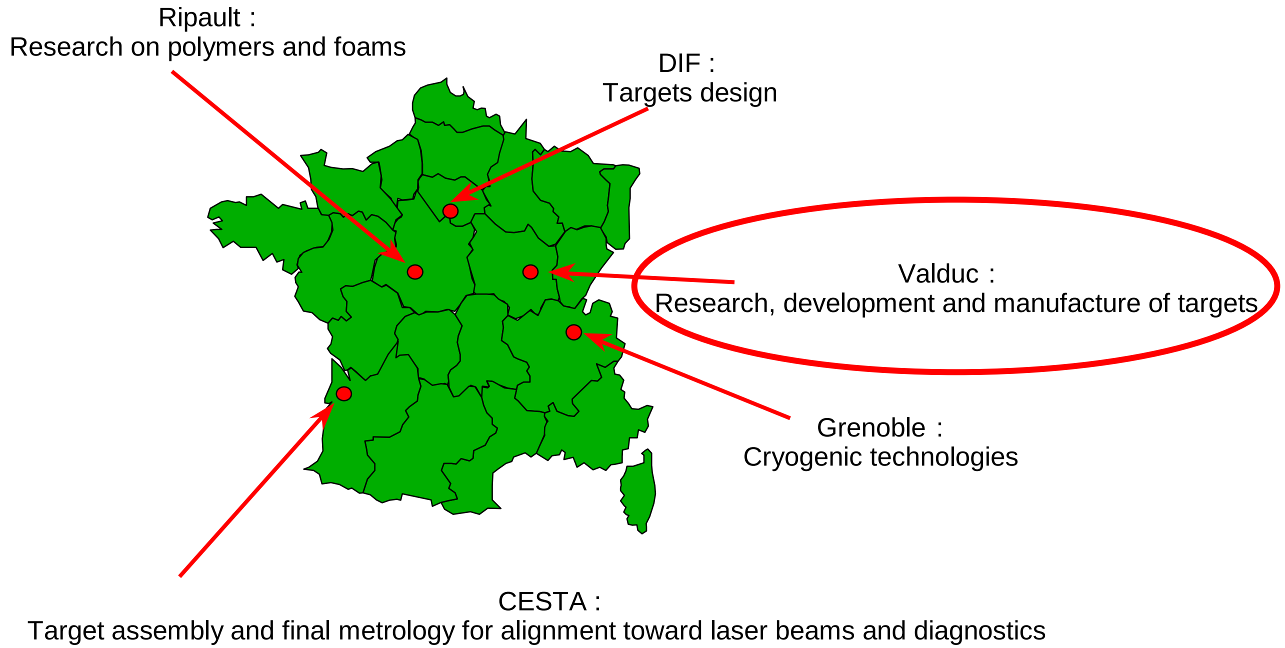
Overview of the LMJ cryogenic target program

R. Collier, O. Breton, C. Chicanne, B. Reneaume, M. Théobald, F. Durut, S. Bednarczyk, F. Bachelet, O. Vincent-Viry, E. Fleury, A. Choux, C. Dauteuil, L. Jeannot, M. Martin, G. Pascal, O. Legaie

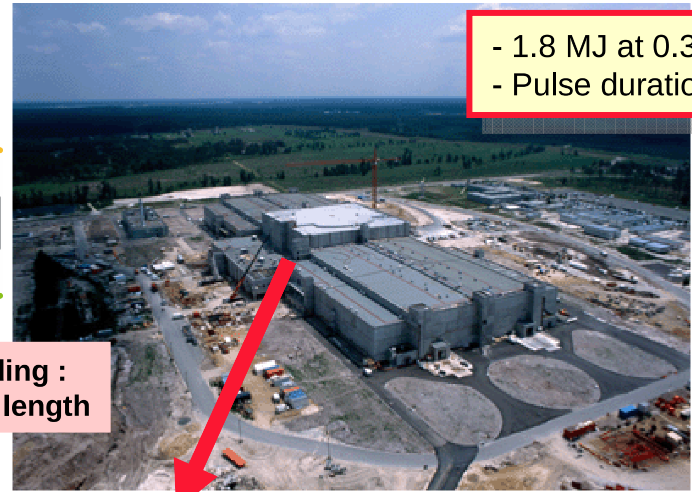


3rd Moscow Workshop on Targets and Applications

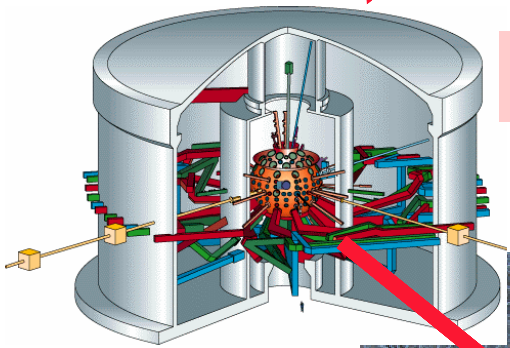
October 15 through October 19, 2007
Moscow, Russia

Inertial Fusion Experiments on LMJ : first experiments at the end of 2012

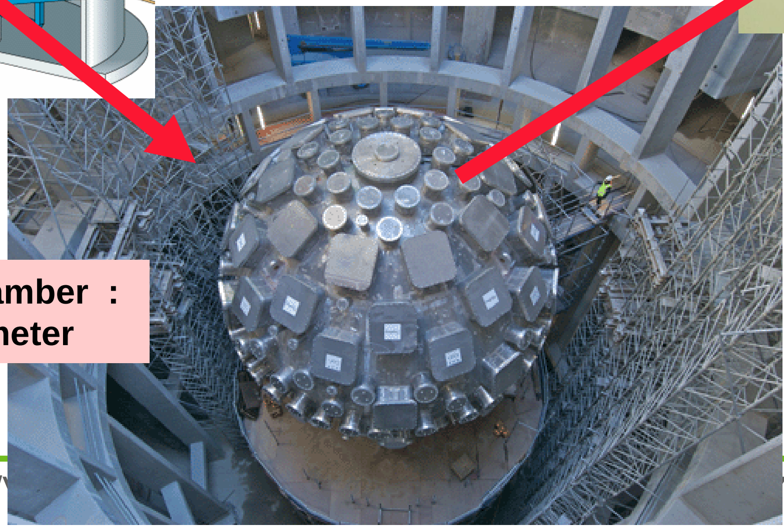
- 1.8 MJ at 0.35 µm
- Pulse duration 0.2 ns to 25 ns at 3 ω.



LMJ building :
 # 300 m in length

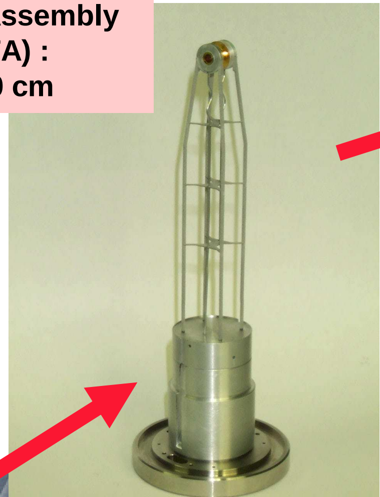


Experimental hall :
 # 50 m in diameter

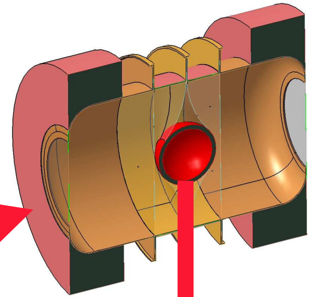


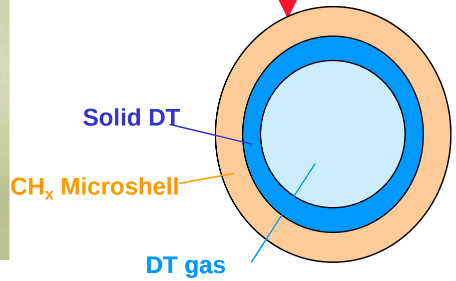
Experimental chamber :
 # 10 m in diameter

Cryogenic Target Assembly (CTA) :
 # 10 cm



hohlraum :
 # 1 cm





microshell :
 # 2 mm in diameter

Nominal ignition target design adapted to 300 eV :
- Indirect drive,
- Solid DT layer inside,
- CHGe plastic shell,
- DT permeation filling.

