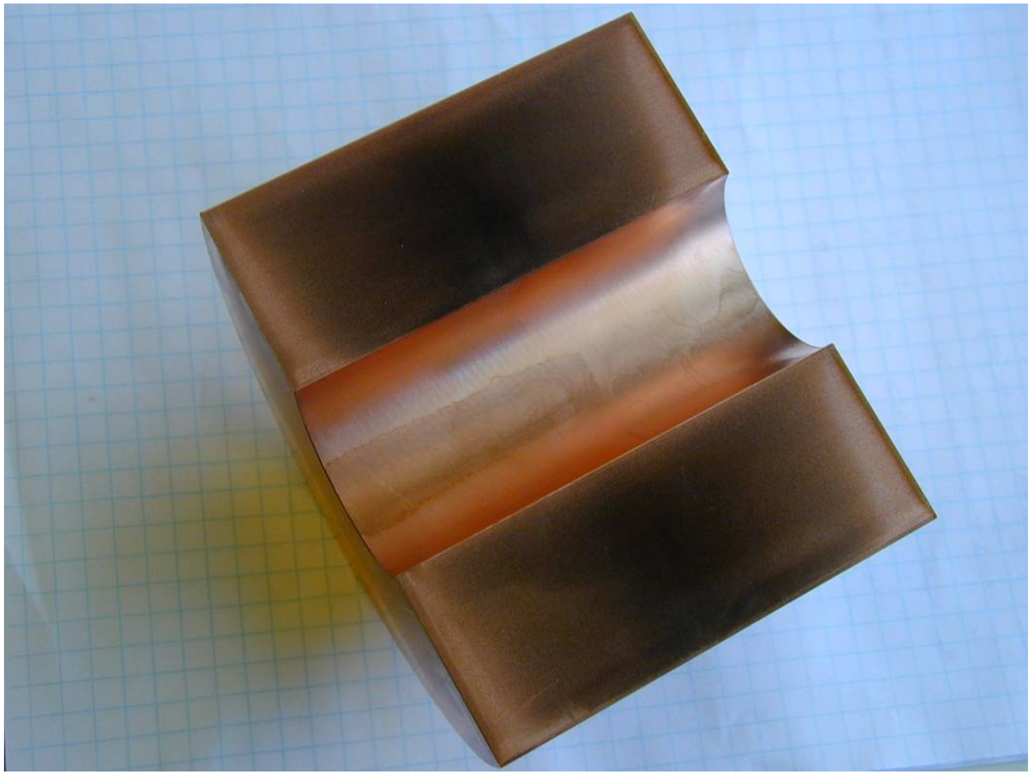
- **one braze cycle in the 900 C range**
- **grain boundary cracks located in interior regions**
- **believed due to excessive heating rate**
- **Glidcop to be tested**

