Large scale He hydrodynamic facilities at CEA/SBT

1) First high Re number experiments performed at SBT in the framework of LHC cooling scheme studies

2) Experiments on large scale two-phase superfluid flow and associated instrumentation

3) Current experiment on grid turbulence with HeII and HeI flows

4) Perspectives and conclusion

Large scale He hydrodynamic facilities at CEA/SBT

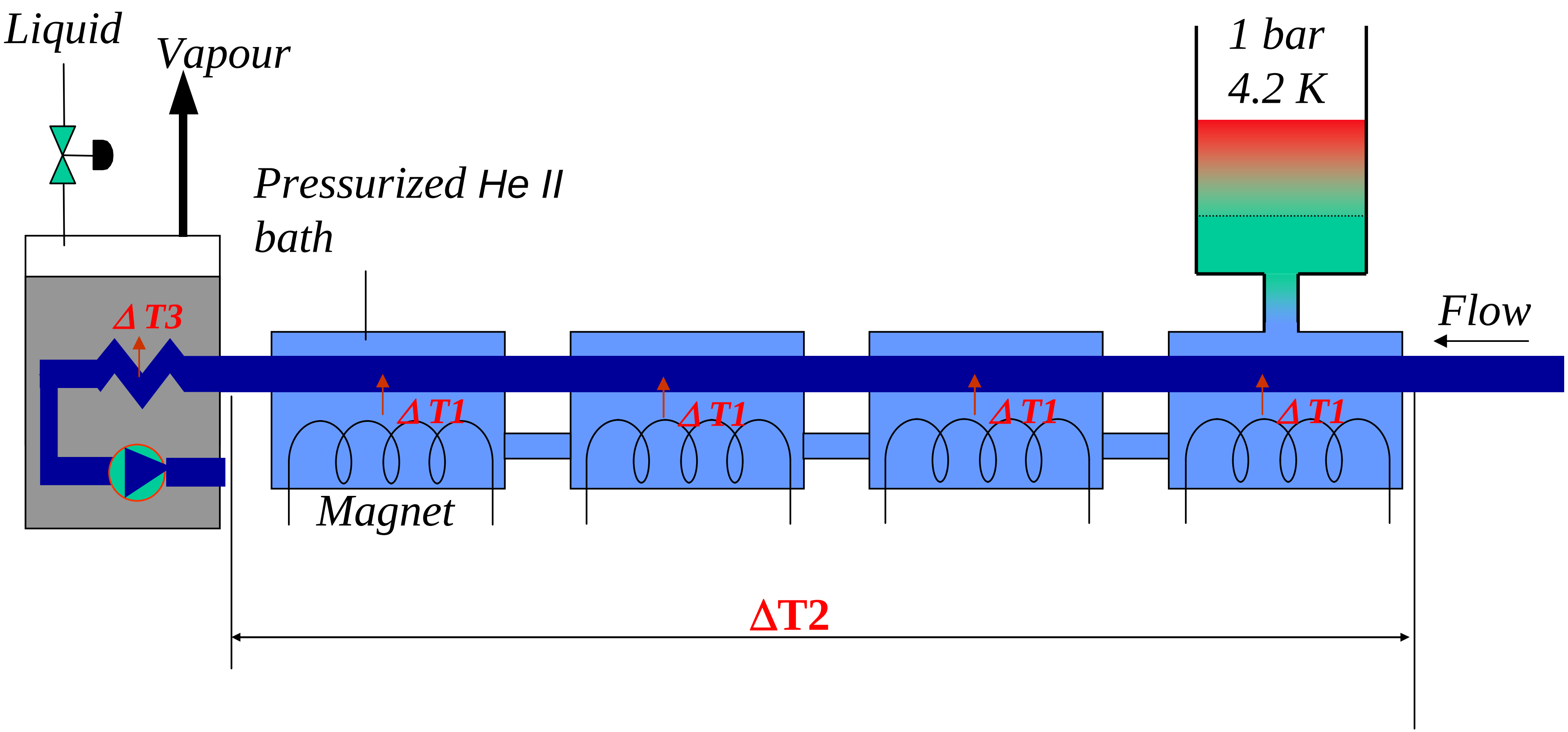
At the very beginning of the LHC project, The CEA/SBT was asked to study the cooling scheme of the superconducting magnet as it was one of the world leader in that topic. The head of the lab was Claudet wich has developed the application of the so-called "Claudet bath"* to cool down the superconducting magnets of the Tore supra Tokomak.

To answer to this unprecedent cryogenic large scale, a test facility was built at the end of the 80 at SBT.

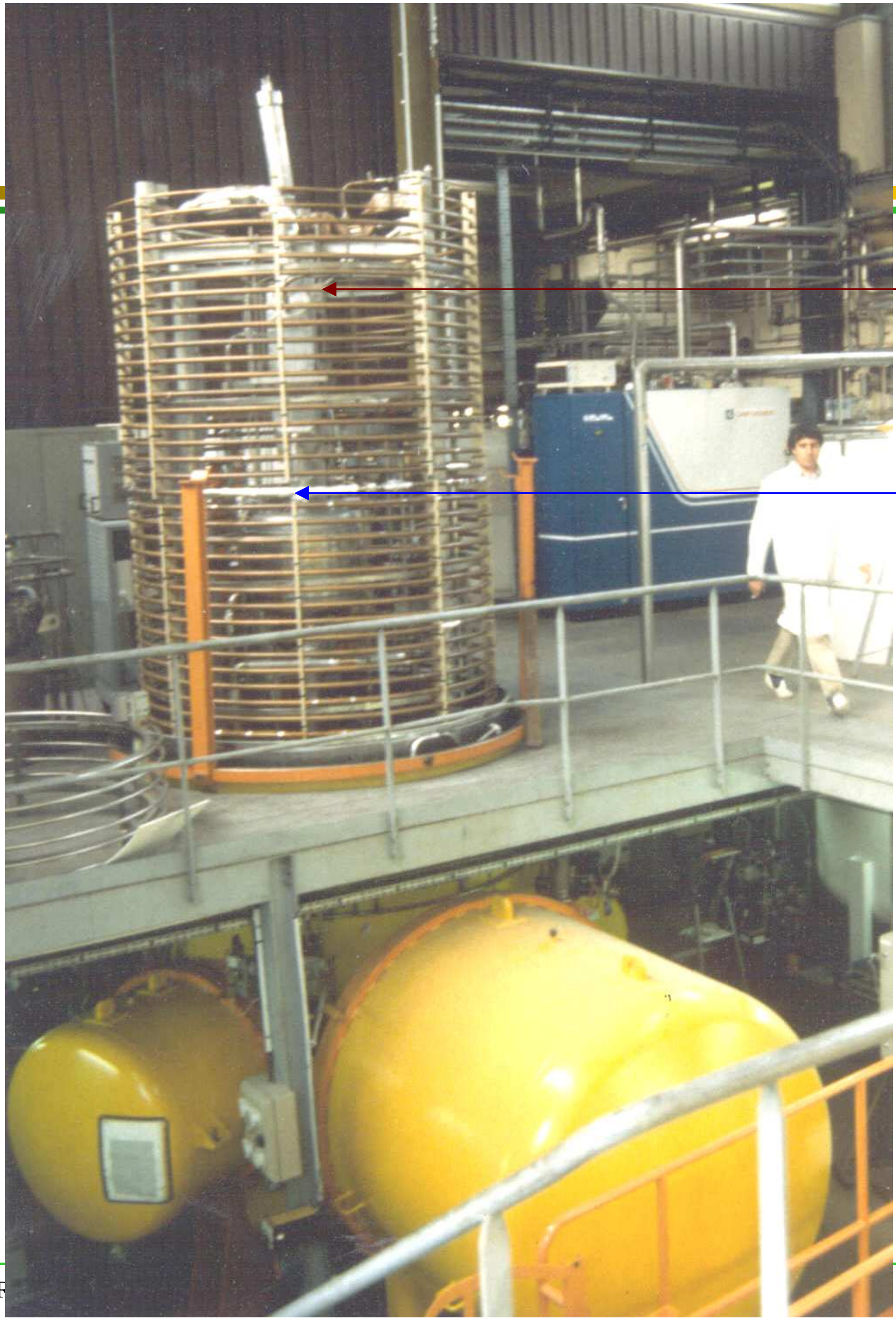
First cooling scheme envisaged used a subcooled superfluid forced flow loop.

