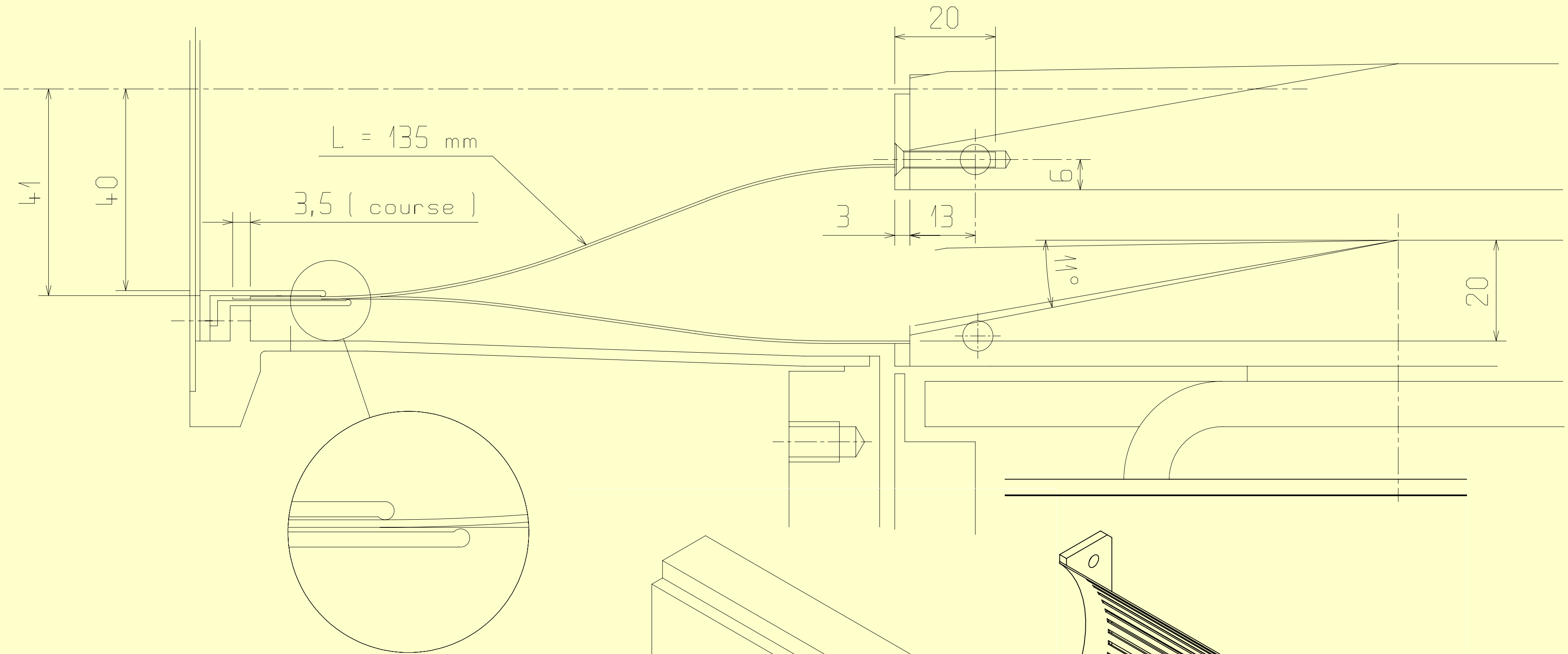
RF Fingers for Secondary Collimators

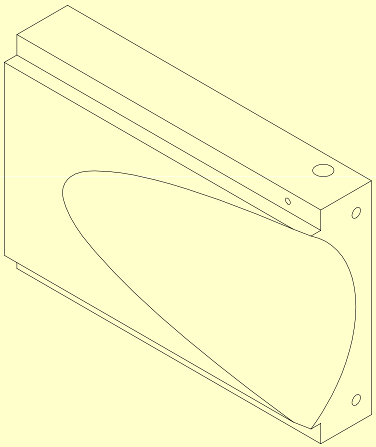
- Layout & constraints: heating, contact resistance
- Choice of materials
- Experimental results on contact resistance
- Calculations of thermal load
- Estimates of mechanical load and long term stability

