PRINCIPE des CRYOSTATS A DILUTION SANS LIQUIDES CRYO (DRY)

Patrick Pari, Philippe Forget, Matthieu De Combarieu CEA-SPEC

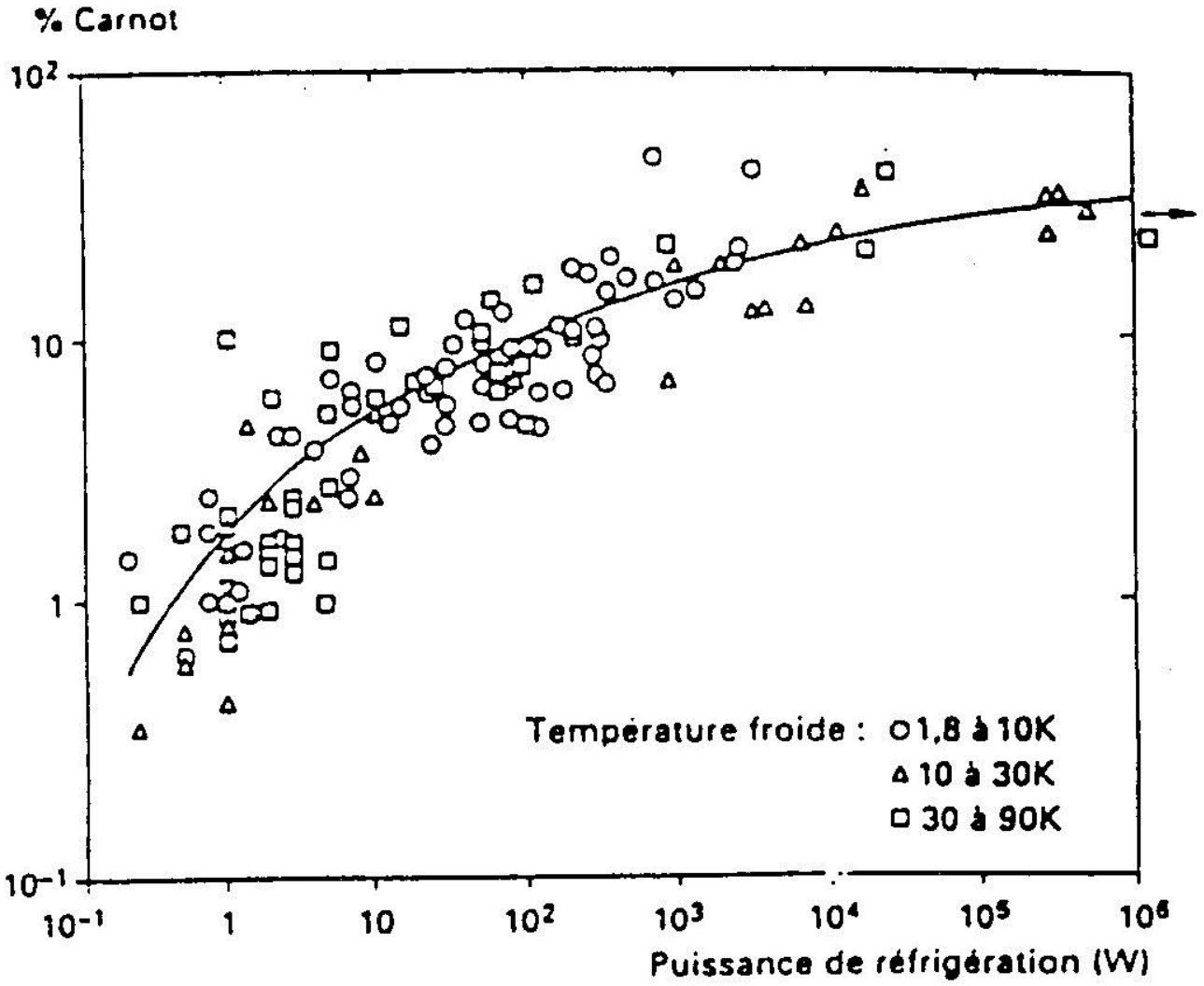
- Comparaison énergie/techno entre systèmes DRY et WET
- Caractéristiques comparées PT : 0.7W@4.2K /0.9W@4.2K
- La dilution en deux mots. He3 : *4000€ /l (NTP).* Sport couteux..
- Canne à dilution sans étage 1K, source d'inspiration…..
- La machine historique de 87 (Stirling). Quelle drôle d'idée…..
- Les premiers prototypes de laboratoires.
- Performances de notre première machine DRY (PT) (2008)
- Prototype de la Quantronique (D.Estève) autour d'un PT407
- La machine de Claire et Emiliano. Histoire de famille….
- Les machines commerciales
- Conclusion

COMPARAISON 4K WET/DRY

- **Cryogénie avec hélium liquide (WET) (vase DEWAR)**
- **Liquéfacteur type LPS (Air Liquide HELIAL)**
- 75KWh, 350l/J, Eau : 9 m^3/J

- **Cryogénie sèche (DRY)**
- **Tube pulsé type PT410 CRYOMECH**
- 7.5KWh, 10l/J, (18l/J), Eau : 7 m^3 /J

Rendement de Carnot *VS* puissance



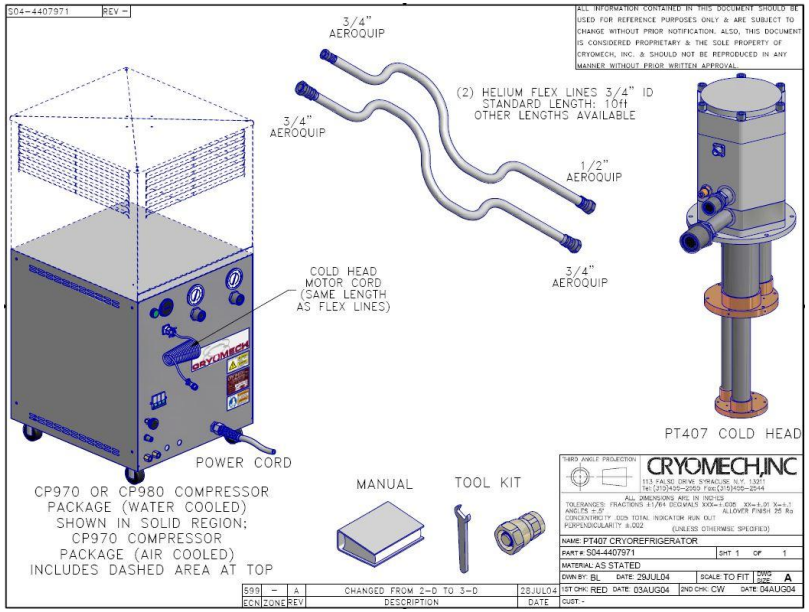
Coût moyen journalier par manip DRY
Nécessité d'utiliser une boucle froide

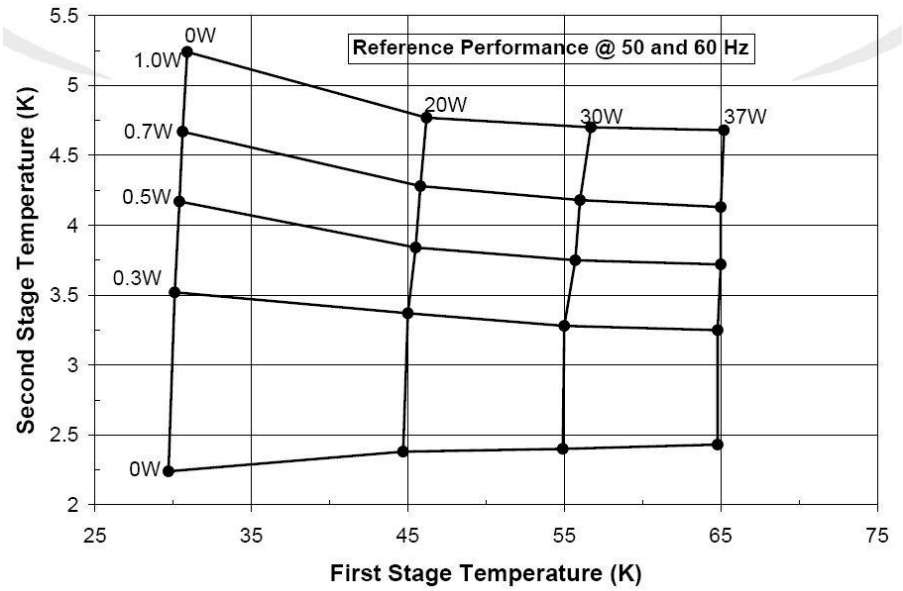
Prix de l'électricité : 0.06 €/KWh

- Prix de l'eau de ville : **3** €/m^3 (7 m^3 /J)
- Coût journalier en eau perdue:

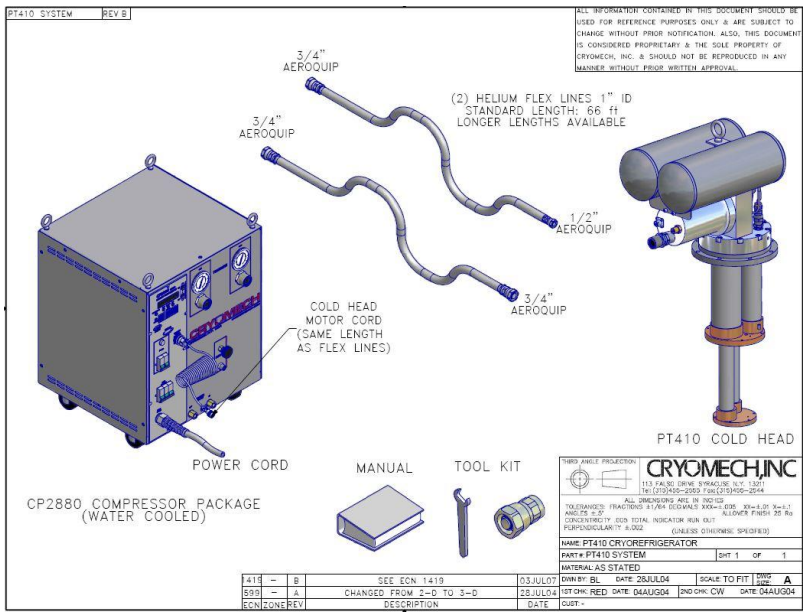
11 € (électrique) + **21** € (eau) = 32 €/j

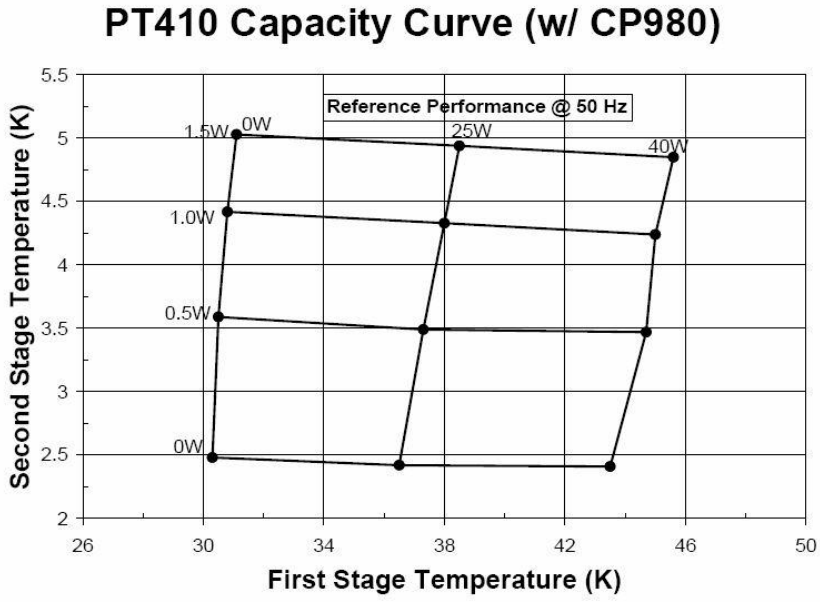
CRYOMECH PT 407 , 700mW@4.2K





CRYOMECH PT 410 , 1000mW@4.2K





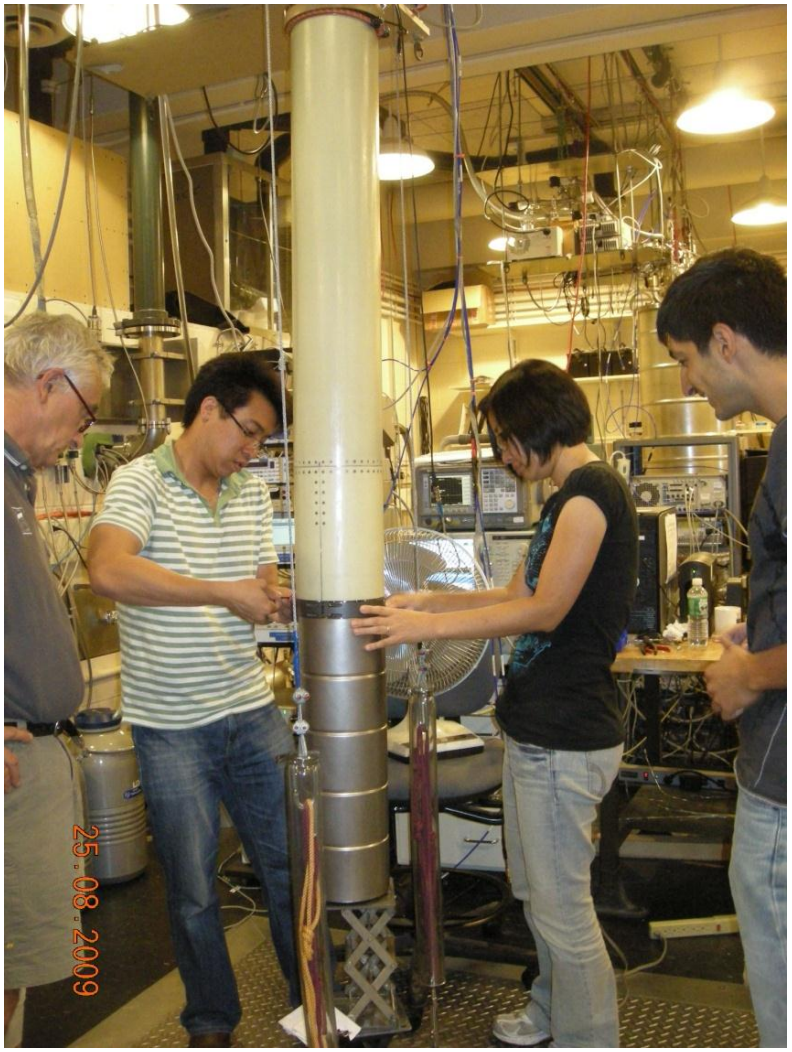
CRYOSTATS WET

Avantages

-moins d'eau (pompes turbo 2m^3/J)
-moins d'électricité (banc de pompage 4KWh)
-moins de vibration et de bruit
-aucune pièce mécanique (pas de maintenance)

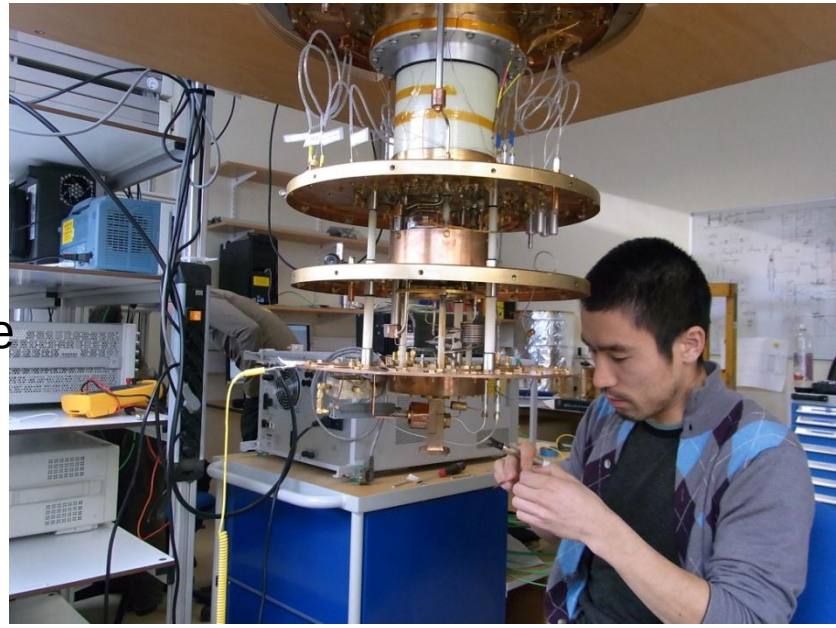
Inconvenants 40€/j (base 10l/j à 4€/l)

-Espace expérimental plus réduit
(Ø : 150mm H:150mm)
-Mise en œuvre délicate (IVC)
-Fonctionnement Manuel à semi automatique.
Donc + de présence.
-Mauvaise utilisation → conséquences importantes sur la consommation He .
-Ne permet pas d'accueillir plusieurs expériences.
-Puissance disponible faible sur l'étage 4K:
-350 mW →12l/j d'hélium



CRYOSTATS DRY

Utilisation avec boucle eau froide



Avantages 11€/j

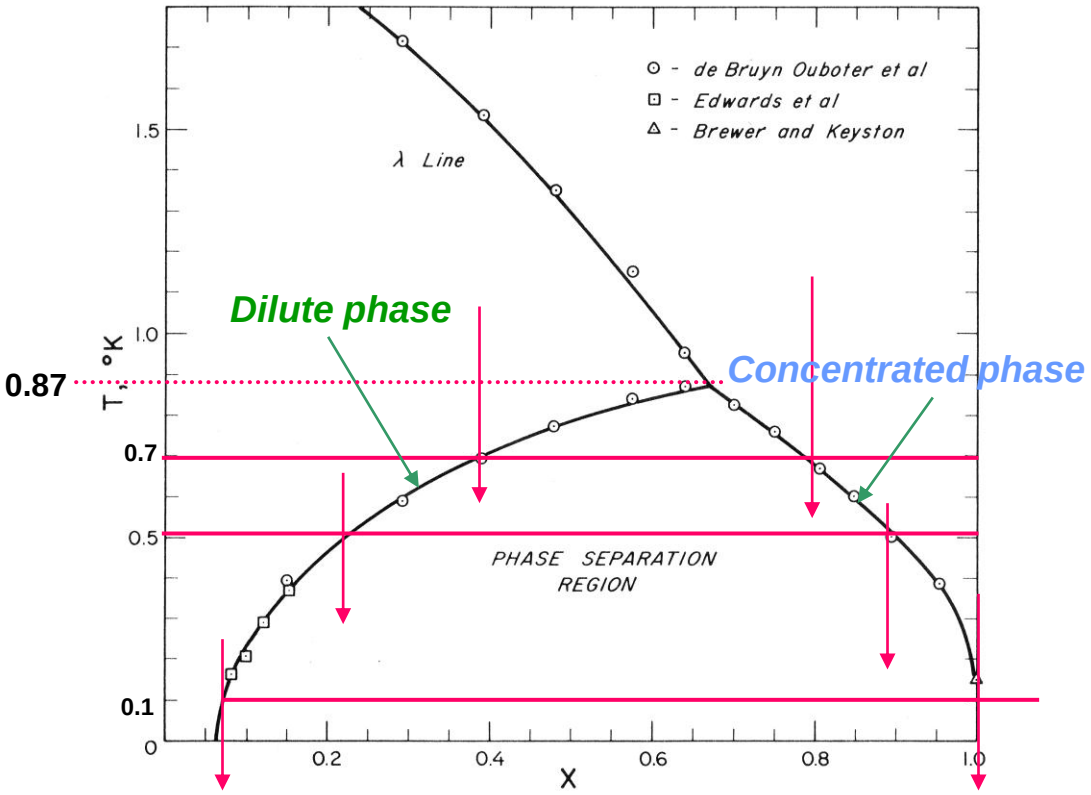
-Espace très important (Ø : 300mm H:300mm)
-Mise en œuvre très simple (pas d'IVC)
-Fonctionnement automatique, contrôle a distance
-Mauvaise utilisation (vide) sans conséquence sur la consommation électrique (7.5KWh).
-Permet d'accueillir plusieurs types d'expériences.
-Puissance disponible importante sur l'étage 4K:
-200mW pour un PT407 (0.7W@4K)
-350mW pour un PT410 (1W@4K)
-Pas de calorimètre à 4.2K, uniquement des écrans.