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

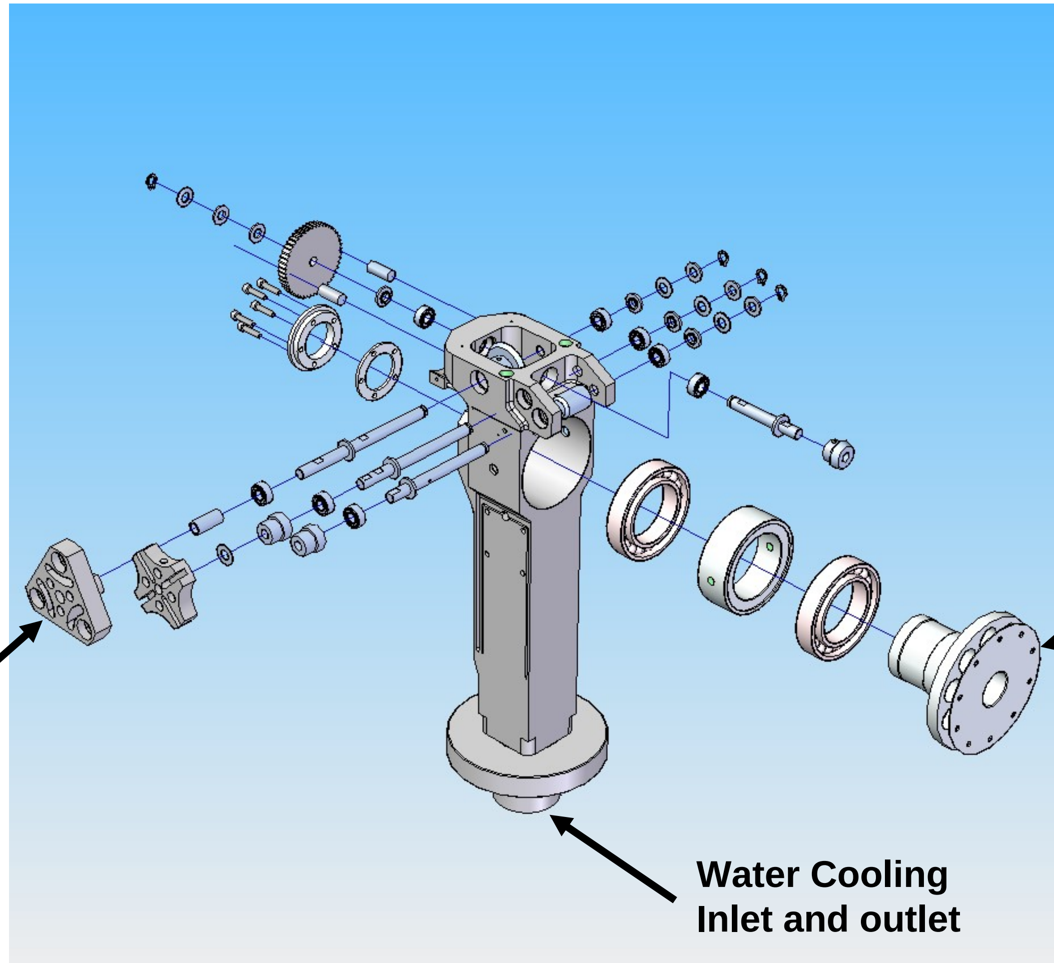


2 Heats (at Jaw brazing temperature)

No grain boundary cracking is apparent

Metallographic samples are being prepared for microscopic inspection

Exploded view of CAD model of Flex Mount

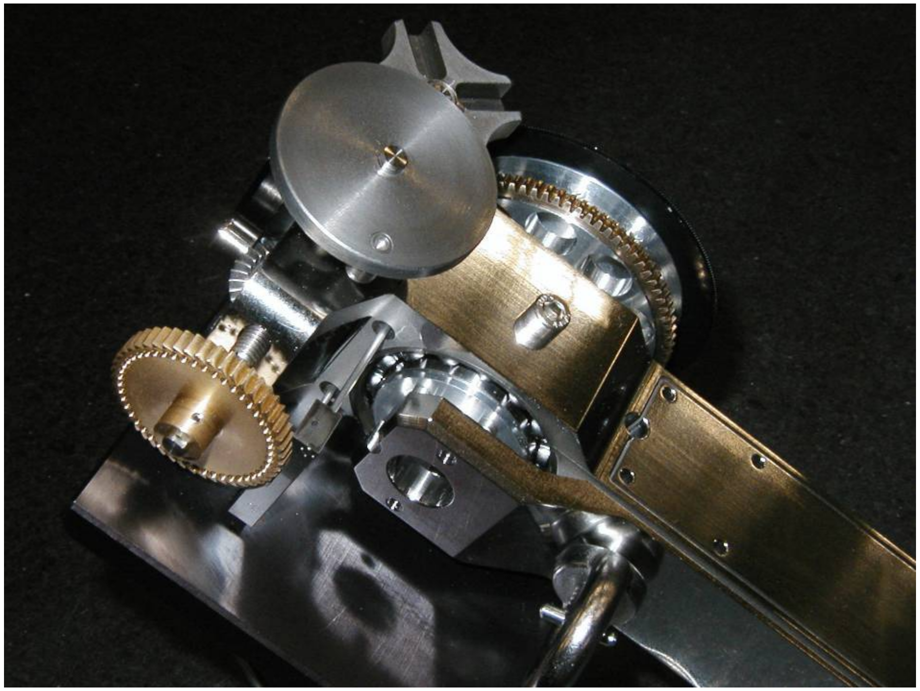


Triple Cog Geneva Drive Wheel required for 512 clicks per facet

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

Water Cooling Inlet and outlet

Up Beam Flex Mount Assembly showing Ratchet and Actuator



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

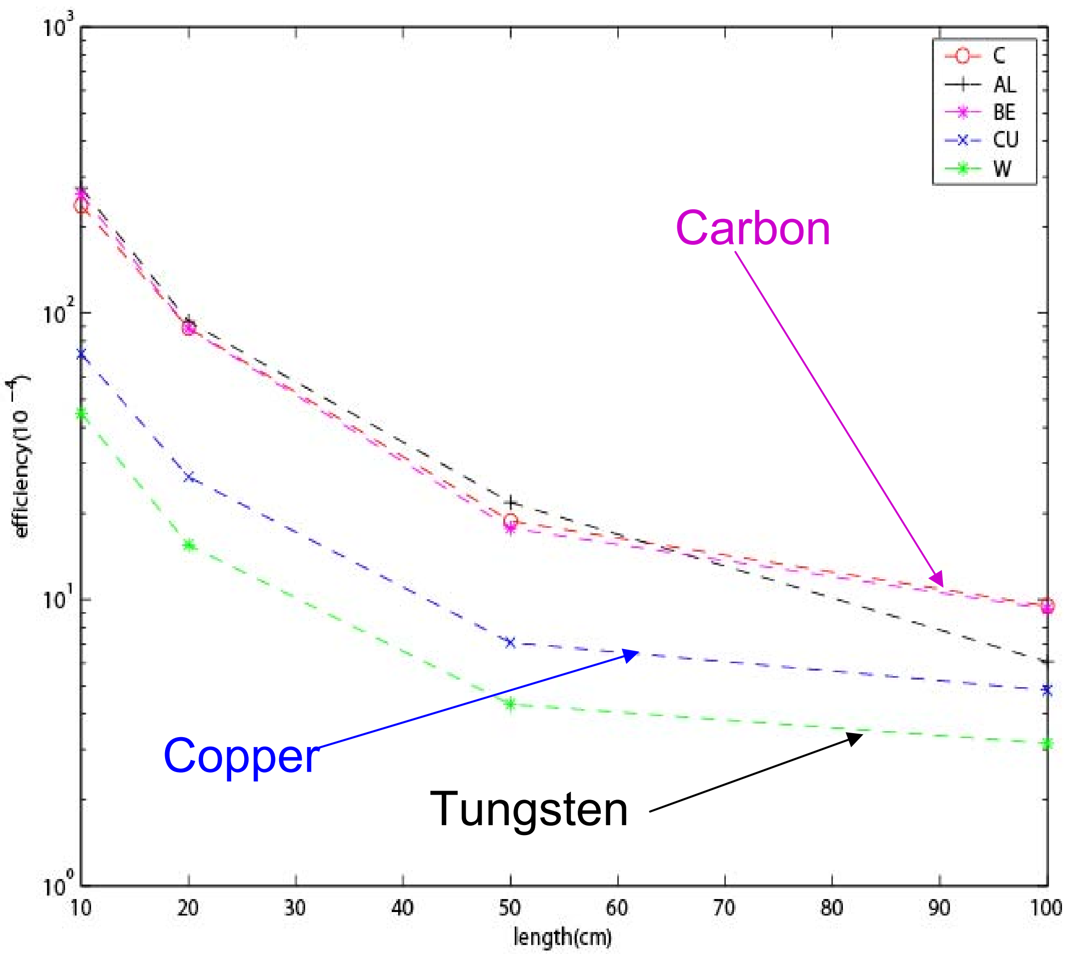