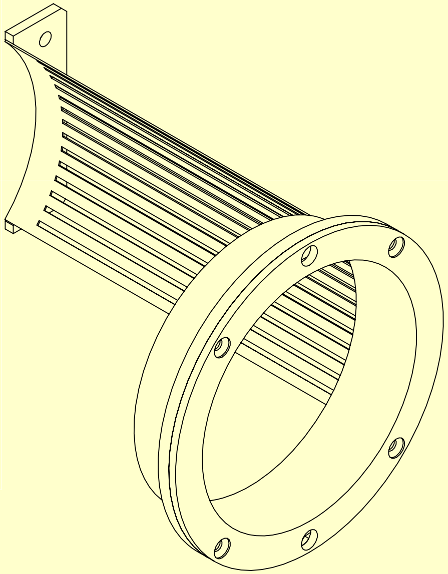
Boundary conditions (nominal beam, normal run)

- Power from particle bombardment on the RF contacts of the first secondary collimator TCSGA6 (from V. Vlachoudis data):
  - Peak power deposition: 5 W/cm^3
  - Average power deposition: 2.6 W/cm^3
- Power deposition on RF contacts of secondary collimators 1 to 8 (relative to the first):
  - 1, 0.14, 0.22, 0.08, 0.01, 0.03, 0.04, 0.04
- Power deposition from RF trapped modes (from A. Grudiev):
  - 1 W per each set of 15 fingers assuming they are made of Cu
  - Same power for CuBe fingers plated with at least 6 µm of Ag ($\cong 3\delta$)
- Contact resistance for each side of a collimator jaw (from F. Ruggiero):
  - < 1 mOhm
- Vacuum bakeout at 250 ºC

Present layout







Choice of materials: contact resistance

- Based on the experience of the cold interconnects and LEP (of course...)
  - For the best contact resistance a pair of noble metals (soft-soft or hard-soft) has to be used. No oxide that reduces contact resistance.

- RF fingers of CuBe, Ag plated 25 µm
  - Au cannot be used because of bakeout at 250 ºC
  - Thick plating withstands wear

- Centring rings of s.steel Rh plated 2 µm
  - Round contact corner, electropolished
  - Rh is very hard
  - No interdiffusion Rh-Ag up to 600 ºC

Choice of materials: which CuBe alloy? General properties

Standard alloy (CERN stores): low conductivity, high yield strength (~“elastic limit”)

Alloy	Temper (note 2)	Tensile Strength (ksi)	Yield Strength 0.2% offset (ksi)	Elongation Percent (note 3)	Fatigue Strength (ksi) R = -1, 10^8 cycles	HARDNESS (see note 4) Diamond Pyramid	Rockwell B or C	Rockwell Superficial	Electrical Conductivity (% IACS)
25 C17200	A Dead Soft (TB00)[1]	60-76	28-36	35-65	30-35	90-144	B45-78	30T46-67	15-19
	A Planished (TB00)[1]	60-78	30-55	35-60	30-35				15-19
	1/4 H (TD01)	75-88	60-80	20-45	31-36	121-185	B68-90	30T62-75	15-19
	1/2 H (TD02)	85-100	75-95	12-30	32-38	176-216	B88-96	30T74-79	15-19
	H (TD04)	100-120	90-115	2-18	35-39	216-287	B96-102	30T79-83	15-19
	AT (TF00)[5]	165-195	140-175	3-15	40-45	353-413	C36-42	30N56-62	22-28
	1/4 HT (TH01)[6]	175-205	150-185	3-10	40-45	353-424	C36-43	30N56-63	22-28
	1/2 HT (TH02)[6]	185-215	160-195	1-8	42-47	373-435	C38-44	30N58-63	22-28
	HT (TH04)[6]	190-220	165-205	1-6	45-50	373-446	C38-45	30N58-65	22-28