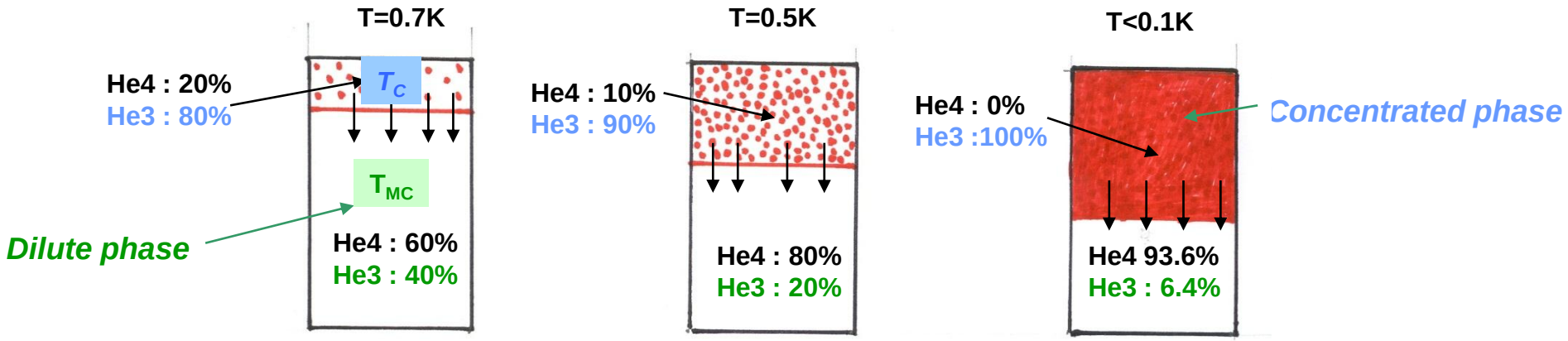
-***Inconvénients***

-Vibrations (pb pour les expériences à basse fréquence)
-le bruit
-Maintenance mécanique (compresseur +tête froide)
--Machine thermique donc pas de de température de référence (T=4.2K hélium liquide)

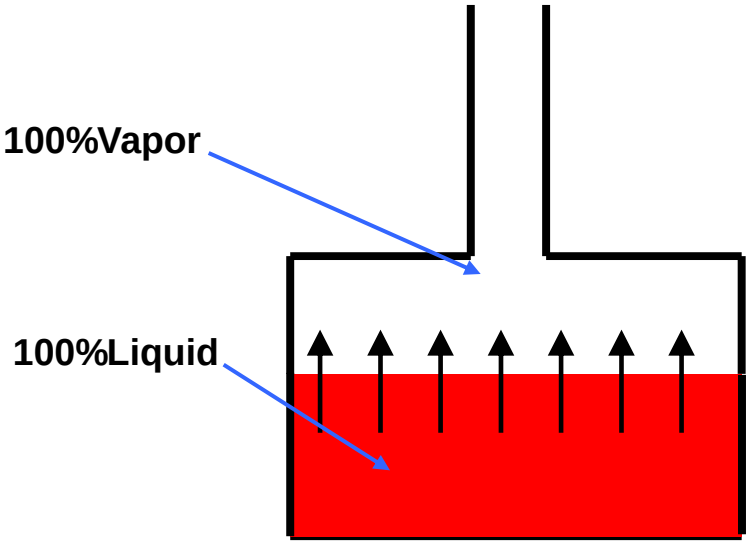
Compresseur 7.5KWh + 7m³/j d'eau

Cryostat à dilution


⊙ - de Bruyn Ouboter et al
⊡ - Edwards et al
△ - Brewer and Keyston
λ Line
Dilute phase
Concentrated phase
0.87
T, °K
1.5
1.0
0.7
0.5
0.1
0
PHASE SEPARATION
REGION
0.2
0.4
0.6
0.8
1.0
X

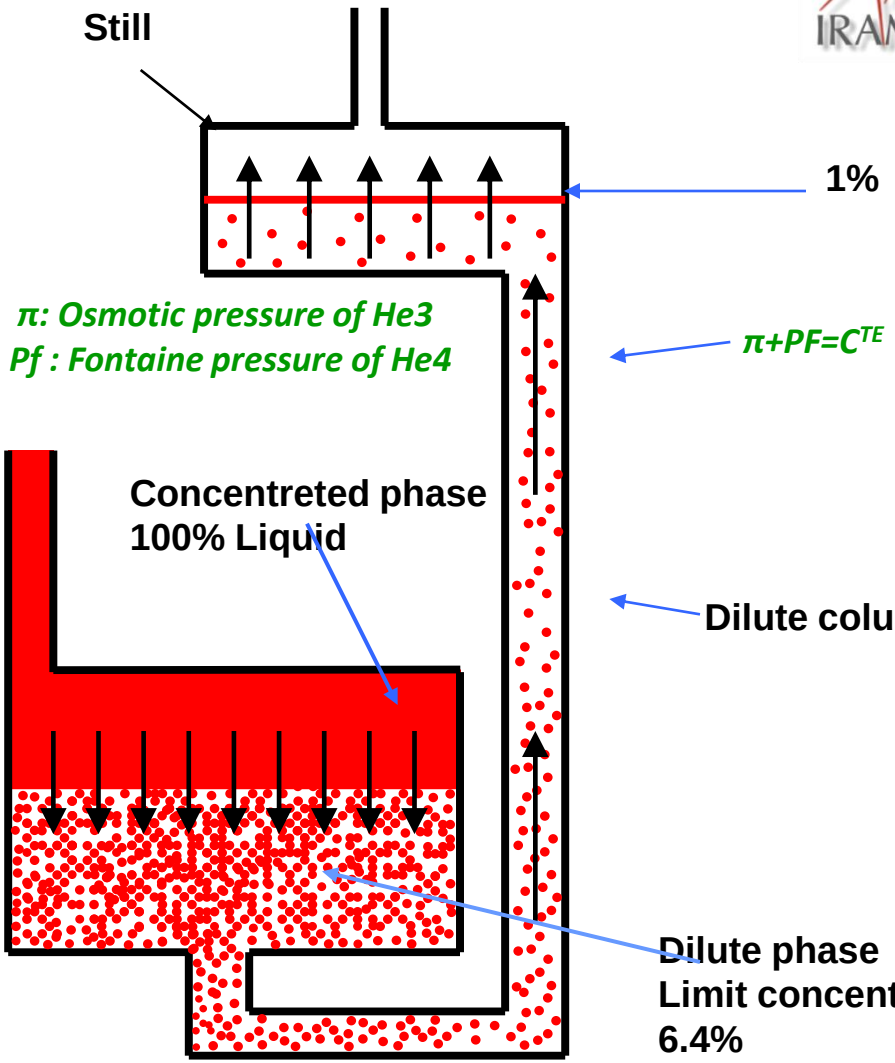

T=0.7K
He4 : 20%
He3 : 80%
T_C
T_{MC}
Dilute phase
He4 : 60%
He3 : 40%
T=0.5K
He4 : 10%
He3 : 90%
He4 : 80%
He3 : 20%
T<0.1K
He4 : 0%
He3 :100%
Concentrated phase
He4 93.6%
He3 : 6.4%

Pur He3 fridge



[He3 : plus de 4000€/l (NTP)]

Dilution

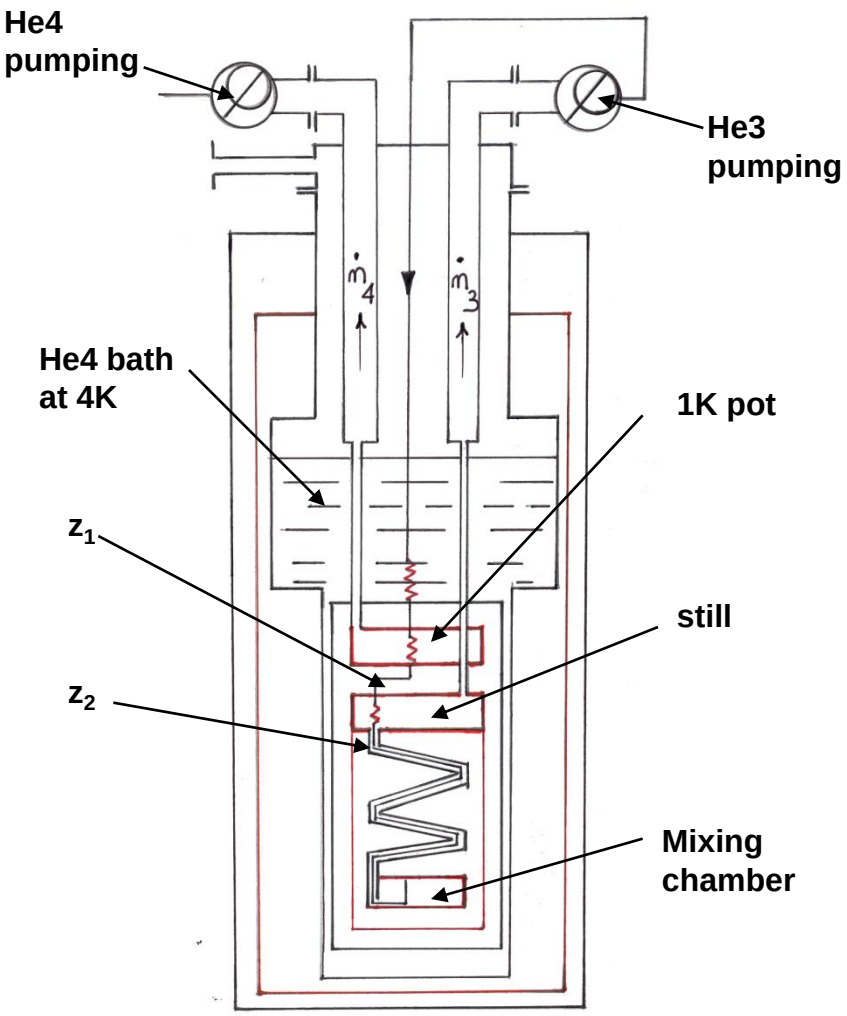


$Q_{EXT}=n_3 (96 T_{mc}^2-12 T_C^2)$ Js^{-1}

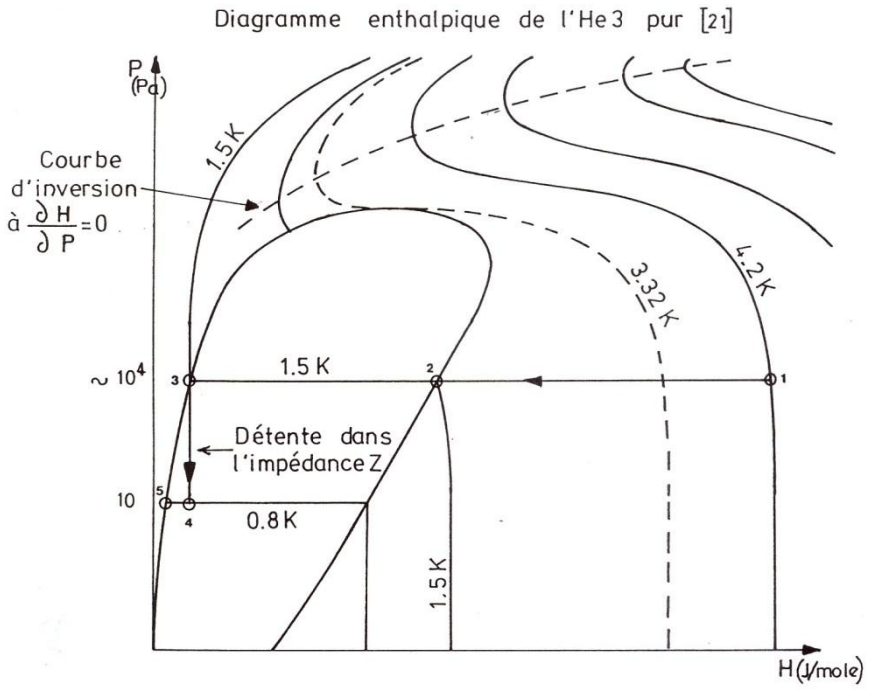
$Q_{EXT}=84\, n_3\, T_{mc}^2$ $J\, s^{-1}$ *perfect exchangeurs*