* Claudet and al. "Procédé pour la production d'hélium superfluide sous pression", French Patent N°74-06206 (1974)

First LHC cooling scheme



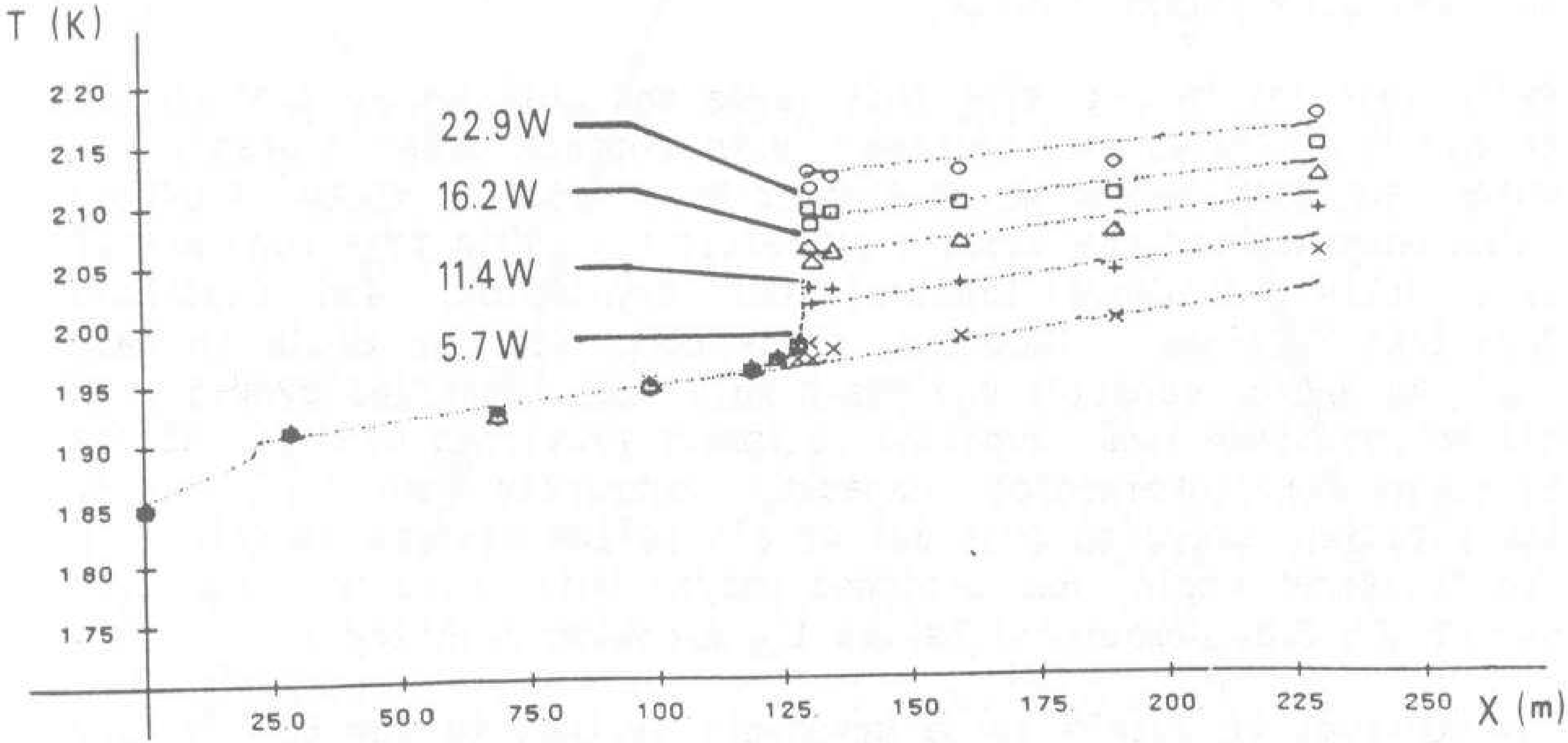
Support from CERN and Euratom/NET



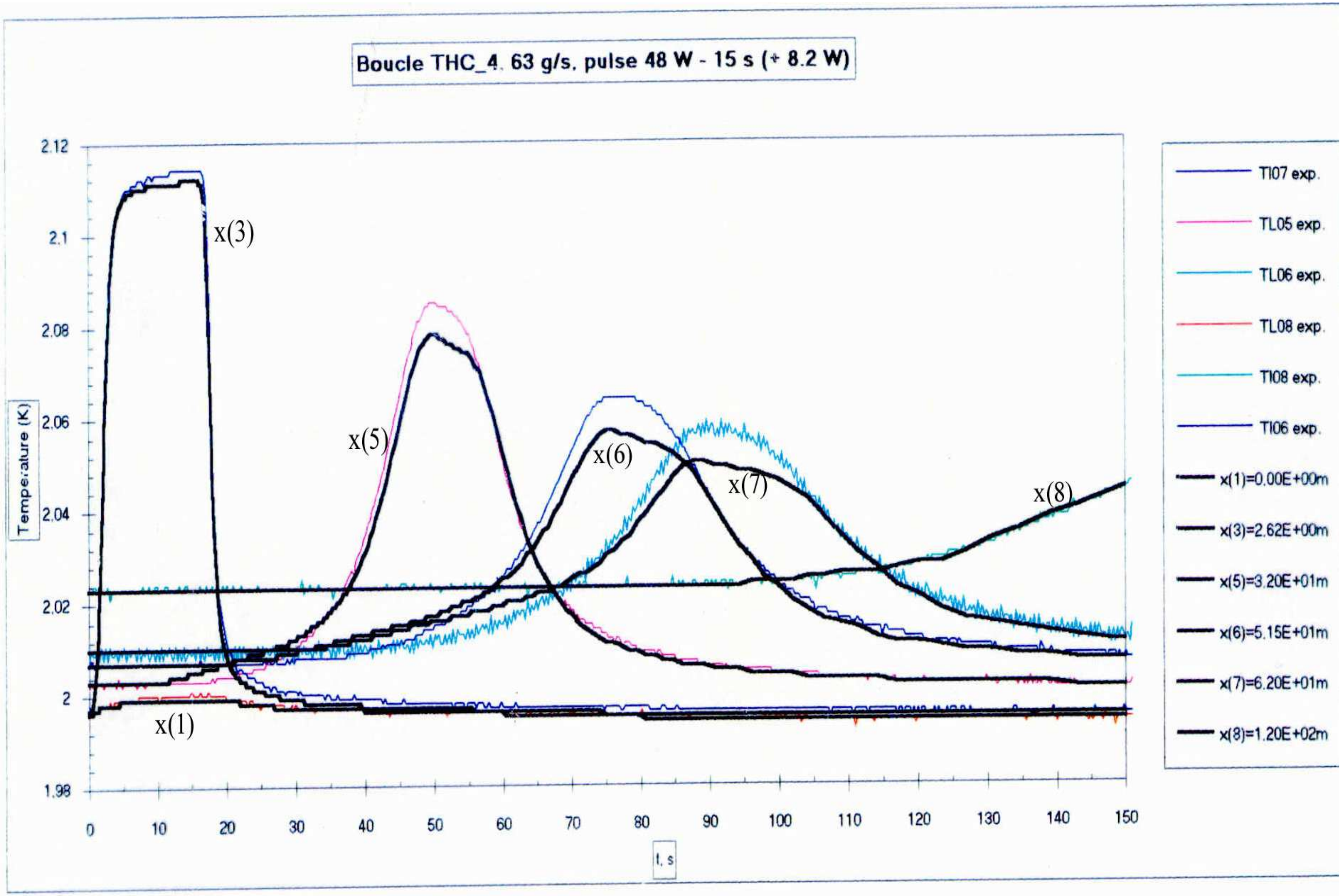
Inner diameter pipe : 28 mm, Length=200 m, slope 1.4 %