100 kpsi= 6.89 MPa

High conductivity alloy (ex. “cold interconnects”), lower yield strength

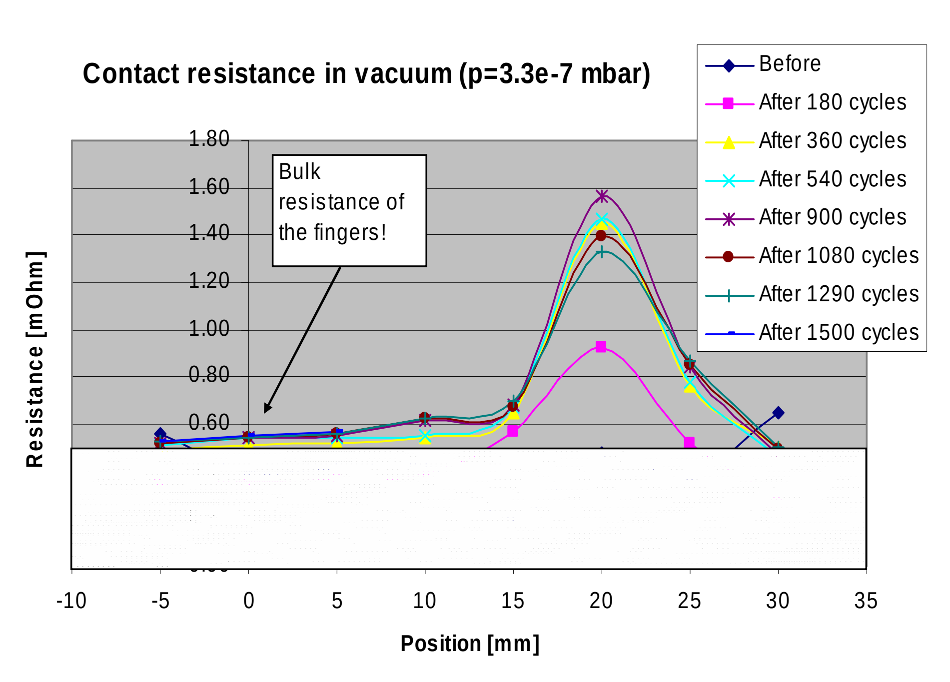
174 C17410	1/2 HT (TH02)	95-115	80-100	10-20	40-45	180-230	B89-98	30T75-82	50 min
	HT (TH04)	110-130	100-120	7-17	40-45	210-278	B95-102	30T79-30N48	45-60

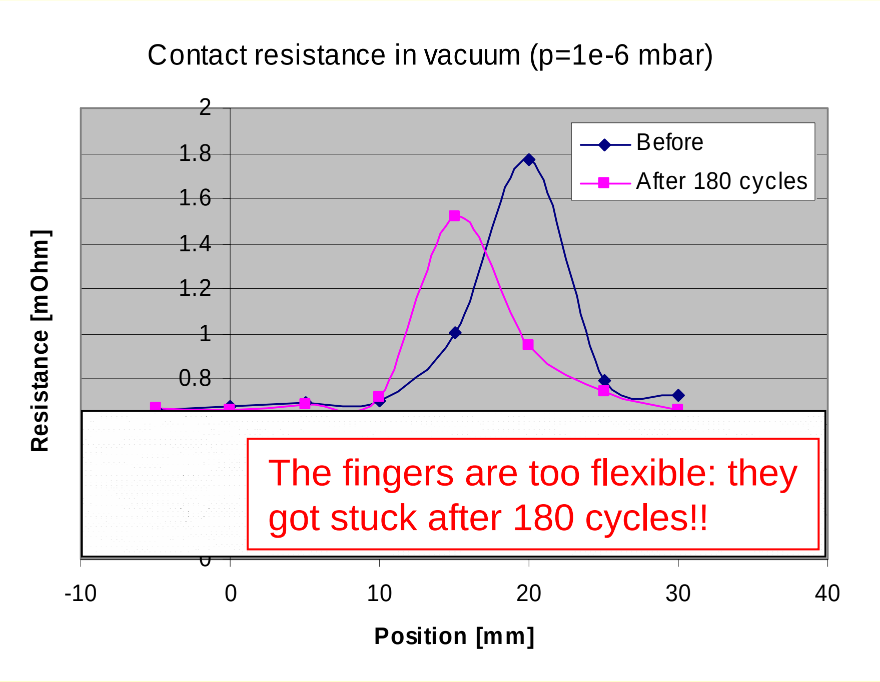
All have E=130÷140 GPa independent of composition or of thermal treatment (“age hardening”)