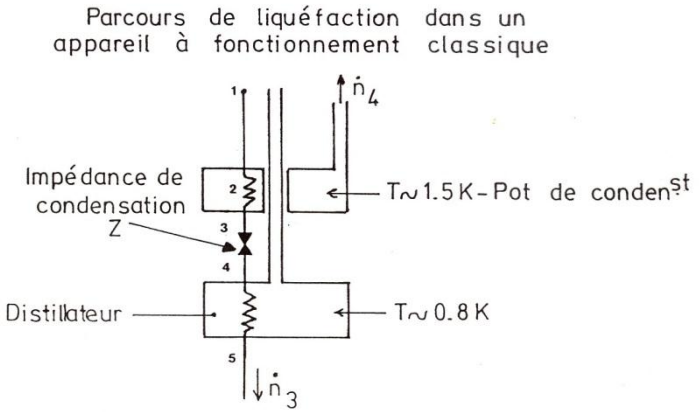
CLASSICAL DILUTION REFRIGERATOR CYCLE AND DIAGRAM

0.2 l/h < liquid helium flow < 1 l/h

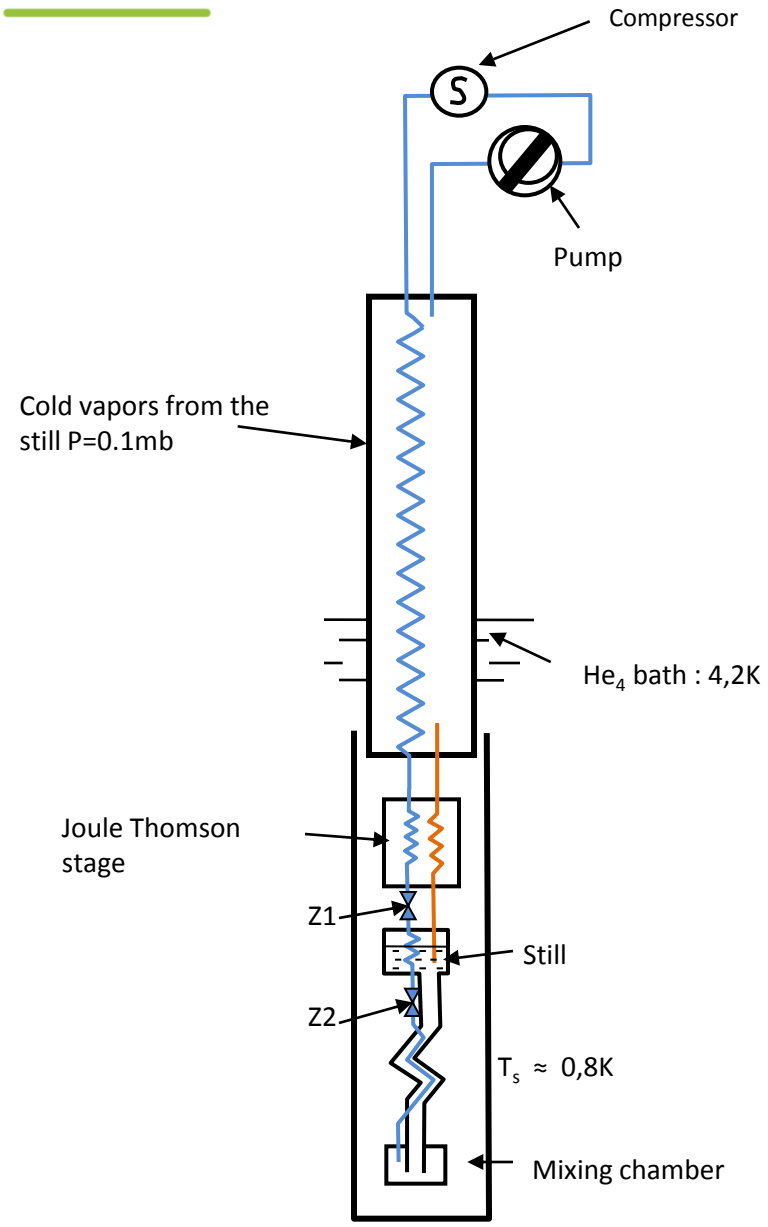


CLASSICAL DILUTION REFRIGERATEUR CYCLE

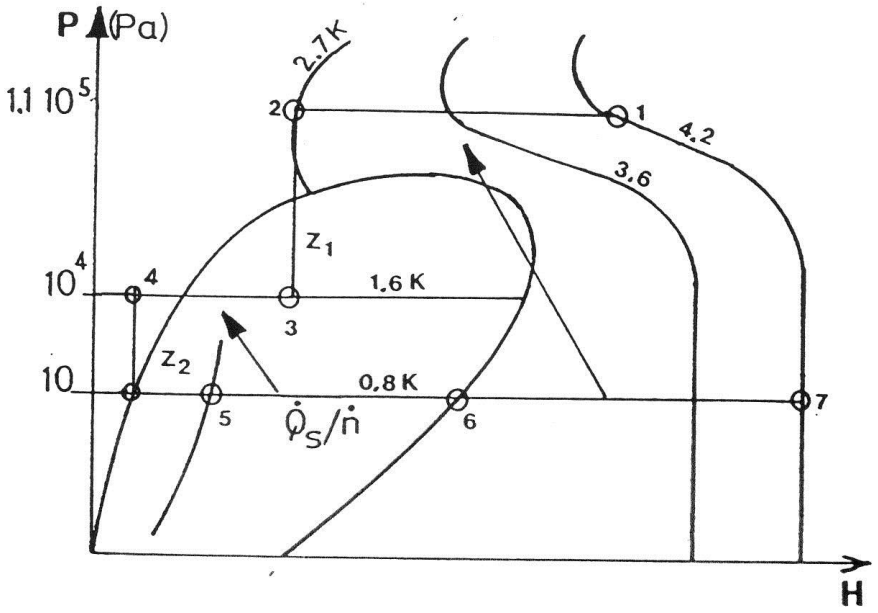




DILUTION STICK

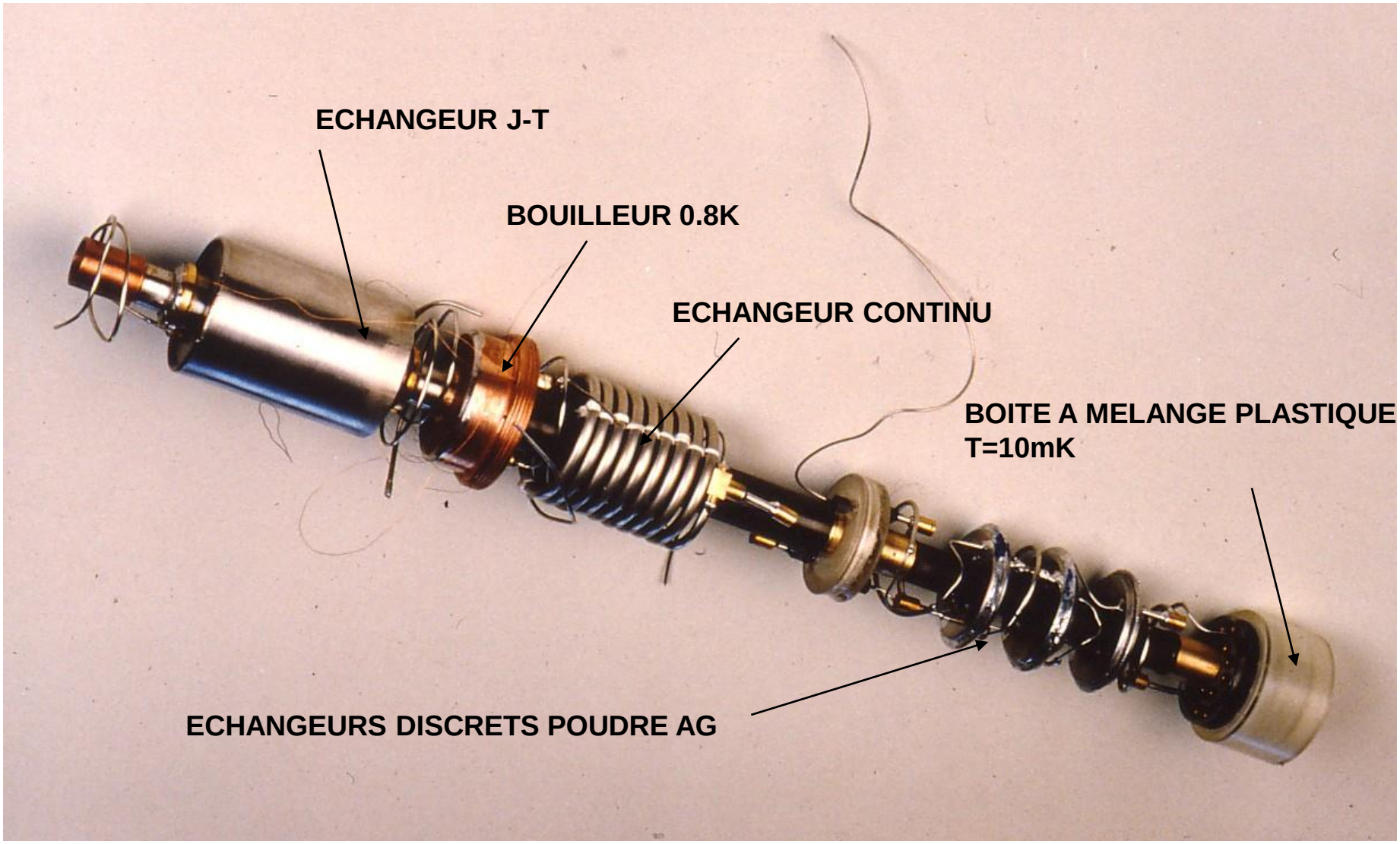


Condensation from 4.2K
Précooling mixture in the counter-flow exchanger



Moins de 5l d'He3

MINI FRIDJE 10mK DIAMETRE 30mm



FREE DILUTION REFRIGERATOR OF 1987

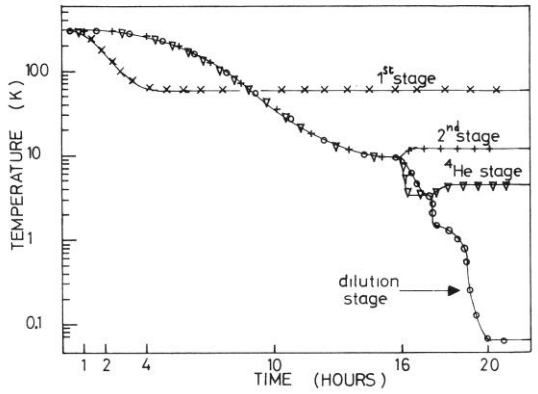
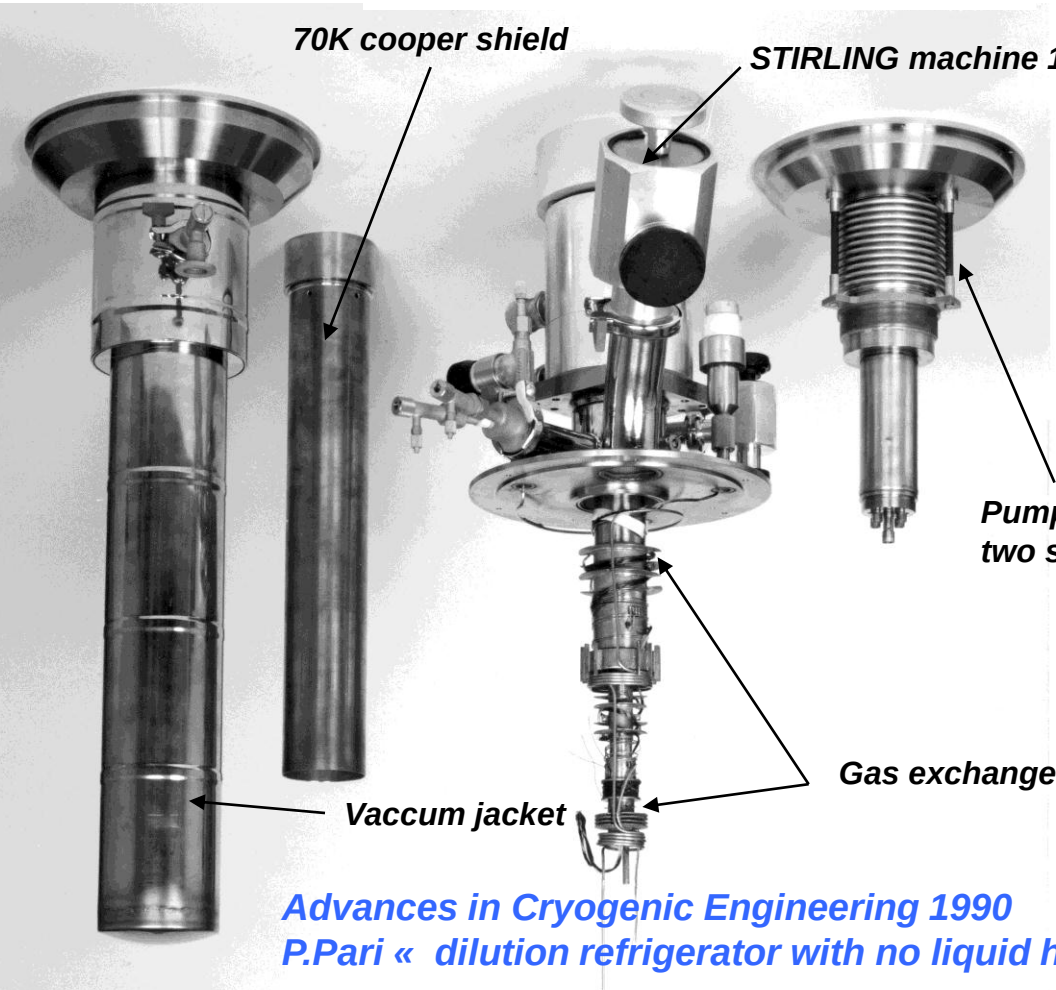
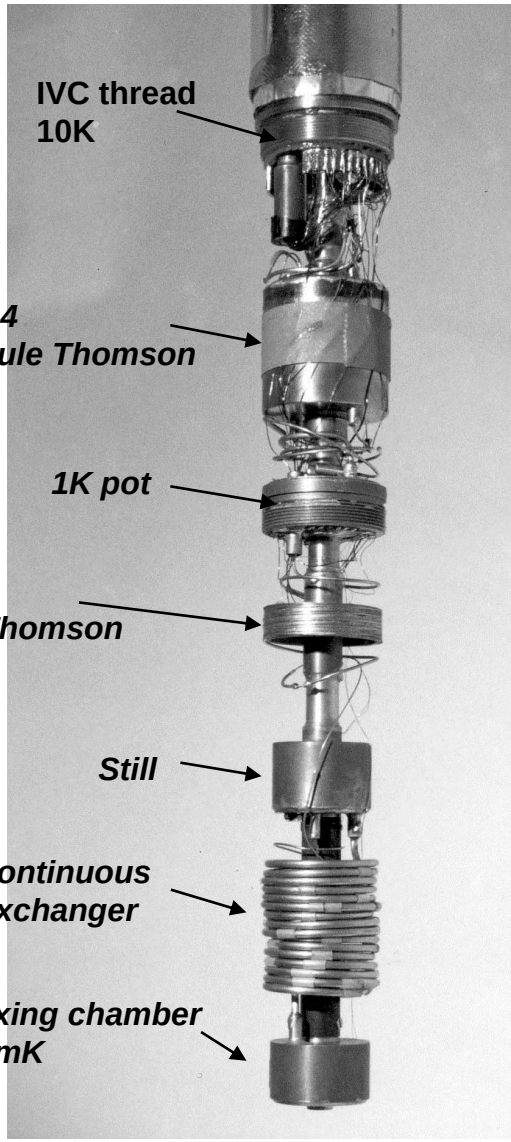


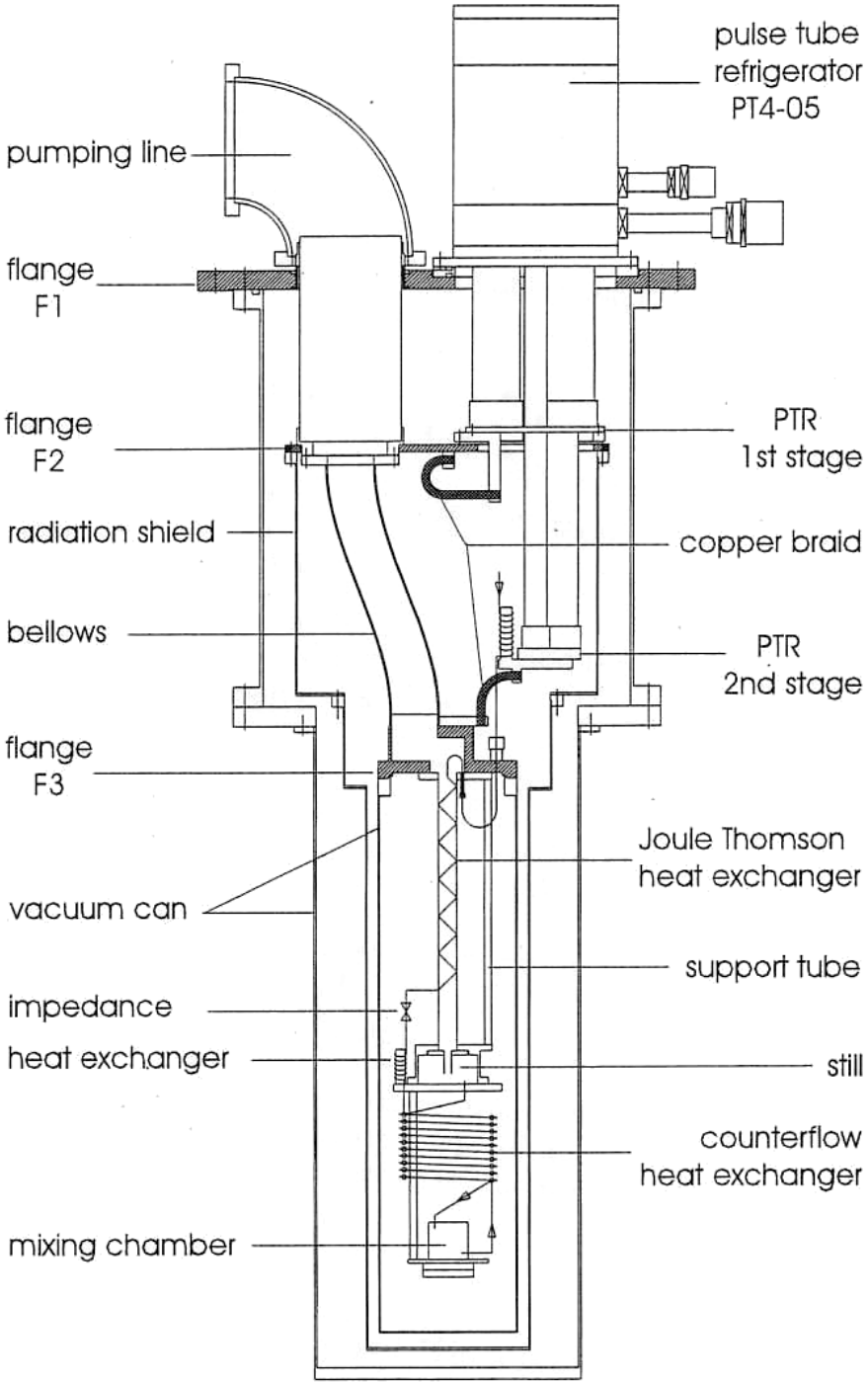
Fig. 6. Cooldown diagram.