Heater : 0.8 m long located at centre of the 200 m long line

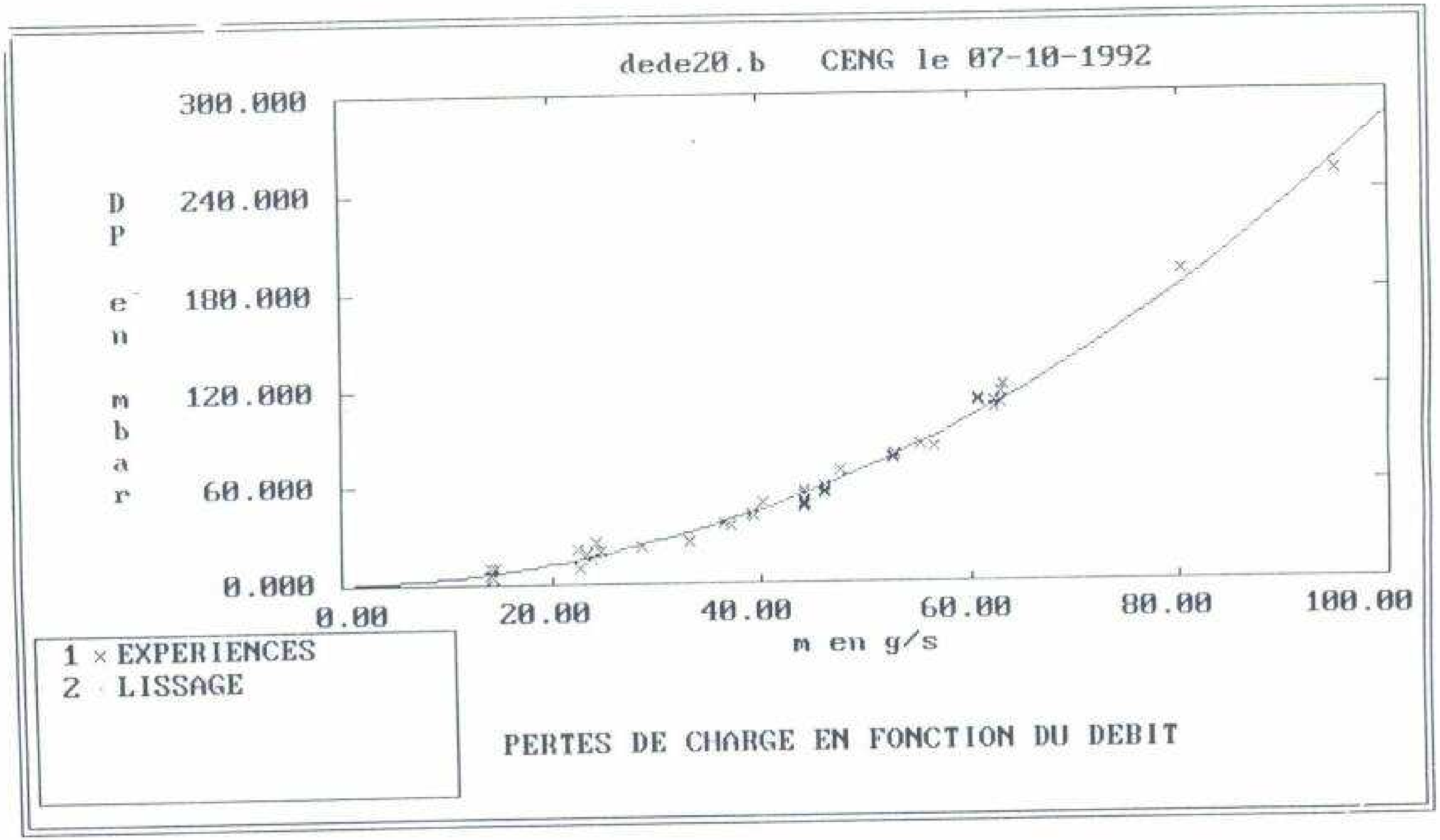
Steady state thermal behaviour



Transient thermal behaviour



Hydraulic behaviour



Maximum Re number achieved 6.5 10^6 in a 14 mm I.D. 16 m long line

Large scale He hydrodynamic facilities at CEA/SBT

• From this previous results (increase in temperature as a function of heat losses and mass flowrate) we can concluded that this cooling scheme using subcooled superfluid forced flow could be used to cool down the LHC superconducting magnets. So we stopped to run this facility in 1993.

Other largest helium flow facilities from 1994 to Nowadays :

• The CHEF at NHMFL : Experiments performed in a 10 mm I.D. Between 0.86 and 1.2 m long pipe Re up to 2.4 10^7 achieved during 10 s (corresponding to the discharge of a 20 liter below) : corresponding mass flow 250 g/s and Temperature 1.7 to 2K

• Oregon facility : dependence of DP versus Re from 10^1 to 10^6 measured in the same pipe with use of liquid helium for the largest value (discharge of a 1.3 liter below)

• Test of the CSMC at Naka : supercritical helium mass flow of 1100 g/s at 4.5 K 5 bar