Contact resistance: results (carried out with CERN CuBe)

- Thick fingers
- CuBe C17200 ½ HT, 0.5 mm thick, 8 µm Ag plating, old centring rings (with sharp contact point)
- R contact < 0.5 mOhm for the entire set of fingers (value limited by the bulk resistance of the fingers)

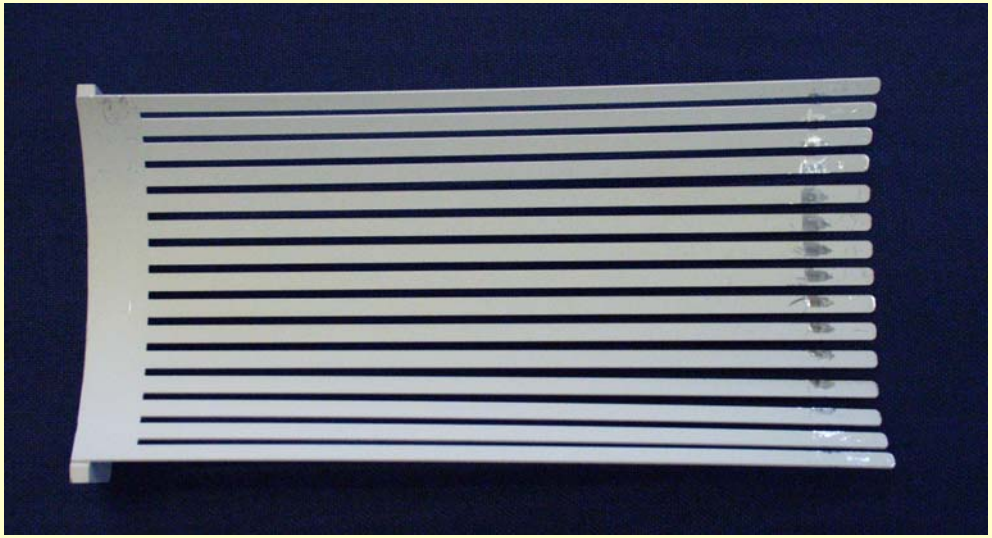
- Thin fingers
- CuBe C17200 ½ HT, 0.3 mm thick, 25 µm Ag plating, new centring rings (with rounded contact point)
- R contact < 0.7 mOhm for the entire set of fingers (value limited by the bulk resistance of the fingers)