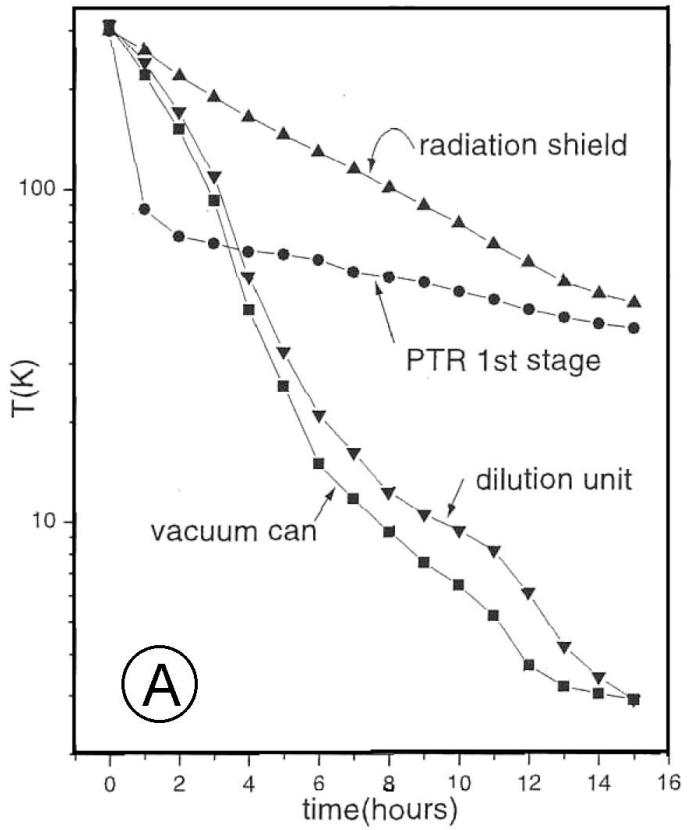


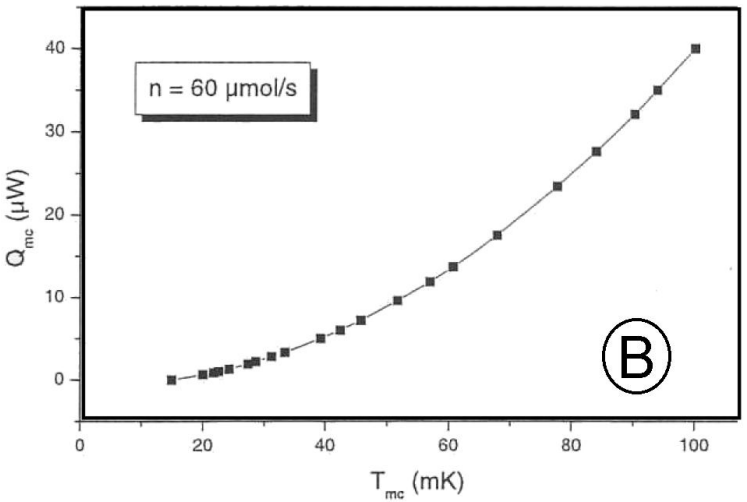


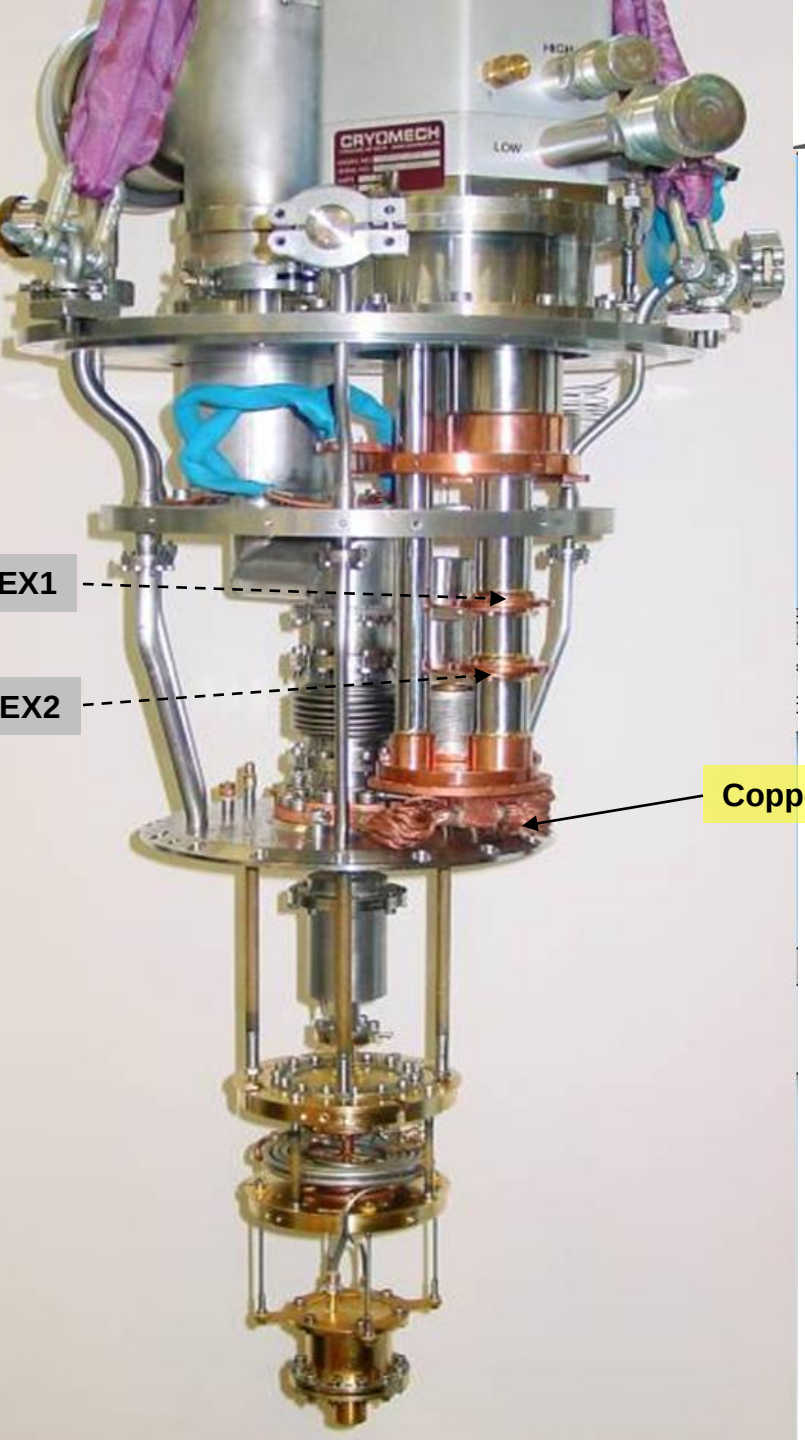
Advances in Cryogenic Engineering 1990
P.Pari « dilution refrigerator with no liquid helium supply »

Bibliographie :
many papers by Kurt Uhlig









T. Prouvé, H.Godfrin, C.Gianèse. S.Triquenaux, A.Ravex

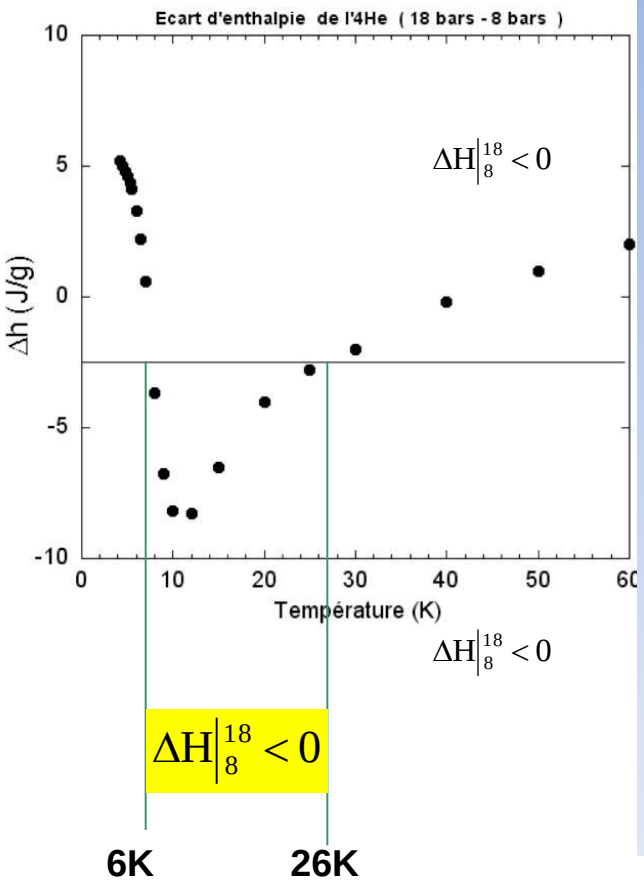
DEVELOPPEMENT OF DILUTION REFRIGERATOR PRECOOLING BY A PULSED TUBE

Thesis of Thomas Prouvé

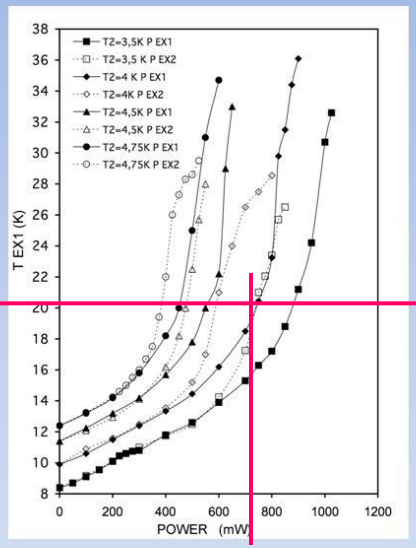
(Joseph Fourier University, GRENOBLE) 2007

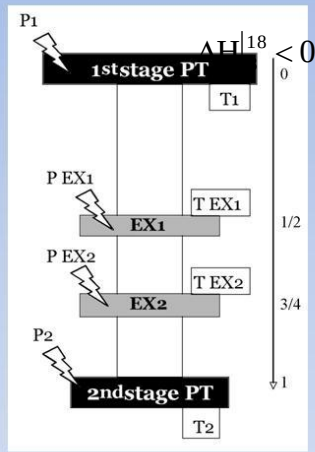
BETWEEN 6K AND 26K $\Delta H\big|_8^{18} < 0$ **ITS POSSIBLE TO CHARGE THE REGENERATOR**

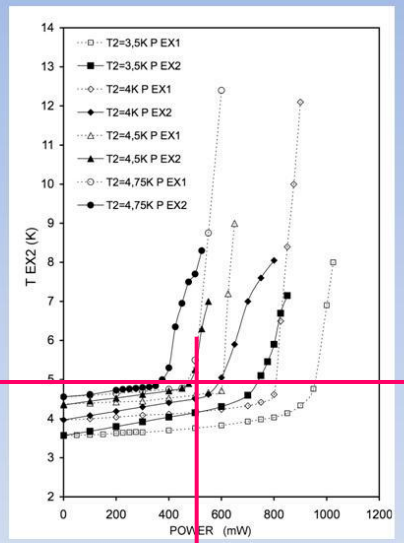
WITHOUT REDUCING THE COOLING POWER ON THE SECOND STAGE OF *PT*



"Free" cooling Power of PT = fast cooling!







Temperature of the first intercept T EX1 as a function of the power P EX1 applied to this intercept (solid lines and symbols), or to the second intercept PEX2 (dashed line and open symbols) for different temperatures T2 of the second stage.

Temperature of the second intercept T EX2 as a function of the power PEX2 applied to this intercept (solid lines and symbols), or to the first intercept P EX1 (dashed line and open symbols) for different temperatures T2 of the second stage.

Pulse-tube dilution refrigeration below 10 millikelvins, T. Prouvé, H. Godfrin, C. Gianèse, S. Triqueneaux, A. Ravex
J. of Low Temp. Phys. 148, 909 (2007)

Pulse-tube dilution refrigeration below 10 mK for Astrophysics, T. Prouvé, H. Godfrin, C. Gianèse, S. Triqueneaux, A. Ravex
J. of Low Temp. Phys. 151, 640 (2008).

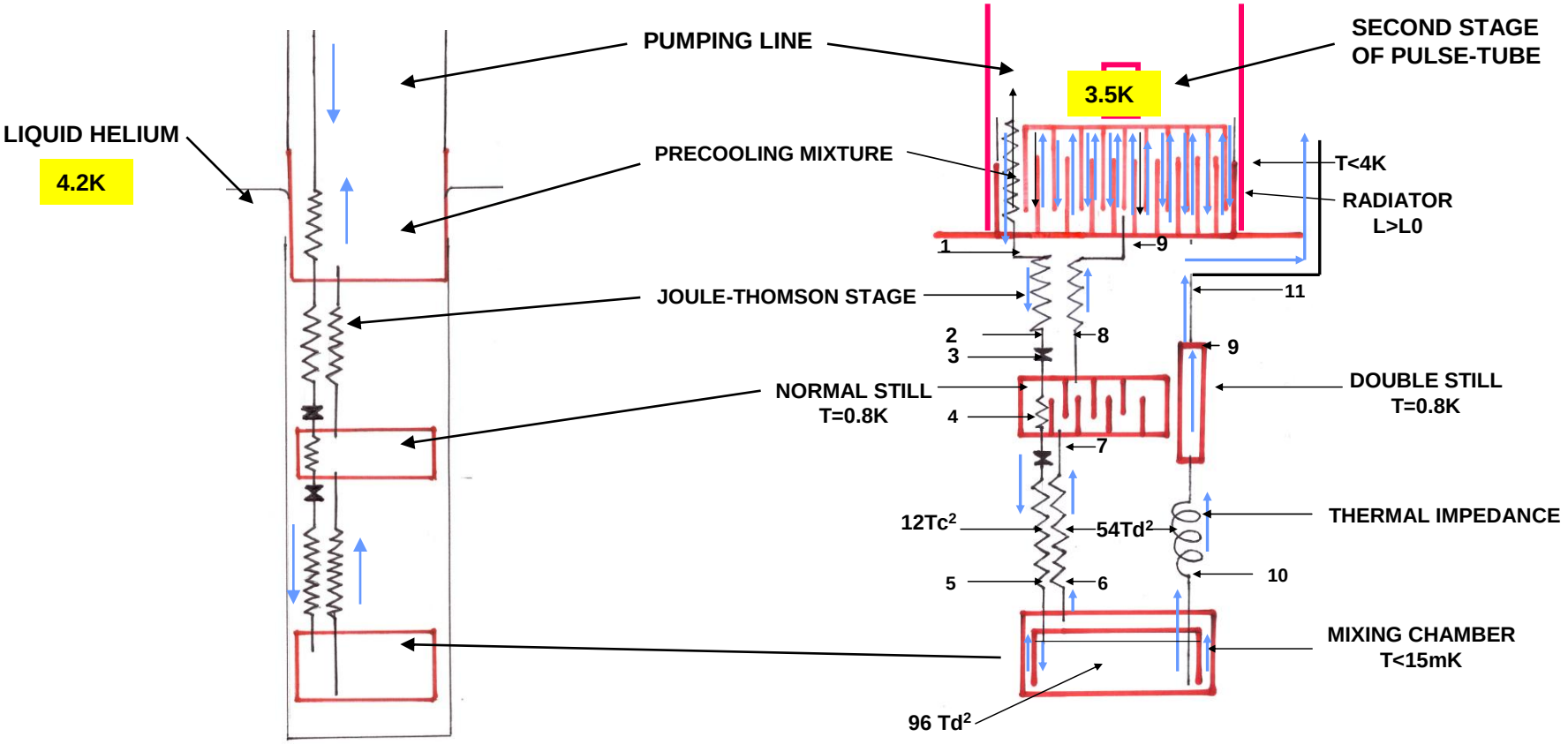
Air Liquide, U.S. Patent 6,915,642 and CNRS-Air Liquide Patent FR07 53945

