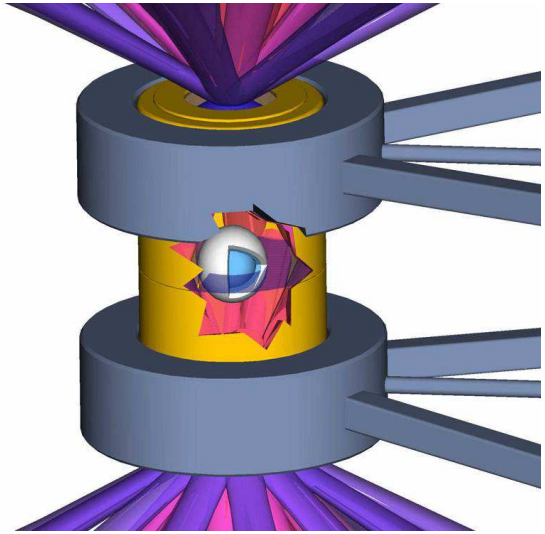
energie atomique • energies alternatives

Update on thermal simulations of LMJ cryogenic target



20th Target Fabrication Meeting
Santa Fe (NM)
May 2012

Géraldine MOLL, Michel MARTIN, Ghislain PASCAL, Olivier LEGAIE, Julien SCHUNCK

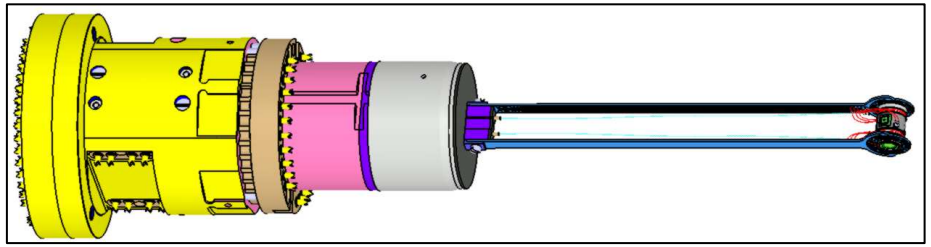
CEA VALDUC, 21120 Is sur Tille, France

Ignition experiments at Laser Méga Joules require cryogenic targets

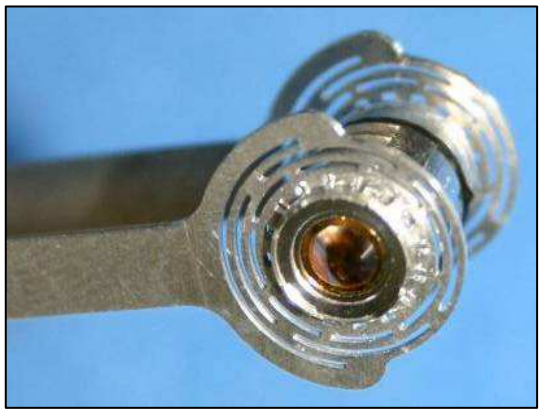
LMJ Facility (1.8MJ, 550TW)