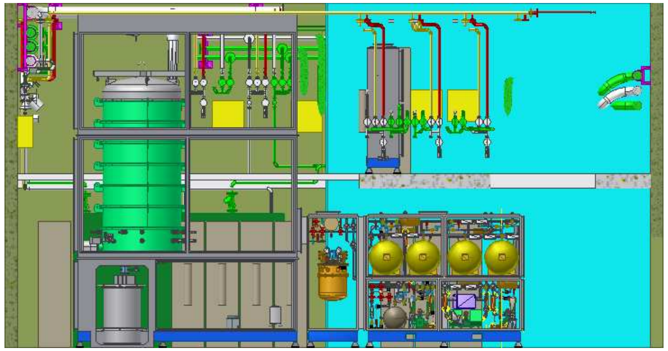
The « cold chain » for CTA from Dijon to Bordeaux

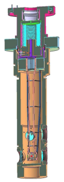
CEA Valduc (Dijon)

Cryogenic Target Assembly (CTA)

(Room temperature)

Cryogenic Filling Station (IRCC)



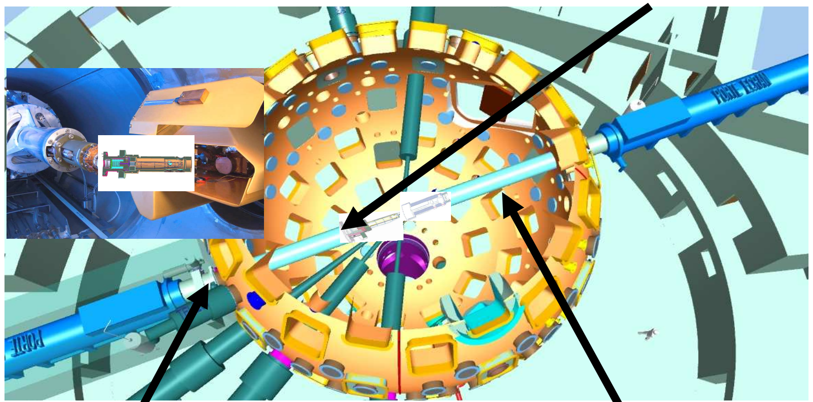


CTA + Thermal Shield (TS)

Cryostat transport (VTCC)

CEA CESTA (Bordeaux)

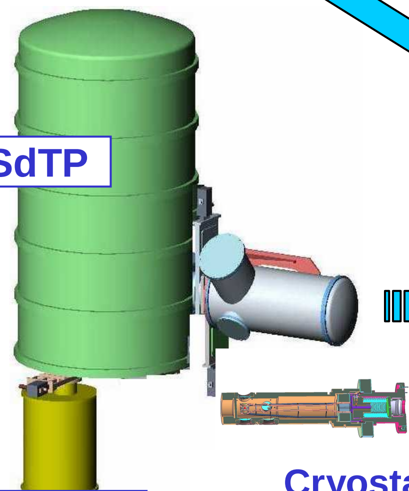
LMJ Chamber with cryogenic target positionner (PCC)



UTCC

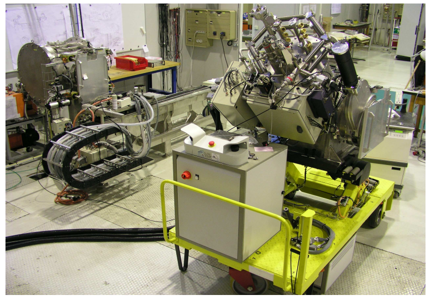
Cryogenic thermal shield extractor

SdTP



VTCC

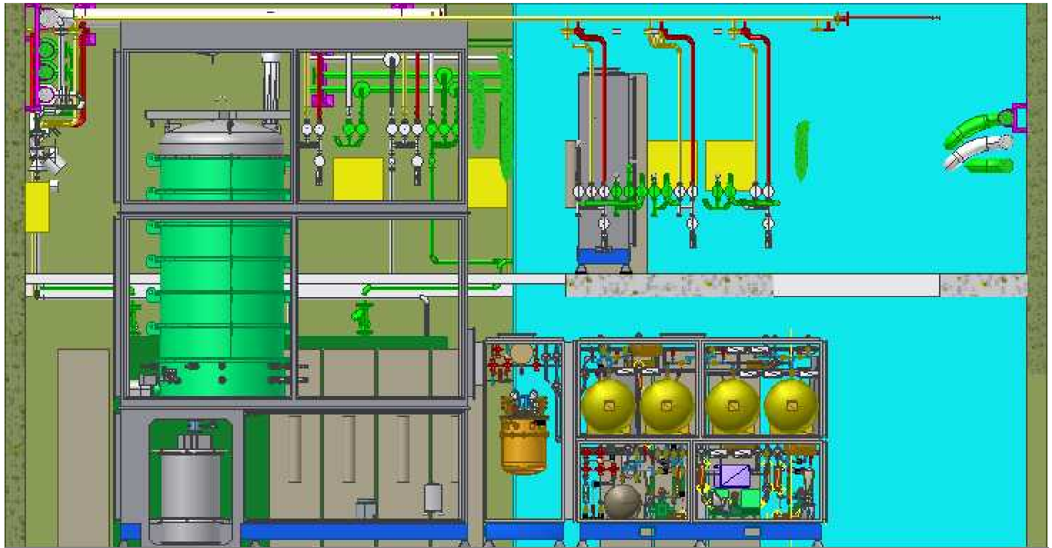
UTCC



Cryostat transfer (SdTP + UTCC)

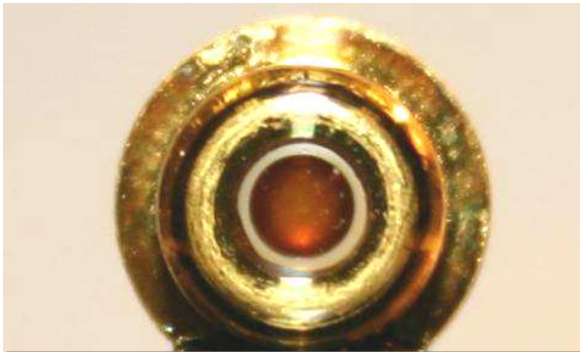
CEA Grenoble (in charge of design of cryogenic systems), see MWTA-D. Chatain

Cryogenic Target Assembly (CTA)



Cryogenic target filling station (IRCC) and transport (VTCC)

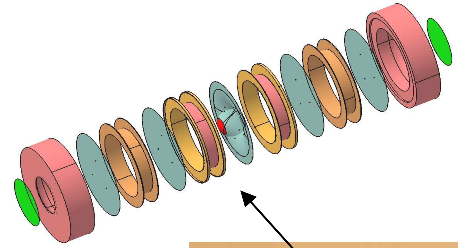
Main program : cryogenic targets for LMJ

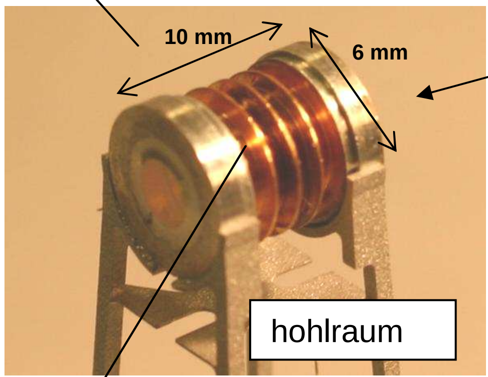


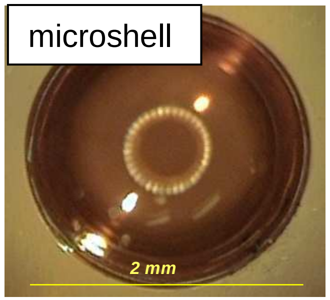
Redistribution in hohlraums

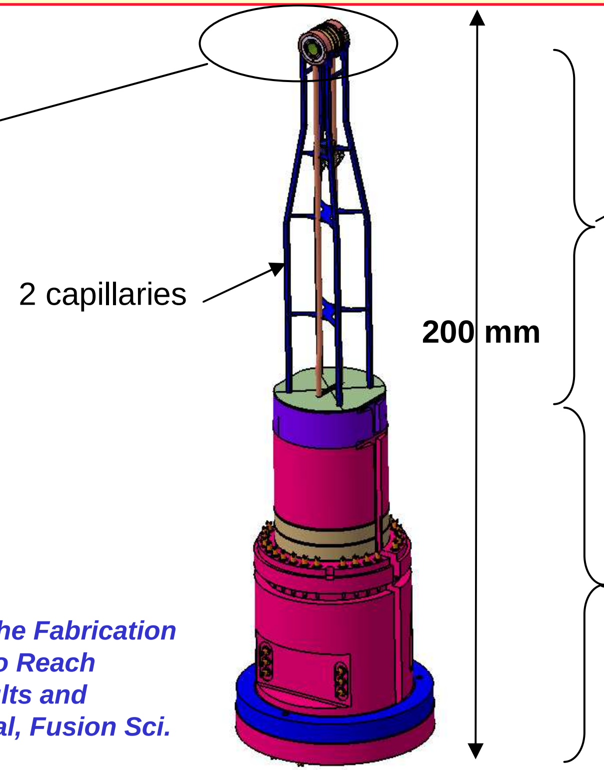
Cryogenic Target Assembly (CTA) : permeation is the nominal path