- Finalized a workable design (modulo rf design) and produced most full length mechanical fabrication drawings and models
- Finished all pretests, tooling and examinations that also required many fabrication drawing
- Is on track (?) to deliver full length operational prototypes on time
- Expected performance
  - 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

SIXTRACK simulation

compare materials' collimation efficiency tradeoff with mechanical performance

Yunhai Cai



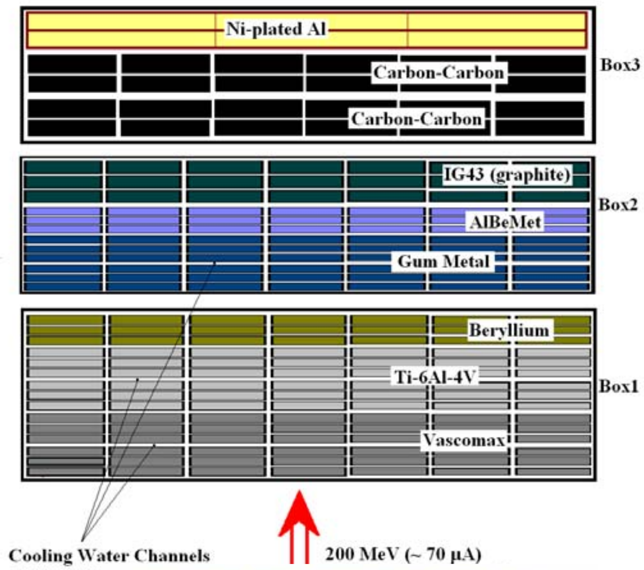
- High Z materials improve system efficiency but generate more heat
- Copper considered because its high thermal conductivity and ease of fabrication
- Available length for jaws is about 1 meter

