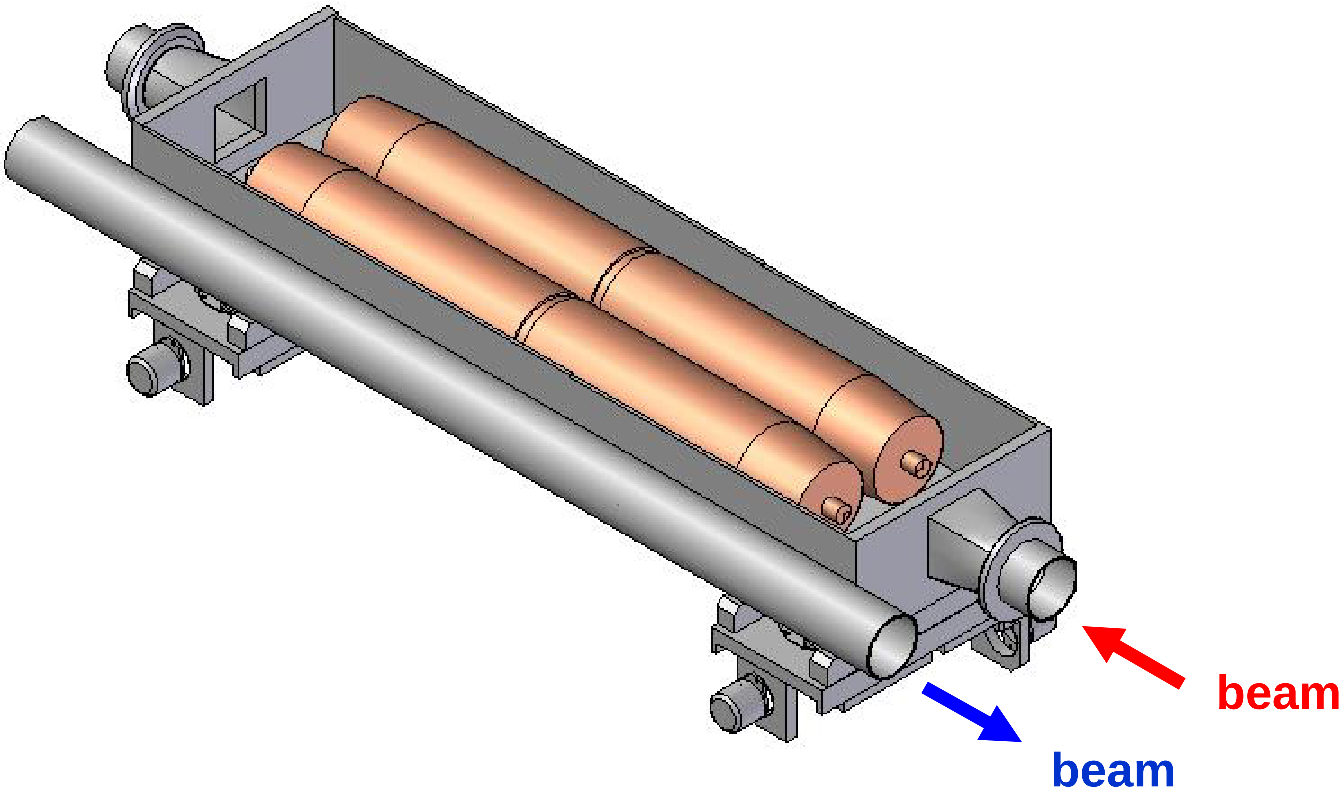
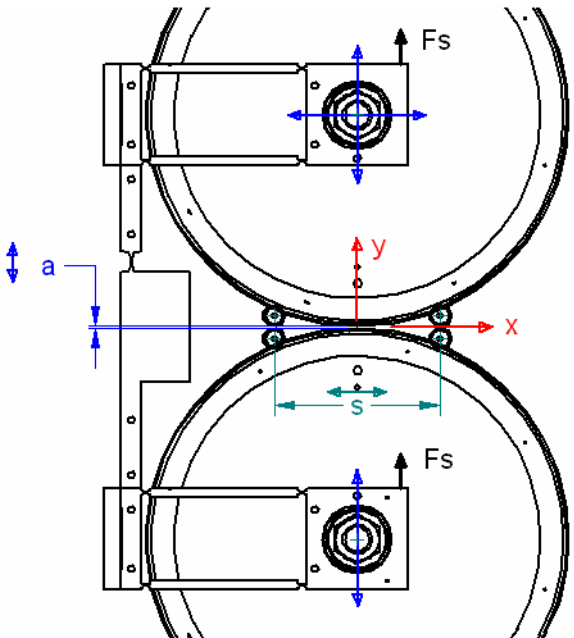
Phase II Collimator Engineering Studies



The Model: NLC Rotatable Collimator



independent d.o.f

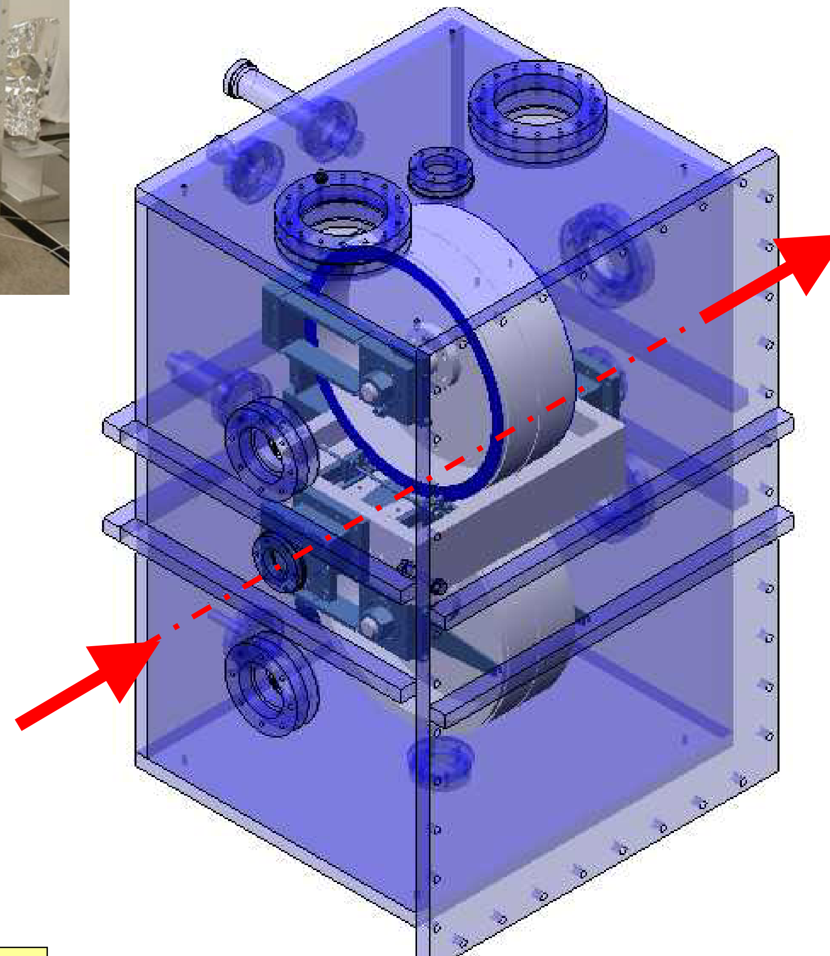
dependent d.o.f.