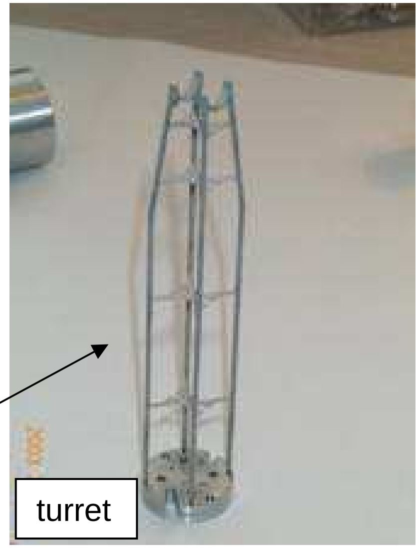
Elements which carry out the CTA design :
- Avoid PCC damaging : 100 mm between hohlraum/base
- Excellent conduction at 20K : ultrapure aluminum turret
- Mechanical resistance
- Target alignment
- Interfaces with cryogenic grippers and thermal shield

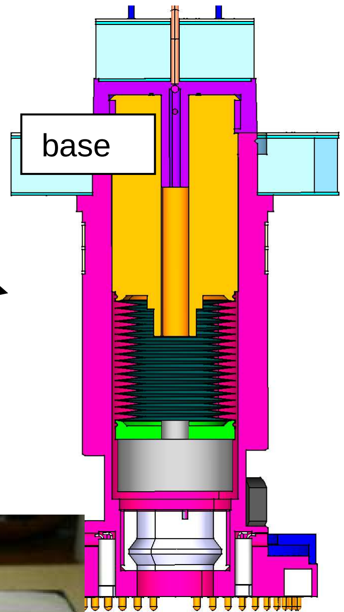








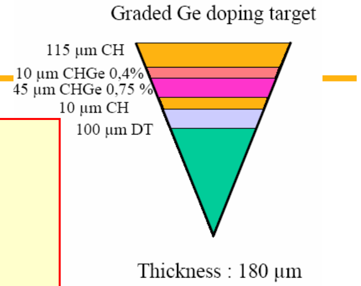




« Research Program for the Fabrication of the Cryogenic Target to Reach Ignition on the LMJ, Results and Prospects », P. Baclet et al, Fusion Sci. Technol. 49, 565 (2006)

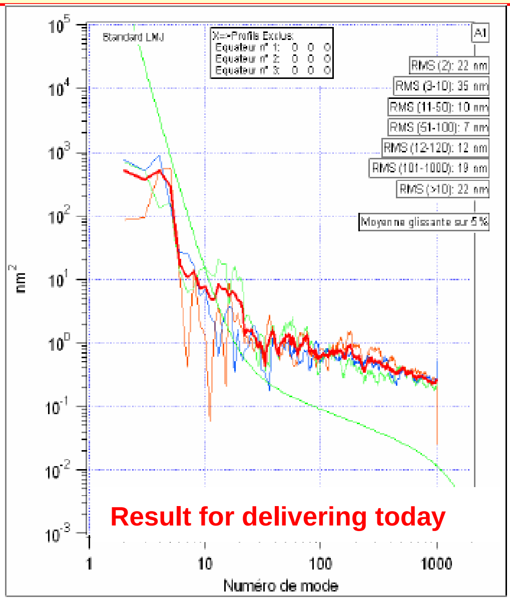
Consequences of permeation for CTA (mesurements in glovebox), we need
- Tritium compatibility of all the target parts : membranes, thermometers,…
- Amount of tritium trapped in each piece

Microshell : uniform and graded CH_xGe (PAMS/GDP technique)



- The main effort is focused on graded CH_xGe design
  - PAMS mandrel : stringent specifications (sphericity) : necessary for the final roughness (polymer see oral presentation MWTA – A. Balland-Longeau)
  - GDP µ shell : 21 stringent specifications are required with sufficient yield, major issues are
    - Thickness control of layers
    - Density mesurements
    - Ge doping
    - Roughness minimization

- Roughness[modes > 10] < 10 nm
- No density defect
- Concentricity > 99%
- Sphericity 99% > 99.99%

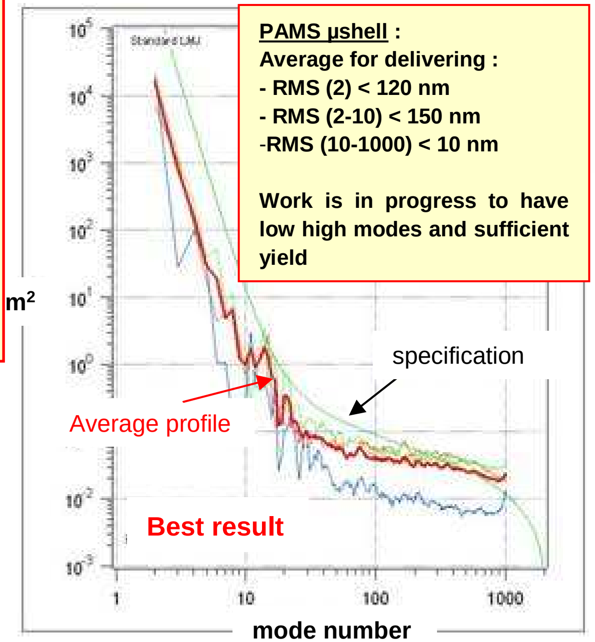


GDP µshell :

Average for delivering (external roughness) :
- RMS (2) < 125 nm
- RMS (2-10) < 175 nm
-RMS (10-1000) < 30 nm

Mode 1 thickness control < 0.5 µm

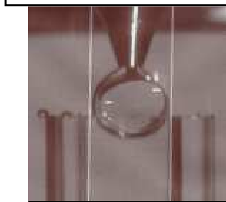
Ge doping :
0.4 % at. ± 0.1 % (measured ± 0.05)
0.75 % at. ± 0.2 % (measured ± 0.1)



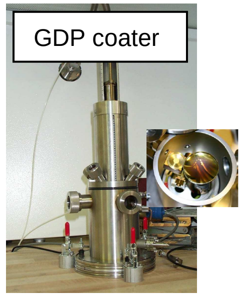
PAMS µshell :
Average for delivering :
- RMS (2) < 120 nm
- RMS (2-10) < 150 nm
-RMS (10-1000) < 10 nm

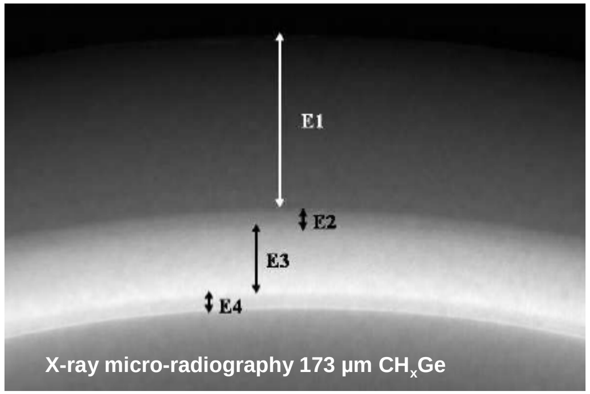
Work is in progress to have low high modes and sufficient yield

microencapsulation



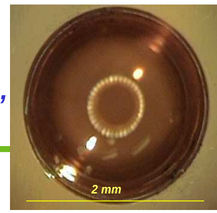
GDP coater





X-ray micro-radiography 173 µm CH_xGe

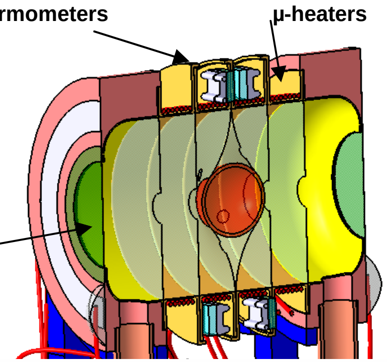
Thermal treatment



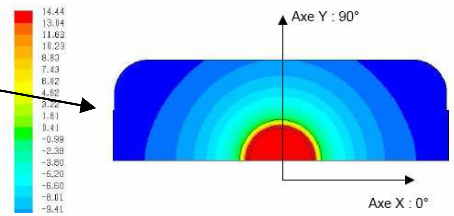
Work is in progress to increase the yield of each specification to have an acceptable final yield for delivering