Similar result was obtained by Ralph Aβmann

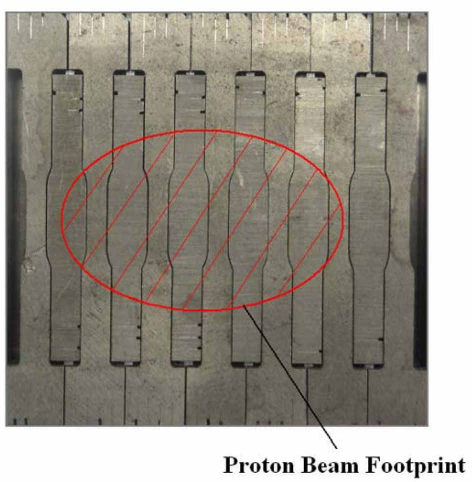
BNL Irradiation (BLIP) and Post-Irradiation Testing Facilities and Set-Up

LARP

Layout of multi-material irradiation matrix at BNL BLIP

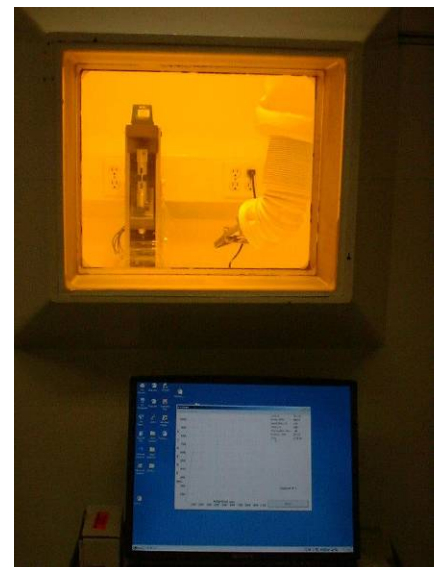


Test Specimen Assembly