Experimental Chamber / Cryogenic Target Positioner

Cryogenic Target Assembly (CTA) *

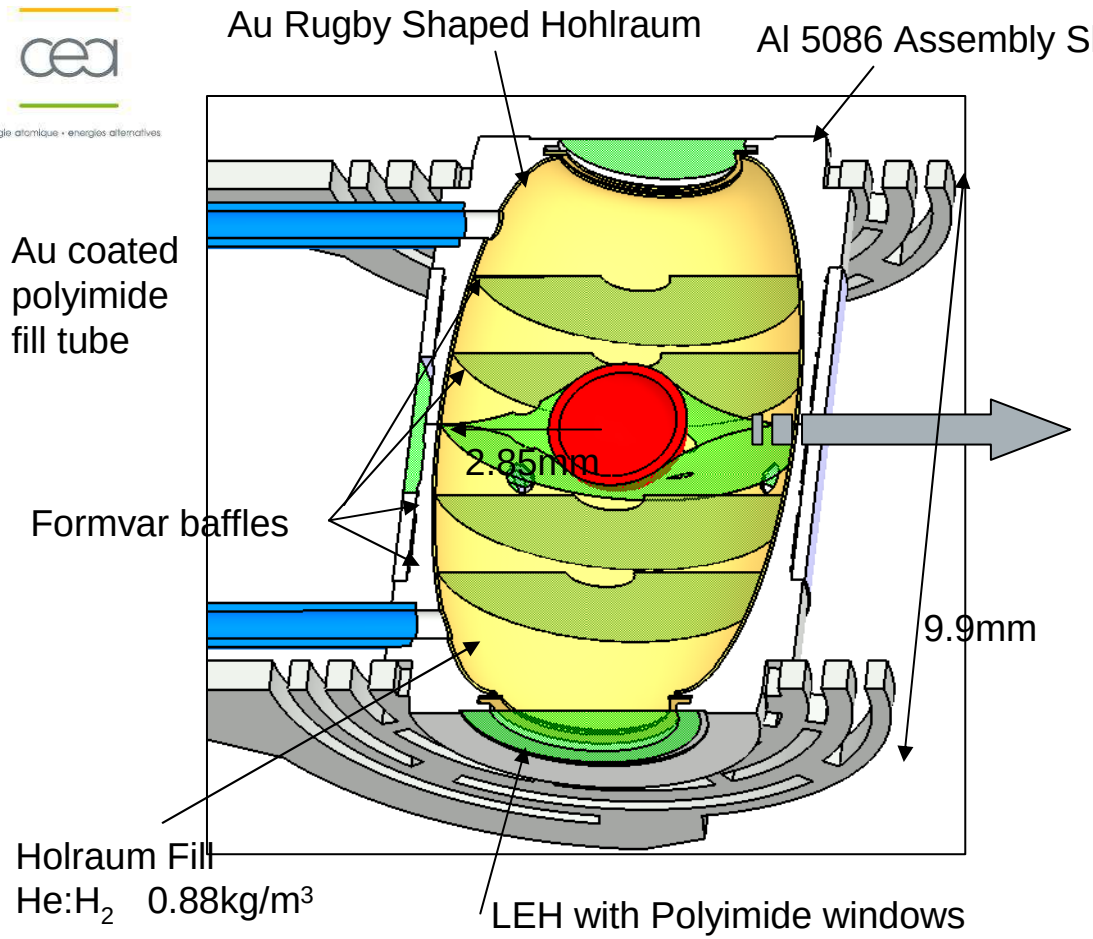


High purity Al cooling arm



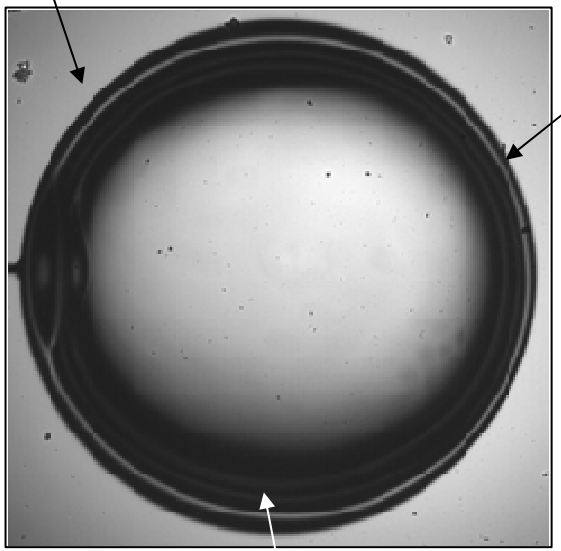
* see details in E.Fleury presentation Monday AM2-4 **: The Filling Facility for LMJ Cryo Targets.**

Cryogenic ice layer (THD or DT) need a special attention



$T_{melting}$ -1.5K

2.220mm ϕ CH_x capsule * (A-943)



DT or THD ice layer 87µm

Fuel layers are formed by β-layering in an isothermal wall capsule.

* See Tuesday AM1-2 : **Doped CHx Capsule Fabrication for Cryogenic LMJ Targets by** C. Chicanne,

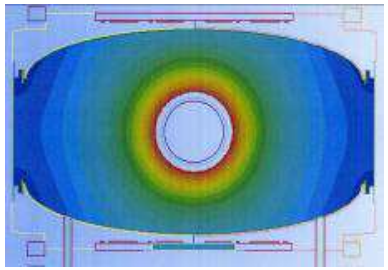
Successful ignition experiments need high-quality fuel layers

Physic specifications for high-quality layers :

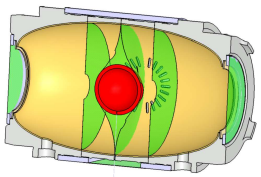
- Ice roughness (inner surface with no local defects),
- Ice layer (uniformity→$\delta e = \pm 0.5 \mu m$),
- Central vapor density of $0.3 kg.m^{-3}$ for laser shot (i.e. at T_m -1.5K).

How to be sure that the DT or THD ice layers meet physic specifications?

By controlling the thermal environment around the capsule → Spherical isothermal wall → ΔT

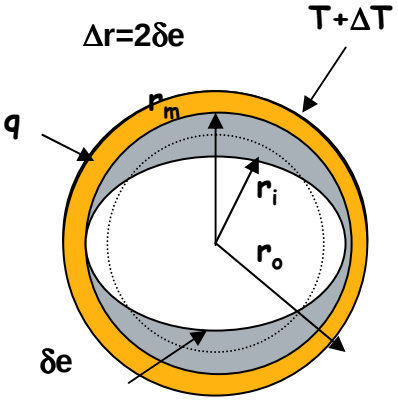


By means of:
- Material and shape,
- 4 Heaters,
- Anti-convection baffles.



How can we estimate ΔT for steady state ?

Thermal criteria C_{DT} and C_{THD}



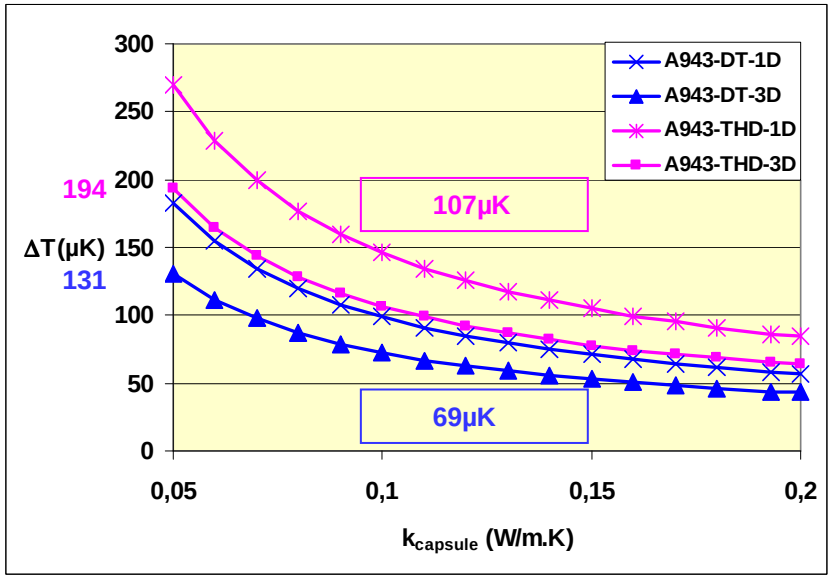
k : thermal conductivity
Φ :self-heating flux