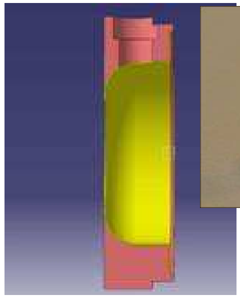
« Graded germanium doped CH_x microshells meeting the specifications of the megajoule laser cryogenic target », M. Theobald et al, Fusion Sci. Technol. 51, 586 (2007)

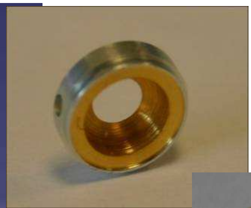
Hohlraum : a difficult challenge to reach all specifications



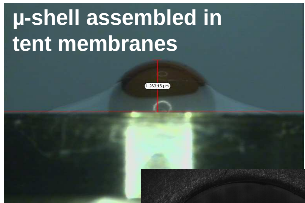
- Main functions (at cryogenic temperature) are
  - microshell must be centered less than 10 µm (3 directions) for thermonuclear gain (implosion symmetry) and thermal reasons
  - contain mixture of He/H_2 to avoid the gold plasma blow-off
  - 2 windows for laser entrance hole (LEH) : add polyimide membrane
- A uniform DT layer has conducted the design which needs
  - a perfect uniform temperature around the microshell (< 80 µK) : add microheaters
  - to avoid convection of He/H_2 to be compatible with thermohydraulics, implosion physics and fabrication (450 mbars) : add anti-convective membranes, so add holes to avoid jet during shot

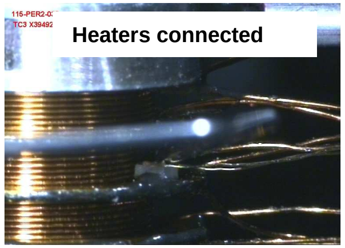




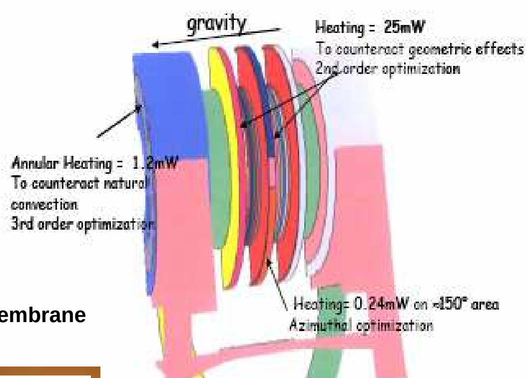


Aluminum/gold ring



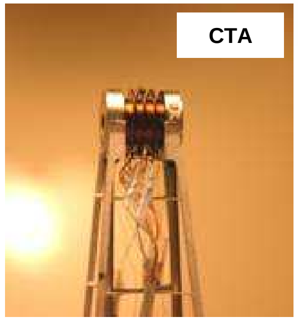


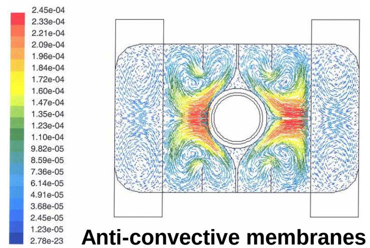
Top view of an anti-convective membrane on a gold ring



Correction of azimuthal temperature

- **Substantial steps of fabrication have been reached :**
  - **Fabrication of 2 aluminum/gold rings (µ-heaters+µ-thermometers)**
  - **Fabrication of 4 gold rings with µ-heaters**
  - **Fabrication and mounting of membranes (1 µm polyimide and 100 nm Formvar)**
  - **Centering of microshell (X,Y ≤ ± 20 µm, en Z ≤ ± 30 µm)**
  - **High accuracy assembling**
  - **Successfully tested in cryogenic and vacuum environnements**





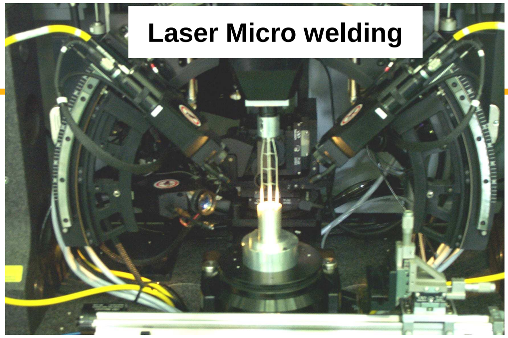
Anti-convective membranes to decrease convection

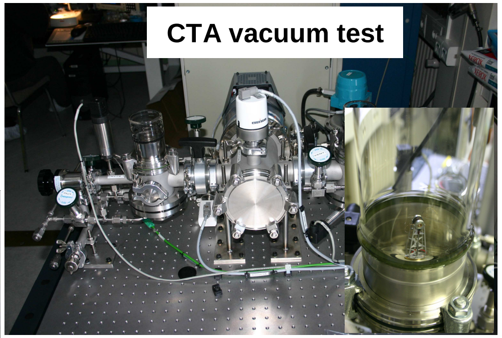
« Thermal Simulation of the LMJ Cryogenic Target », G. Moll et al, Fusion Sci. Technol. 51, 737 (2007)

« Aromatic Polyimides with High Performances and Deuteration », E. Anselmi, American Nuclear Society, 2004, 45, 2, 157-164

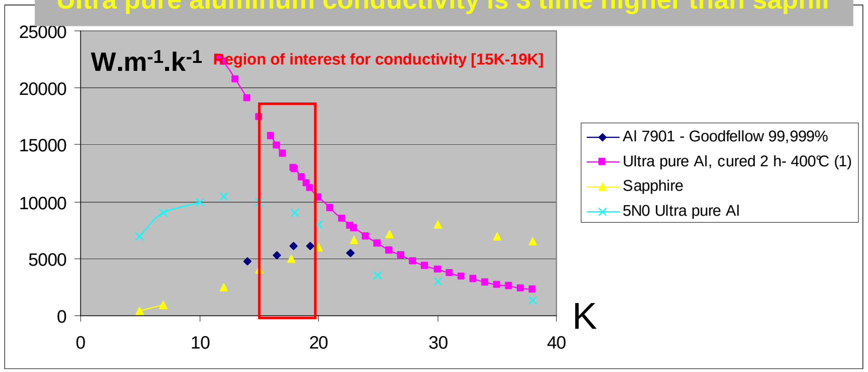
CTA assembling and test

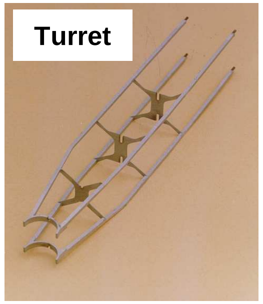
- Main functions (at cryogenic temperature) are
  - To protect de Cryogenic Target Positioner (CTP) : 100 mm needed between microshell and the base
  - High conductivity without gaps at junctions (base/turret + turret/aluminum ring)
  - Severe dimensionnal tolerances for turret (± 20 µm)
  - Low gas leak
  - Compatibility with DT