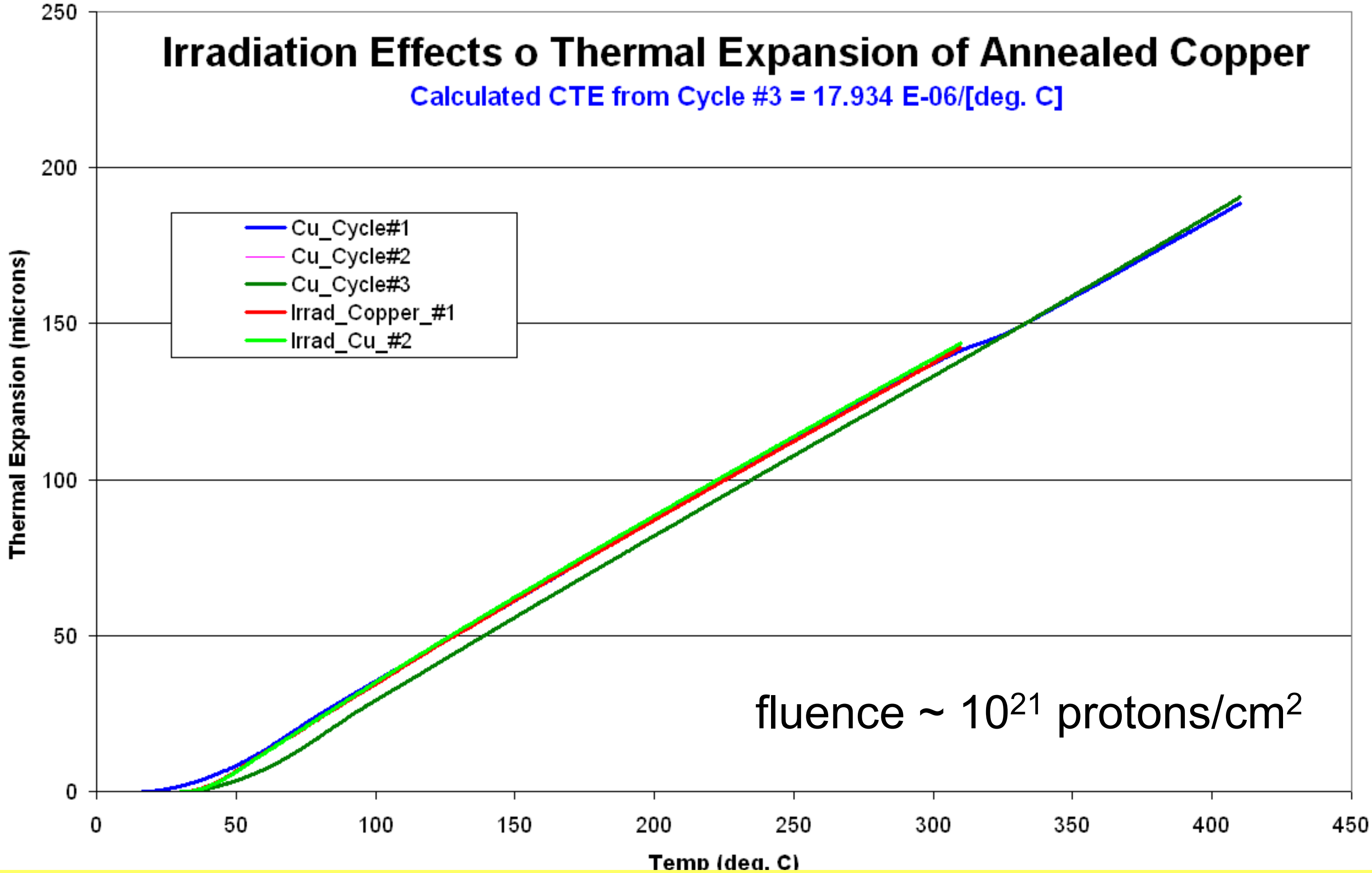


Dilatometer Set-up In Hot Cell #1

Remotely-operated tensile testing system in Hot Cell #2

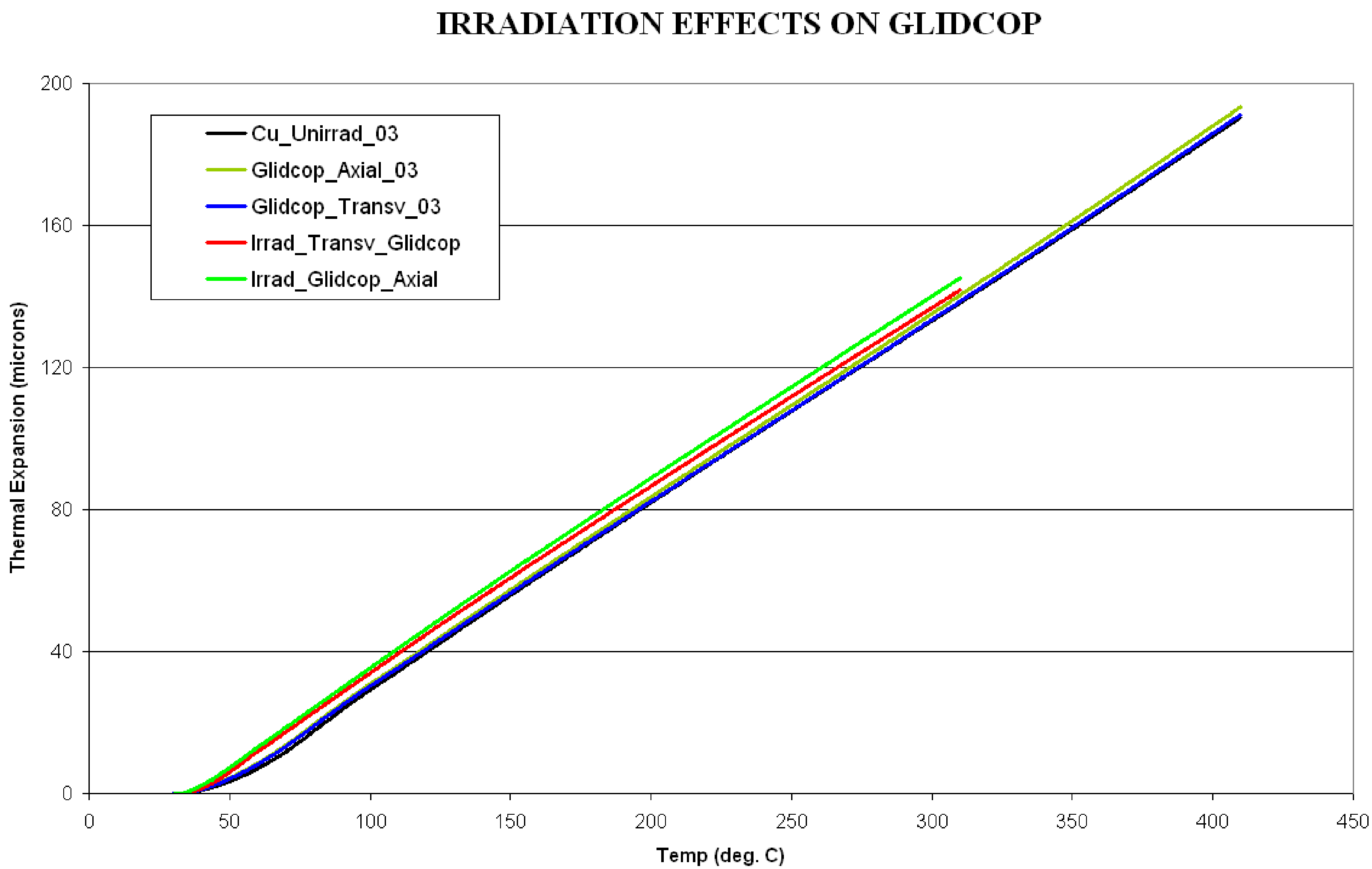


CTE Measurements of Irradiated Copper



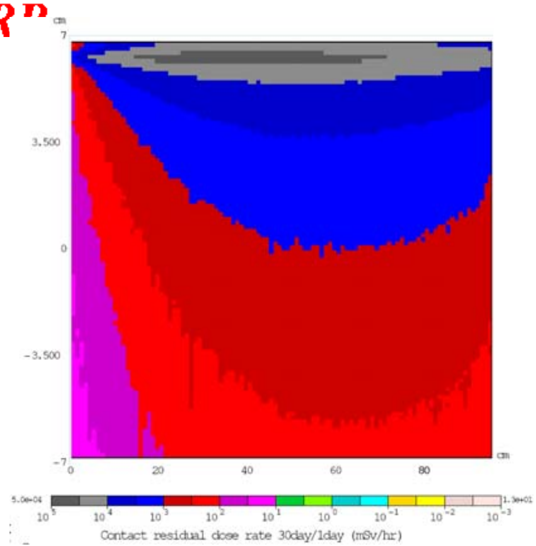
To Do: Measurements of Thermal Conductivity & Mechanical Properties