• TOSKA facility at FZK piston pump :maximum mass flow of 150 g/s for 1.8 K -5 K range and centrifugal pump : mass flow up to 400 g/s at 4.4 K

• Test of the first prototypes of ATLAS pump at CEA/Saclay : up to 850 g/s at 4.3 K 1.7 bar

• Test of 1200 g/s ATLAS pump at CERN 4.3 K 1.7 bar

• The GREC experiment at CERN 300 g/s of vapour Helium 5 K 1 bar

And what's happened at CEA/SBT during that period ?

- The previous cooling scheme using subcooled superfluid forced flow has proven to be valid but presents a low efficiency (mainly due to negative J-T effect, additional heat exchanger and cold circulating pump).

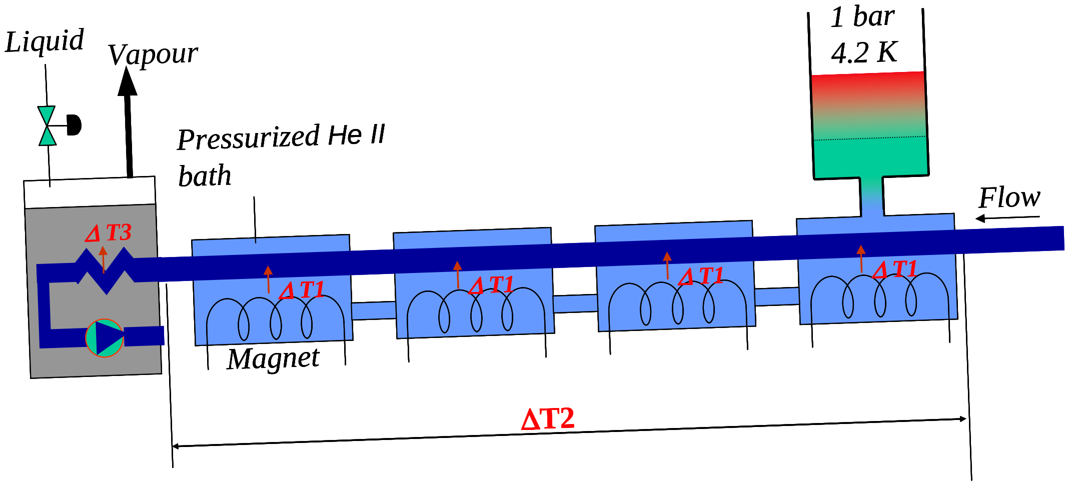
- As a result, it was decided to study an alternate cooling scheme using directly two-phase flow (cold source) inside the bayonet heat exchanger pipe. Main problems addressed were :

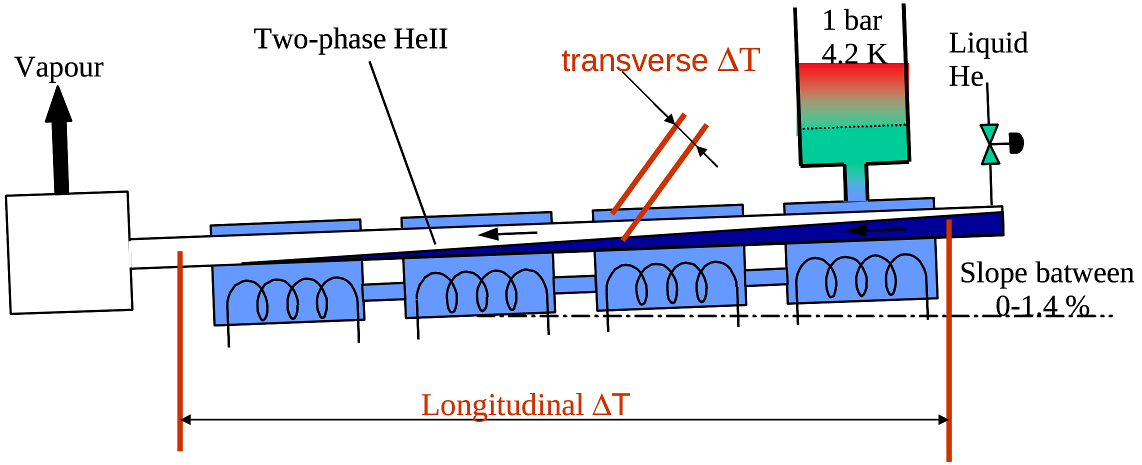
    - Can we operate without any instabilities (and does it works also in counter-current flow or with an ascending co-current flow?)

    - Is the pressure drop small enough to not exceed maximum temperature allowed at the inlet of one string (107 m long) ?

    - Is the heat transfer coefficient (related to wetted surface) large enough to not exceed maximum temperature allowed at the outlet of one string ?