α = rotor angle

a = aperture

Fs = spring force

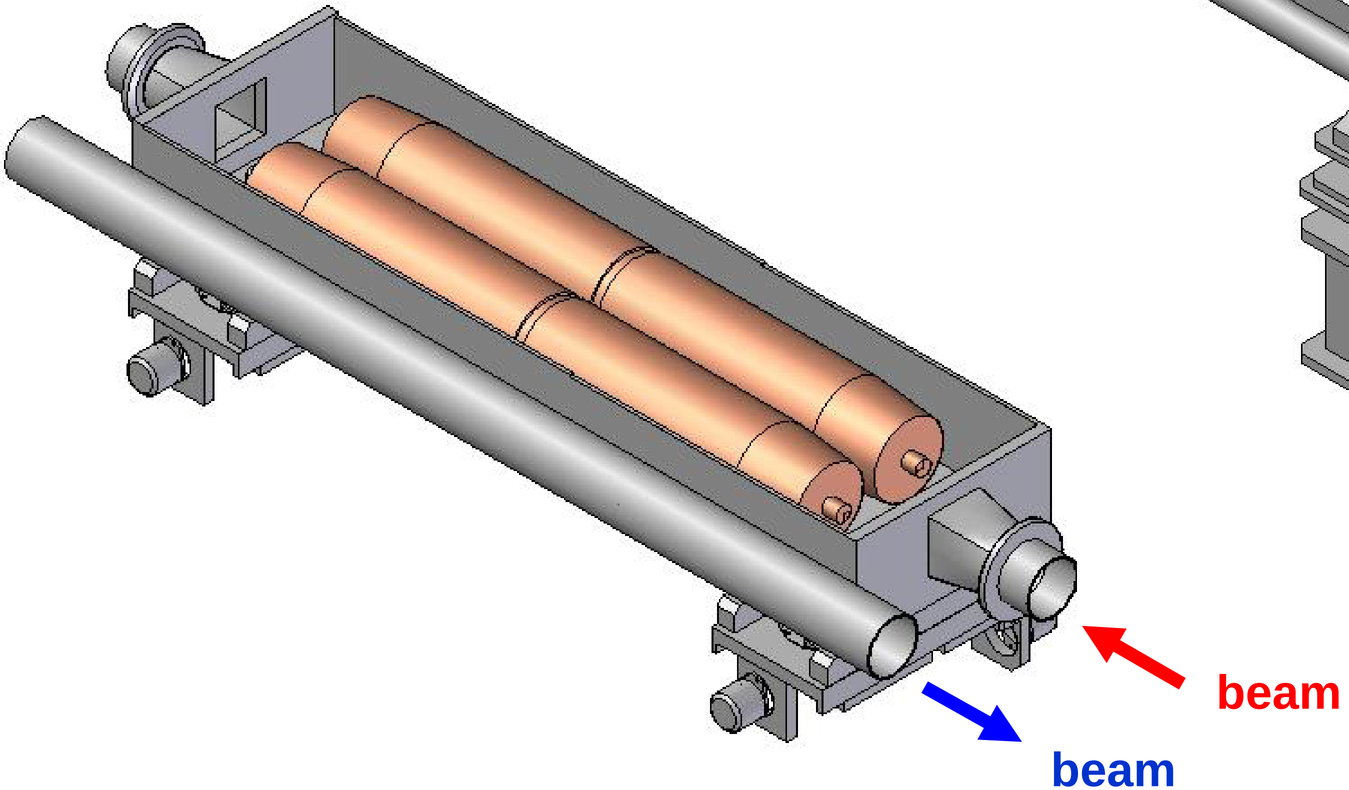
s = stop roller spacing

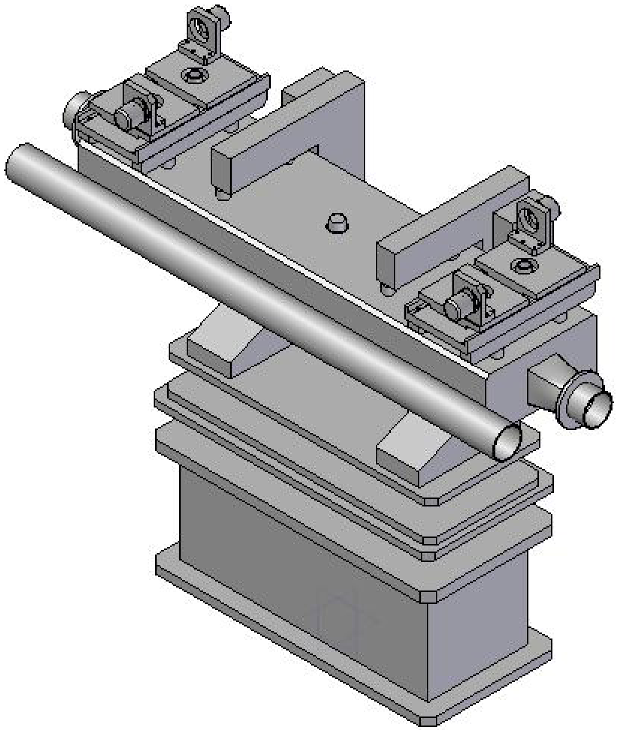


Jaws can be rotated to present new collimation surface if damaged by beam. Typical accuracy, stability ~ 5um.

Adapted to LHC Phase II Requirements

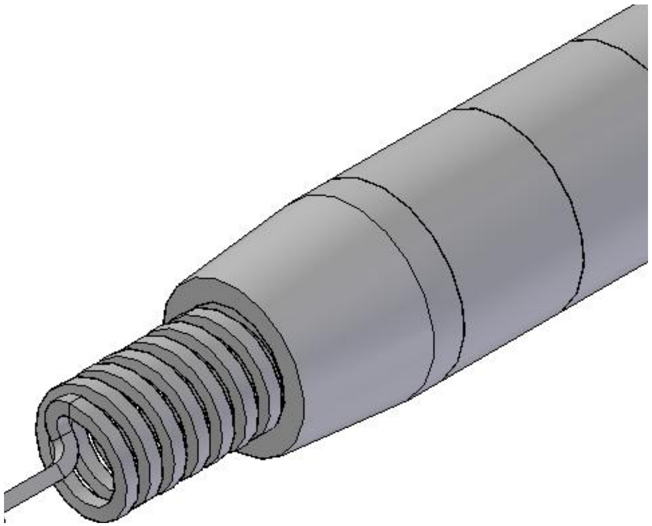
- **136mm diameter x 950 mm long jaws (750 mm effective length due to taper).**
- **Vacuum tank, jaw support mechanism and support base derived from CERN Phase I.**



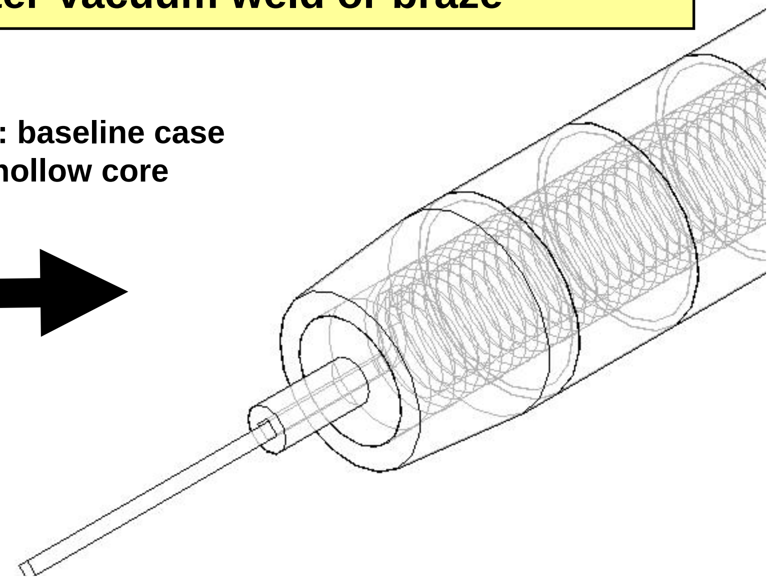


Helical cooling passages chosen for manufacturablity, beamline vacuum safety

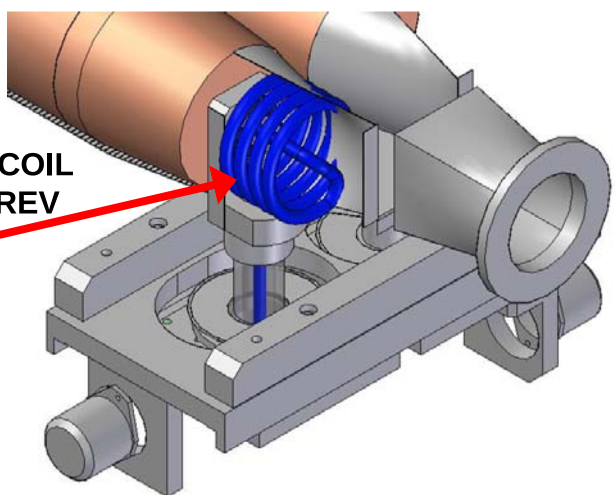
Per CERN's Phase I design – no water-vacuum weld or braze

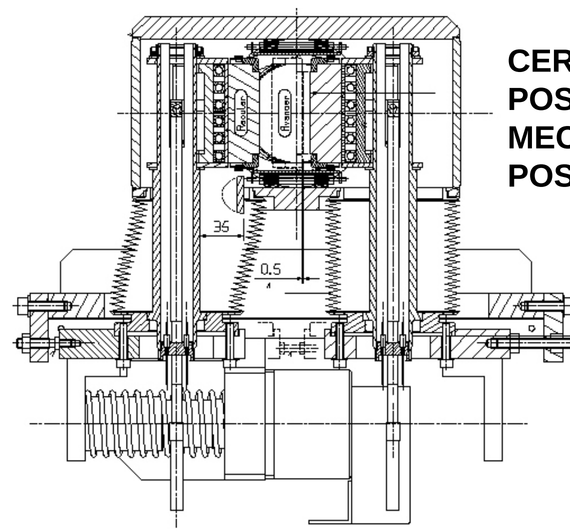


Note: baseline case has hollow core



EXTERNAL COIL PERMITS 1 REV OF JAW





CERN PHASE I JAW POSITIONING MECHANISM – USE IF POSSIBLE

NLC & original LHC specs – major differences

Specification	NLC	LHC	Comments
beam pipe ID	1cm	8.4cm	LHC: two opposing beam pipes
gap range (full aperture)	0.2 – 2.0mm	0.5 – 45mm	
Jaw diameter	318 mm	136 mm	LHC: Function of beam pipe diameter/spacing and gap range
jaw length	10 cm total 6mm active L/D=.02	95 cm total, ~75 cm active L/D=5.5	LHC: length controlled by 1.48m flange-flange space and need for flexible transitions; thermal bending problem results from length
jaw deformation – toward beam	5 um	25 um *	NLC: short jaw => no bending; close coupled support controls effects of swelling
SS power, per jaw	~1 W	~ 12 kW	Cooling NLC: radiation - 4C temp rise. LHC: water cooling, possible power densities in boiling regime