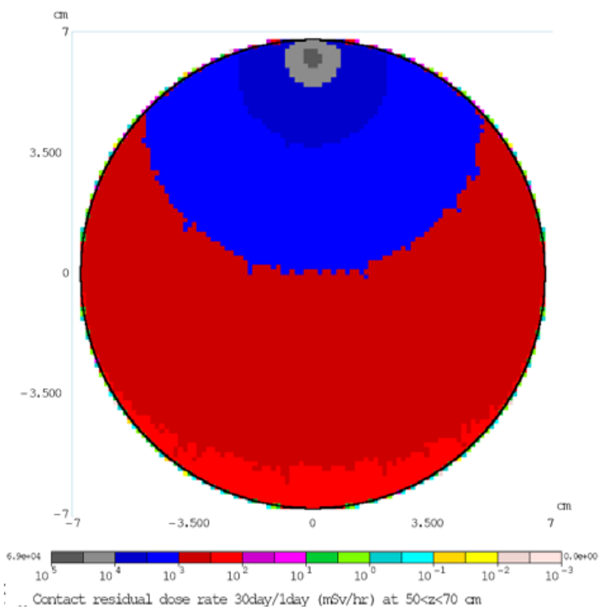
CTE Measurements of Irradiated GlidCop

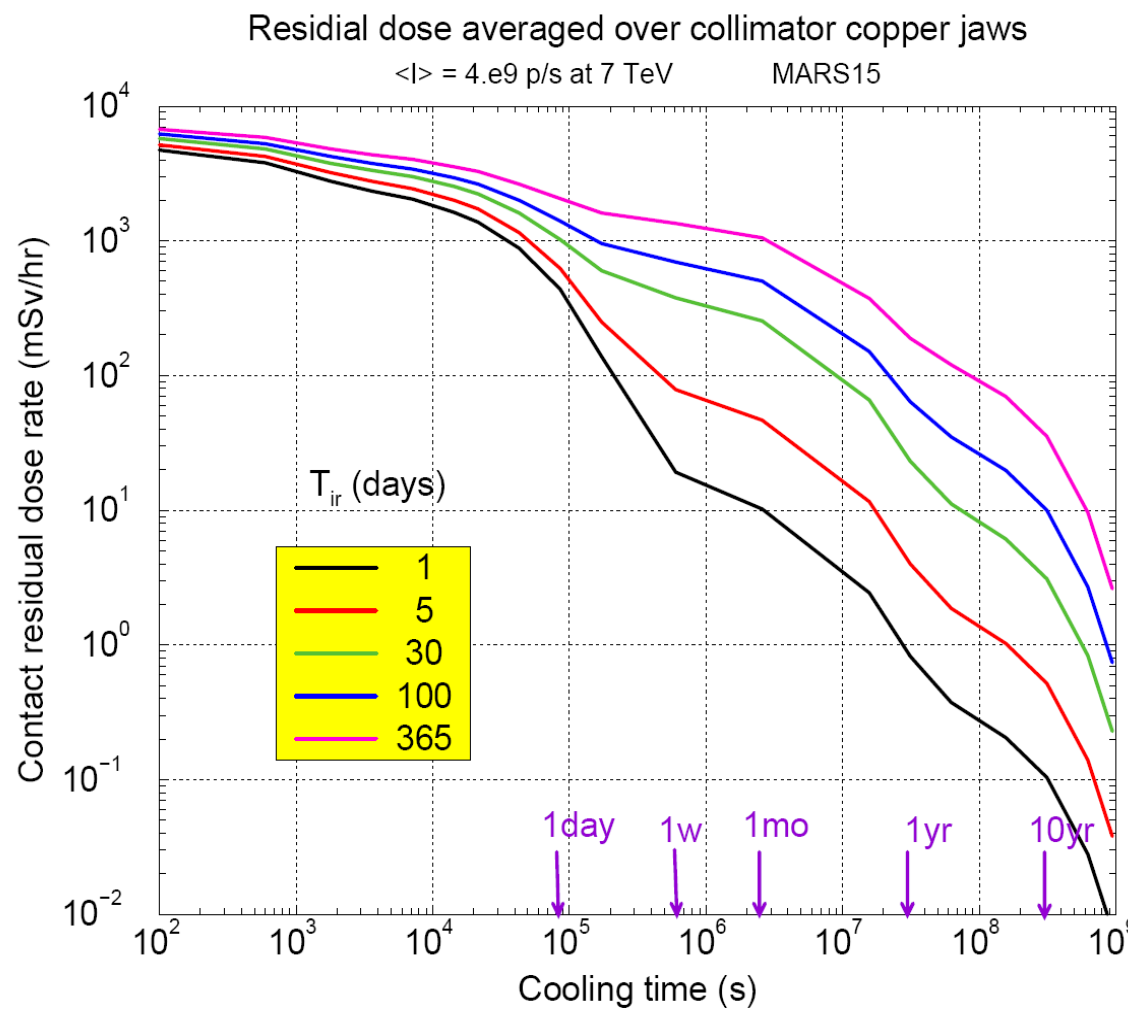


fluence ~ 10^{21} protons/cm^2

Rotatable Collimator Activation & Handling







Need dose rate at ~1m; Mokhov et al

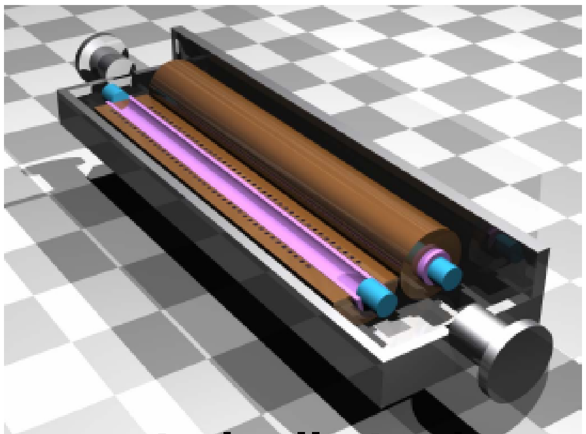
Inter-Lab Collaboration

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