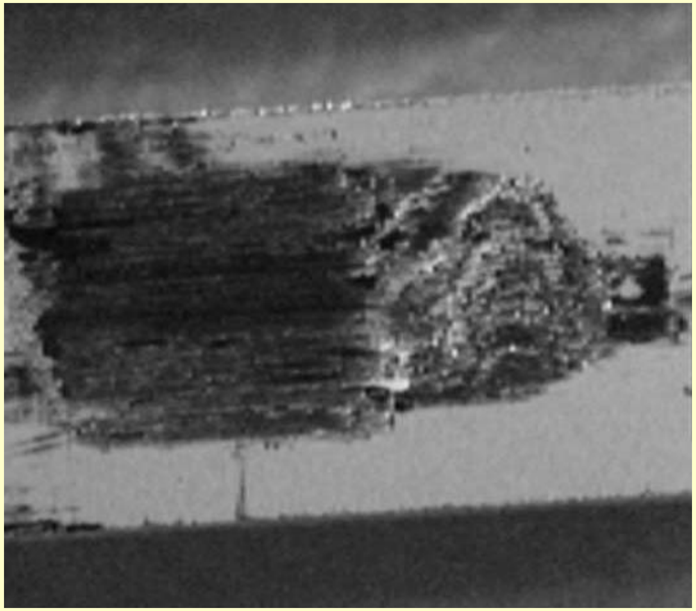




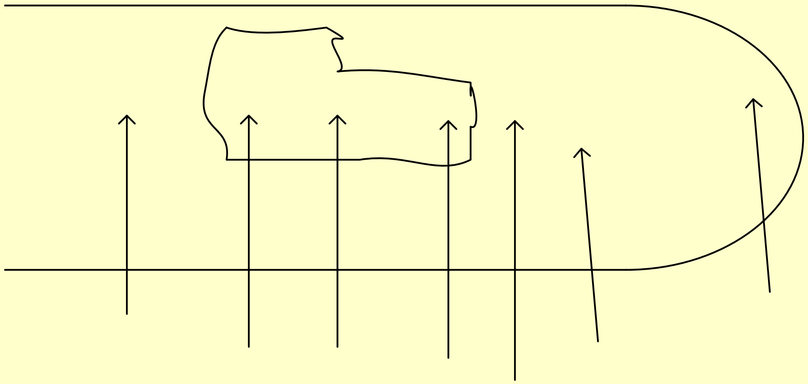
The contact resistance is correct with this choice of materials and platings

Wear after 1500 cycles (4 years LHC life) CuBe 0.5 mm thick

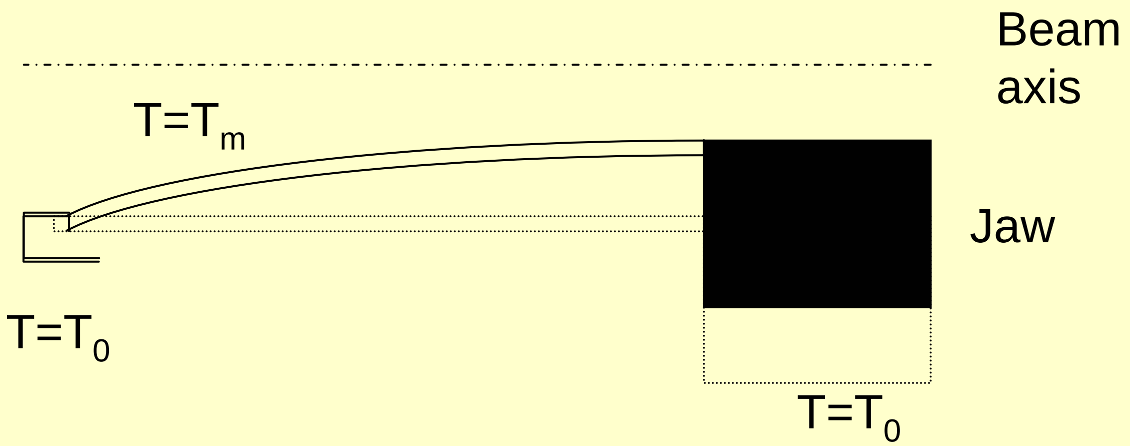




Ag thickness in µm on



Heating effect including particle bombardment and RF



The Wiedemann-Franz law relates the bulk thermal conductivity to the electrical conductivity for metals.

$$K_{thermal}/\sigma_{electrical}T = 2.45\text{x}10^{-8}\ \text{W.}\Omega/\text{K}^2 \ (\textit{Lorenz}\ \text{number})$$

This law can be extrapolated to estimate the contact thermal conductance from the measured contact electrical resistance (extrapolation at 300 K)

$$R_{contact} \cong 8\ \text{m}\Omega \Rightarrow C_{contact} \cong 0.001\ \text{W/K}$$

Heating effect including particle bombardment and RF (first collimator)

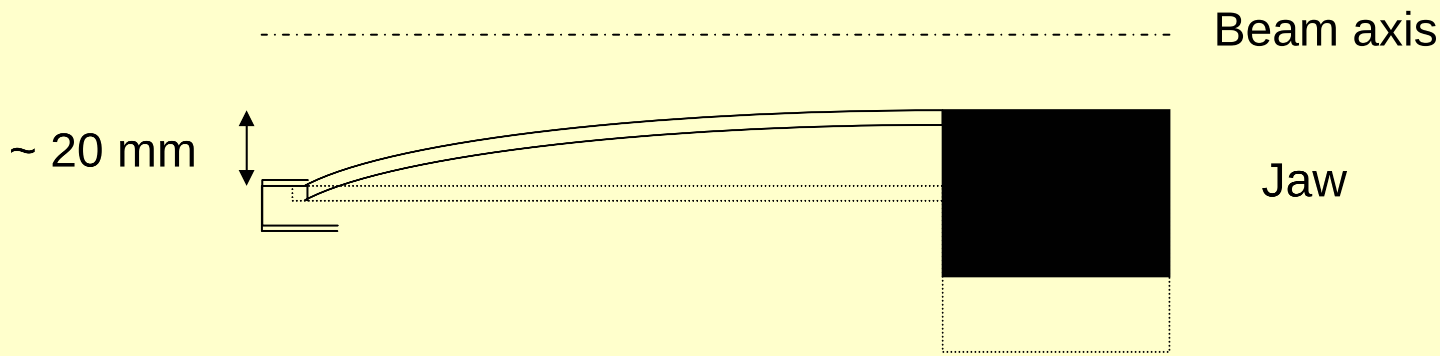
Power deposition: From particles 1.1 W / finger at 0.55 mm thickness (CuBe+Ag)
From trapped modes 0.07 W / finger if Ag plated