1-D analytical model :

$$\Delta T = \frac{\phi_{DT}\Delta r}{k_{DT}}\left[r_i - r_m - \frac{k_{DT}}{k_{Capsule}}(r_o - r_m)\right]$$

3-D analytical model :

$$\Delta T = \frac{\phi_{DT}\,\Delta r}{k_{DT}}\left[\frac{r_i^2}{r_m} - r_i - \frac{k_{DT}}{k_{Capsule}}\left(\frac{r_o - r_m}{r_o \cdot r_m}\right) r_i^2\right]$$

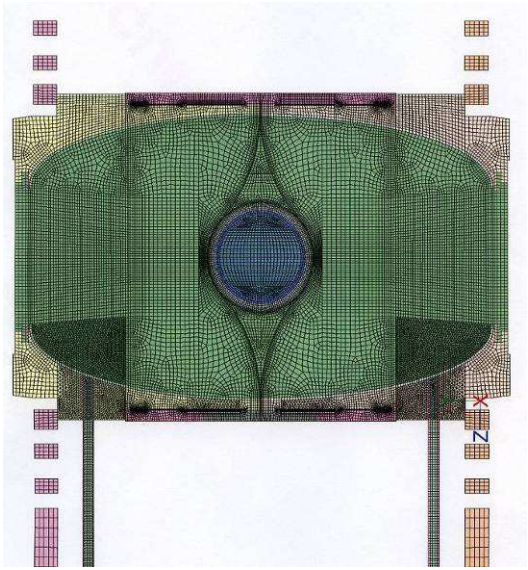


→ Cryogenic target modeling is a useful tool for finding ideal thermal environment.

Thermal simulations with a commercial CFD software

Mesh is created in Gambit

- Symmetry along the target:



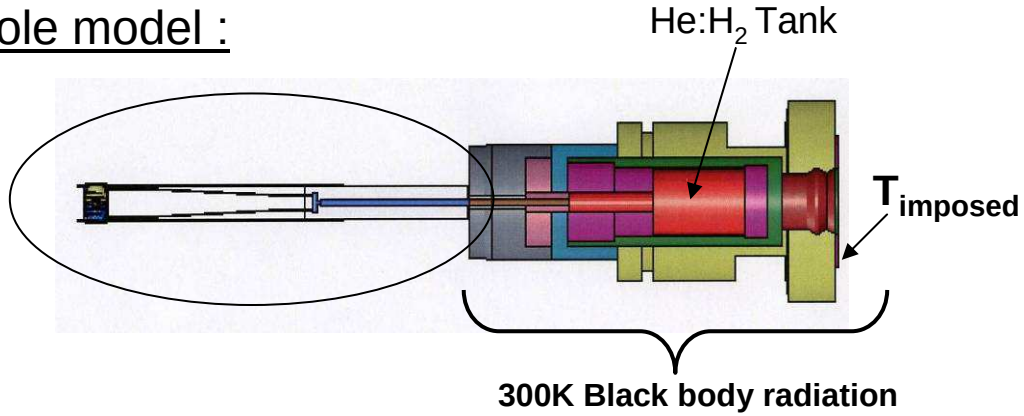
- Total number of cells:

Simplified model : 1,224,727

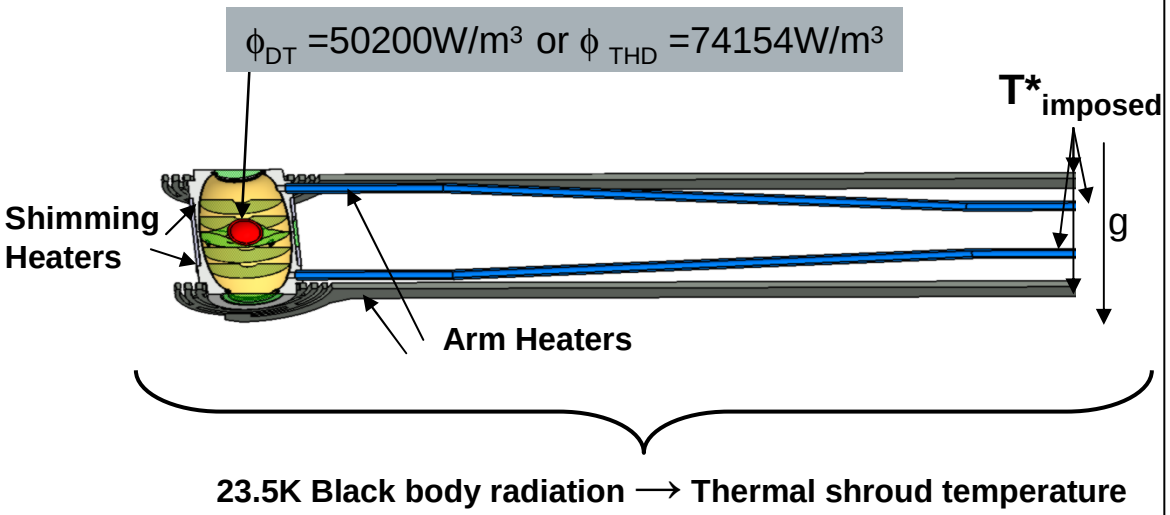
Whole model : 2,828,188

Boundary conditions (FLUENT/ANSYS)

- Whole model :



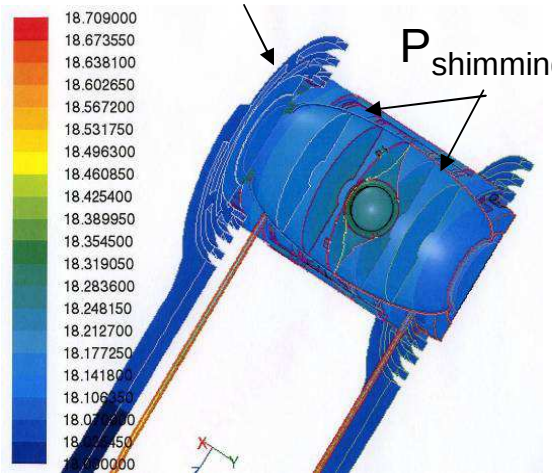
- Simplified model :



Results for current point design value of ρ_{He-H2} =0.88 kg.m^{-3} : DT layer.