* This spec infeasible, has been relaxed

Bottom Line: LHC & NLC collimators are different animals

Baseline Jaw Performance

Exceeds spec, or other possible problem as noted (red circle)

Collimator			TCSM.A6L7	
Cooling scheme			**Helical**	**Axial (36°)**
Cooling		# channels	1	2
		Diam (m)	.008	.006
		Velocity (m/s)	3	3
		Total flow (l/min)	9	10
Beam heat	SS	Power (kW)	11.7	
	Trans	Power (kW)	58.5	
Temp (C)	SS	Jaw peak	86.5	91.5
		Cooling chan. peak	68.3	69.7
		Water out	36.0	36.1
	Trans	Jaw peak	231	223
		Cooling chan. peak	154	130
		Water out	43.6	47
Deflection (um) [4]	SS		394	107
	Trans		1216	778
Eff. length (cm) [5]	SS		43	75
	Trans		24	31

Max Cu temp 200

Possible boiling

Max water return temp

} Deflection 325 & 750 (SS & trans)

All temperature simulations based on 20C supply. For CERN 27C supply add 7 to all temperature results. CERN max water return temp 42C

IR7 secondary collimators heat generation, deflection and effective length

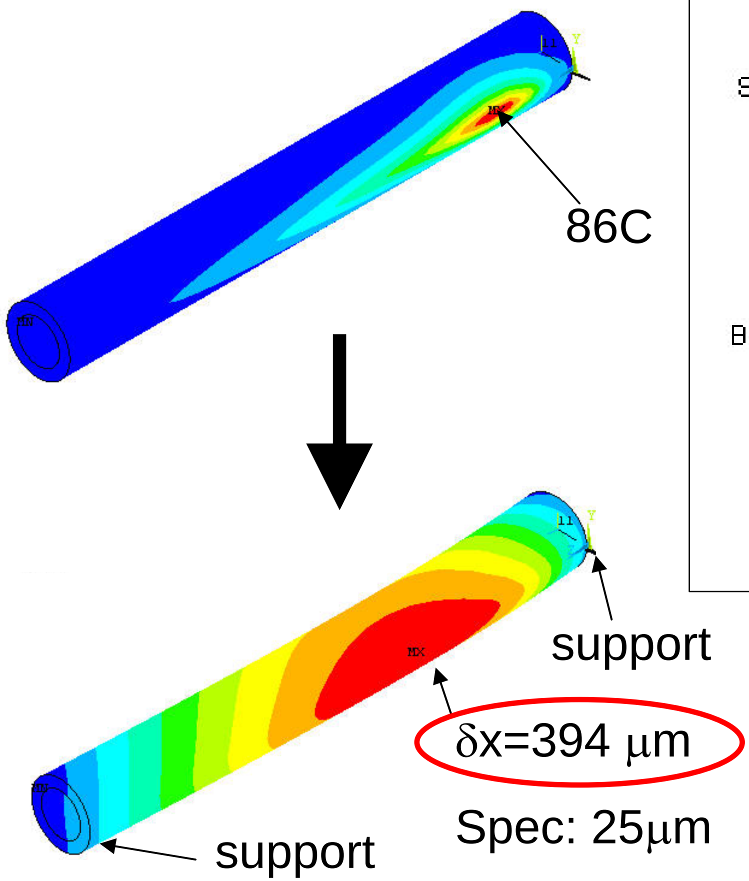
Deflection and effective length based on ANSYS simulations for TCSM.A6L7. Power scaled from TCSM.A6L7 according to the distribution on secondary collimators provided by CERN. Note: first collimator in the series absorbs the bulk of the energy.

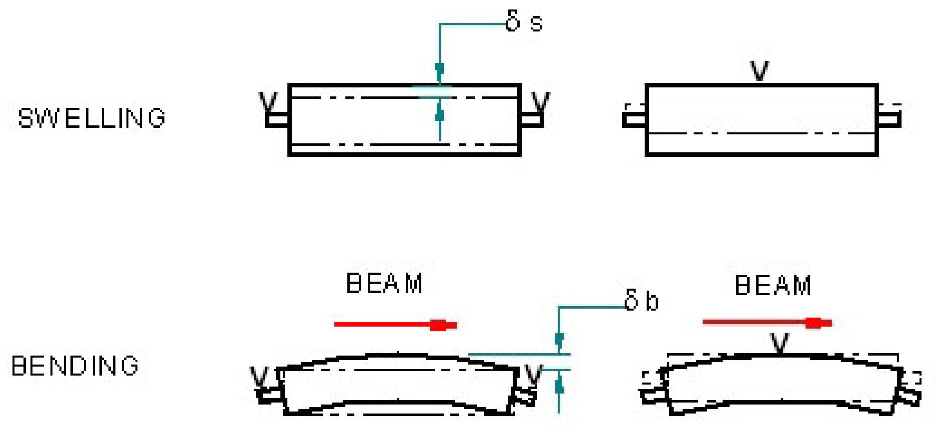
		Steady State			Transient			
No.	**name**	**Power (kW)**	**Defl (um)**	**Eff. Lngth (cm)**	**Power (kW)**	**Defl (um)**	**Eff. Lngth (cm)**	**note**
1	TCSM.A6L7	11.7	394	43	58.5	1216	24	simulated
2	TCSM.B5L7	2.7	137	75	13.5	422	46	scaled
3	TCSM.A5L7	.69	35	75	3.44	108	75	scaled
4	TCSM.D4L7	.18	9	75	.92	29	75	scaled
5	TCSM.B4L7	.20	10	75	1.01	31	75	scaled
6	TCSM.A4L7	.19	10	75	.96	30	75	scaled
7	TCSM.A4R7	.16	8	75	.81	25	75	scaled
8	TCSM.B5R7	.22	11	75	1.10	34	75	scaled
9	TCSM.D5R7	.19	9	75	.93	29	75	scaled
10	TCSM.E5R7	.13	6	75	.62	19	75	scaled
11	TCSM.6R7	.25	12	75	1.23	26	75	scaled

Bending far exceeds 25um spec => Compromise:

Central aperture stop prevents deflection *toward* beam

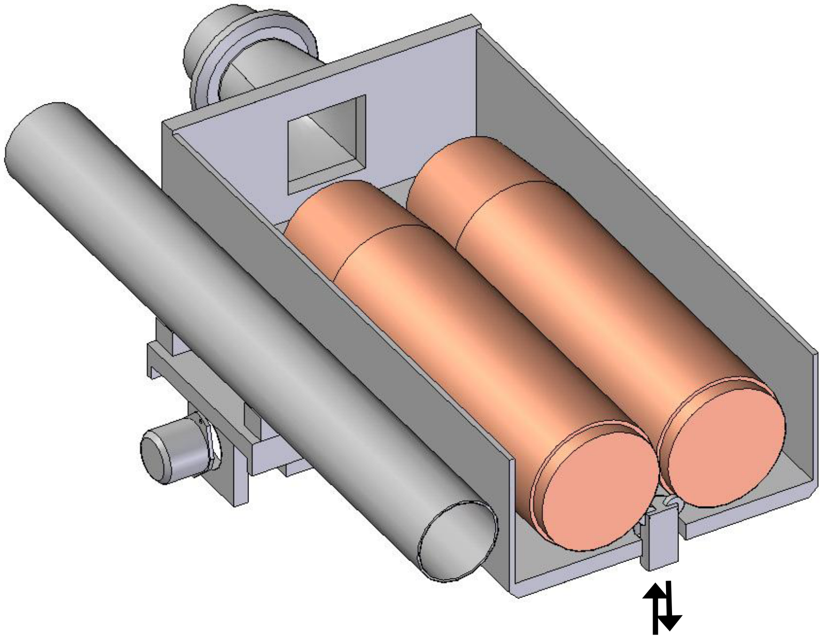
Steady State operation

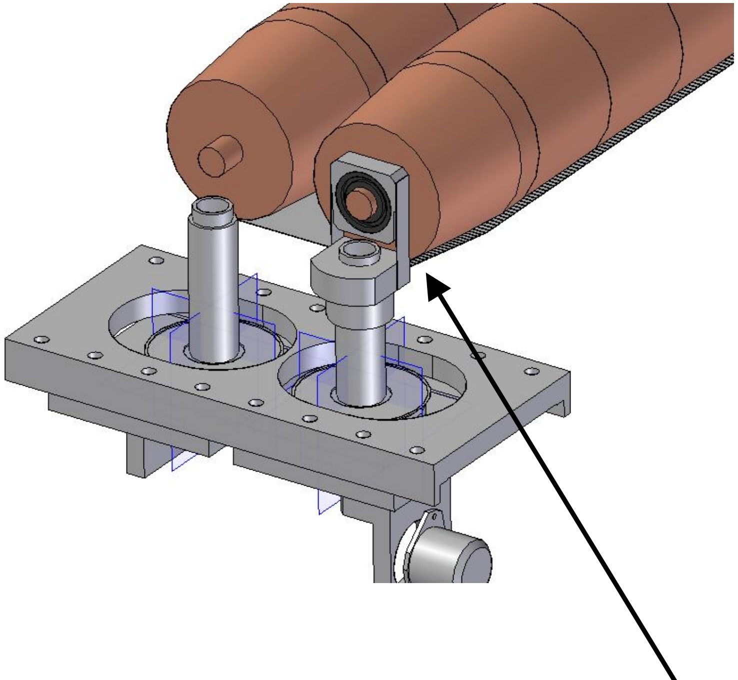




Shaft support (Phase I)	Central Aperture Stop
-Swelling toward beam	-Swelling neutralized
-Bending toward beam	-Bending neutralized