Blackbody heat radiation: 0.18 W per finger at 300 ºC

	T_{max} for 0.3 mm thickness of the fingers (T_{max} without contact at the flange side)	T_{max} for 0.5 mm thickness of the fingers (T_{max} without contact at the flange side)
CuBe C17200 ½ HT (standard alloy) + Ag plating 2*25 µm	T_{max} = 200 ºC (T_{max} = 325 ºC)	T_{max} = 225 ºC (T_{max} = 350 ºC)
CuBe C17410 ½ HT (high-conductivity alloy) + Ag plating 2*25 µm	T_{max} = 125 ºC (T_{max} = 200 ºC)	T_{max} = 150 ºC (T_{max} = 200 ºC)

(Assuming power density by particle bombardment in Ag≅Cu)
(Both the thermal conductivity and contact thermal conductance would increase with temperature)

Bending stress



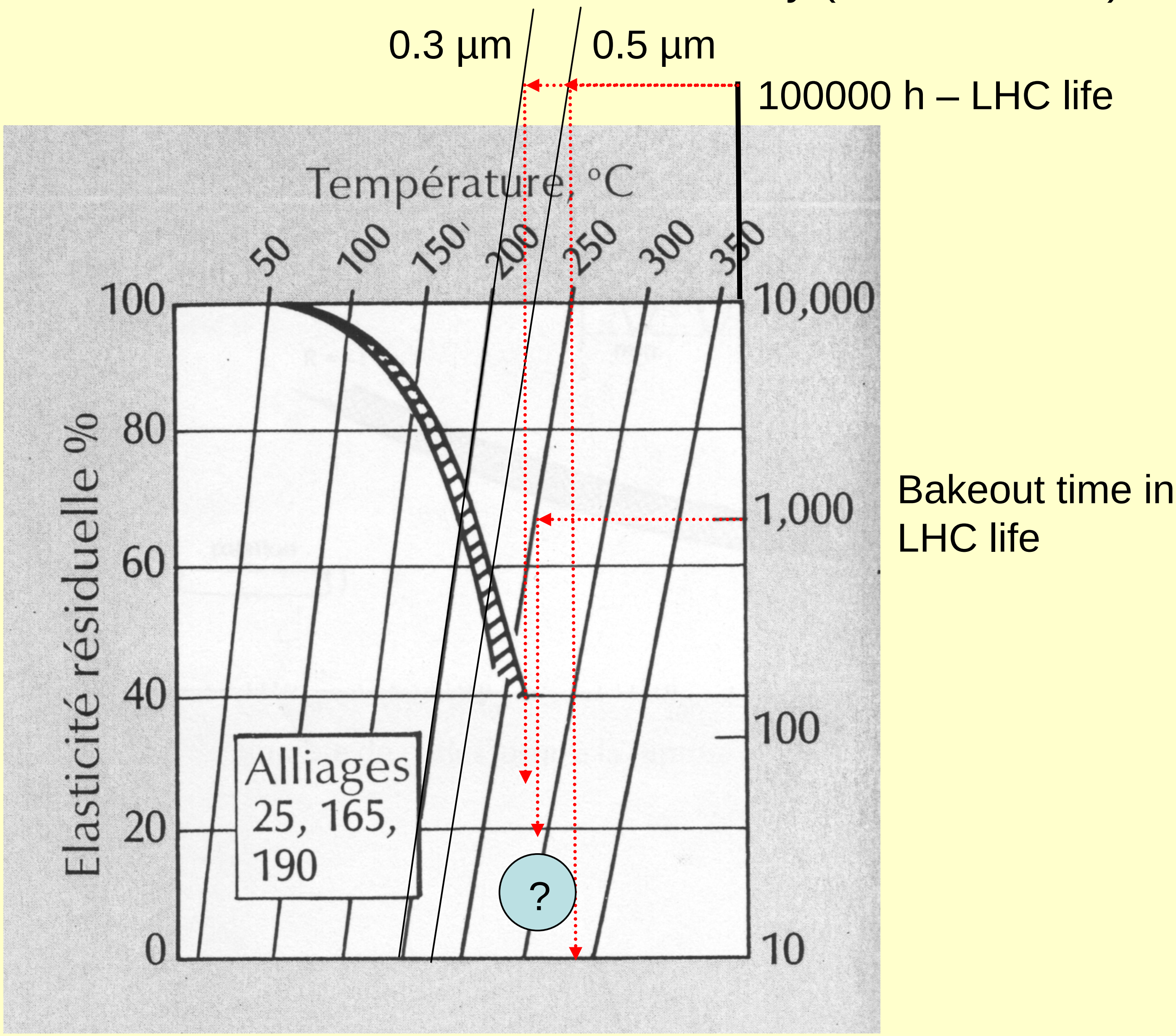
- CuBe thickness 0.5 mm
- Force = 13 grams on centre finger
- Max stress σ_{max} = 130 MPa