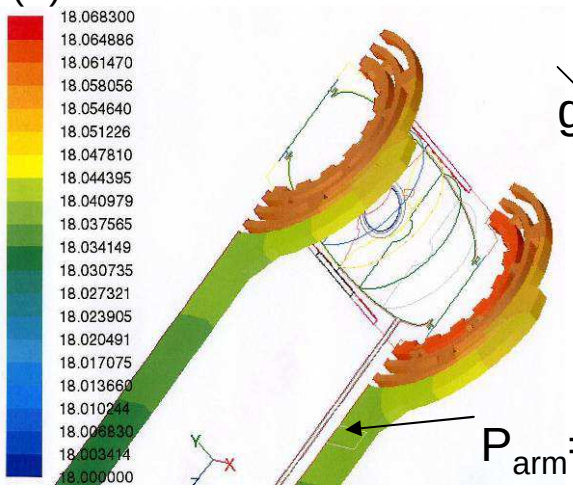
Temperatures

T (K) **Thermal path optimized**



$P_{shimming}$=32.7mW

T (K)

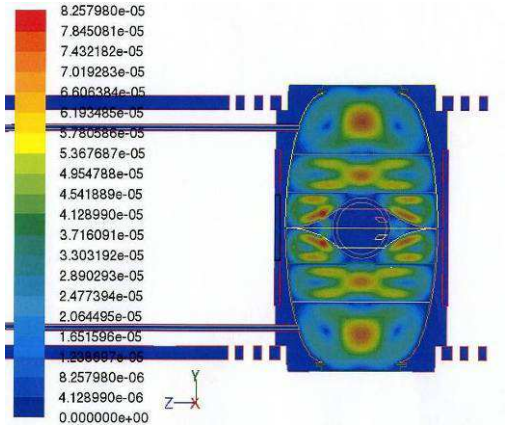


g

P_{arm}=0.32mW

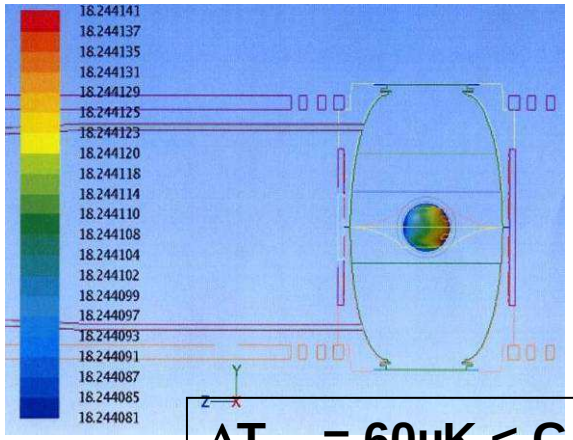
Velocity

V (m.s^{-1})



<u>With 4 baffles :</u> DT layer is OK

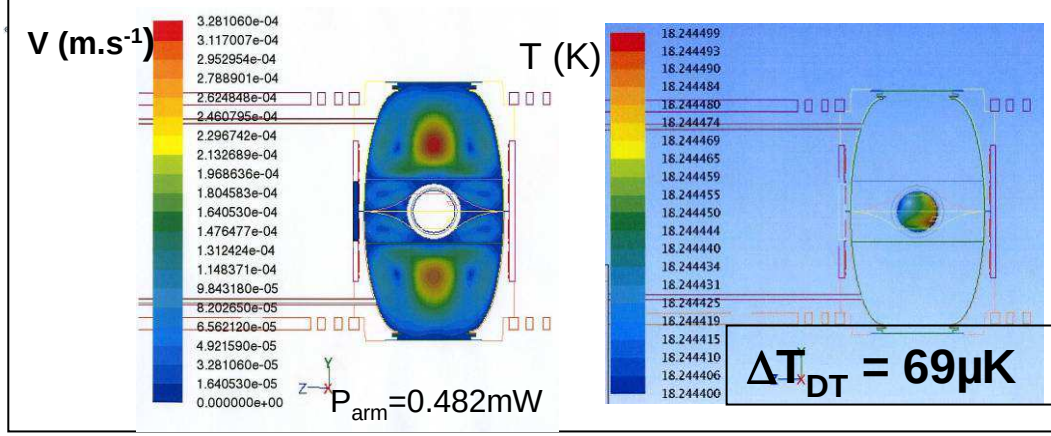
T (K)