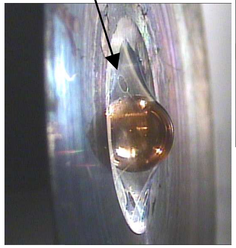


Ultra pure aluminum conductivity is 3 time higher than saphir



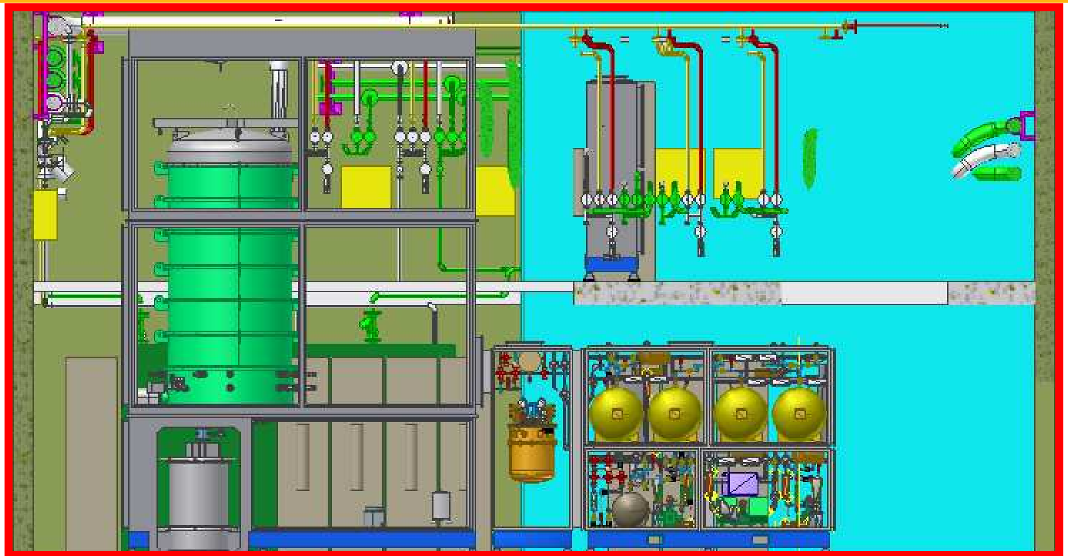


µshell assembled between 2 Formvar films after DT exposure



- Upgraded version of CTA are routinely fabricated for cryogenic studies
  - Turret : machined in a single piece of utra pure aluminum (± 20 µm)
  - Junction without thermal resistance by YAG laser welding
  - Vacuum test of CTA on a specific device
  - All CTA parts are tested in a specific DT gloveboxes
    - Filling : 400 bars for 6 hours
    - Quantitative analysis after DT exposure are carried out :
      - Mechanical and permeation properties of membranes at 20K : ok for Formvar and polyimide (250 µm under 0.5 bar and K ~ 10^{-21} mol.(msPa) $^{-1}$
      - Mechanical properties of µshell : more than 100 bars in decompression
      - Properties of electrical pieces (resistant thread, µ-heaters,…) : ok
      - Amount of T_2 absorbed in CTA = around 100% inside µshell

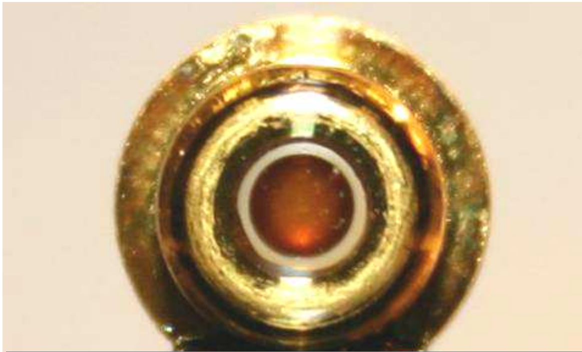
DT glovebox for test of CTA parts



Cryogenic target filling station (IRCC) and transport (VTCC)

Cryogenic Target Assembly (CTA)

Main program : cryogenic targets for LMJ



Redistribution in hohlraums

Nominal filling process of operational cryogenic targets for LMJ : permeation

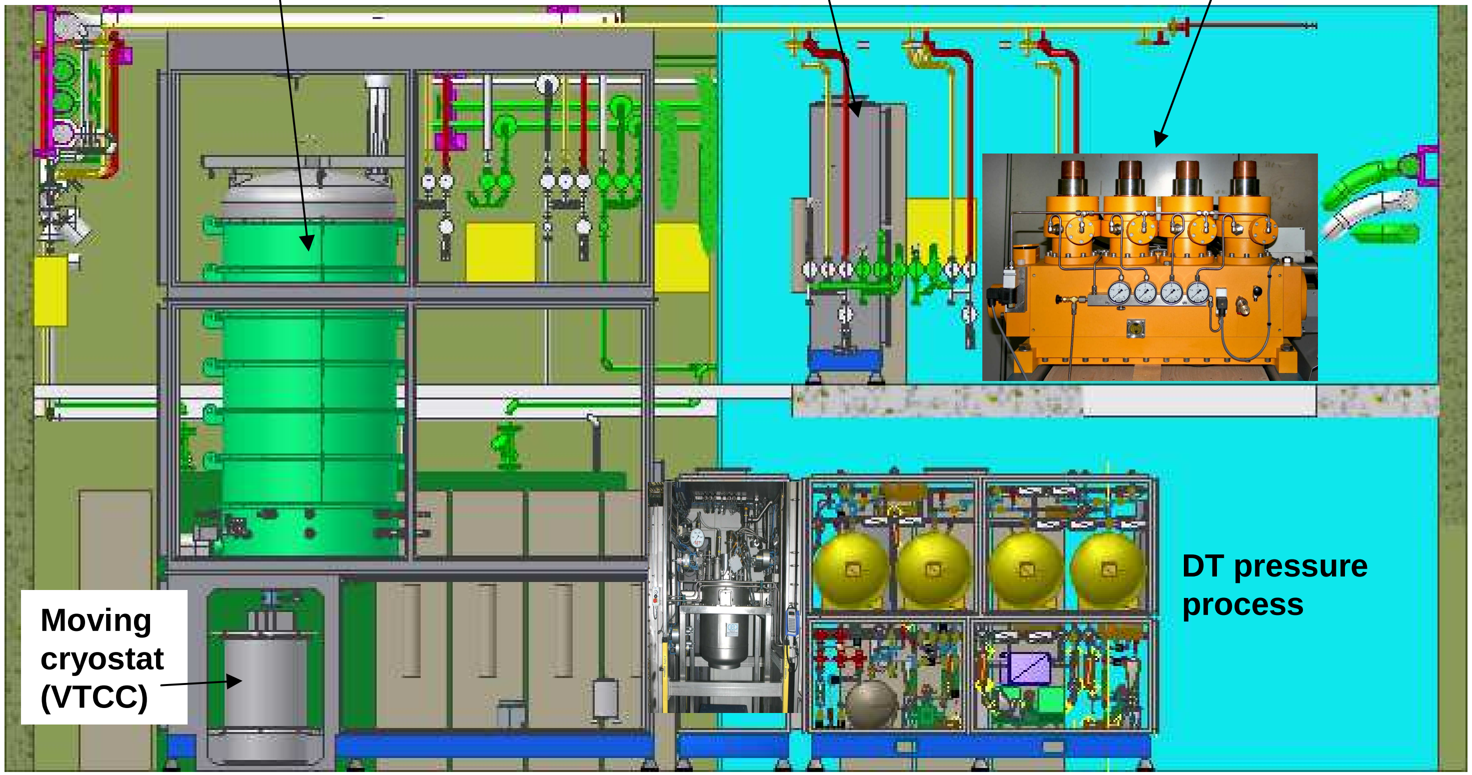
- **Permeation filling at room temperature (max 1300 bars DT pressure)**
- **Cooling and pumping**
- **The beginning of cryogenic interfaces from Valduc to CESTA**

CRCC : 3D cryogenic system + permeation cell (CP)

Back pressure process

Cooling system for permeation cell and cryo gripper (Stirling device)

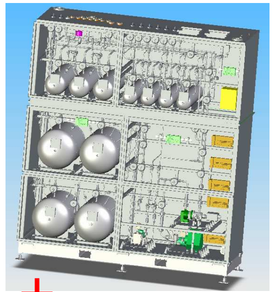
6 meters



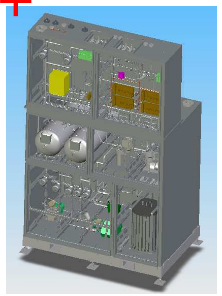
12 meters

Side view

Filling station (IRCC) : under manufacturing



+



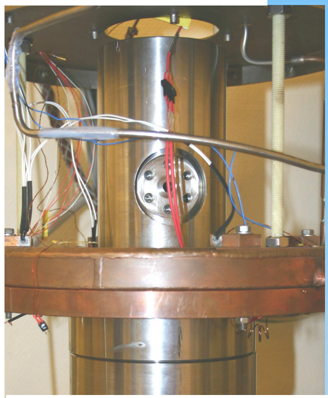
Tritium purification and gas storage systems : under manufacture