- CuBe thickness 0.3 mm
- Force = 2.9 grams on centre finger
- Max stress σ_{max} = 80 MPa

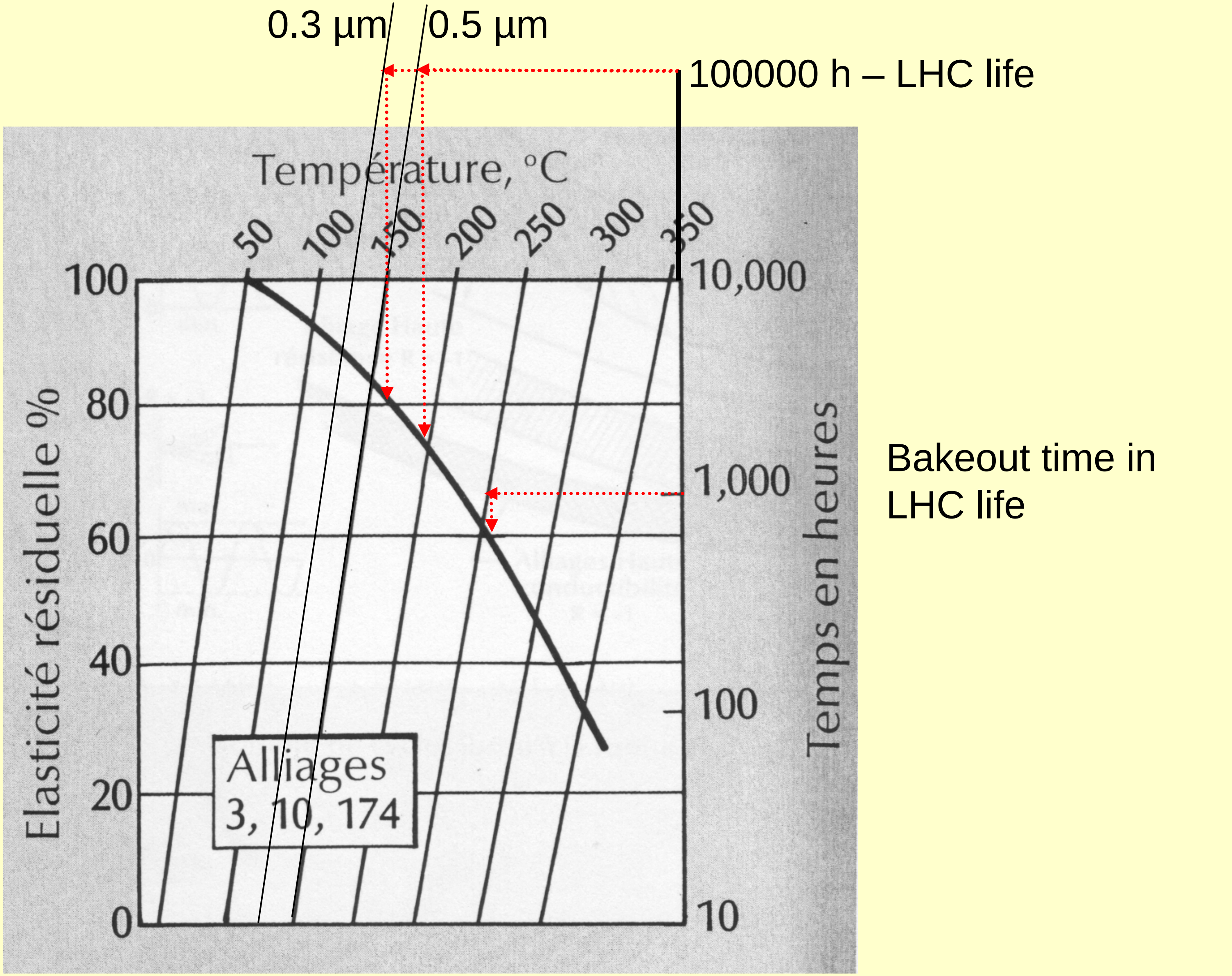
CuBe standard C17200 ½ HT $\rightarrow$ $\sigma_{0.2}$ = 1240 MPa
CuBe high conductivity C17410 ½ HT $\rightarrow$ $\sigma_{0.2}$ = 620 MPa