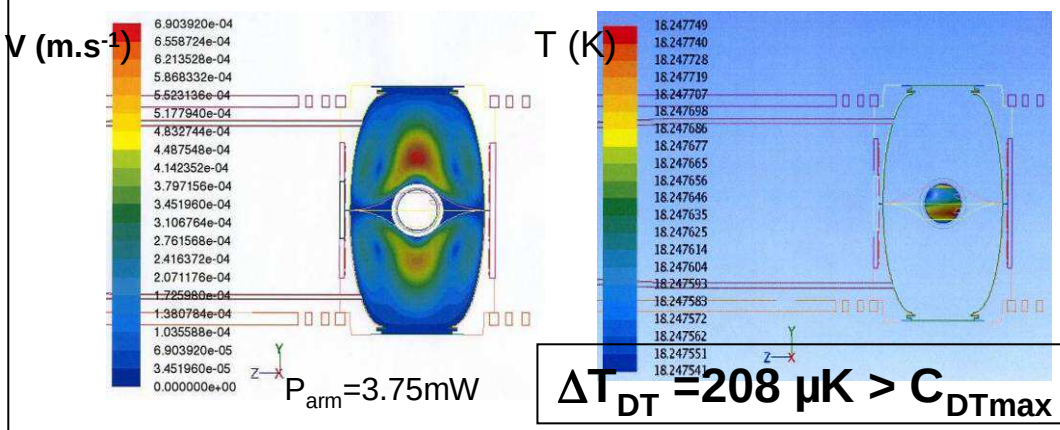
ΔT_{DT} = 60µK < C_{DT}

Is it possible to remove anti-convection baffles ?

At current point design (case of He:H_2) :

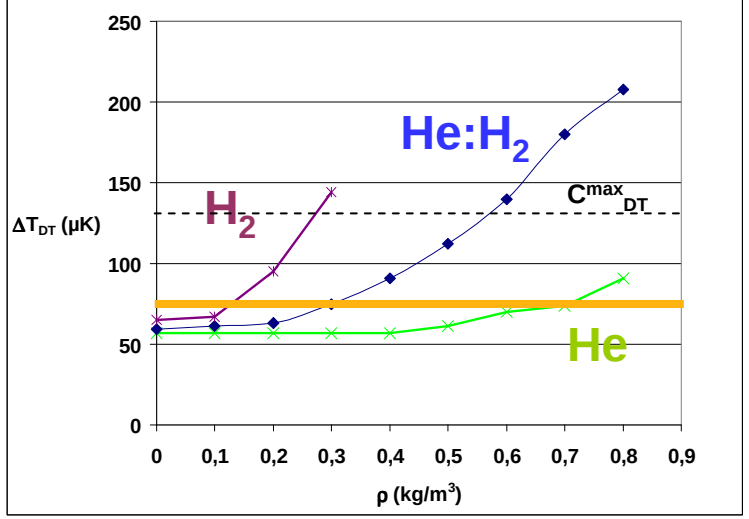


With 2 baffles : DT layer is still OK



With none : a poor quality layer is expected !

Without :



Maximum gas density allowed to avoid thermal deformation due to convection :

H_2 → 0.1 to 0.25kg.m^{-3}

He:H_2 → 0.3 to 0.55kg.m^{-3}

He → 0.65 to 1kg.m^{-3}

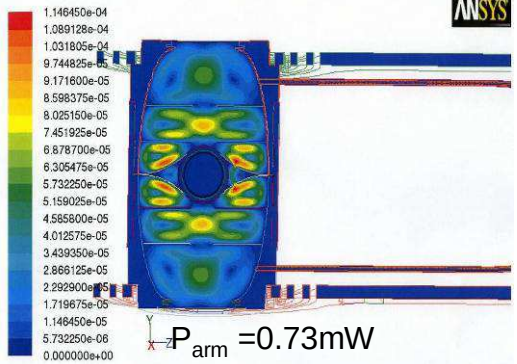
Reduction of H_2 content increases the maximum density allowable.

What about THD layer at current point design?

$\rho He\text{-}H_2 = 0.88\ kg.m^{-3}$

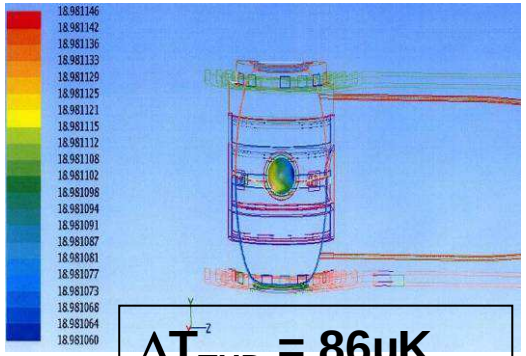
$P_{shimming} = 50.3mW$

V ($m.s^{-1}$)



P_{arm} =0.73mW

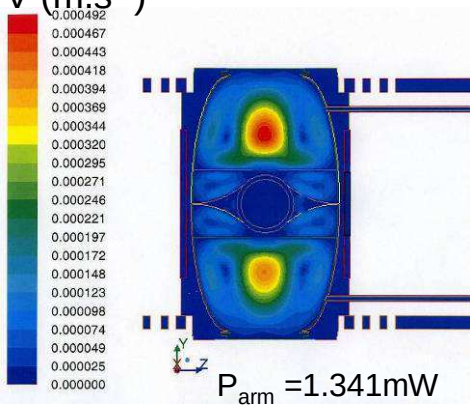
T (K)



ΔT_{THD} = 86µK

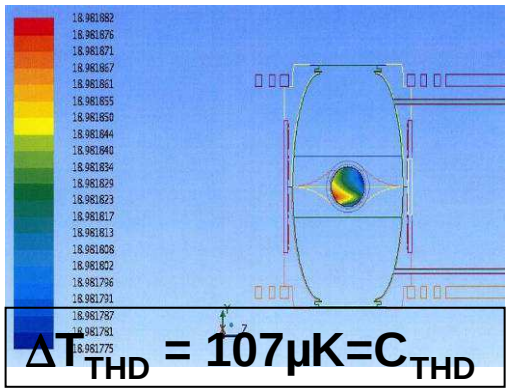
<u>With 4 baffles :</u> THD layer is OK

V ($m.s^{-1}$)