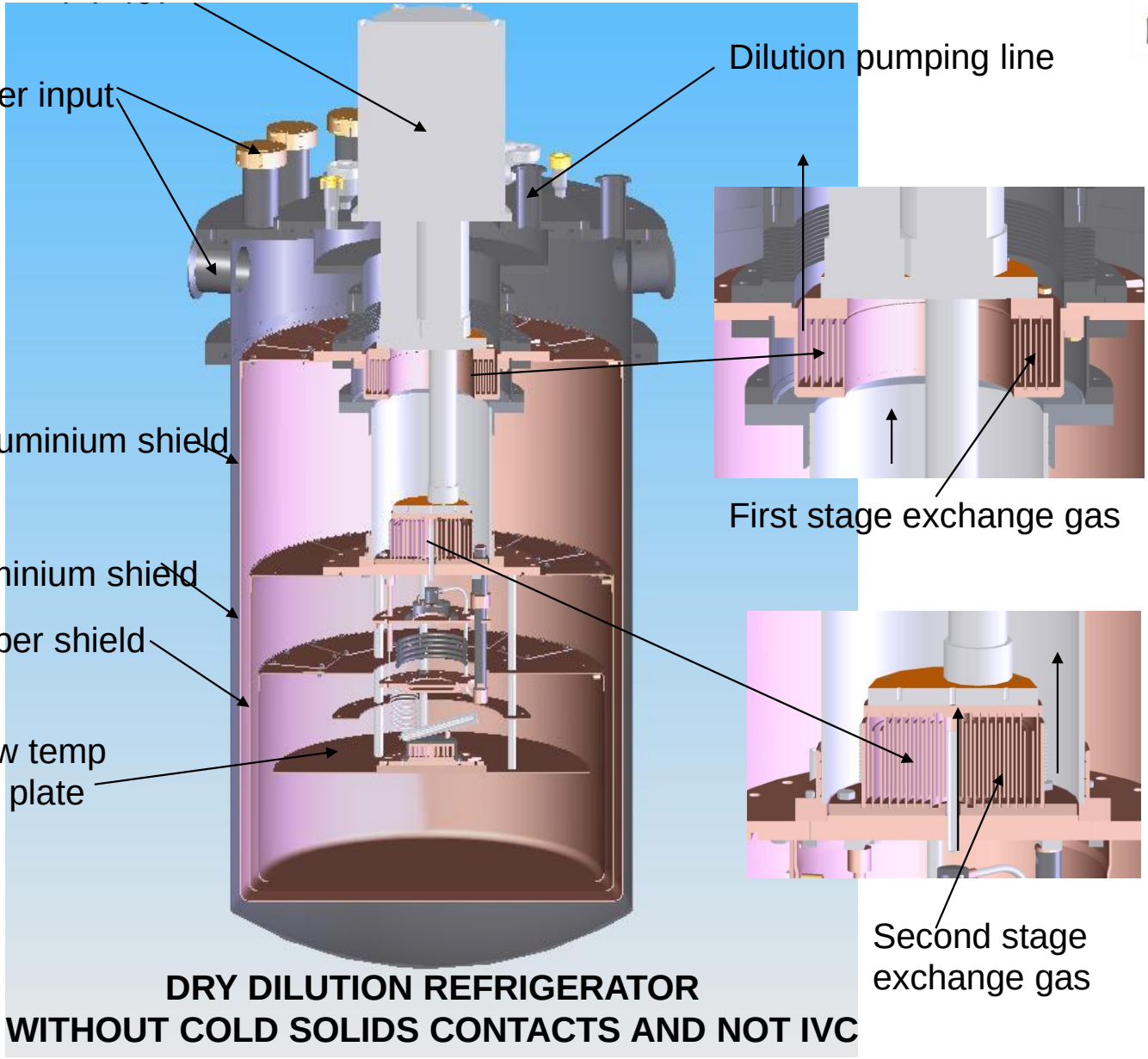
EX1 700mW@20K

EX2 500mW@6K

NORMAL JT DILUTION STAGE

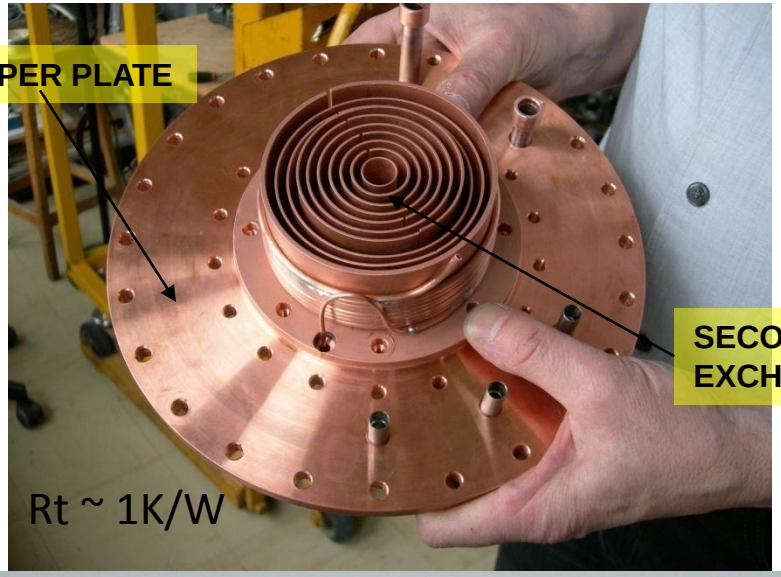
DOUBLE STILL JT DILUTION STAGE

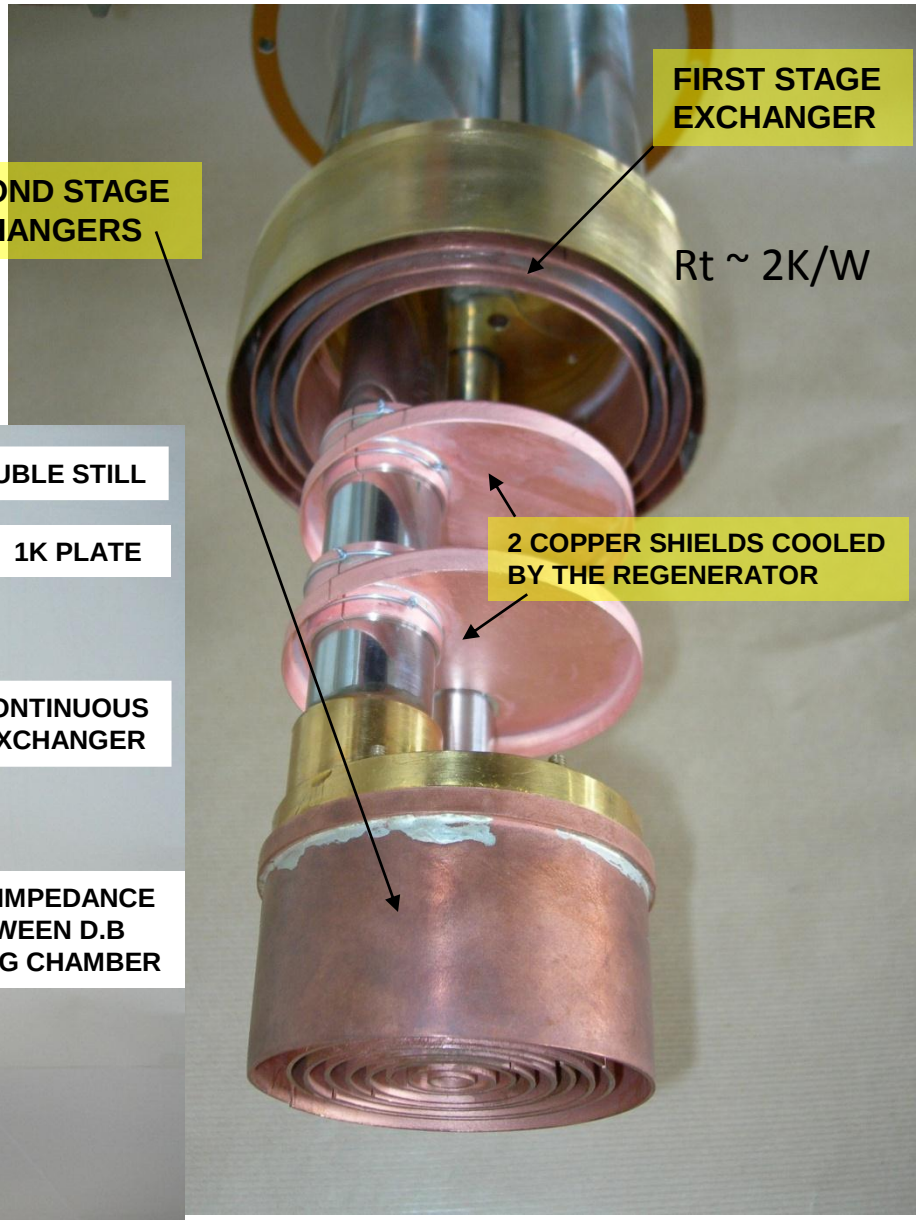


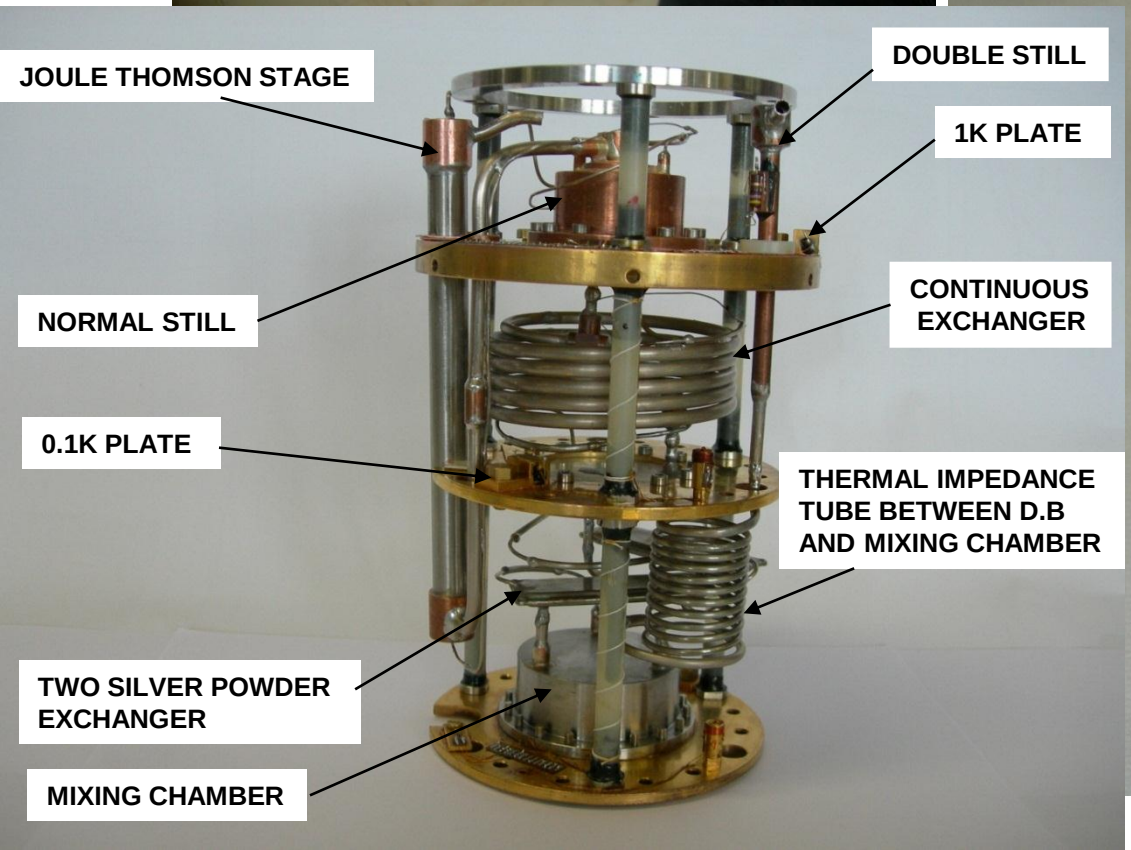


DRY DILUTION REFRIGERATOR
WITHOUT COLD SOLIDS CONTACTS AND NOT IVC

EXCHANGERS BETWEEN FIRST STAGE AND SECOND STAGE OF *PT* .



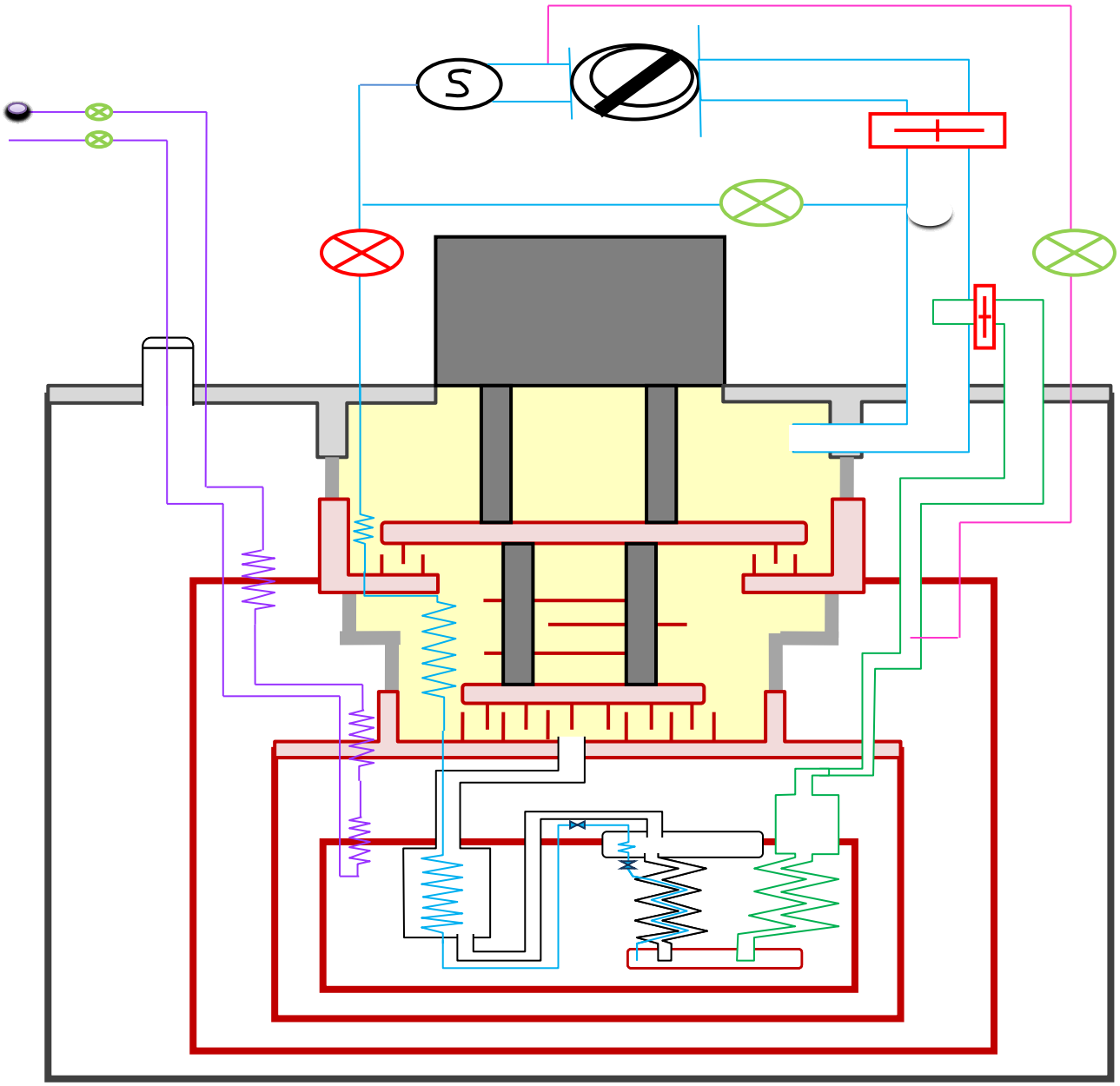




Start

Click to echap to quit

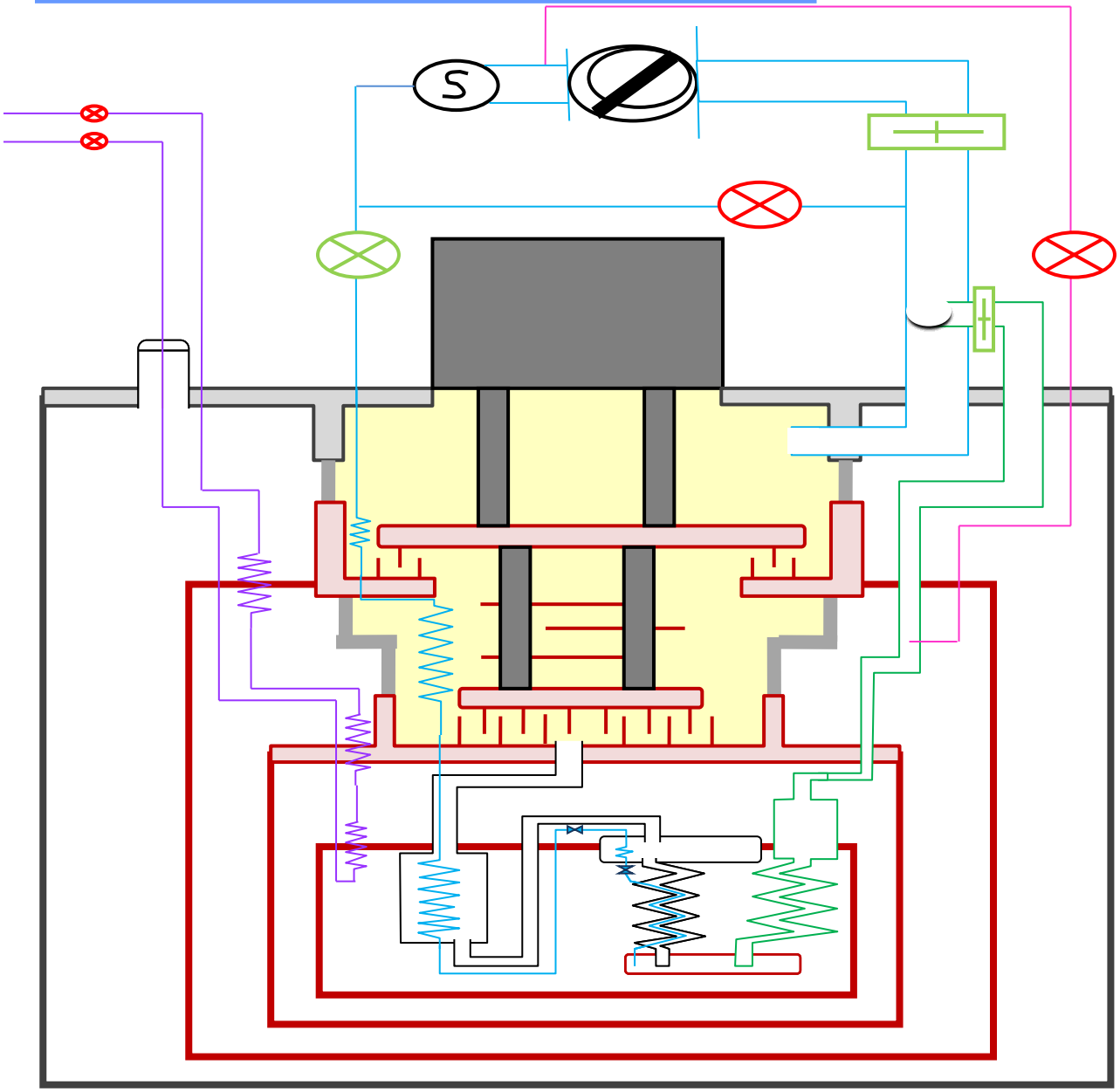
DIAGRAMM OF RAPID COOLING 3<T(K)<300



Start

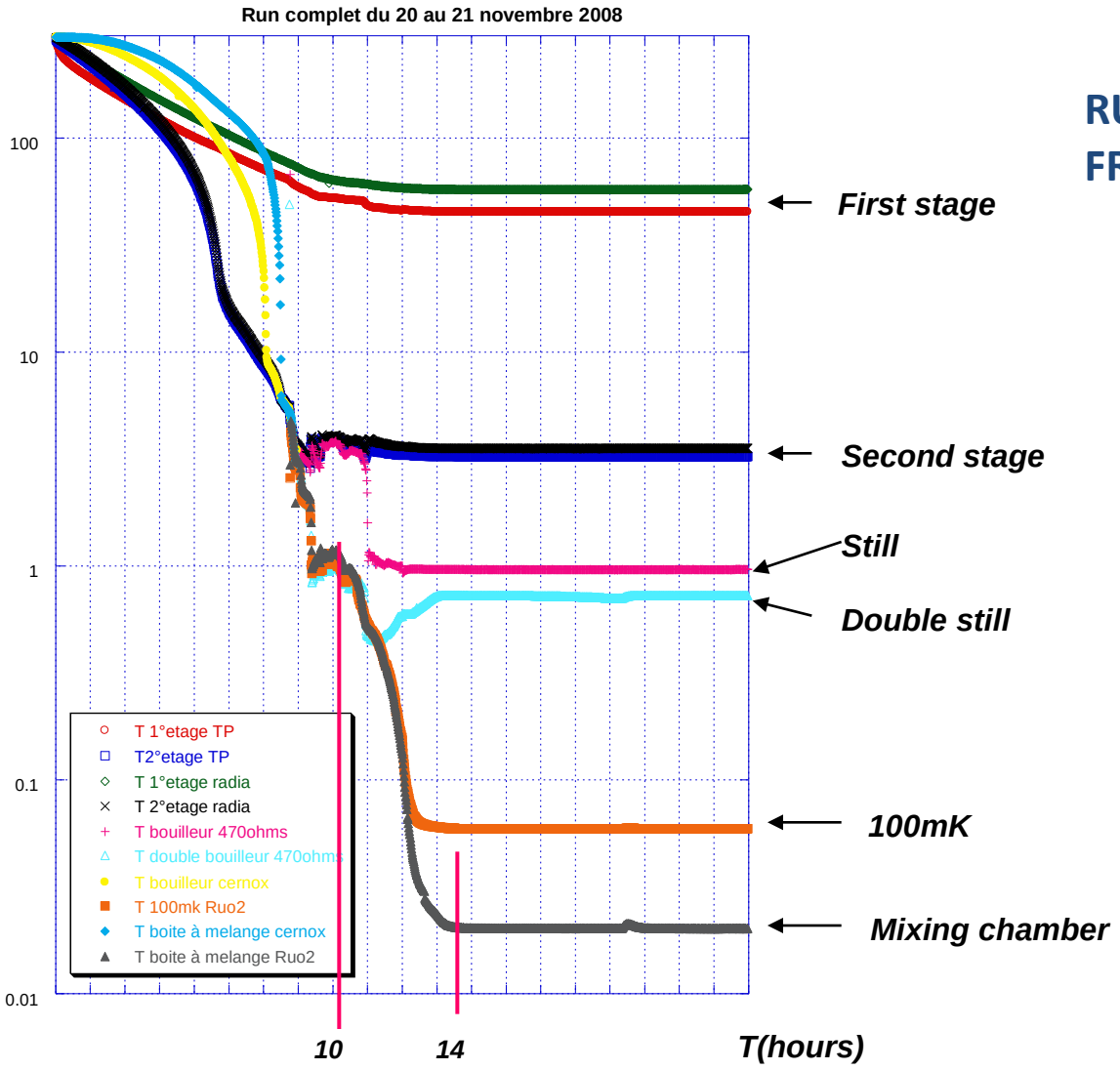
Click to echap to quit

DIAGRAMM OF NORMAL COOLING 16mK<T<3K



GENERAL VIEW OF FREE DILUTION REFRIGERATOR PROTOTYPE MODEL WITH PT407

PT1	RPT1	PT2	RPT2	Still	Double Still	100mK	MC	P_P	P_{INJ}	n
47K	61.6 K	3.34 K	3.64 K	0.937 K	0.72 K	60.5 mK	16mK	$9.8\ 10^{-2}$	410mb	210µmoles/s