Adjustable central aperture-defining stop

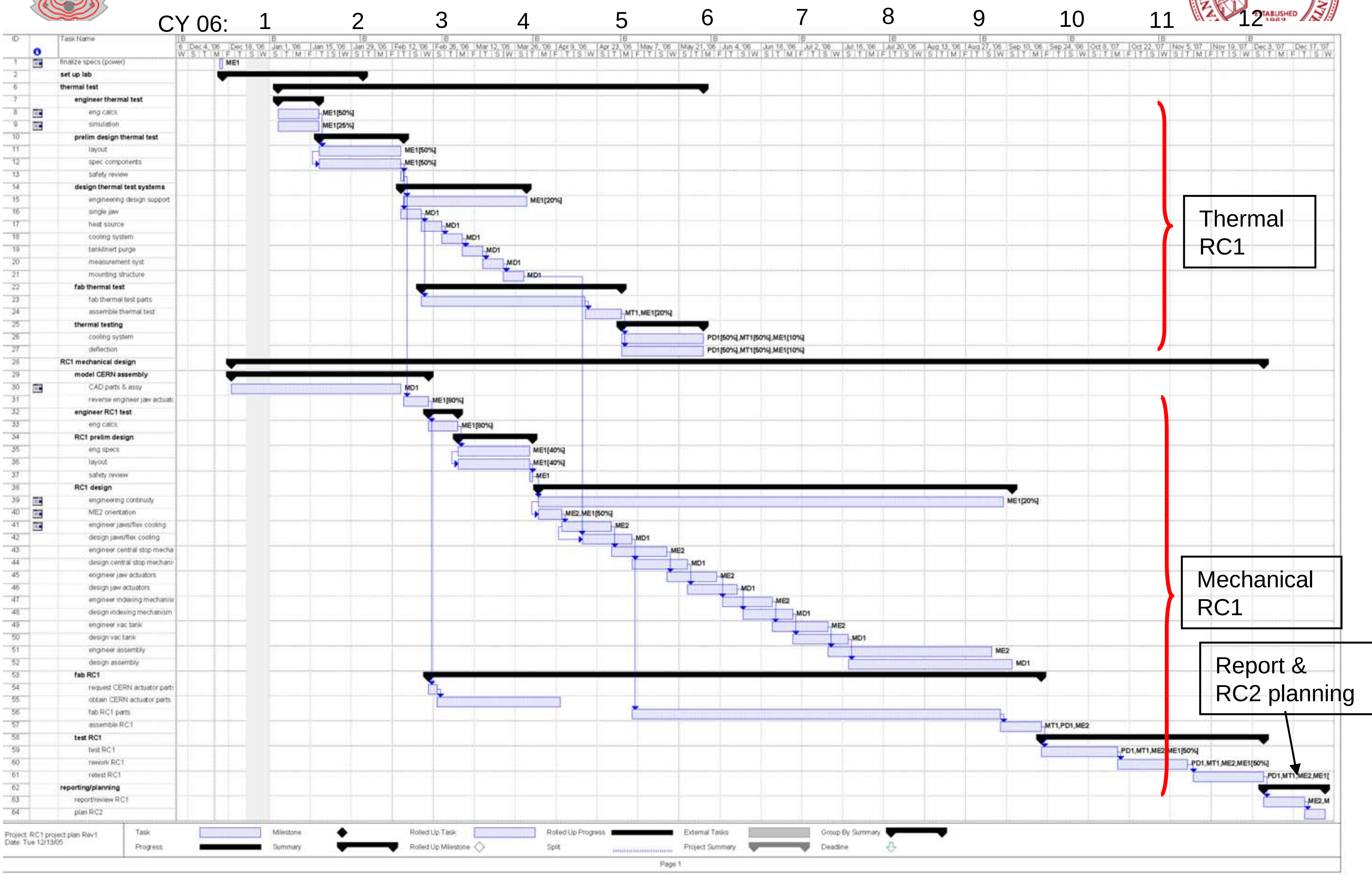




Stop in/out position controls aperture, actuator external, works through bellows.

Leaf springs allow jaw end motion up to 1mm away from beam

RC1 Thermal & Mechanical Test Plan (12/05)



12/15/05 Review - Summary

Major Concerns Expressed by Review Committee

1. Refine detailed engineering before proceeding
   - a. tilt stability of flexible end supports
   - b. accuracy of jaw fabrication & placement
   - c. lack of jaw indexing concept
   - d. cooling/thermal stability of bearings, central stop, springs, etc
2. Possible permanent deflection due to thermal transients
3. Try stiff core of SST to reduce deflection
4. Insufficient manpower

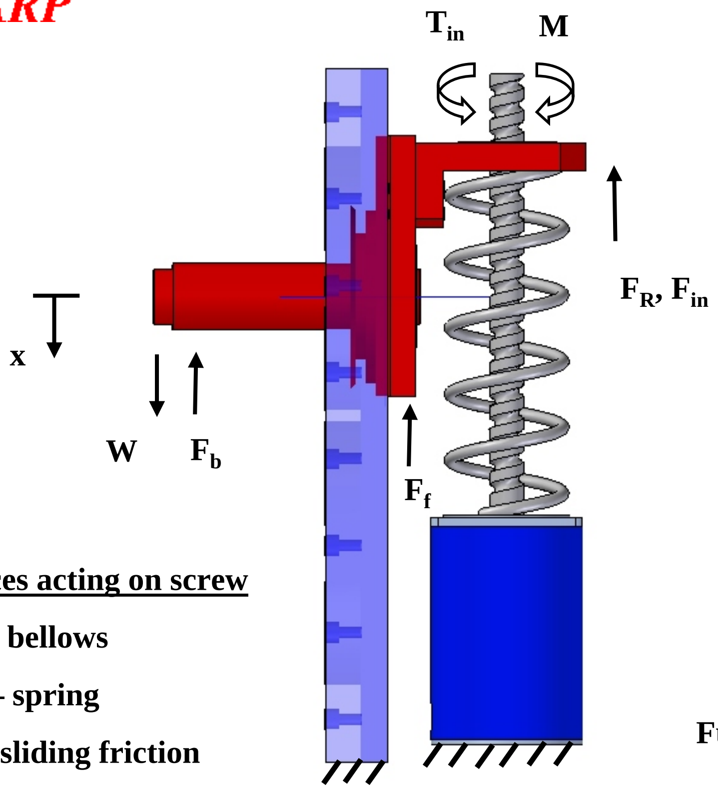
SLAC's Response

1. Detailed engineering of mechanism proceeding (concurrent w/ thermal test)
   - a. reverse engineered Ph I mechanism (jaw support spring compatibility)
   - b. jaw will be made sufficiently accurately
   - c. indexing via ratchet or escapement mechanism (NLC concept)
   - d. began simulations of heat loads on vulnerable systems (bearings)
2. Confirmed plastic deformation
   - a. adopting Glidcop as jaw material
   - b. begun transient analysis of errant beam "accident case" – jaw deflection
3. SST core no benefit, solid Cu core does help, but adds weight
4. Hired ME and designer.
   - a. new engineer is proceeding with thermal test (separate presentation)

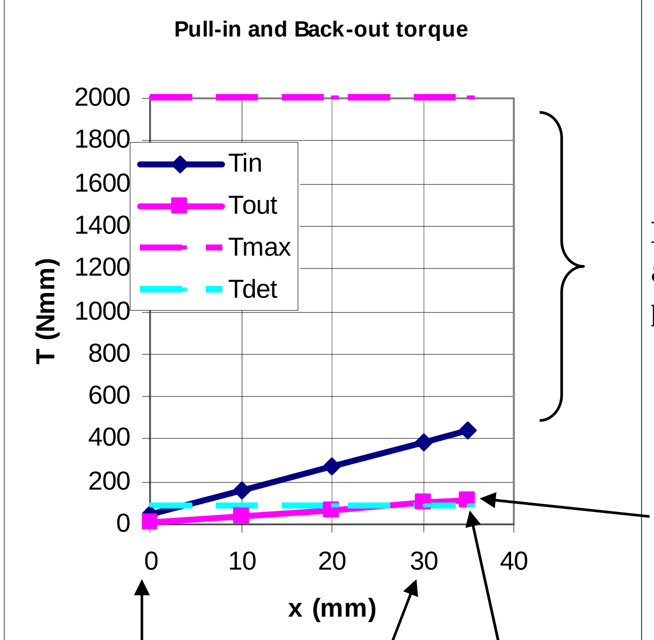
Note: Schedule has slipped ~6 mo. RC1 complete 4/07