P_{arm} =1.341mW

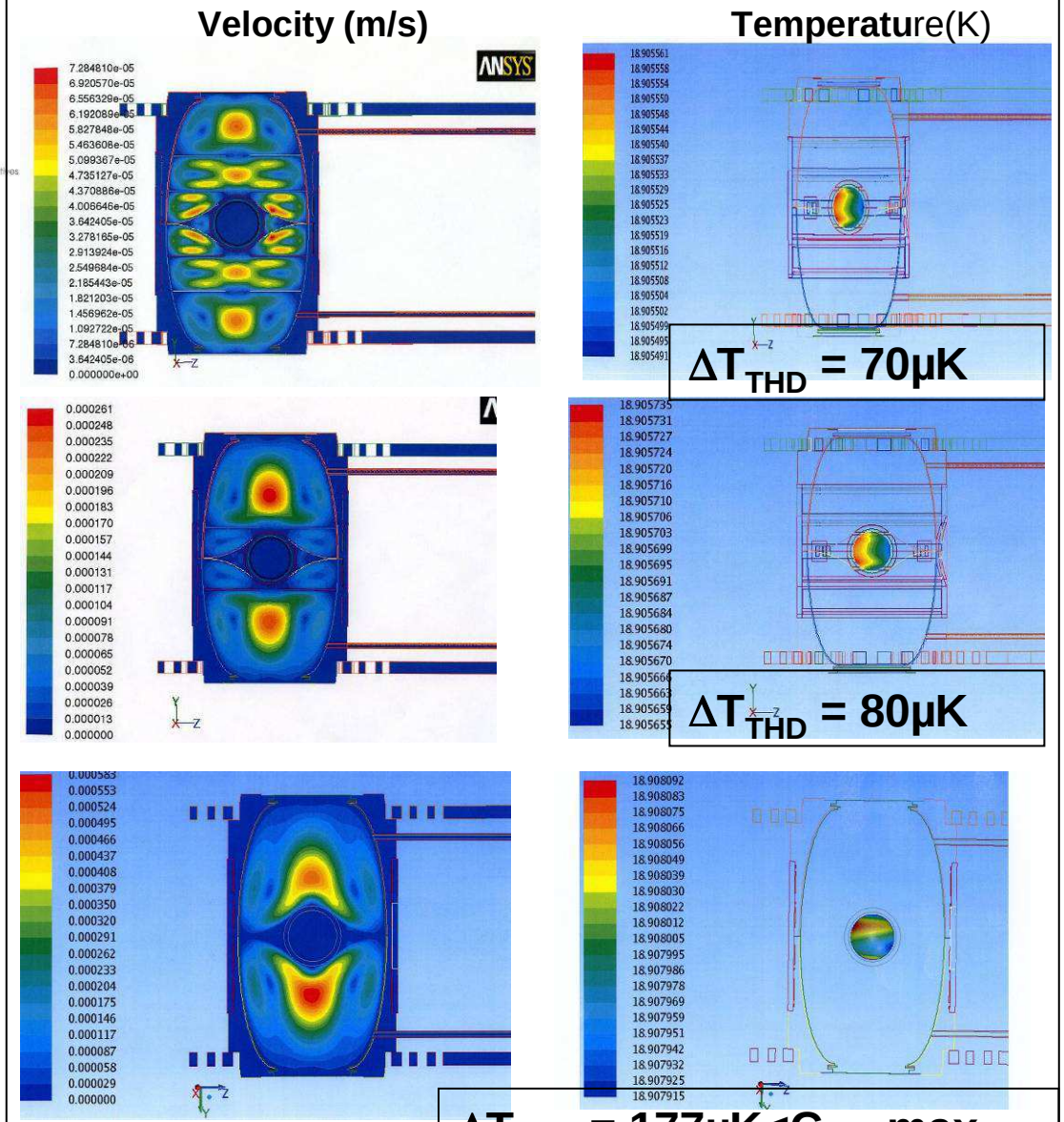
T (K)



ΔT_{THD} = 107µK=C_{THD}

<u>With 2 baffles :</u> THD layer is still OK.

THD layer : ρ_{He}=1kg.m^{-3}



OK without baffles

Rapid cooling : Temperature adjustments prior laser shot (1/2).

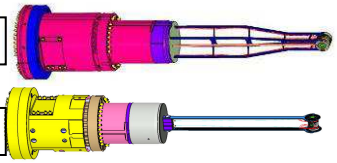
Layering protocol near T_m but central vapor density is required for shot at T_m -1.5K

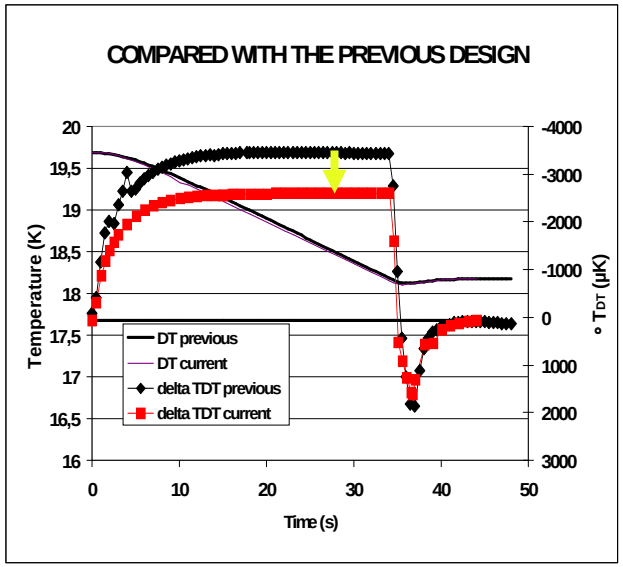
Rapid cooling by controlling → Cryostat temperature (v =-3K/min),
→ Arm heaters and cryostat kept at constant T (v ≤-3K/min).