First stage

Second stage

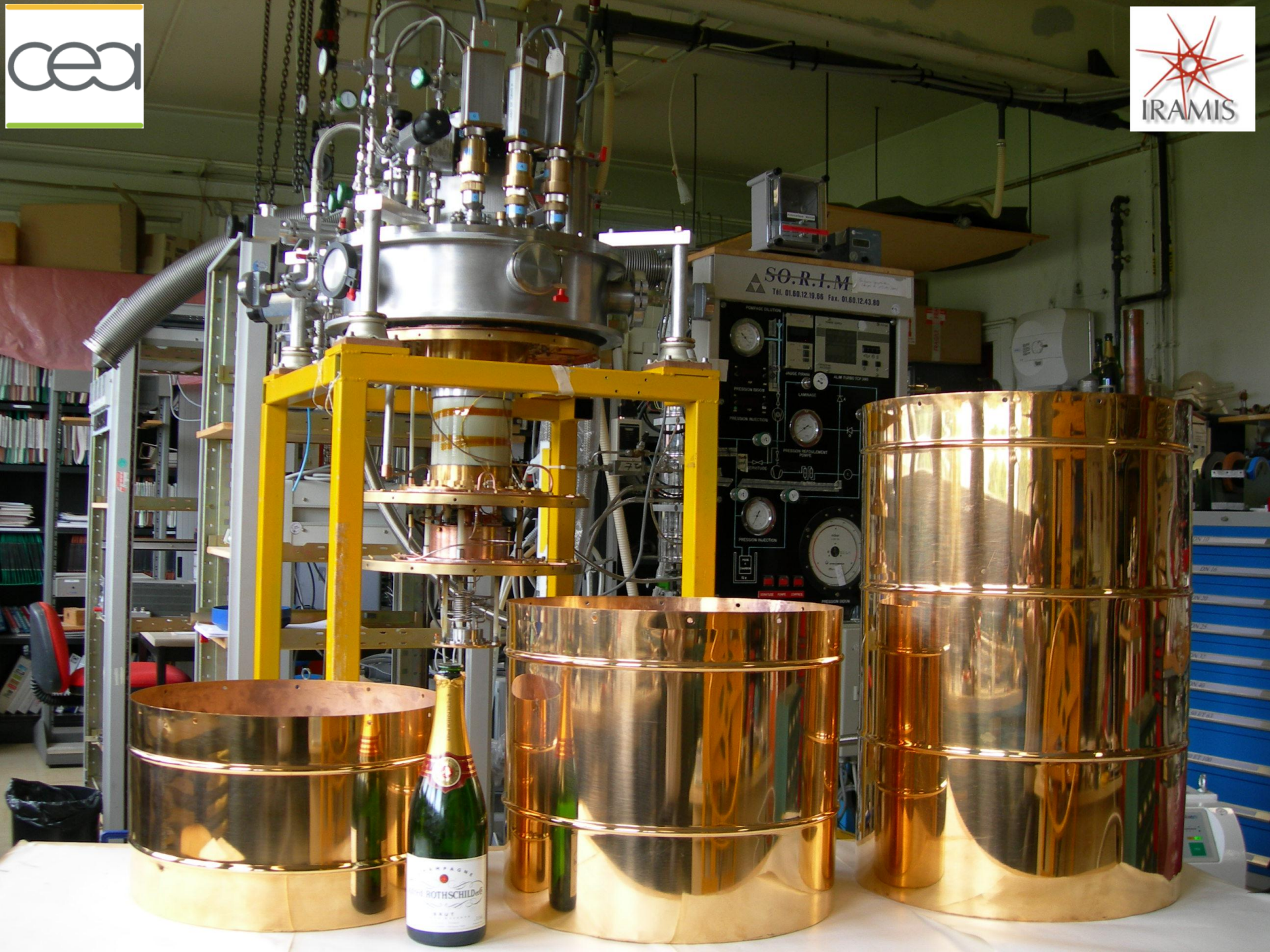
Still

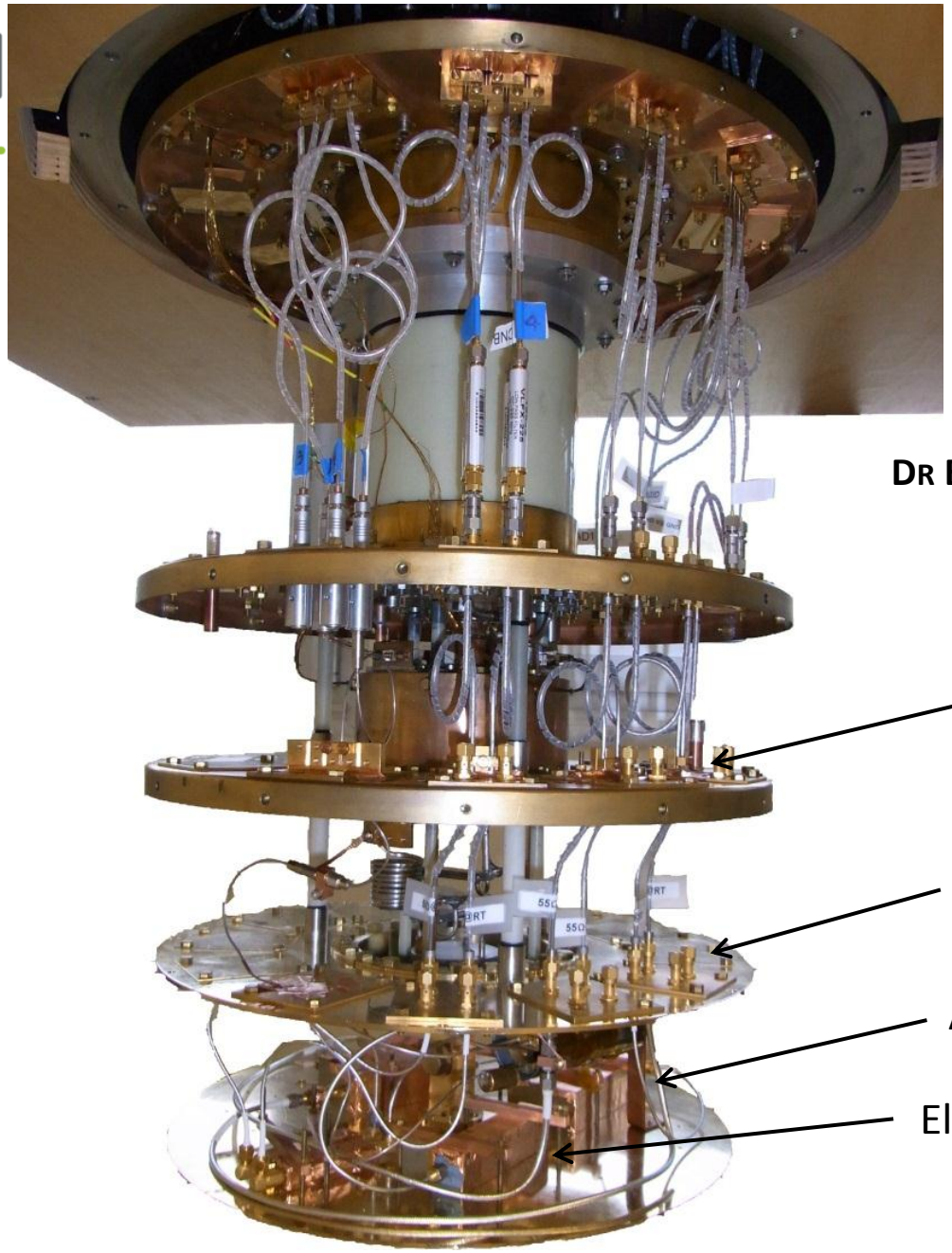
Double still

100mK

Mixing chamber

RUNING PARAMETER OF FREE DILUTION REFRIGERATOR


cea
IRAMIS
SO.R.I.M
Tél. 01.60.12.19.66 Fax. 01.60.12.43.80
BROTHSCHILD



DR ESTEVE DEVICE (SPEC/SACLAY) : QUANTUM ELECTRONIC EXPERIMENTS @ 20 mK

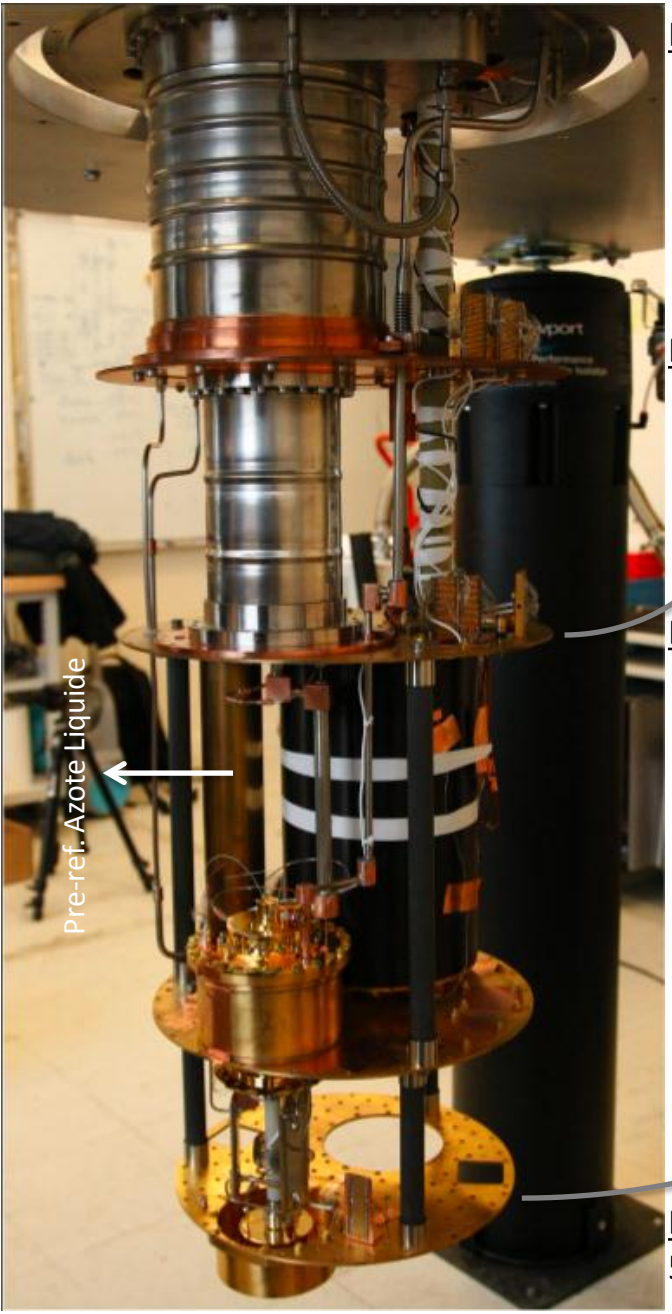
Electronic devices @ 1K
(pre amplifiers, …)

Mixing Chamber plate

Additional 20 mK plate

Electronic devices @ 20 mK

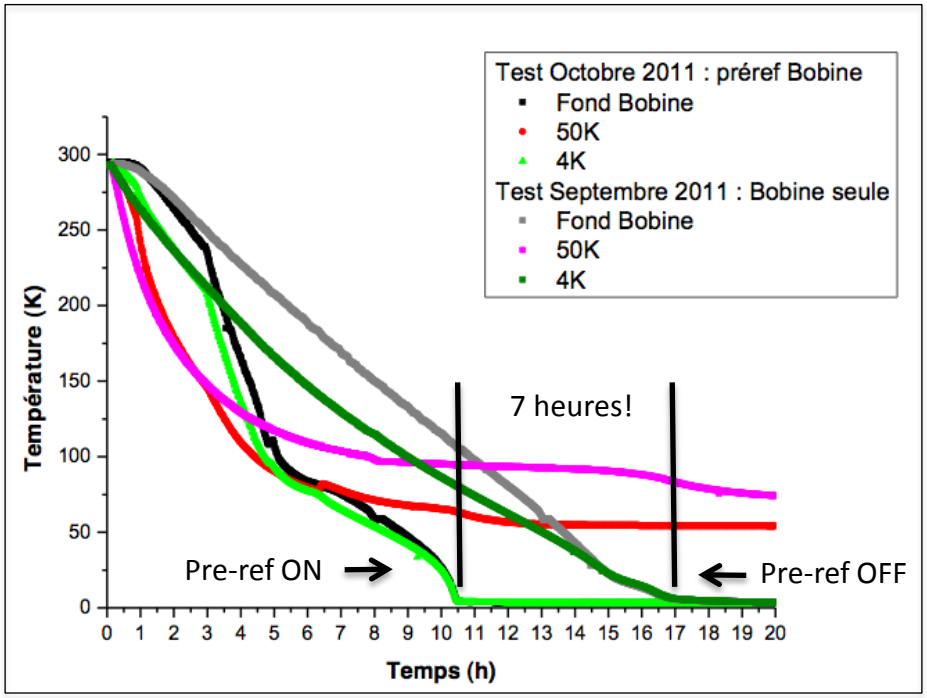
Projet Marrache @ CSNSM



Bride 300 K

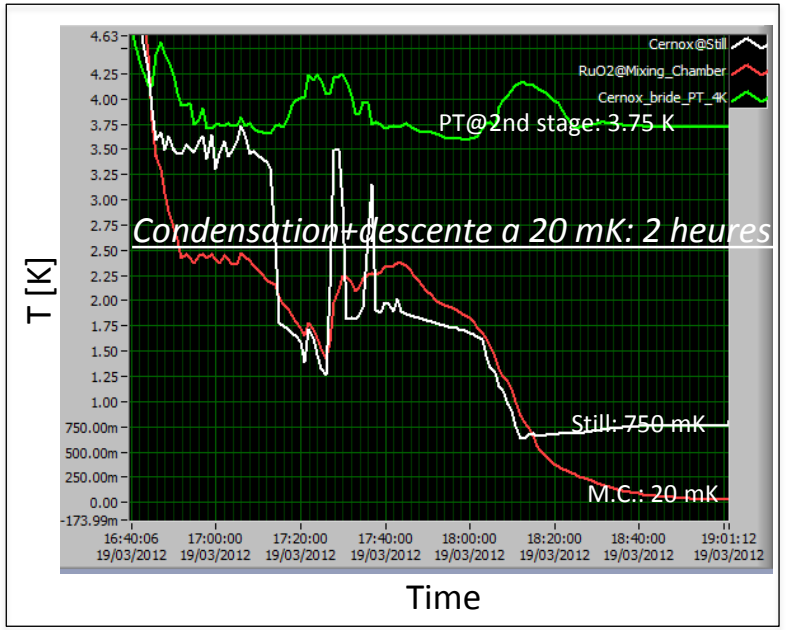
Bride 70 K

Bride 4 K

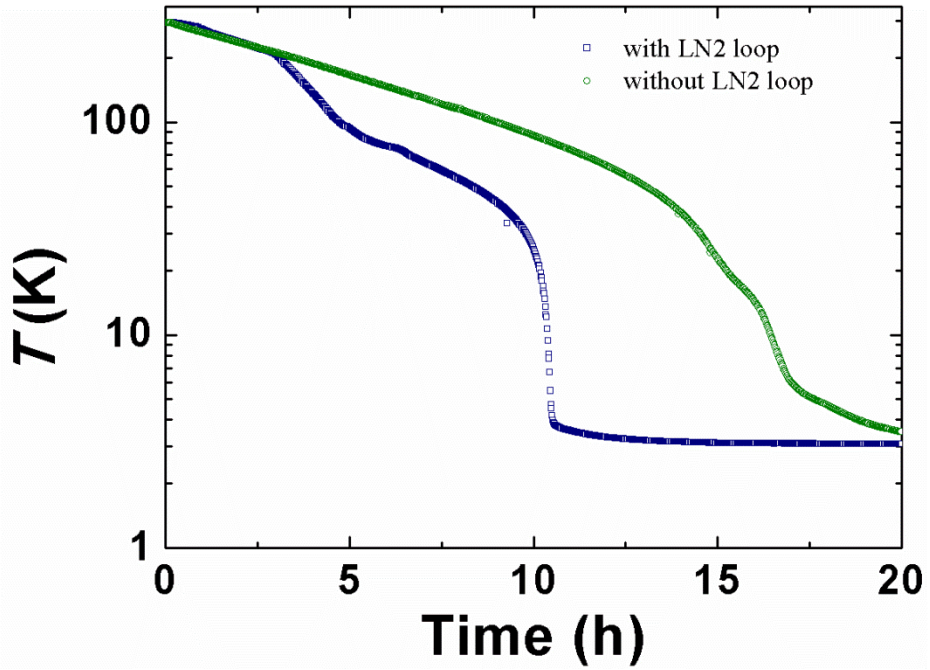


Etage 1 K (Still):
5 mW@850 mK

Etage 10 mK (Mix. Chamber):
5 uW@20 mK, T_{min}=13 mK



PERFORMANCES – COOLING A 9 T MAGNET



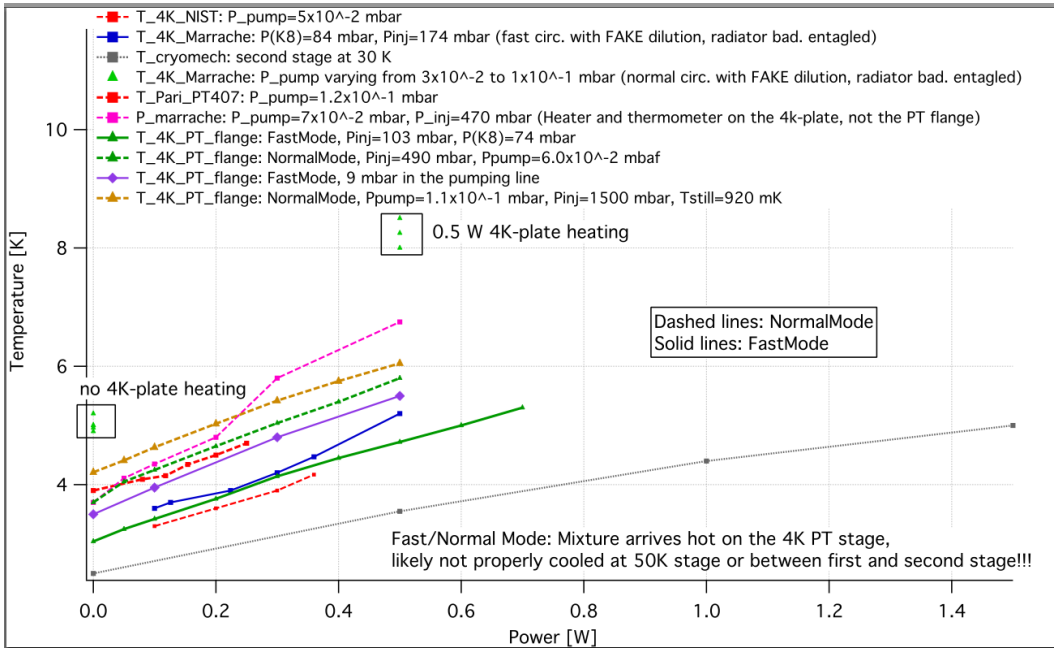
energie atomique • energies alternatives