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

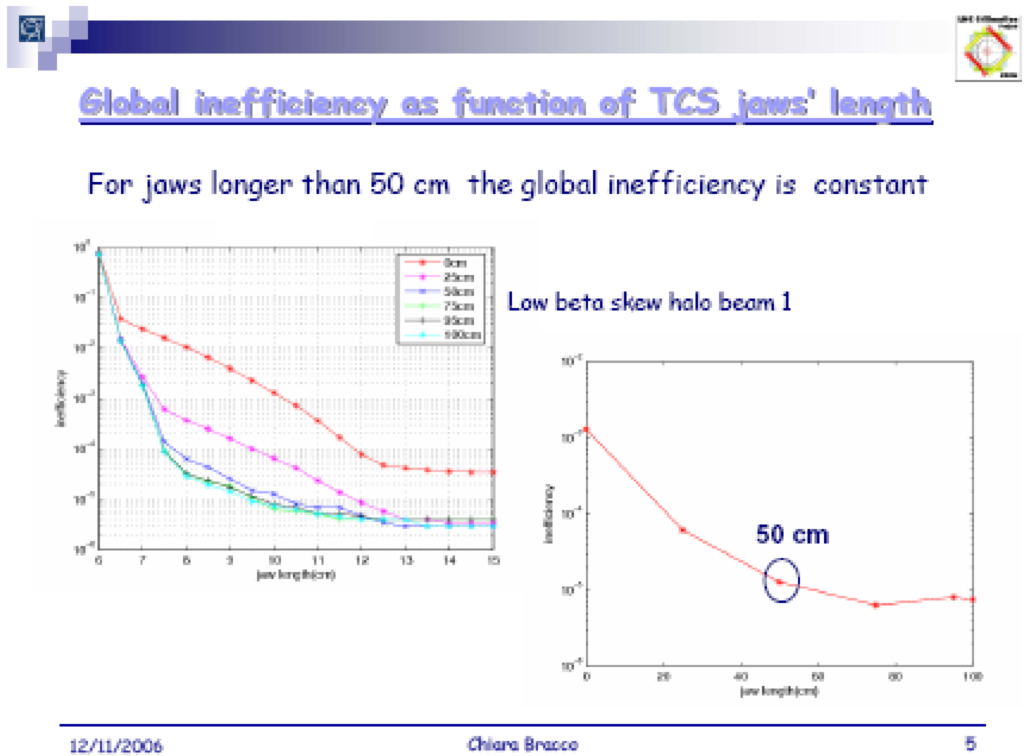
Alessandro Bertarelli
Alessandro Dallocchio
Pawel Smas

Monthly LARP Collimator Video Meeting
2007-03-07

Collaboration on ANSYS

LARP

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 – 1^{st} 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

LARP

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 $\rightarrow$ "Geneva Mechanism"