Rapid Cooling at -3K/min

Previous

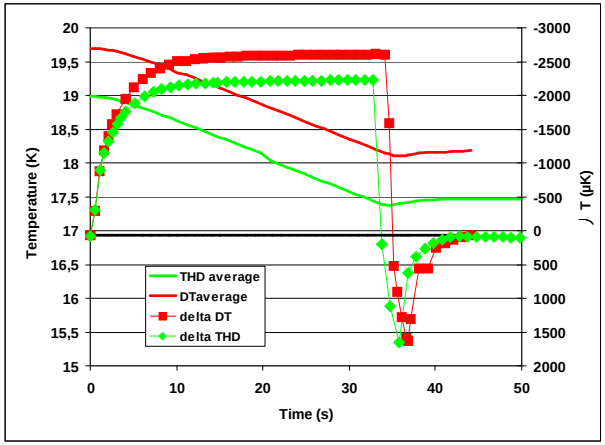
Current





Current design is more robust

THD versus DT



Ice layer response time during rapid cooling *:

ΔT_{DT} = 2600µK t_{DT} = 40s
ΔT_{THD} = 2200µK t_{THD} = 54s

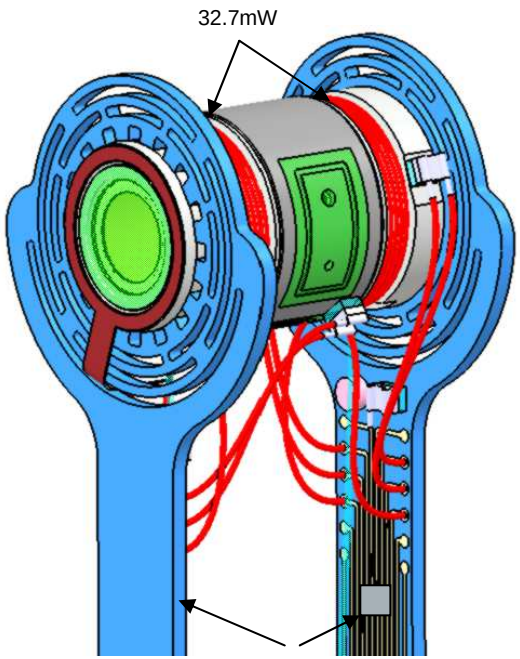
Ice layer is not affected with this new design

* See poster P-18 M.MARTIN → With regards to the low mode target Lifetime : experimental results »

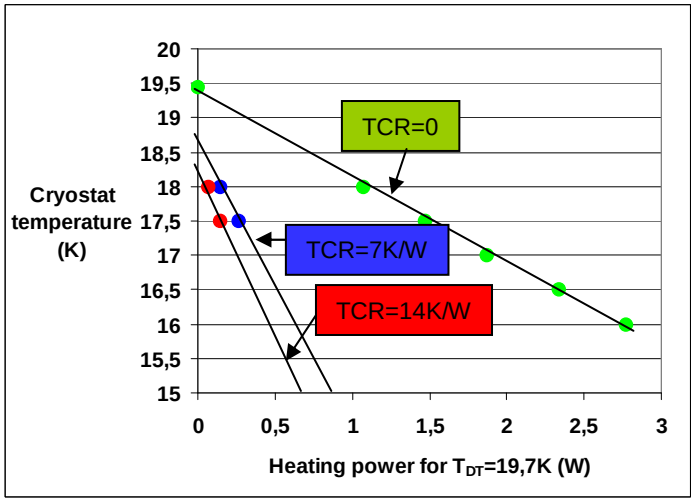
Rapid cooling : Temperature adjustments prior laser shot (2/2).

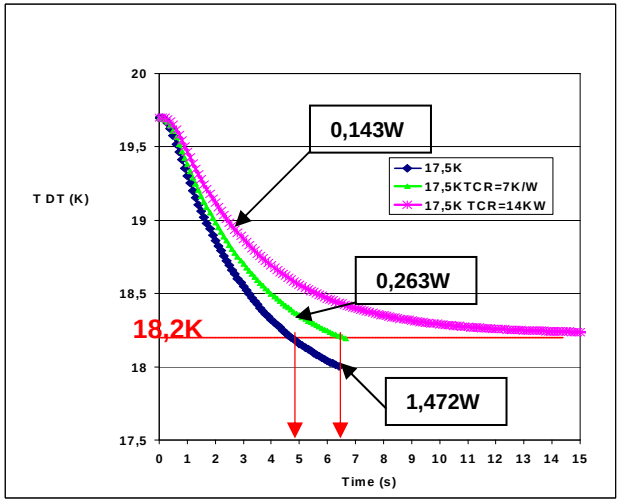
Alternative way : rapid cooling controlled by arm heaters.