Jaw Positioning Forces – Phase I

LARP



Ph II jaw weight on Ph I mechanism



Headroom – protection against motor slippage in pull-in mode

Autoretract mode – torque available to open jaws against motor detent torque in event of power failure

Fully retracted

Operational

Detent torque – when avalable torque falls below detent torque, further retraction ceases

<u>Forces acting on screw</u>

Fb – bellows

FR – spring

Ff – sliding friction

Fw – weight of jaw and table

<u>Torque acting on motor</u>

M – bearing friction

Tout – backing out torque

<u>Torque supplied by motor</u>

Tin – pull in torque

<u>Pulling in</u>

Fin = FR + Fb – Fw + Ff

Tin = Fin*(pull-in factor + bearing frict factor)

Tin < Tmax/2

<u>Backing out</u>

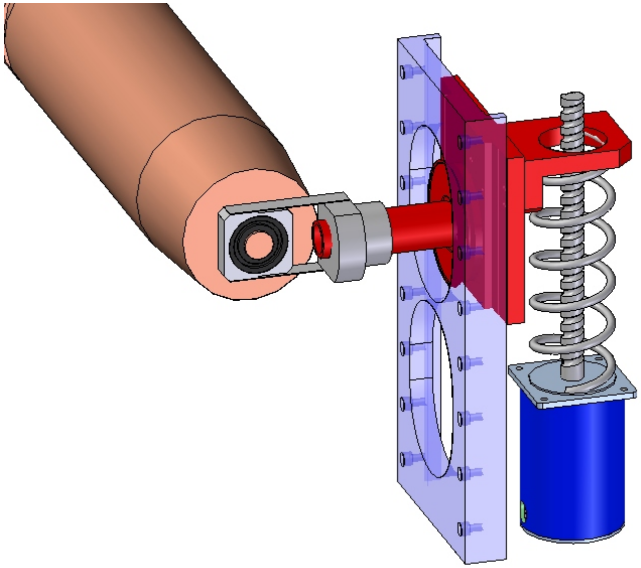
Fout = FR + Fb – Fw - Ff

Tout = Fout*(back-out factor - bearing frict factor)

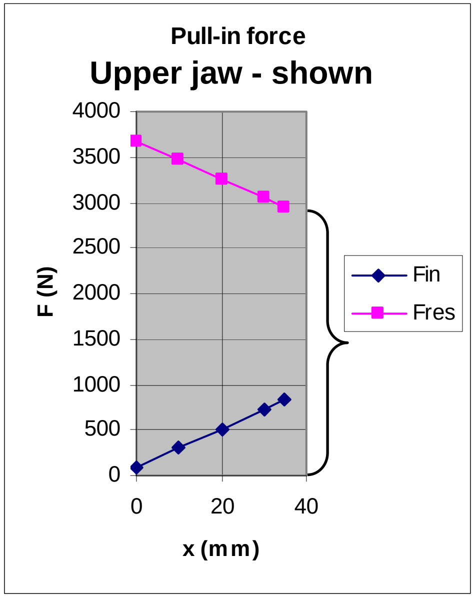
Tout > Tdetent

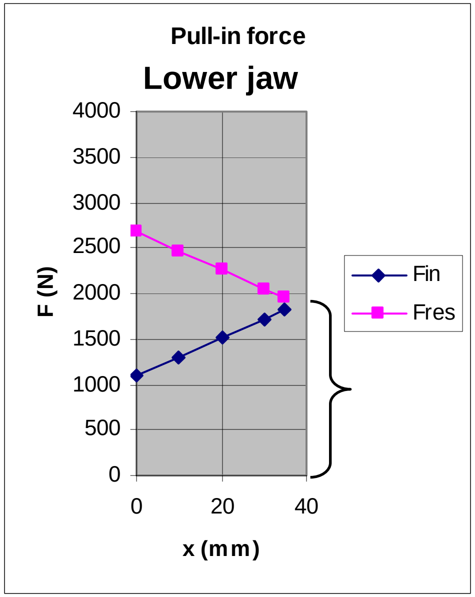
Jaw Positioning Forces – Phase I => Phase II

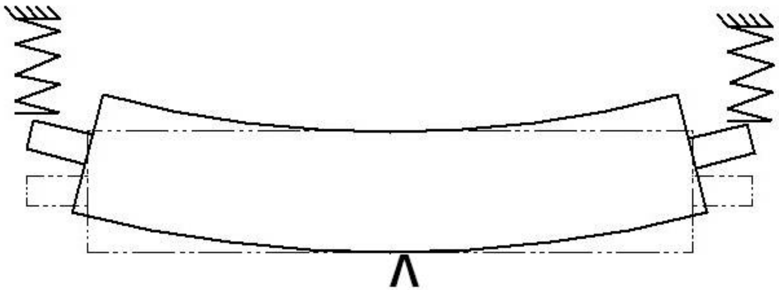
LARP



Pull-in headroom expressed as force at nut





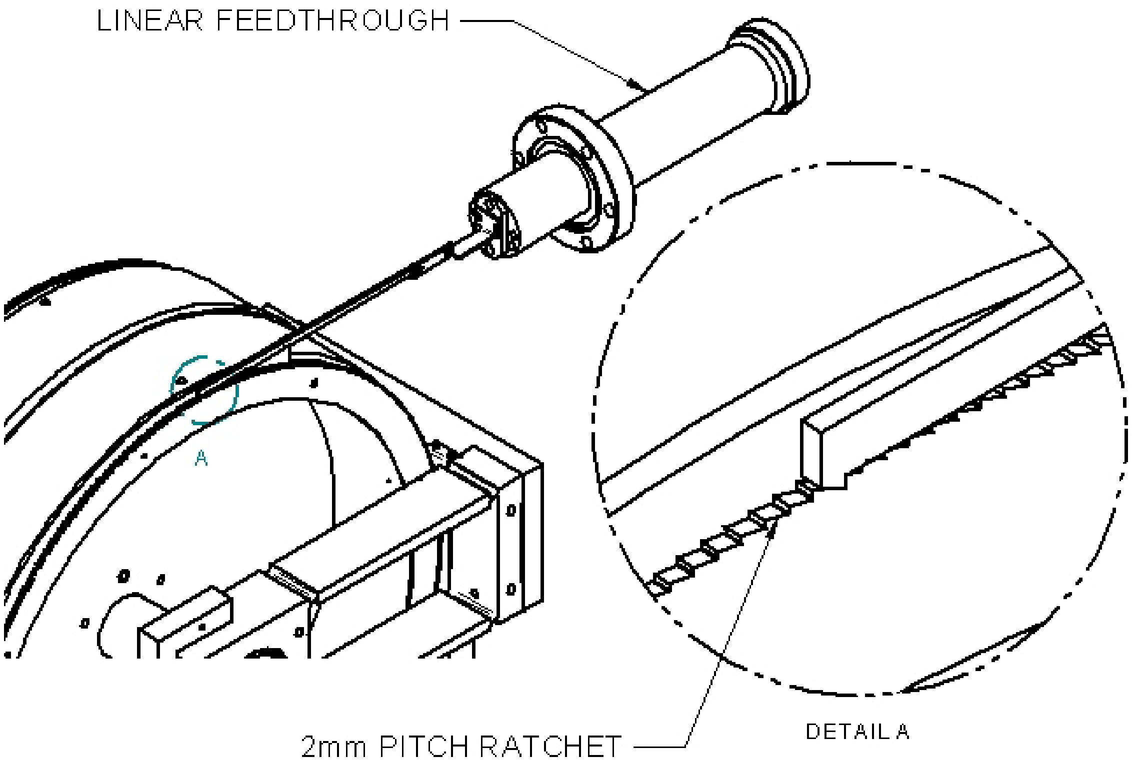


Jaw deflection = 400 um for 1 hr beam lifetime case, 1200 um for 10 sec transient @12 minute lifetime power level

Jaw end springs will be sized as compromise 1) bending-generated force applied to nut 2) static deflection due to jaw weight

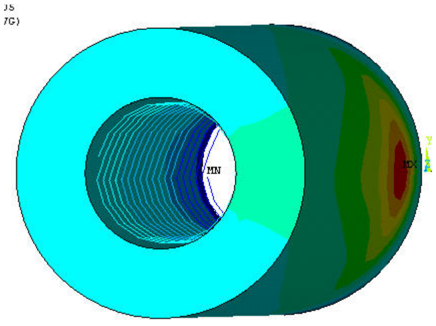
NLC Jaw Indexing Mechanism

Reciprocating linear motion advances jaw by one or more ratchet pitches. **LHC system will require opposing ratchet to hold jaw position against cooling tube deformation torque. Mechanism probably will be designed to actuate only when jaw fully retracted.**