« Overview of the Filling Station for LMJ Cryogenic Targets », R. Collier et al, Fusion Sci. Technol. 51, 758 (2007)

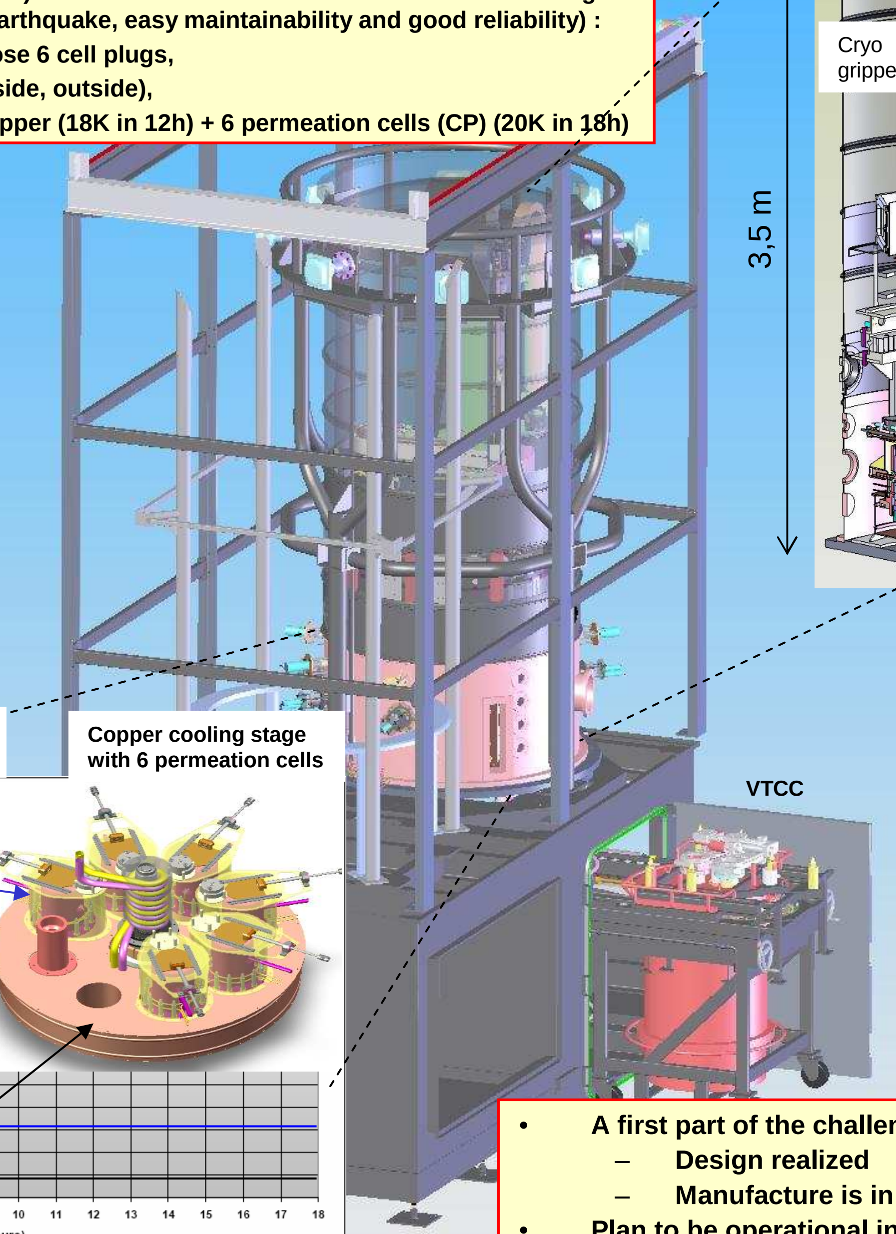
CRCC : a challenge among others

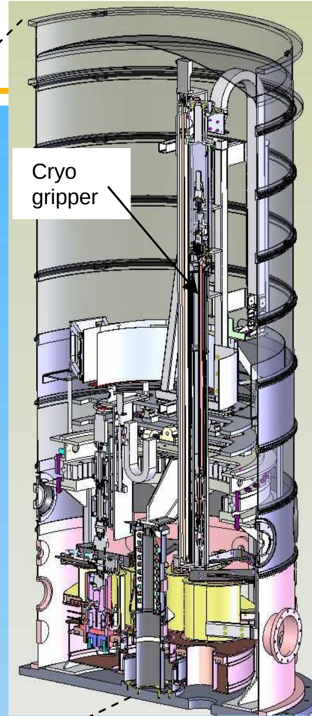
- **Functions required (T_{room} and 20 K) in a constraint context of tritium nuclear building (limited LHe, small space, norms, earthquake, easy maintainability and good reliability) :**
  - **To move and open/close 6 cell plugs,**
  - **To move 6 targets (inside, outside),**
  - **To cool down cryo gripper (18K in 12h) + 6 permeation cells (CP) (20K in 18h)**

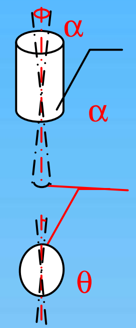
Permeation cell (CP)



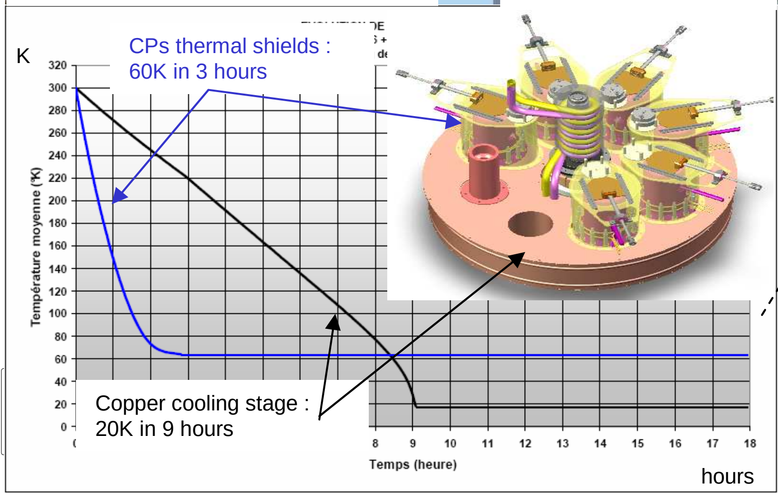
Stirling device + triple cryogenic loops with He under 20 bars)







Copper cooling stage with 6 permeation cells



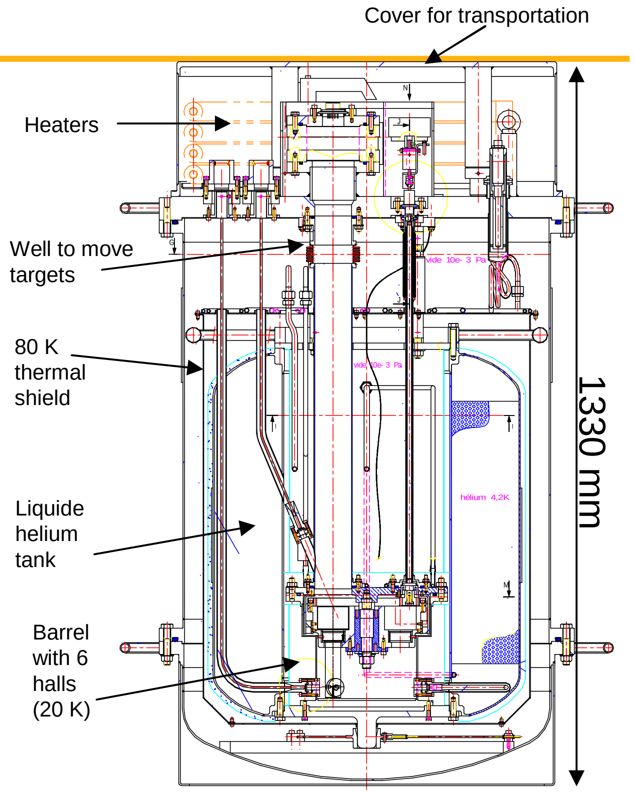
- **Mechanical performances required to move the cryo gripper / CP and VTCC (T_{room} and 20 K)**
  - **Accuracy of movement : ± 0.02 mm**
  - **To bring into line cryogenic gripper and CP or VTCC**
    - **$\alpha < 0.1°$**
    - **$\Theta < 1°$**
  - **Positioning sensor ± 0.01 mm**
  - **Gap between inside CP and target : 290 µm**
- **Solution found : piezo sensors with tacticle areas**