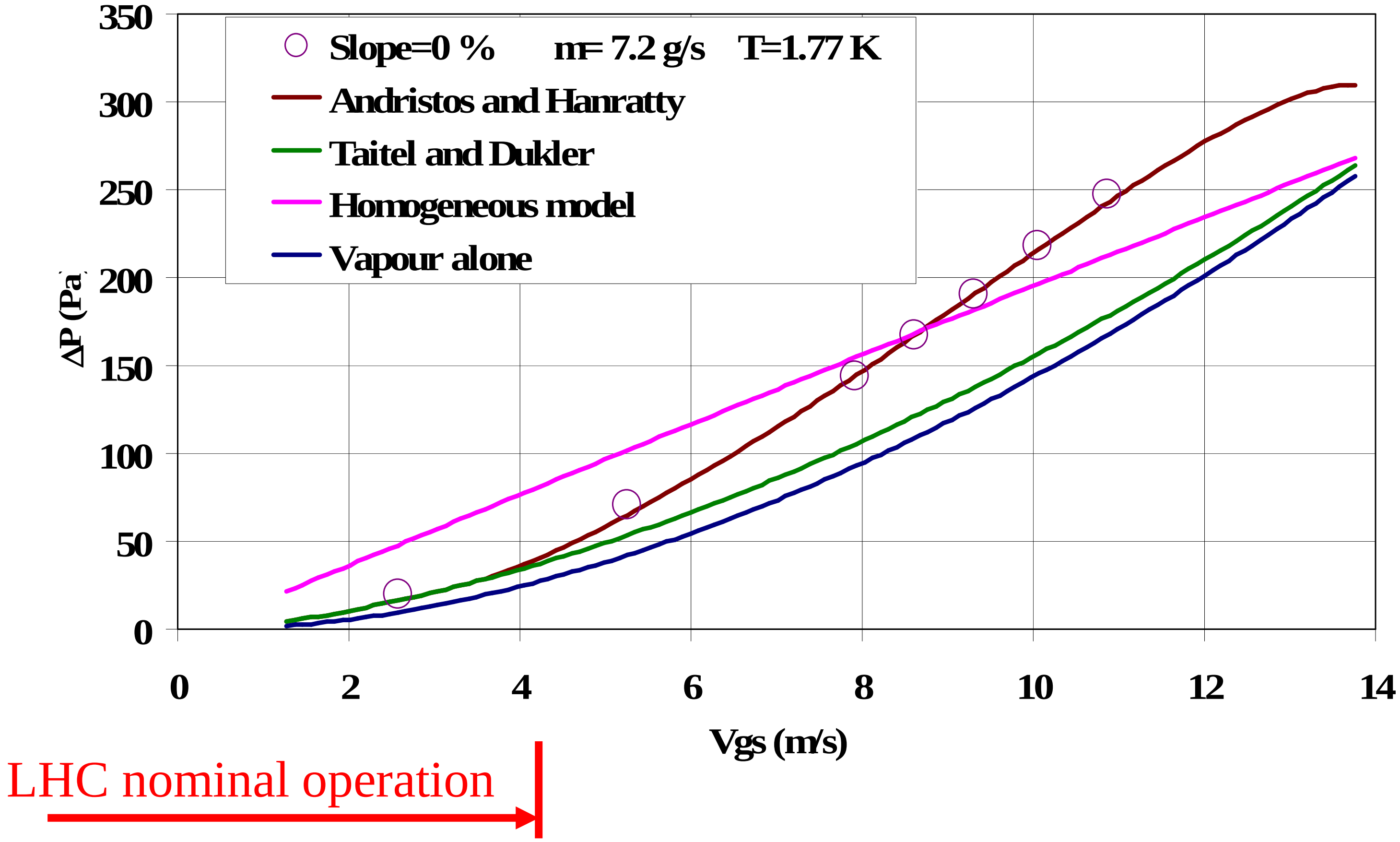
New LHC cooling scheme

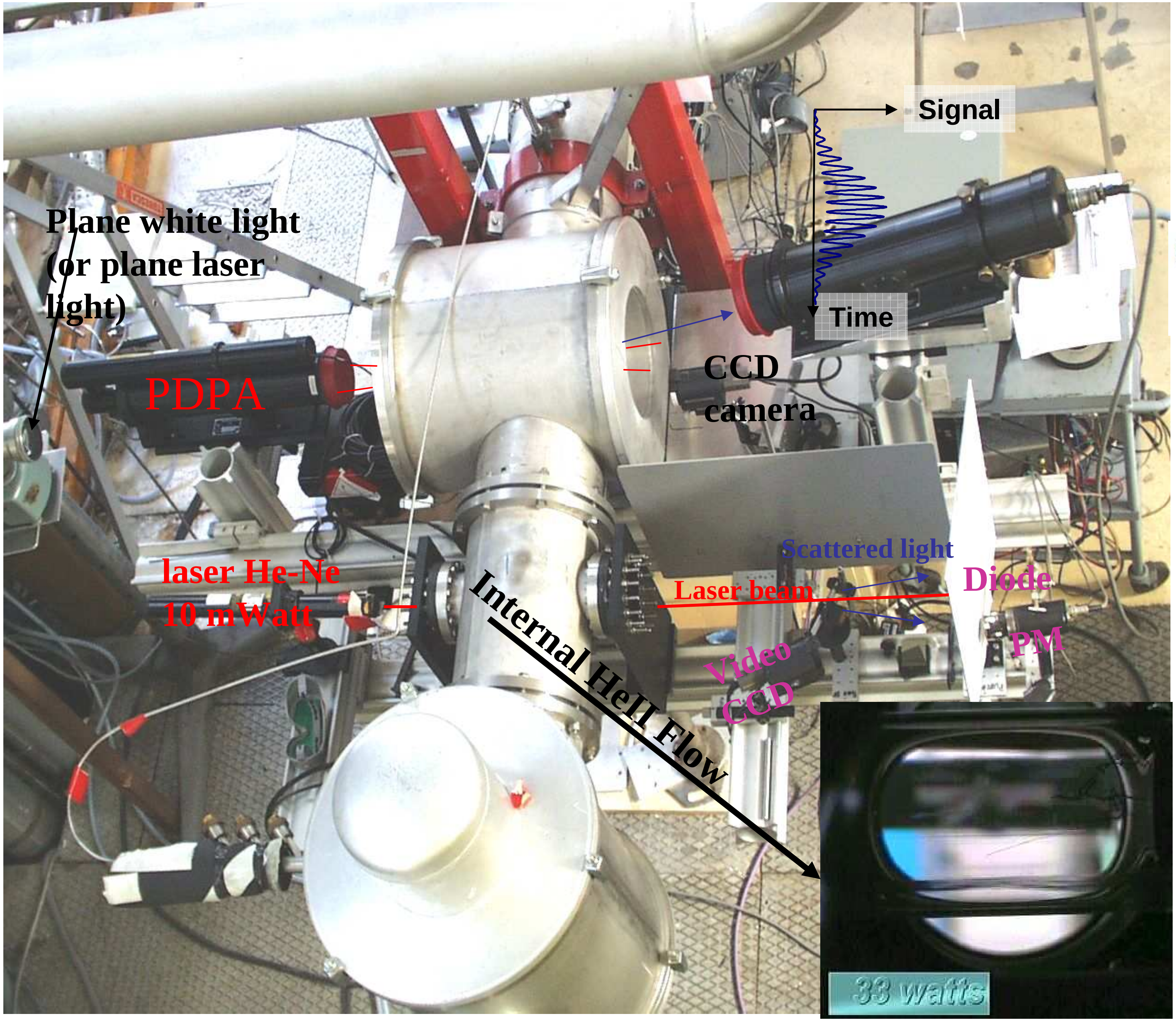




Main results concerning pressure drop

Comparison between experiments and various theoretical models





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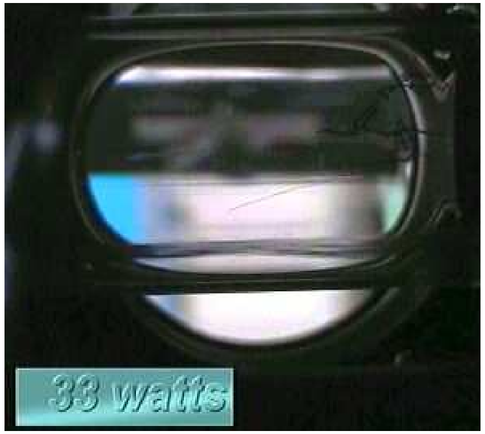
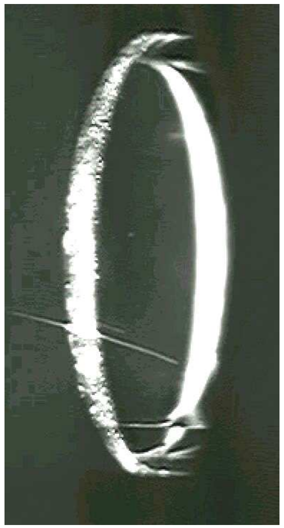
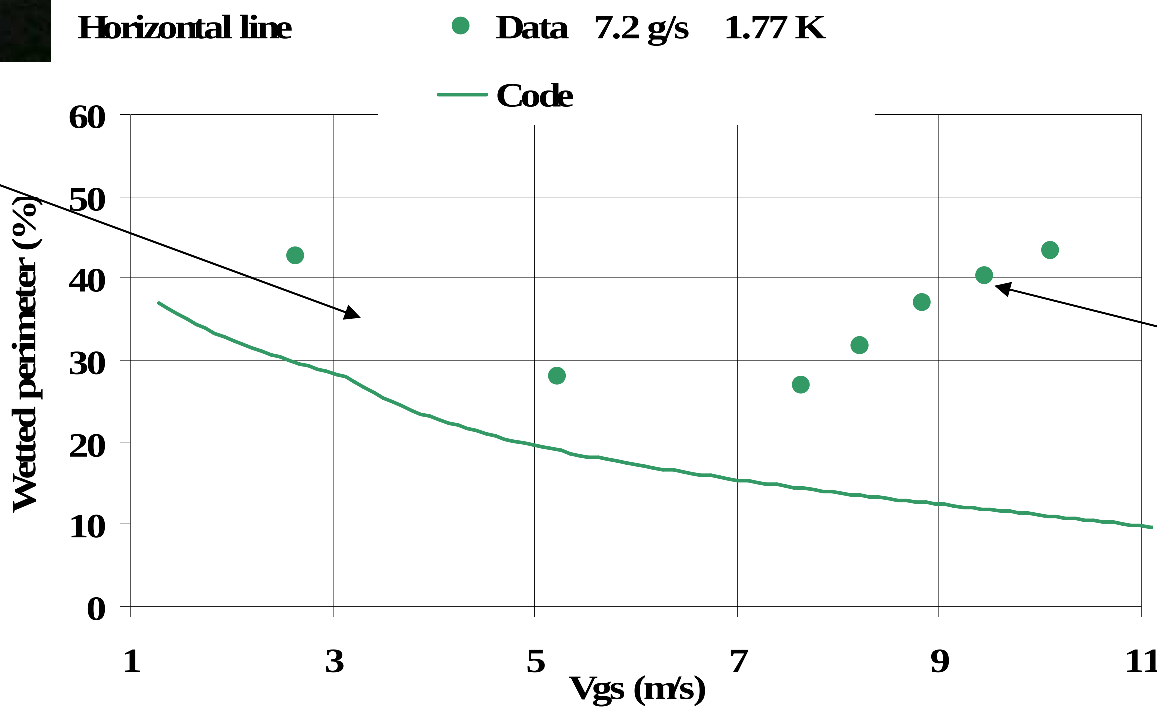
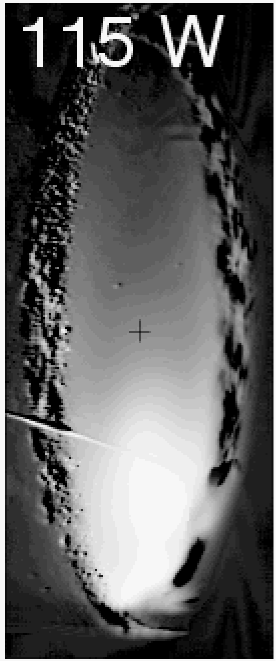
Main results concerning heat transfer



Low vapour velocity
No liquid droplets







High vapour
Velocity
Lots of droplets

• From this results on co-current HeII two-phase flow (no instability for descending co-current two-phase flow, longitudinal and transverse DT small enough to correctly cool down the magnets) we concluded that this cooling scheme will be used to cool down the LHC superconducting magnet strings. So we stopped to run this facility in 2002.