Bimetallic jaw (SST/Cu) no benefit
Solid Cu beneficial

LARP



10 σ, primary debris + 5% direct hits		SS @ 1 hour beam life					transient 10 sec @ 12 min bea				
material	cooling arc (deg)	power (kW) per jaw	Tmax (C) [3]	Tmax water side (C)	defl (um) [4]	water Tout (C) 2	power (kW)	Tmax (C)	Tmax water side (C)	defl (um) [4]	
CERN ray file, 7 σ, 83.8% 60cm TCPV, 4.8% direct hits											
Cu solid, 136x950-,750 heated, 2 ch, fluid p	36	11.7	91.5	69.7	107.0	36.1	58.5	223.3	129.6	778	
Cu, 136x71x950- ,750 heated, (helical), fluid	-	11.7	86.5	68.3	394.0	36.0	58.5	231.3	153.5	1216	Baseline Hollow Cu
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	66.1		203.0	36.4	58.5	186.0		793	all cu shallow 10mm helix
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	65.1		198.0	36.4	58.5	184.0		781	all cu shallow helix new
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	75.5		209.0	36.0	58.5	208.9		919	all cu deep 25mm helix
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	54.3		136.0	36.4	58.5	158.5		606	all cu shallow, 2cm pitch
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	85.2		402.0	36.0	58.5	231.4		1135	bimet, thk 25mm Cu
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	95.3		448.0	36.4	58.5	256.0		1111	bimet, thin 10mm Cu
Cu, 136x11x950- ,750 heated, (helical), fluid	-	11.7	97.7		475.0	36.3	58.5	265.2		1158	bimet, thin Cu, sst cooled

Solid Cu (rows: all cu shallow 10mm helix; all cu shallow helix new; all cu deep 25mm helix; all cu shallow, 2cm pitch)

SST/Cu (rows: bimet, thk 25mm Cu; bimet, thin 10mm Cu; bimet, thin Cu, sst cooled)

Color	Legend
(green)	12/05 review baseline
(cyan)	12/05 review baseline plus solid Cu core
(orange)	12/05 review baseline plus solid SST core
(pink)	12/05 review baseline, thinner Cu plus solid SS

1. power per jaw is nominal - power deposited in rectangular FLUKA grid
2. Tin = 20C, T rise based on power, 9 L/min flow
3. simulation of jaw conduction and convection to water - no transport of heat by water
4. deflections referenced to end O.D. At the gap.

No benefit from SST core – same CTE as Cu, poor conductivity – temperature distribution unchanged. Cu core => alt heat path to opposite side, reduces ΔT therefore bending.

BONUS SLIDES

Specifications for baseline Phase II collimator

		spec	value
	Beam	sigma	200um
		location	Centered in pipe +/- 5mm
	Beam pipe	Spacing	224mm c-c opposing beampipes
		diameter	88mm OD
		clearance	8mm vacuum tank to opposing beampipe
	Jaw	Length	95cm including 10cm tapers on ends
		Diameter	136mm
		Material	Copper
		cooling	Embedded helical channel
		cooling	No water-vacuum joints if possible
		Special features	Circumferential slots to reduce thermal-induced bending, if no RF problems
*		deformation	<25um toward beam; <325mm away, steady state; <750um away, 10 sec transient
		Peak temp.	200C operating, 250C bakeout
		Range of motion	25mm per jaw, including +/- 5mm beam location drift
		Damage extent	15mm
	Aperture stop	Range of motion	Positively controls aperture from 5-15 sigma (2-6mm full aperture), must float +/- 5mm as jaws are moved to follow beam drift
	Heat load	Steady state	11.7 kW
		Transient	58.5 kW
	Vacuum	pressure	<1e-7 Pa (7.5e-10 Torr)
	Vac. tank	length	1.48m flange-flange
		flanges	CERN quick disconnect
		Clearance	Clears opposing beampipe with +/- 10^{o} adjustment in all orientations
	Cooling	Supply	27C
		return	42C max
	RF contacts	configuration	Sheet metal parts per Figures 7-9 subject to CERN approval

(pink box) baseline design deviates

* Relaxed from original spec

Unresolved Issues as of 12/15/05

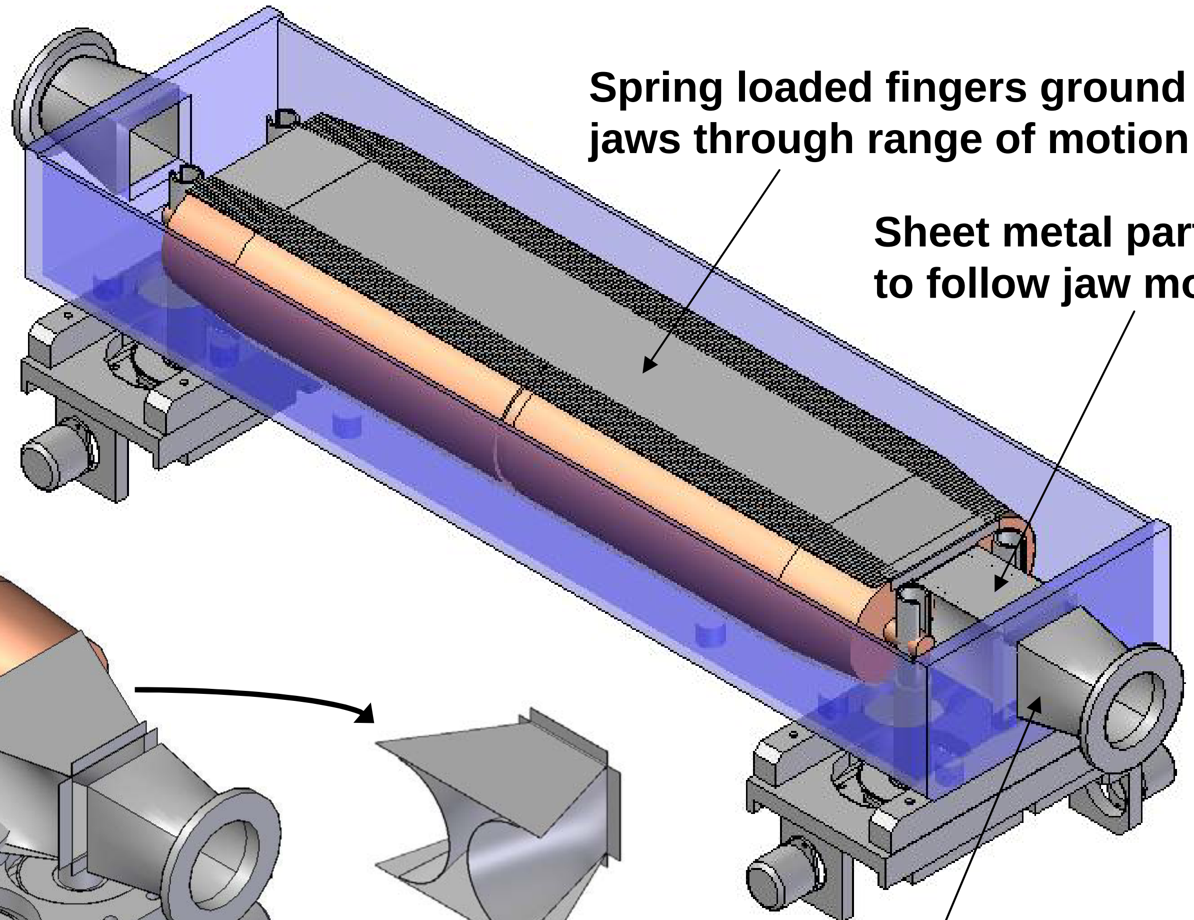
- Jaw actuation mechanism
  - How to handle mass of rotary jaws (fail open springs)
  - Availability of CERN actuation mechanism for SLAC use is being discussed
- Jaw rotary indexing mechanism
  - force to rotate jaws acceptable?
  - concept not developed
  - do we know angular position of jaw at all times?
- RF parts – taper requirement details not clear
  - central groove in jaws (smooth track for central aperture stop)
  - strain-relieving grooves in jaws
  - what is the acceptable range of taper angles for the jaw ends
- Heat generation in thin RF parts
- Need details of CERN support stands, etc
- Effects due to accident
  - does accident cause unacceptable gross distortion of the jaw?
  - do RF fingers work in contact with damaged surface?
  - How much material melts and where does it go? – depends on jaw orientation
  - is central aperture stop safe from contamination by melted material?
  - Beam tests may be required