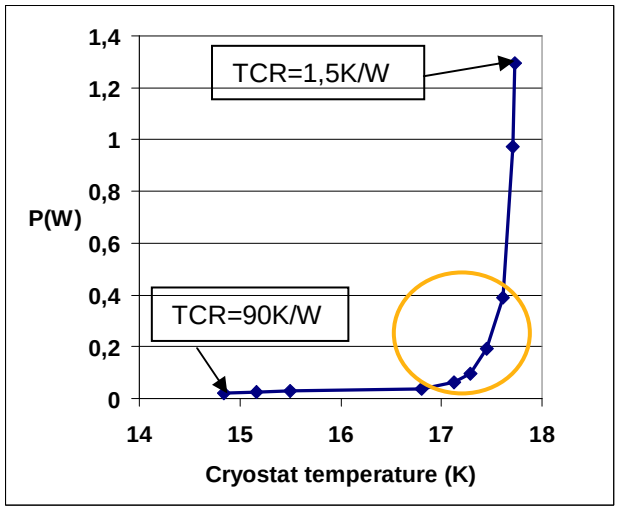
Arm heaters



$P=fn(T_{Cryostat})$







<u>With this protocol :</u>

- A low TCR is not an optimum.
- Adjustable cooling velocity.
- Numerical simulations are in agreement with analytical model*
  → predictive model.

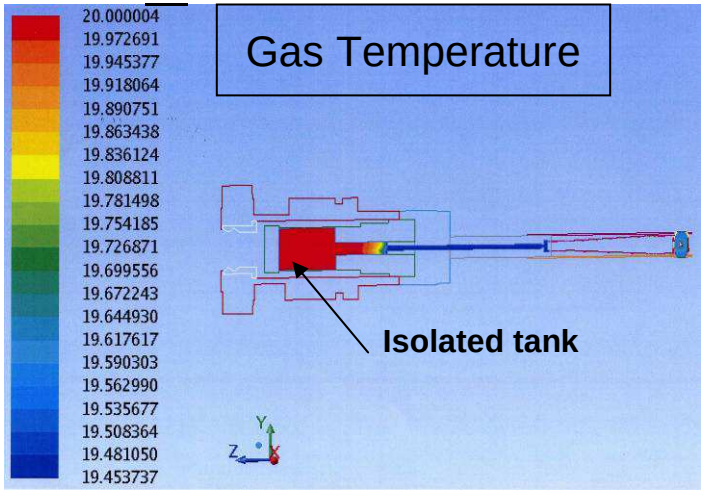
* M.MARTIN , G.MOLL→ Thermal optimization of the target assembly : a thermal resistance problem to be published.

What about gas fill hohlraum density during rapid cooling?

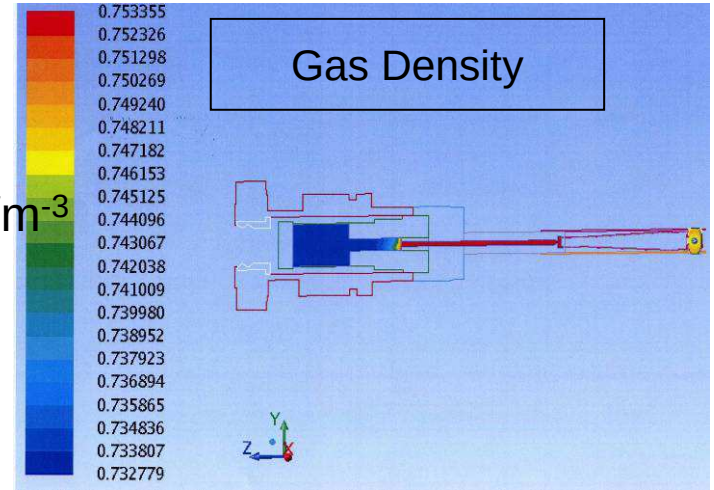
In order to avoid H_2 condensation (~16,1K for this low pressure), He:H_2 tank is heated up to 20K and gas density is set up at 0.745 kg.m^{-3} at 19.7K.

For T_{DT} =19.7K

K



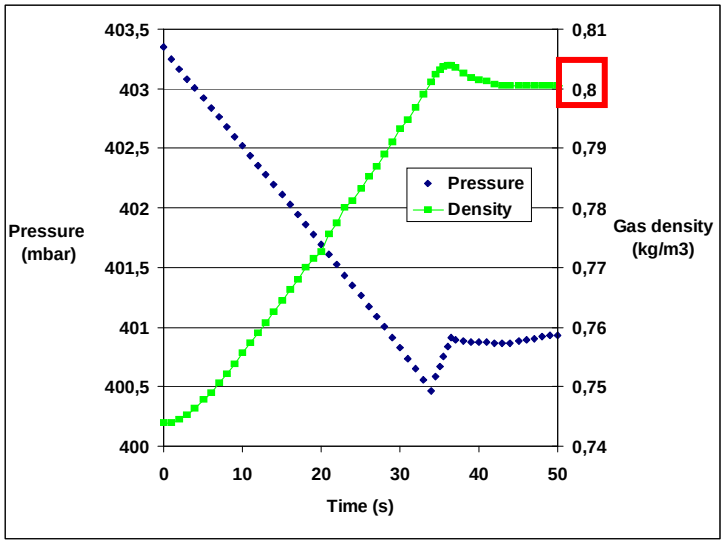
kg./m^{-3}



Ice layer response time during rapid cooling :

ΔT_{DT} = 2500µK t_{DT} = 41s

Pressure and density during rapid cooling :



Gas density meets spec. for laser shot.
A heated-tank allows being free of any gas pressure control during rapid cooling.

Summary

- **This new design allows DT or THD layers to reach physic specifications with well-adapted power on holhraum.**

- **For LMJ current point design two anti-convection baffles are required. None with ρ_{He}=1kg.m^{-3}.**

- **Ice layer is not affected by rapid cooling with this new design. An alternative way is proposed by thermal shimming and constant cryostat temperature.**

- **A heated He-H_2 tank is recommended to prevent H_2 condensation. With a gas density of 0.745kg.m^{-3} during layering protocol, gas density meets spec. for laser shot.**