• As we already worked with some CNRS/CRTBT colleagues, we have heard about the GREC experiment and feel that high Re turbulence may be also studied using the large refrigerator we have at SBT. So …

A grid turbulence experiment with liquid helium flow

• We first submit with GREC teams and other European countries at FP6, but without success

• But we obtain a national support with restricted program and involving french teams alone (ANR project). This program involves the study of homogeneous and isotropic turbulence behind a passive grid both in HeII and in normal helium. It is called TSF (**S**uper**F**luid **T**urbulence)

• Head of the project : Bernard Castaing : *ENSLyon*

• Turbulence theoretician and experimentalist: Bérengère Dubrulle and François Daviaud : *CEA/Saclay*

• Acoustic measurements and associate turbulence analyses : Christophe Baudet and Yves Gagne *UJF/CRNS/LEGI*

• Superconducting hot wire anemometer and second sound probe : Pantxo Diribarne (*Granted by the project*) and Pierre Thibault *UJF/CEA/SBT* and Philippe Roche *CNRS/INéel* (ex *CNRS/CRTBT*)

• Overall design of the experiment and integration to the refrigerator : Bernard Rousset and Alain Girard *CEA/SBT*

• Other specific instrumentation (as home made cold pressure sensor, …) Pierre Thibault *UJF/CEA/SBT*

Conventional turbulence:

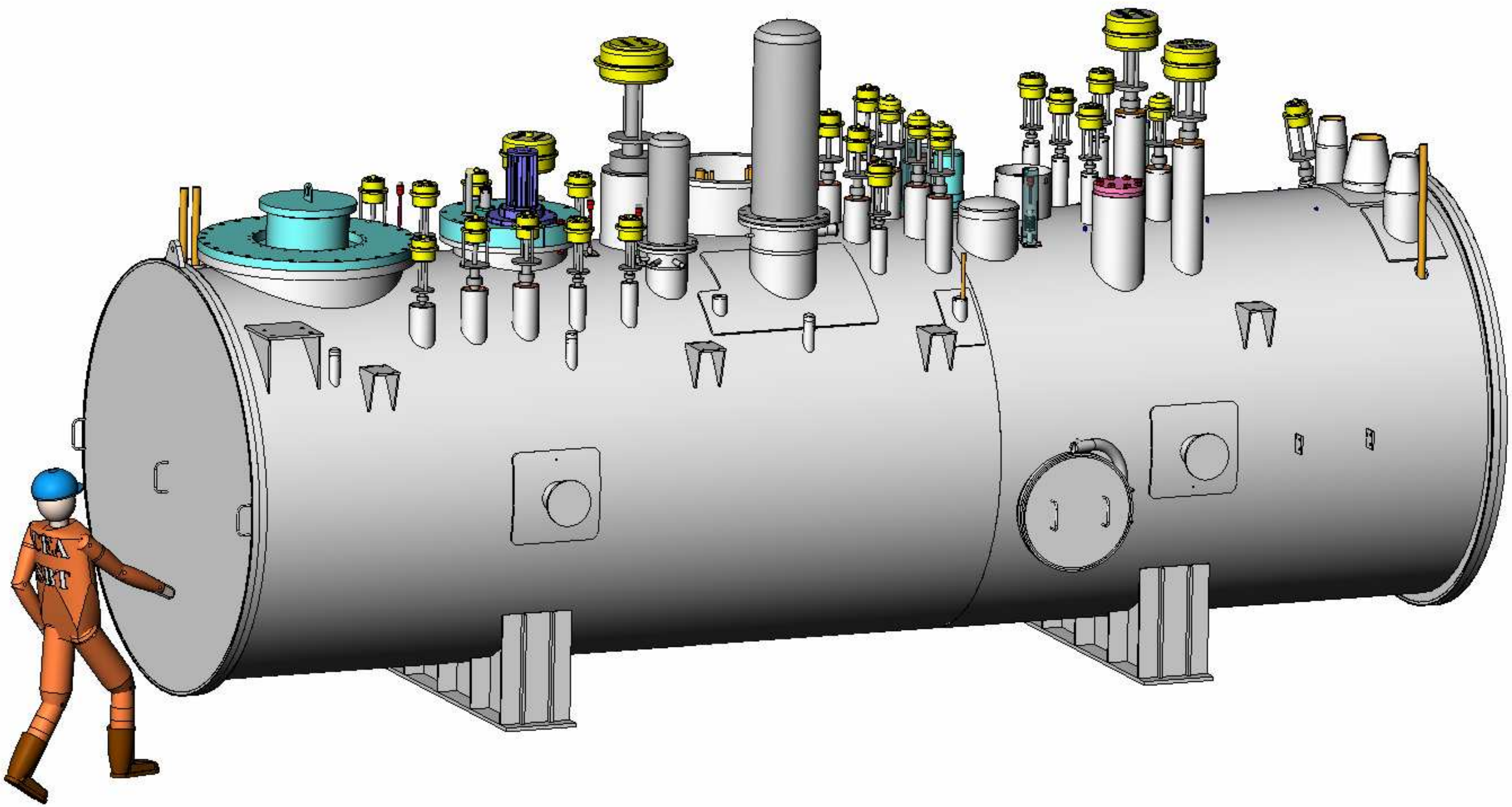
- Grid flows are known to produce a very homogeneous turbulence with **mean velocity fluctuations < 3%.**
- The flow will reach very high R_λ (Reynolds number based on Taylor micro-scale) due to low kinematic viscosity of liquid helium: **R_λ~300**