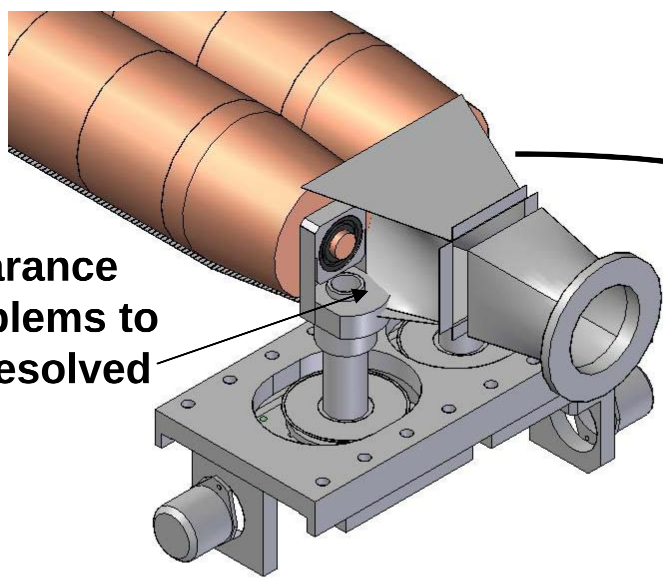
RF contact overview

Concept satisfies CERN RF requirements

- Need sufficient contact pressure

Cooling issues not addressed

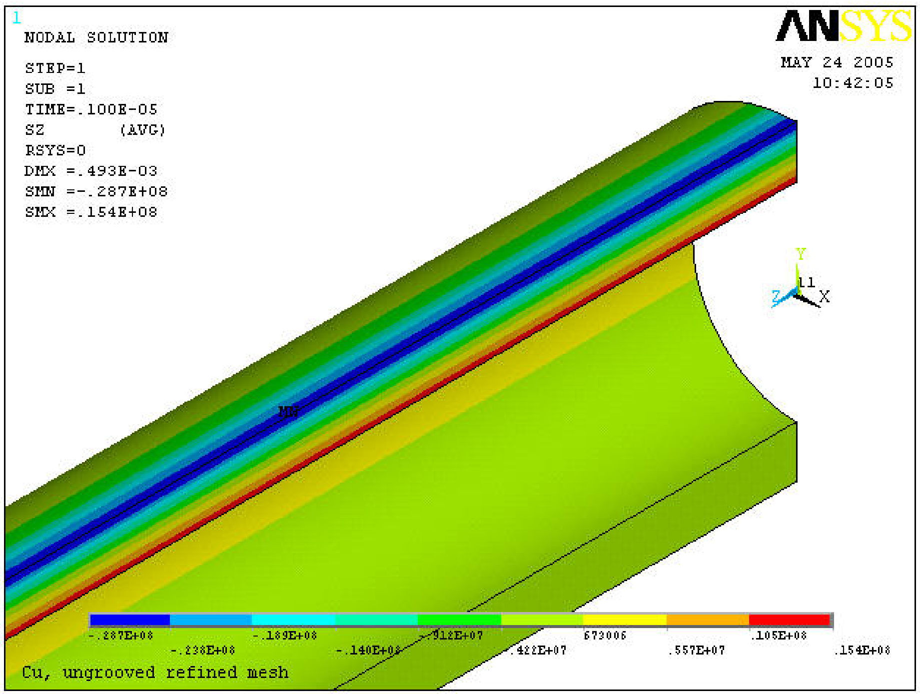


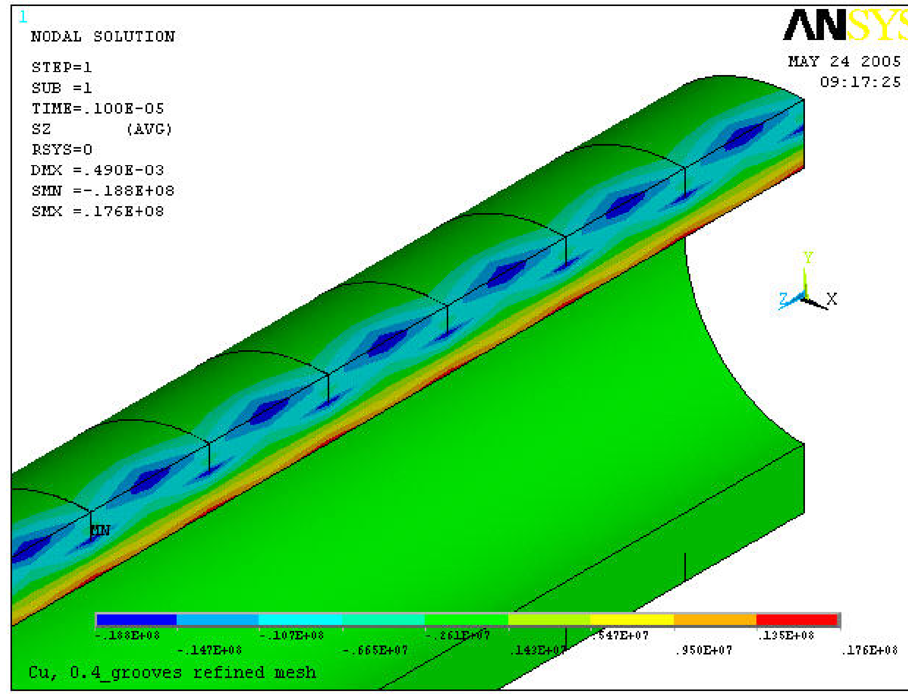


Grooves reduce bending deflection

Case	Tmax °C	Deflection (um)	
		Jaw edge ref	axis ref
Straight	59.5	33	~100
grooved	59.5	15	~74

Note: RF taper requirements may make this concept un-feasible





ANSYS simulation: Axial stress for un-grooved and grooved jaw with axially uniform heat input.