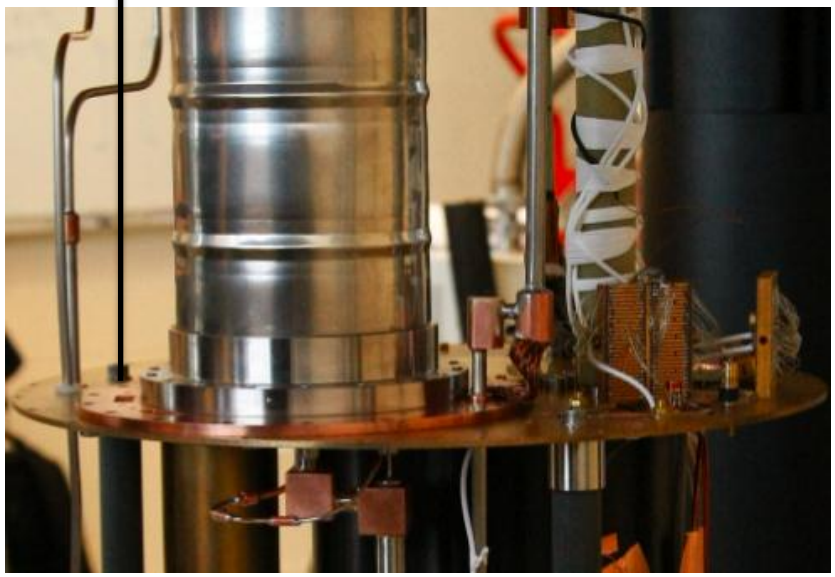
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

CRYOCONCEPT
A Division of Cryomagnetics

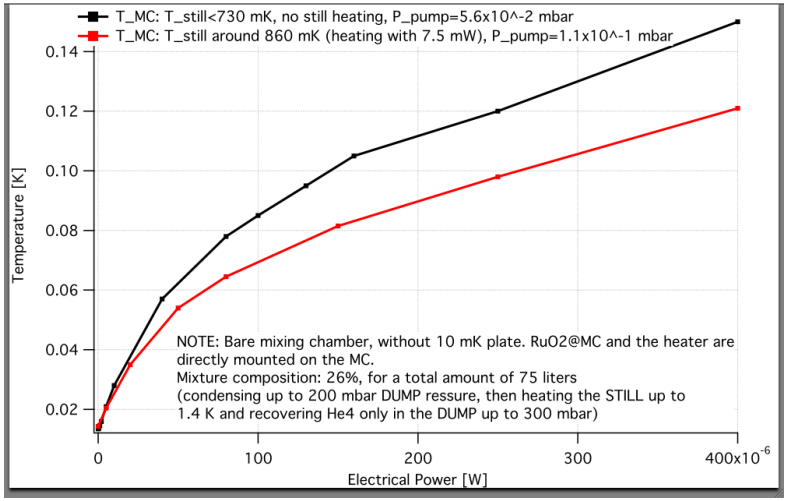
Projet Marrache @ CSNSM

Puissance disponible sur la bride 4 K

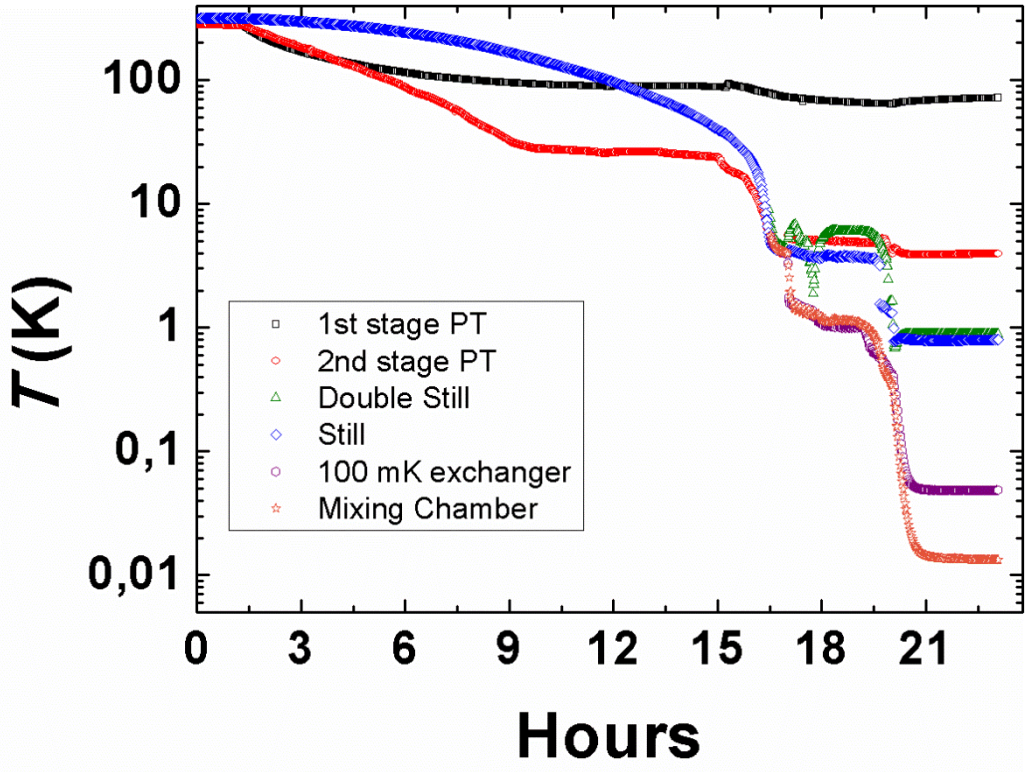




Puissance sur la Mixing Chamber

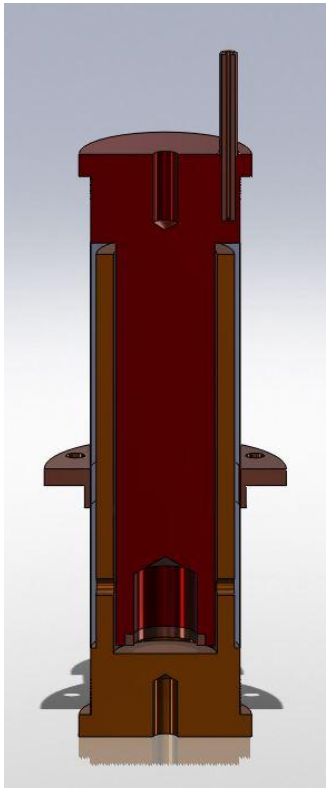


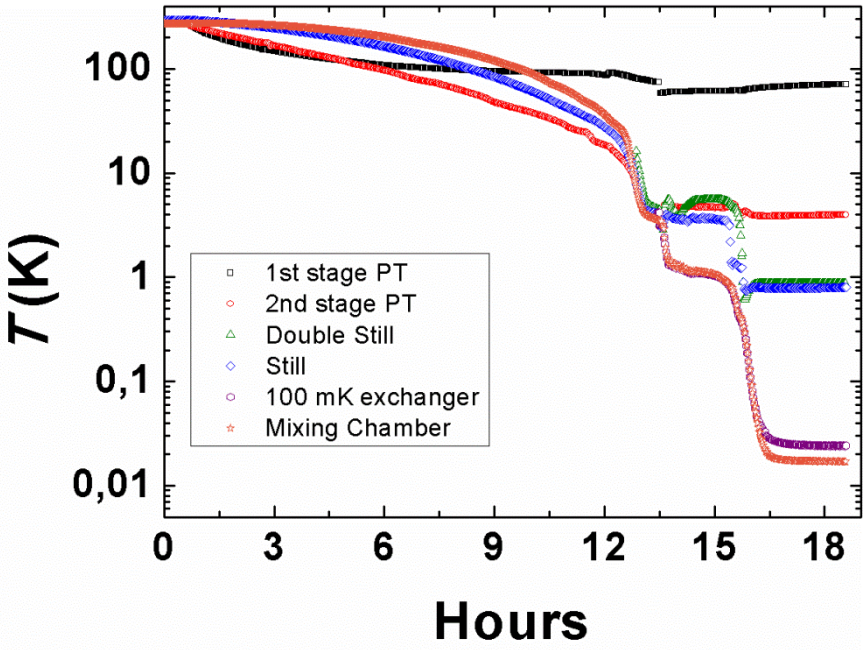
DR GLATTLI DEVICE (CEA/SACLAY) : Φ 276 MM MIXING CHAMBER PLATE



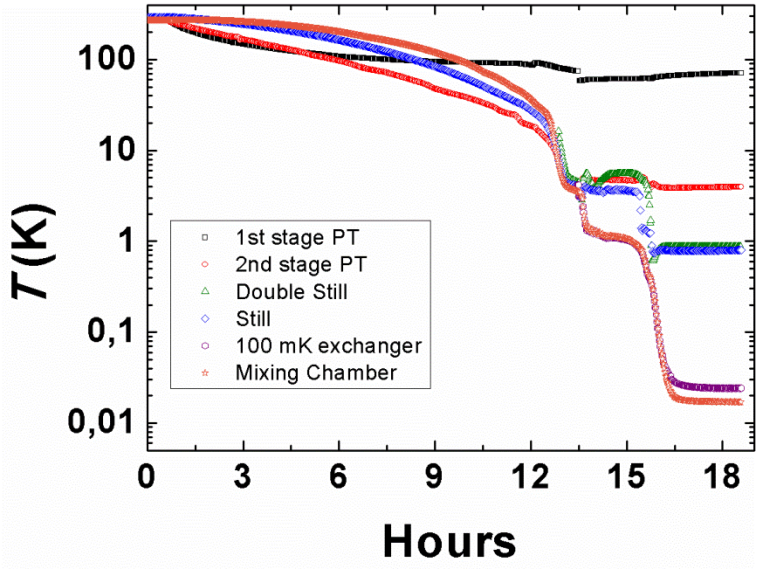
< 21 h from 300 K to < 20 mK

THERMAL SWITCH BETWEEN 4 K STAGE AND 1 K STAGE





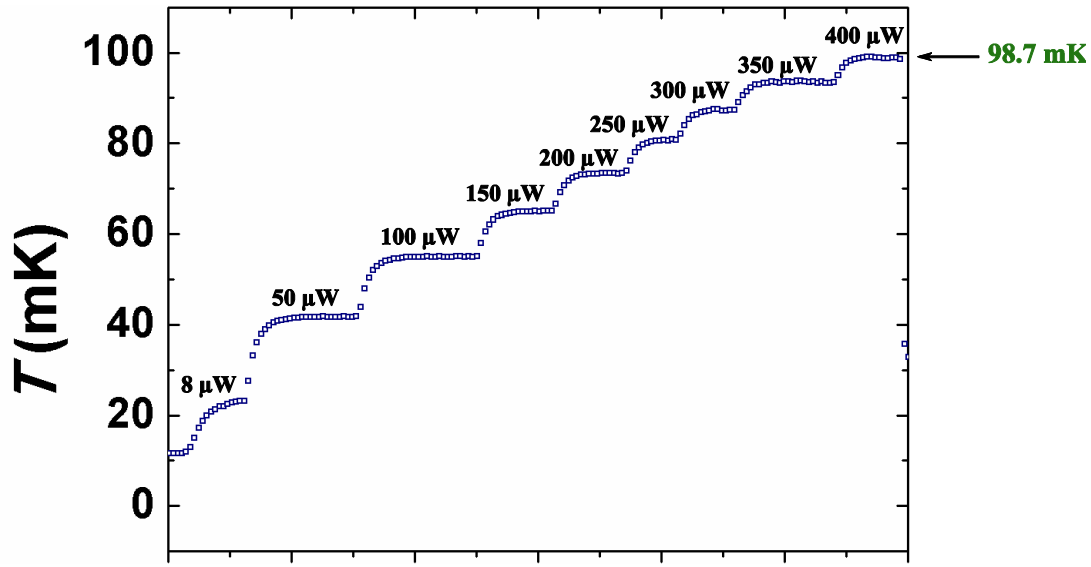
< 17 h from 300 K to < 20 mK

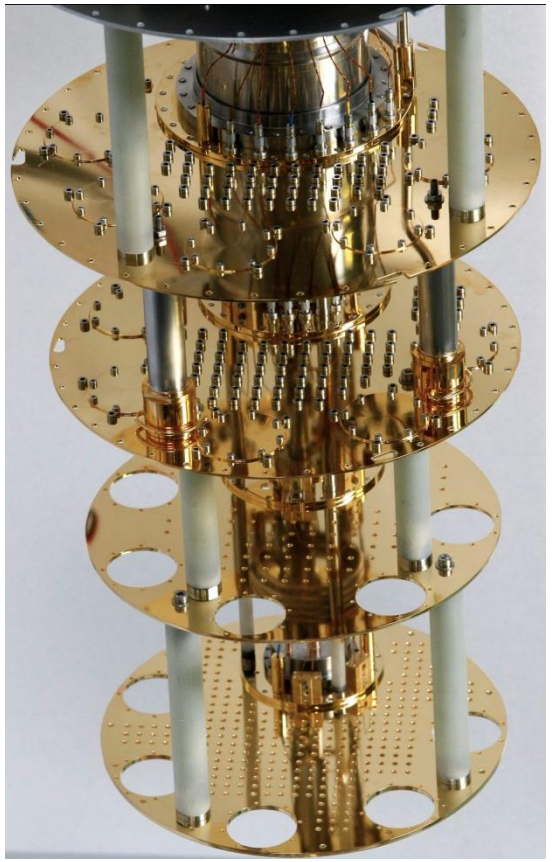


up to 7 μW @ 20 mK
up to 400 μW @ 100 mK

fast cool down (17h from 300 K to < 20 mK)

large experimental space
(up to ϕ300 mm x h=300 mm)