Cu-Mo Hub Braze Test parts

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

#2 #3 #4

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

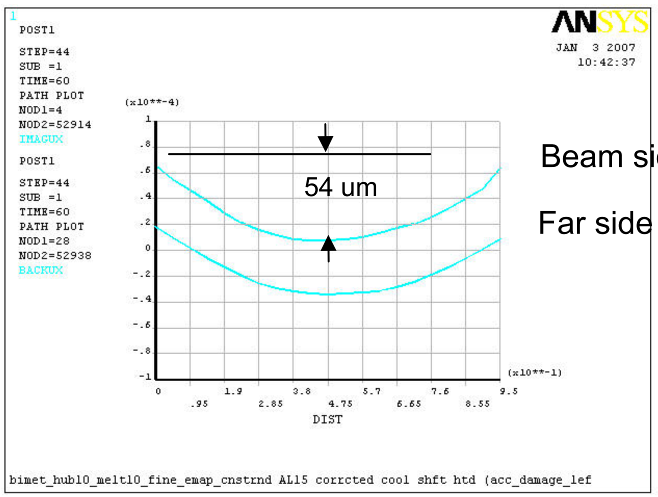
PLASTIC DEFORMATION of ENTIRE JAW after a BEAM ABORT ACCIDENT?

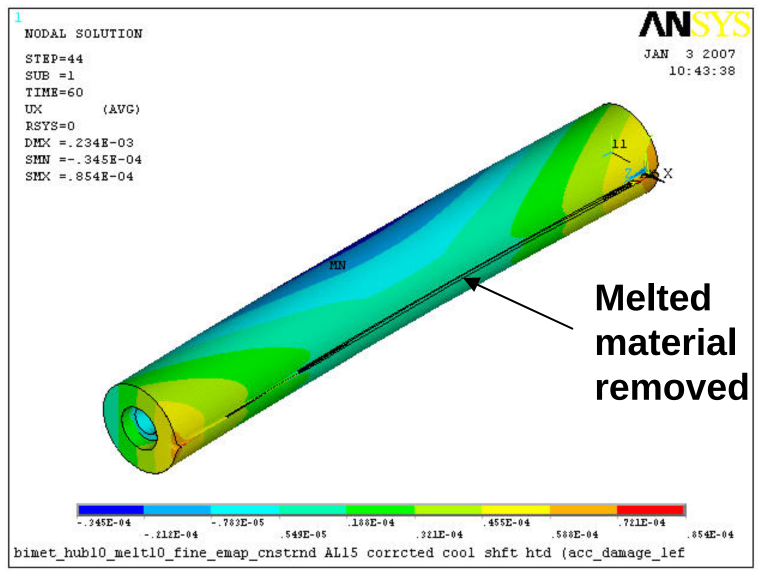
LARP

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