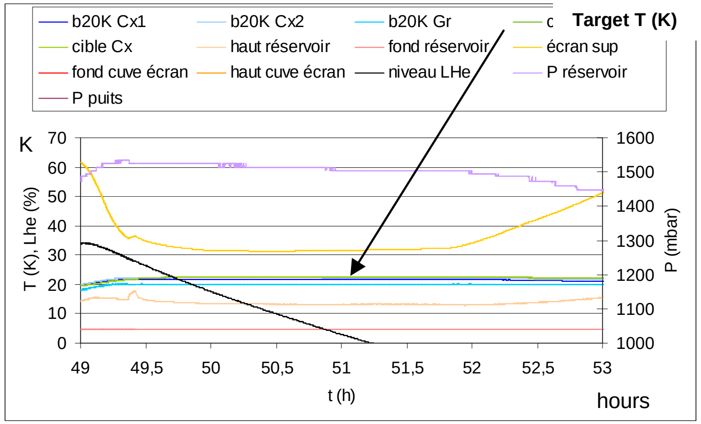
- **A first part of the challenge has been already reached**
  - **Design realized**
  - **Manufacture is in progress**
- **Plan to be operational in DT at the end of the decade**

VTCC : a challenge among others

- Functions required in the constraint context of UE road transport safety rules (ADR) :
  - To move 6 cryo targets with thermal shield filled DT/He+H_2 in a LHe tank
  - To move VTCC with self-cooling during 48 h :
    - T < 25K
    - ΔT < 1K in 1h

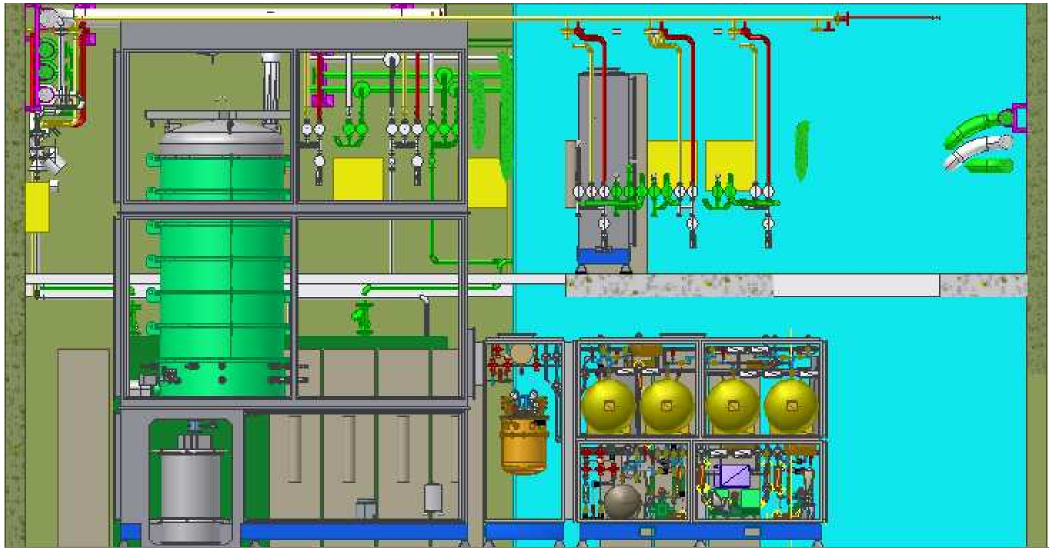
- Main characteristics of the design
  - Tank of LHe : 100 l
  - 3 shields : vacuum, 80K shield and 20K shield
  - Temperature regulation by H_2 « bulb » system
- Performance reached :
  - Decrease the tempeature target down to 20 K
    - < 20 hours
    - Around 100 l LHe
  - Regulation of temperature
    - <0.1K during few hours
  - T < 25K





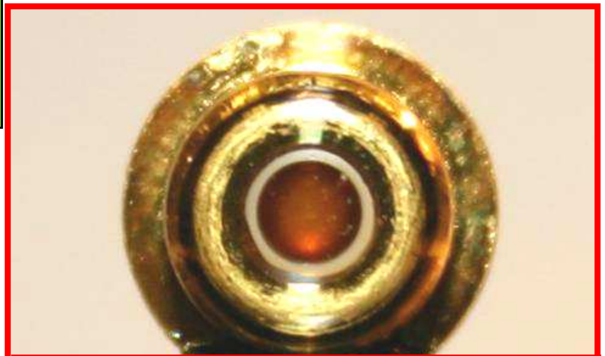
- We now have a sufficient knowledge on this first prototype
  - To up grade the design for longer use
  - To add modifications for CRCC compatibility

Cryogenic Target Assembly (CTA)



Cryogenic target filling station (IRCC) and transport (VTCC)

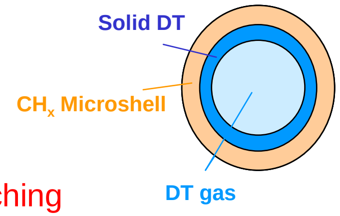
Main program : cryogenic targets for LMJ



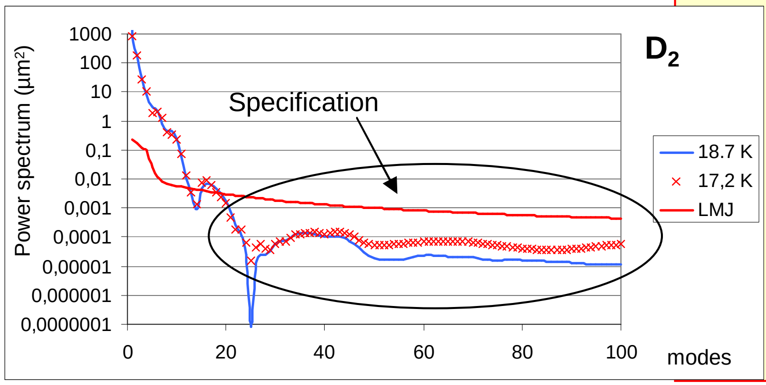
Redistribution in hohlraums

Studies of cryogenic layer (D2 + Infrared)

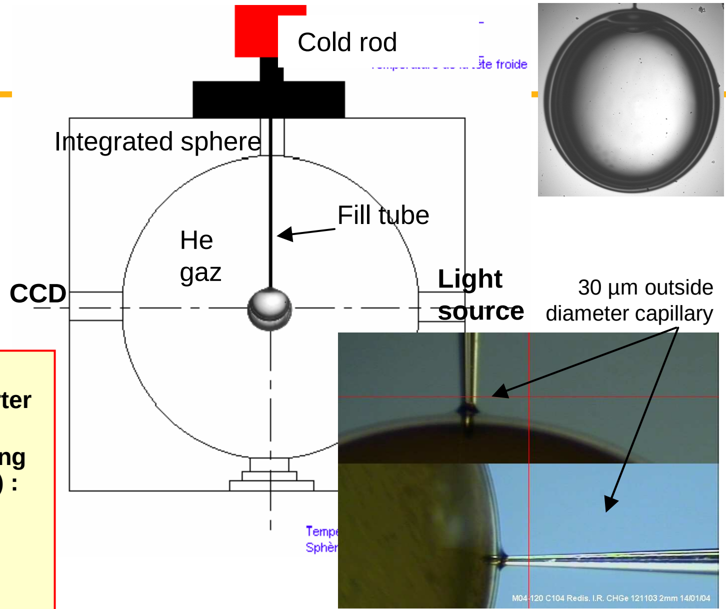
- Two stringent specifications have to be reached simultaneously :
  - Low roughness of DT solid layer (<1 µm, modes > 2) = LMJ spec.
  - Low density of DT central gas 0.3 mg/cc (1.5K below DT triple point (TP))
- Solution : slow cooling (DOE Labs 2005) at -1K/min. in around 50 hours