Even with the high-conductivity alloy the maximum stress is ~ 20 % of the yield strength

Stress relaxation resistance for standard alloy (at 75% stress)



Stress relaxation resistance for high conductivity alloy (at 75% stress)



A final word on...

- Further testing
  – Long wear test (15000 cycles) combined with 250 ºC are under way

- Electrical contact between C-C jaw and CuBe
  – At present is only done with two screws and $R_{contact}$ ~ 0.5 mOhm
  – It is foreseen to use a more stable mechanical fixation (“IKEA” type) that would only improve the contact resistance
  – The front edge of C-C should be plated (“active braze alloy”) or a Cu foil brazed in order to improve the contact resistance for the first collimator. Contact resistance in this configuration has been measured at ~ 0.03 mOhm (included in the previous calculations)
  – Maybe a small edge will be machined in order to guarantee that the current flows at the surface

- Longitudinal contacts
  – They must withstand a wear equivalent to 15000 cycles (open-close of the jaw) times 30 mm $\cong$ 1 km !
  – Silver plated CuBe – Ag plated sliding onto electropolished s.steel plates
  – The wear test has been performed, waiting for microscope observation. No sticking of contacts has been observed in vacuum (but no bakeout test yet)

Heating effect including particle bombardment and RF (first collimator NEW)

Power deposition: - From particles 0.23 W / finger at 0.55 mm thickness (1.1 W/cm^3)
- From trapped modes 0.16 W / finger if Ag plated

(Blackbody heat radiated: 0.02 W per finger at 100 ºC)

New estimates for worst finger – continuous operation of the machine at 0.8e11 p/sec losses

- Includes contact resistance of 8 mOhm / finger at flange side and 1.5 mOhm / finger at C-C side (hoped for with new "IKEA" fixing)

	ΔT_{max} for 0.3 mm thickness of the fingers (ΔT_{max} without contact at the flange side)	ΔT_{max} for 0.5 mm thickness of the fingers (ΔT_{max} without contact at the flange side)
CuBe C17200 ½ HT (standard alloy) + Ag plating 2*25 µm	ΔT_{max} = 125 ºC (ΔT_{max} = 200 ºC)	ΔT_{max} = 125 ºC (ΔT_{max} = 200 ºC)
CuBe C17410 ½ HT (high-conductivity alloy) + Ag plating 2*25 µm	ΔT_{max} = 100 ºC (ΔT_{max} = 150 ºC)	ΔT_{max} = 100 ºC (ΔT_{max} = 150 ºC)

(Assuming power density by particle bombardment in Ag≅Cu)
(Both the thermal conductivity and contact thermal conductance would increase with temperature)