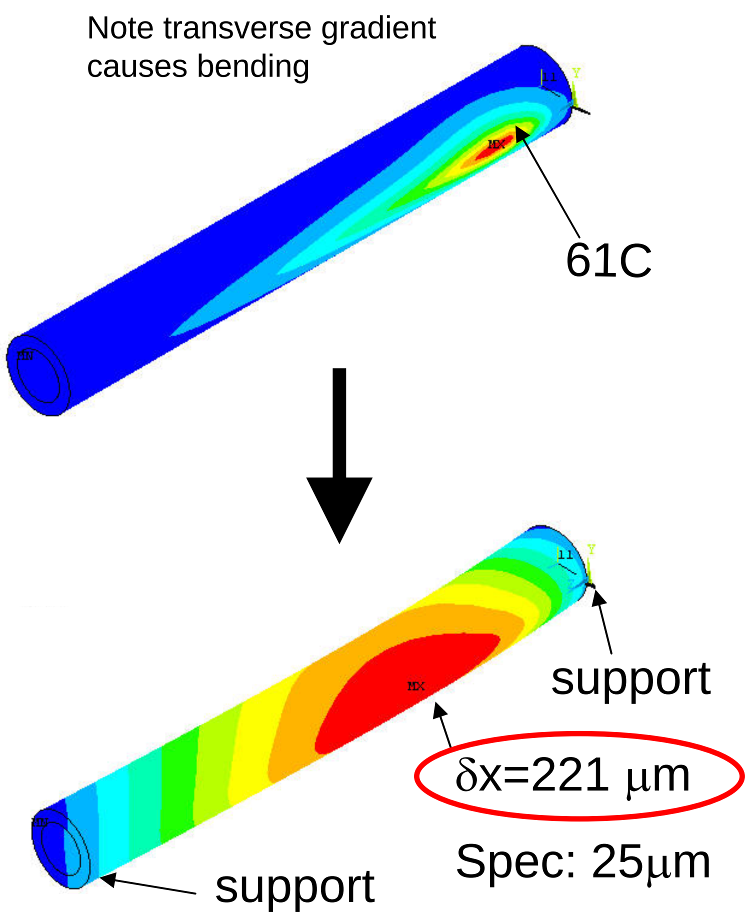
LARP

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

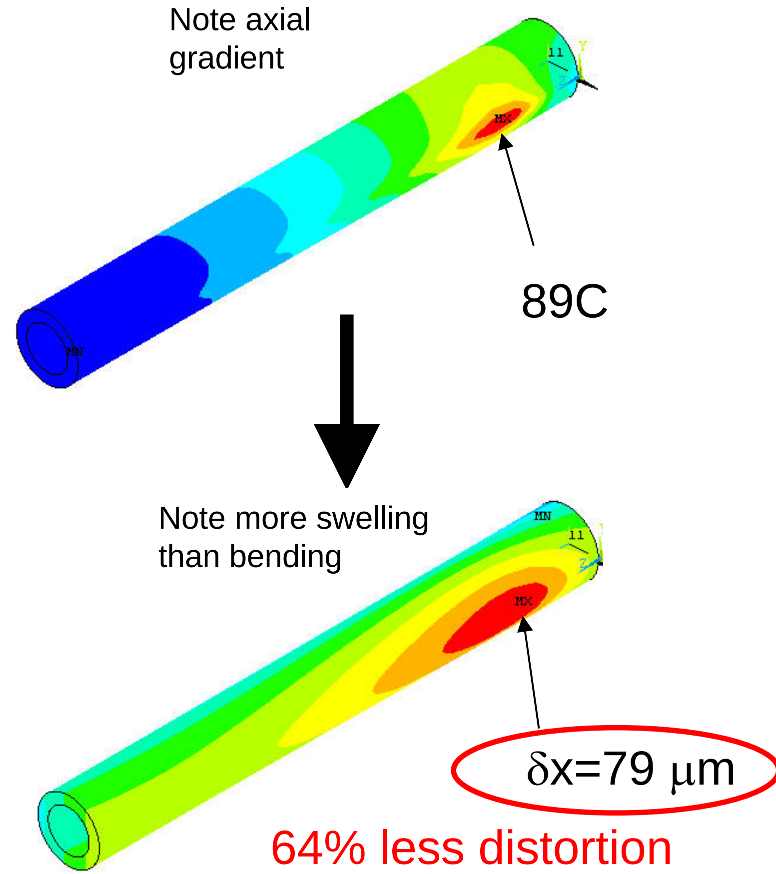
material	reasons for rejection in favor of Cu
BeCu (6% Cu-loaded Be)	Be is prohibited by CERN management, except when no alternatives exist; low cleaning efficiency; fabrication difficulty
Super Invar	poor thermal conductivity => high temperature (866C); desirable properties (low thermal expansion coefficient) disappear at 200C
Inconel 718	poor thermal conductivity => high temperature (T_{mp} = 1400C < 1520C transient peak) & very high deflection (1039um SS, 1509um transient)
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
Aluminum	relatively poor cleaning efficiency, water channel fabrication difficulty
Cu - 5mm wall	deflection only ~50% lower than 25mm Cu, loss of safety zone between surface and water channels
Cu/Be (5mm/20mm)	deflection only ~30% lower than 25mm Cu; Be prohibition; fabrication difficulty

Interesting effect: 64% less distortion if cooling is limited to a 36° arc centered on beam path.

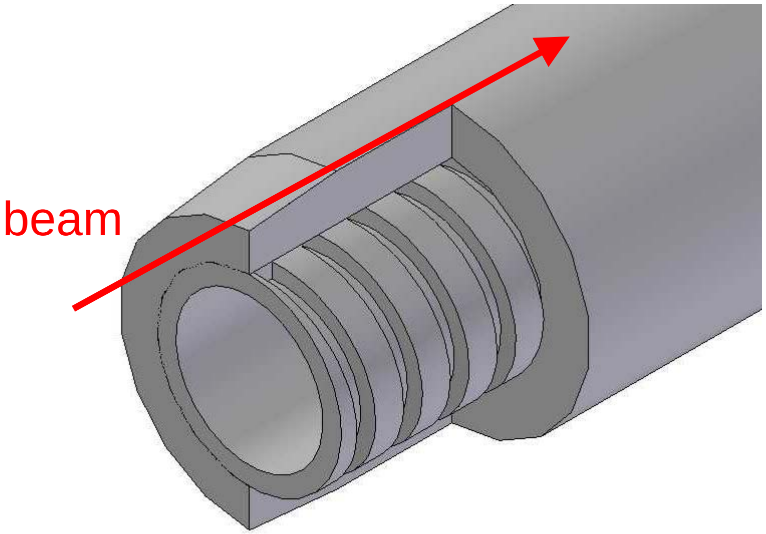
360° full I.D. cooling

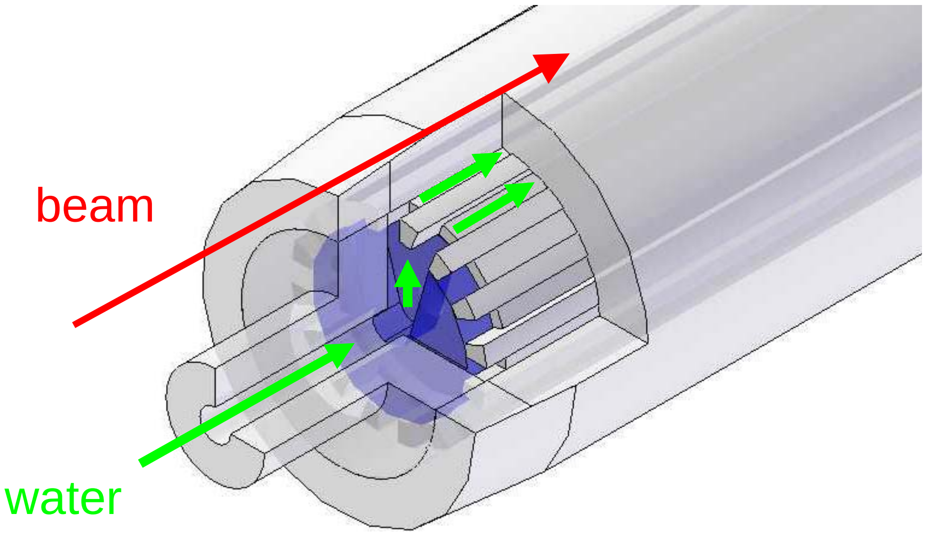


36° arc cooling



Helical and axial cooling channels illustrated





360º cooling by means of helical (or axial) channels.

Pro: Lowers peak temperatures.

Con: by cooling back side of jaw, increases net ΔT through the jaw, and therefore thermal distortion; axial flow wastes cooling capacity on back side of jaw.

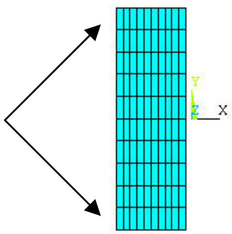
Limited cooling arc: free wheeling distributor – orientation controlled by gravity – directs flow to beam-side axial channels.

Pro: Far side not cooled, reducing ΔT and thermal distortion.

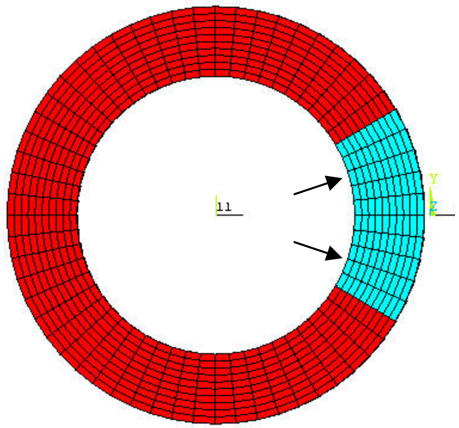
Con: peak temperature higher; no positive control over flow distributor (could jam); difficult fabrication.

Progression of ANSYS models – increasingly realistic

Water cooled

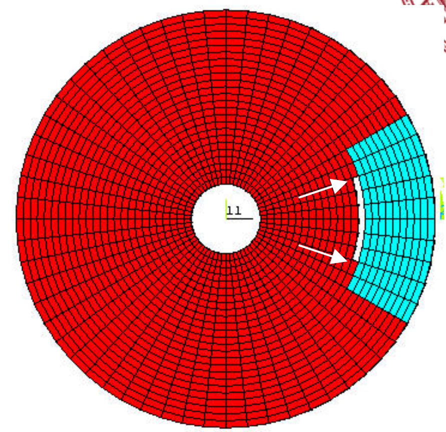


2-d & (3-d rectangular) model

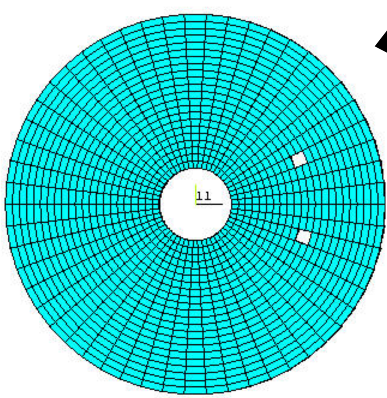


3-d "Hollow cylinder" model

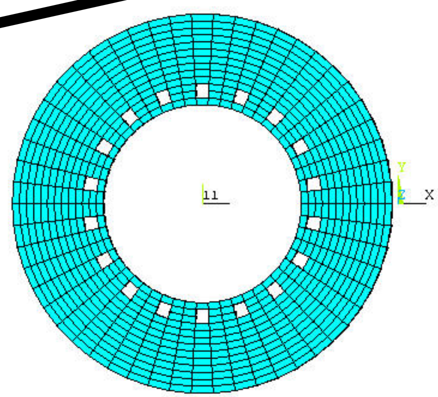
- Uniform or limited arc cooling



"Solid" model

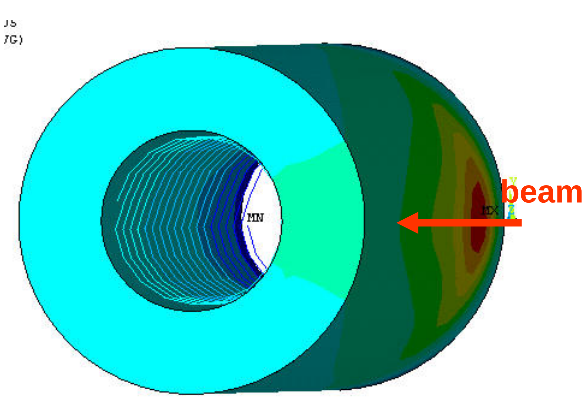


Tubular cooling channels



Uniform ID Cooling

– simulates helical or axial channels



H2O simulation

– helical flow shown