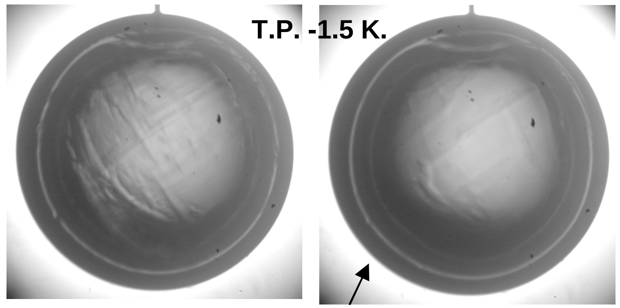
Thermal quenching



- Two original cooling paths were obtained at CEA in 2005 in a shorter time :
  - « Quenching » : fast freezing of the target (few seconds) :
    - « Dynamic thermal Q » : by cooling gripper, need to be coupled with laser shot
    - « Static thermal Q » : if you shut down IR laser
  - « Breathing » : a sinusoidal temperature is applied to the target : repair small defect
  - To combine the 2 ways : « Quenching + Breathing »



Breathing : Temperature oscillation technique



After 2 hours of T° oscillations
(from 1 K to 20 mK amplitudes, 60 s period)

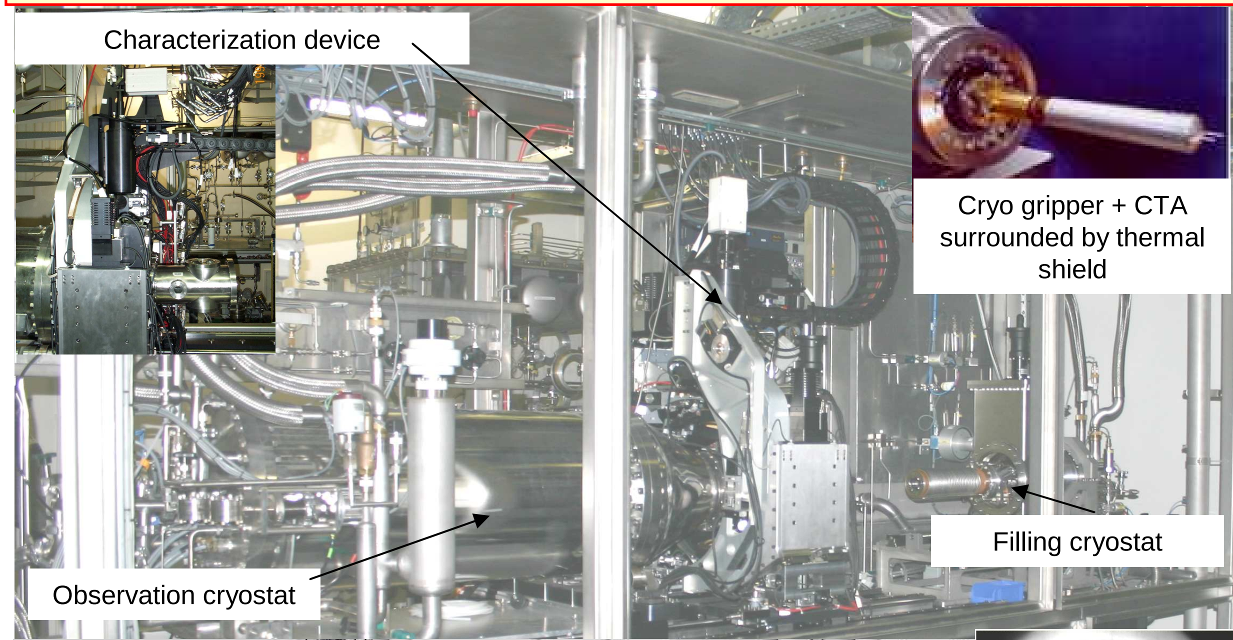
Rq (µm)	LMJ spec.	TP	TP+Tos
Modes > 9	0.36	0.79	0.47
Modes > 19	0.29	0.45	0.17

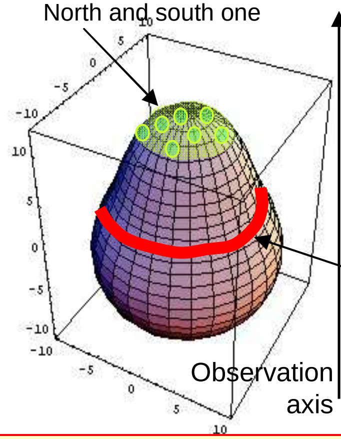
- We have demonstrated that theses techniques are very effective
  - In having a shorter conformation time (good for autonomy of cryo gripper on LMJ),
  - To have low roughnesses at -1.5K T.P.,
  - To be independant of laser shot time (Static thermal Quenching)
- We still have work to do
  - To improve the robustness of these techniques
  - To optimize the temperature oscillation and Quenching process
  - To test these technics in hohlraum (proved by simulation for both)

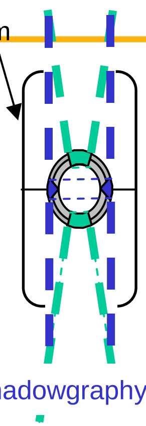
« A Way to Reach the Cryogenic's Temperature and Roughness Requirements for the Laser Megajoule Facility », M. Martin and al, Fusion Sci. Technol. 51, 747 (2007)

Studies of cryogenic layer : filling and conformation in hohlraum

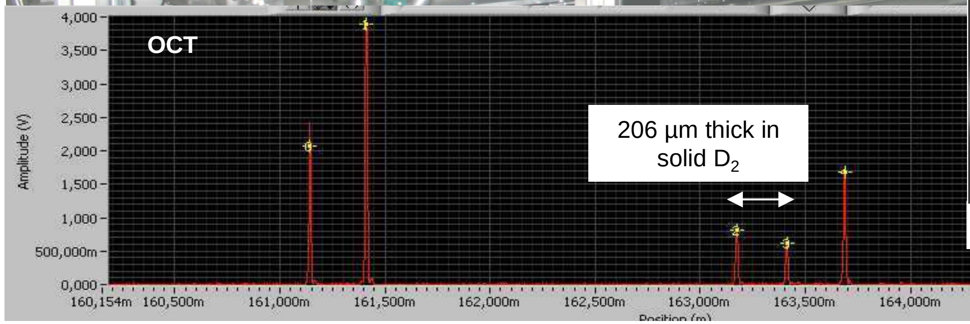
- The Study Filling Station (SFS) is an experimental set up to demonstrate the conformation of a cryogenic layer (D2 and DT) on CTA scale 1 :
  - Filling parameters (see poster MWTA-F. Bachelet)
  - Characterization techniques of cryogenic layer
  - Conformation parameters to reach ice quality required

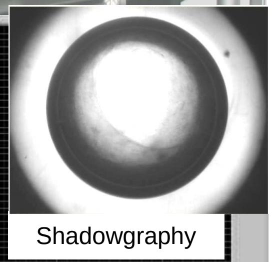






- Two techniques for characterization are installed :
  - Shadowgraphy
  - Optical Coherence Tomography (see poster MWTA-F. Sandras)
- From incomplete data, a global rebuilding of the whole 3D solid DT layer shape is obtained
  - Combining the measurements from 2 techniques,
  - Use mathematical algorithm





- We have integrated and tested the whole experimental set-up
- We have demonstrated a new characterization technique : OCT
- The 3D rebuilding has been validated
- Work is in progress to close the glovebox for the next step with DT

« Spatial Reconstruction Algorithm of DT Layer in Cryogenic Targets using Optical Techniques », A. Choux et al, Fusion Sci. Technol. 51, 727 (2007)

Summary

- Cryogenic Target assembly
  - Microshell : very low roughnesses has been demonstrated for graded CH_xGe : yield with all specifications is the main objective
  - All key technologies and materials for the cryogenic target assembly have been developed : optimization is a daily chore
  - Compatibility of all pieces with T_2 have been demonstrated : still a test in real conditions at scale 1 to do
- Cryogenic target filling station (IRCC) and transport (VTCC)
  - The design of IRCC is now completed and key technology has been successfully prototyped : we are now waiting for the end of manufacturing and testing
  - The first prototype of VTCC has reached its main objectives : next up grade would be compatible to IRCC
- Redistribution
  - « Thermal Quenching » and « Breathing » techniques have shown first evidence to improve β-layered DT solid layers
  - Two characterization means combined with 3D rebuilding model are now operationnel for ice conformation in hohlraum

We still have a lot of work to do…..

R. Collier