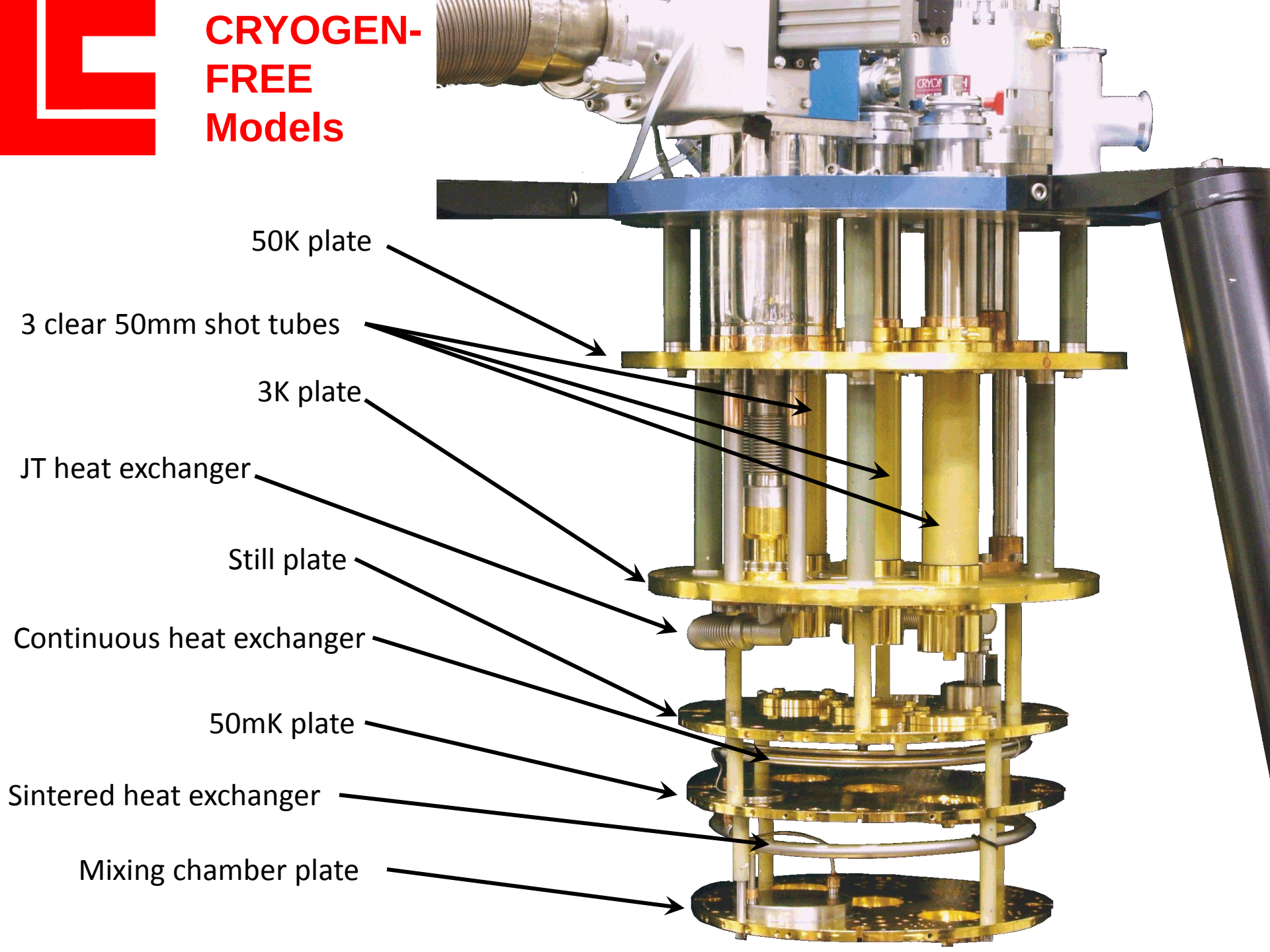




CRYOCONCEPT
A Division of Cryomagnetics

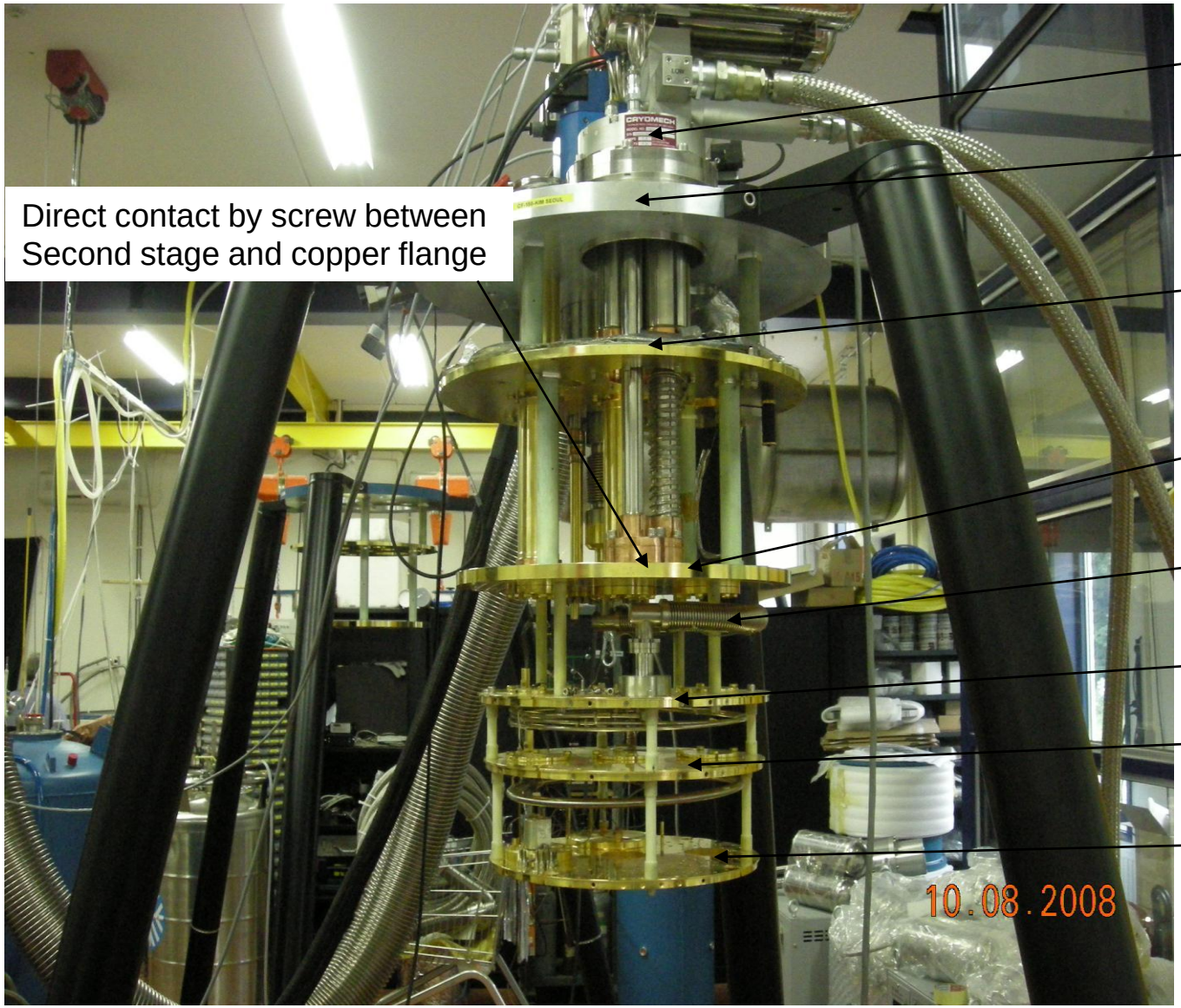
15l d'He3

CRYOGEN-FREE Models

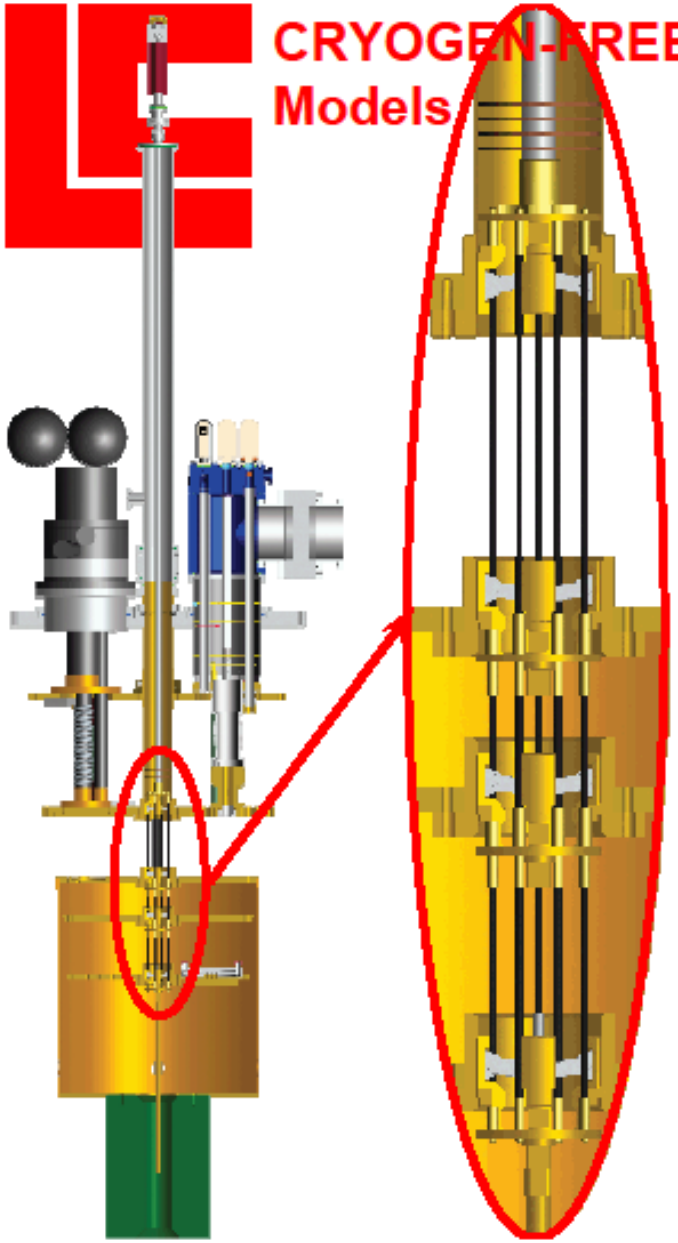


CRYOGEN-FREE Models

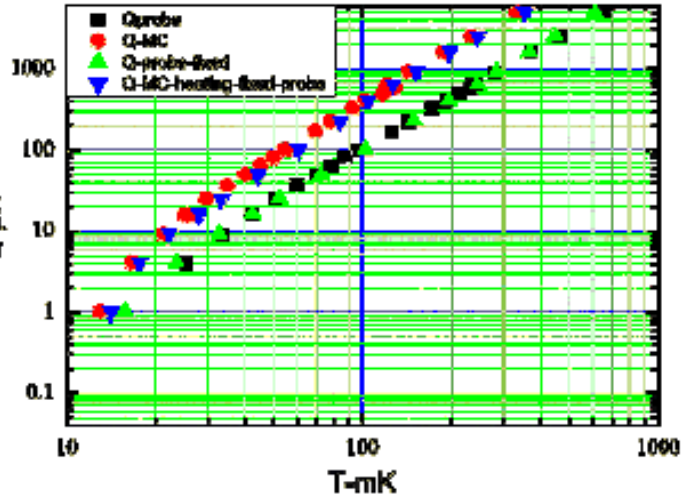
COMMERCIAL DRY DILUTION REFRIGERATOR
LYDEN CRYOGENIC (*Giorgio Frossati)*



CRYOGEN-FREE Models



Insertable Probe



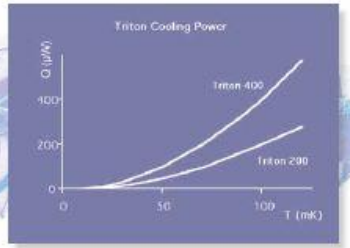
TRITON

Triton Dilution Refrigerator

OXFORD INSTRUMENTS

10 mK without the need for liquid helium!

- Low vibration pulse tube refrigerator technology
- 10 mK base temperature
- 200 and 400 µW cooling power at 100 mK
- 3 µW cooling power at 20 mK
- Fast cooldown times of less than 24 hours
- Excellent temperature stability from 10 mK to 30 K
- Automatic gas handling system
- Oil free circulation pumps
- Single common vacuum, no requirement for exchange gas
- 240 mm x 240 mm sample space enabling integration of complex experimental set-ups
- Built in cryogenic cold trap technology traps contaminants
- Central access for top loading
- Compatible with integrated superconducting magnet systems up to 18 T, wiring services or sample loadlock for a complete Cryofree solution



THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2010

Award winning product

Triton™ family

Environment and sample handling

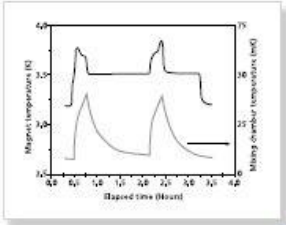
TRITON

Integrated superconducting magnets provide combined B/T environments cooled by a single PTR

A range of integrated superconducting magnets are available for the **Triton** range.

- 3, 5, 8, 12 and 15 T solenoids available as standard options
- **NEW Triton** Ultra offers magnet options up to 18 T
- HTS current leads for low heat dissipation between 50 K and 4 K
- Fast ramping capability using the latest high field, low loss Nb_3Sn developed by Oxford Instruments
- 70 mm cold bore standard on NbTi coils, 57 mm cold bore standard on Nb_3Sn coils
- 1 in 10^3 over 10 mm dsv homogeneity
- 1 in 10^4/hr stability with persistent mode switch fitted
- Custom designs, split pairs and Vector Rotate coils available on request

Triton200 with integrated 12 T Cryofree magnet

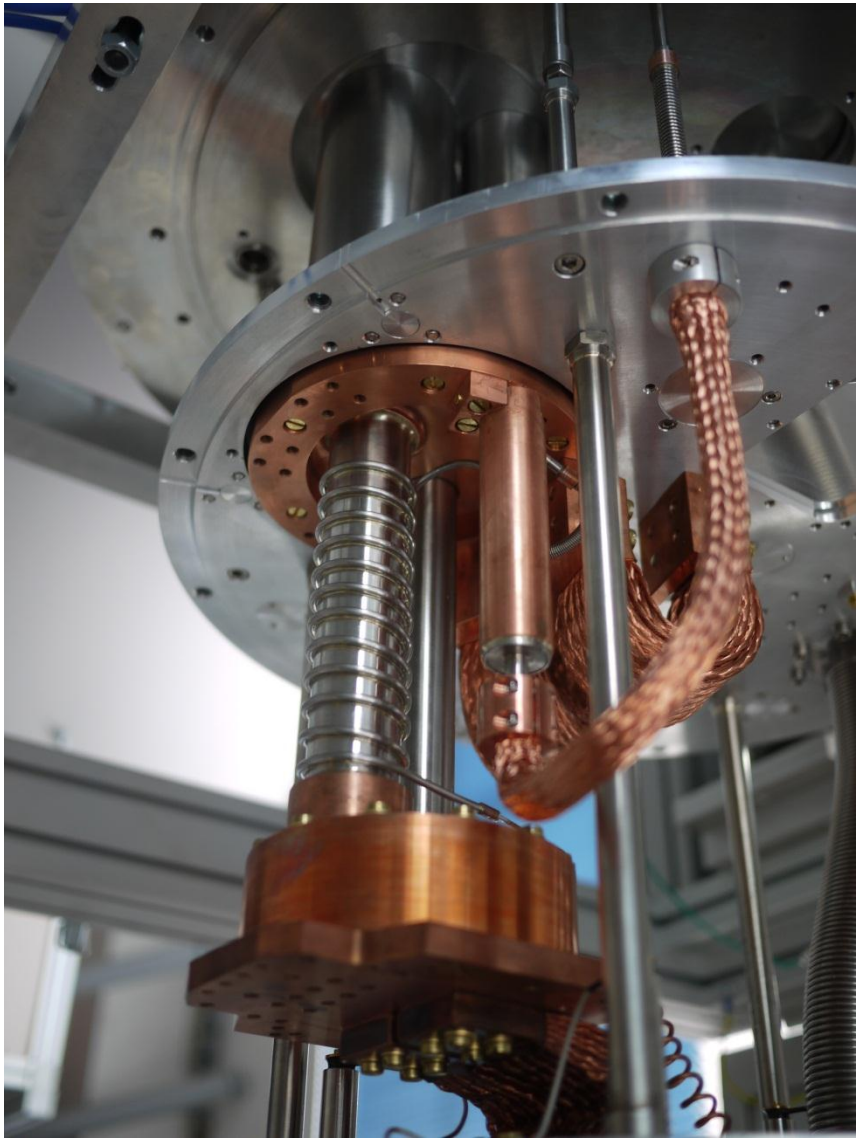


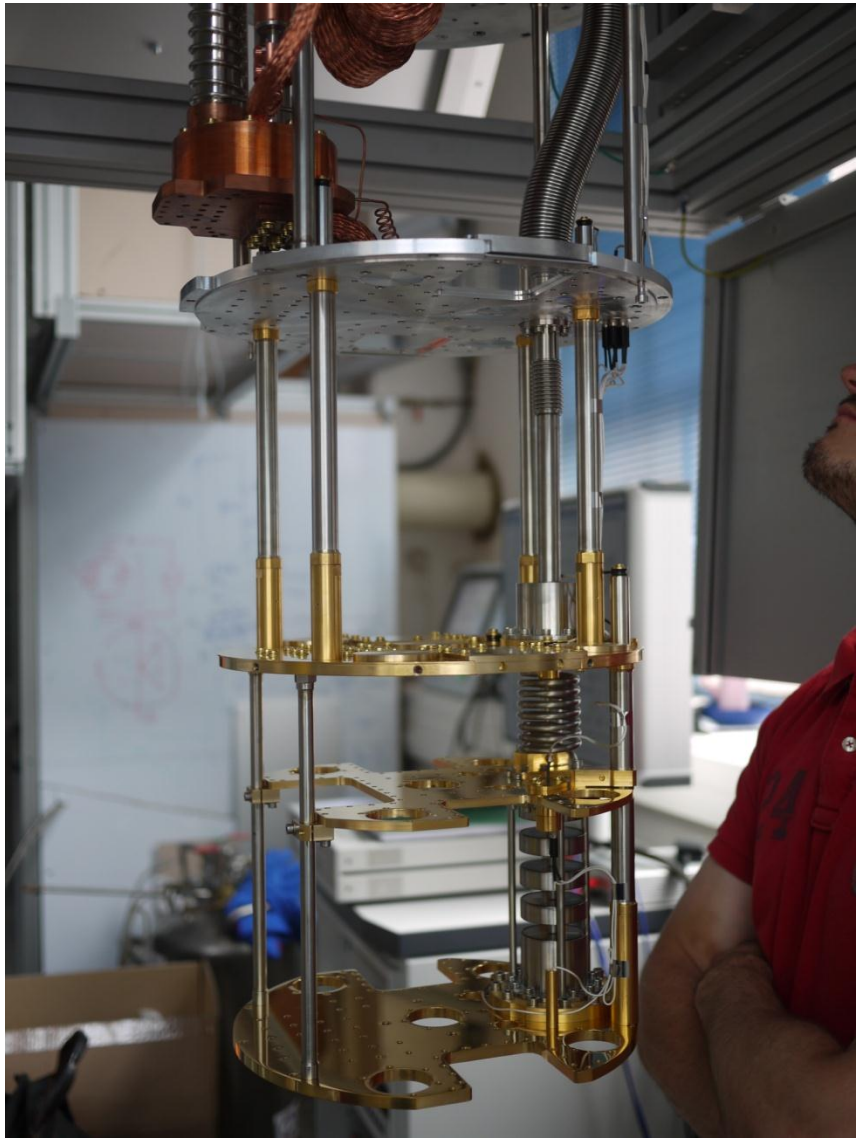
Integrated magnet warming and cooling during 5 T field sweep, hold at field and sweep back to 0 T (sweep rate 0.31 T/min). Local eddy current heating at the mixing chamber also shown during field sweep with time to recover back to base temperature – 1 hour. 3 μW cooling power available at 20 mK.

Top and bottom loading loadlock for fast sample exchange

- Patented design
- 15 min sample exchange
- Cooldown time < 8 hrs
- Top-loading demountable sample carrier cooled to 10 mK
- All wiring efficiently heat sink on the dilution refrigerator

Triton *top loading with sample carrier and loading probe*





BlueFors
CRYOGENICS

CONCLUSION

- **Dilution DRY 4 à 6 fois moins cher à l'utilisation que le WET.**
- **Maximum de place….**
- **Cryogénie DRY : fonctionne + de 300Jours/ an!**
- **Mais on remplace des récipients par des machines….**
- **Pas trop de recul sur la fiabilité des PT.**
- **Écarts de performances entre différentes machines.**
- **Boucle froide indispensable**
- **Technique au point. Minimum 4 Sociétés sur ce marché.**