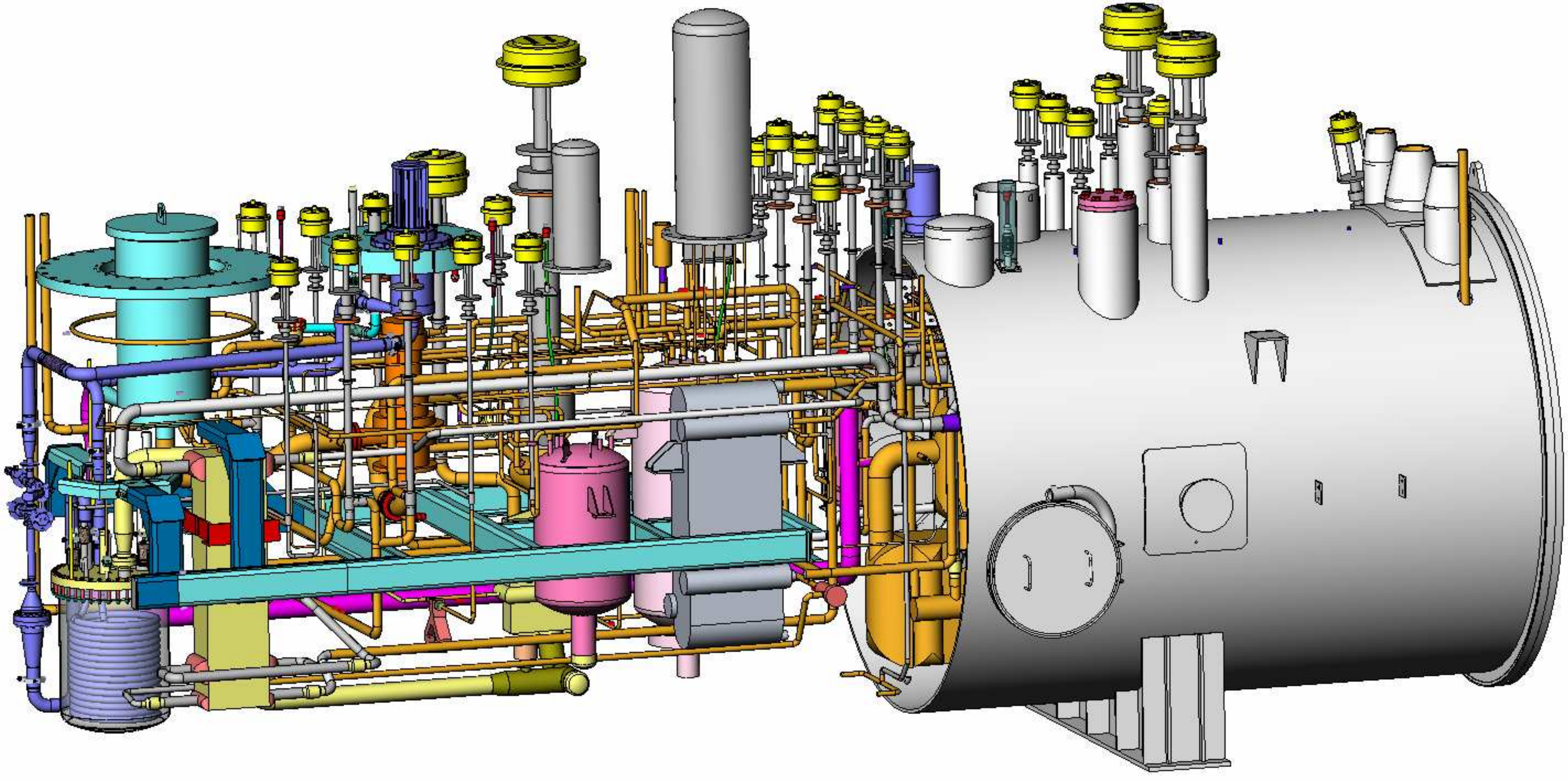
Superfluid turbulence:

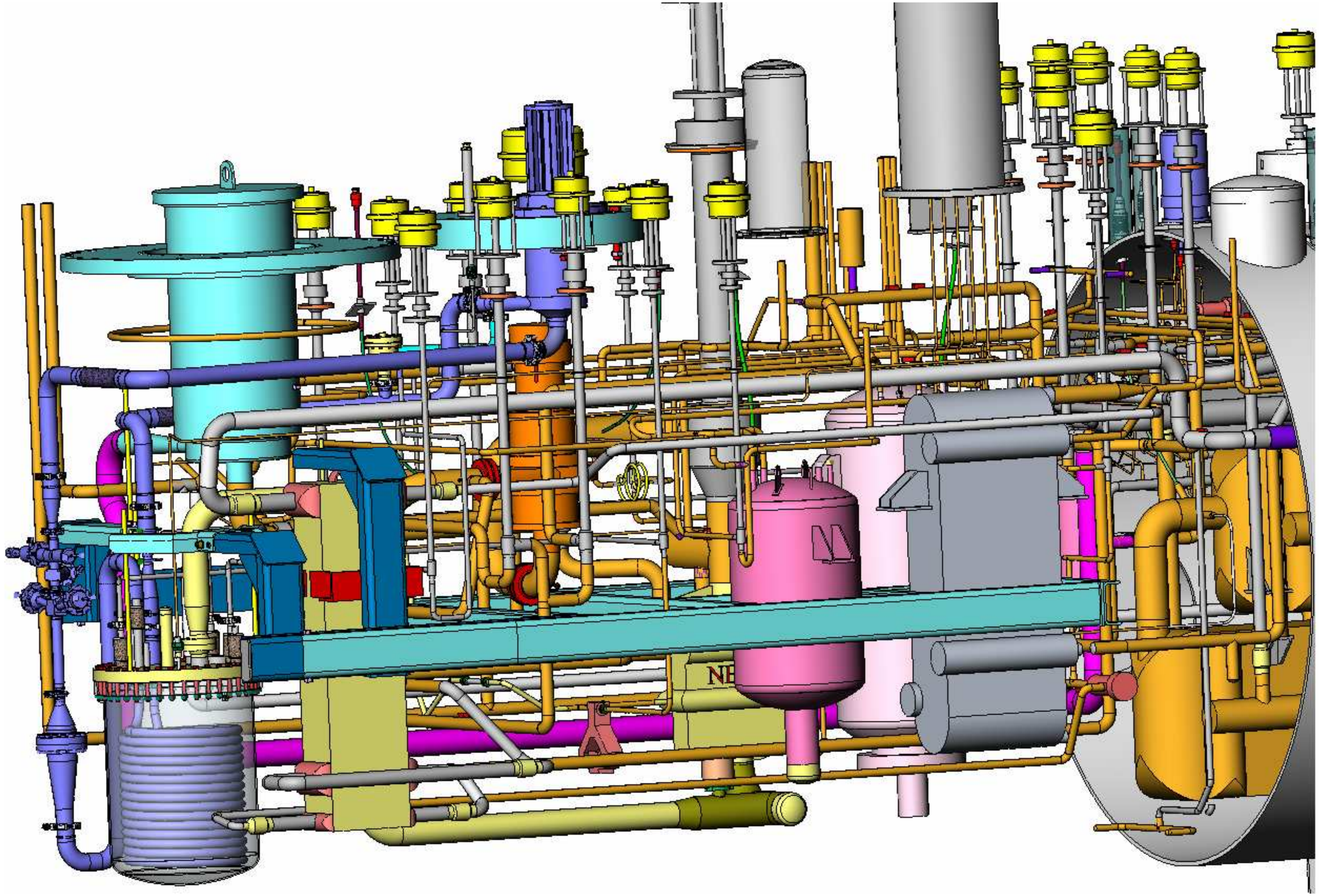
-A steady flow of turbulent superfluid will be obtained, with low velocity fluctuations.

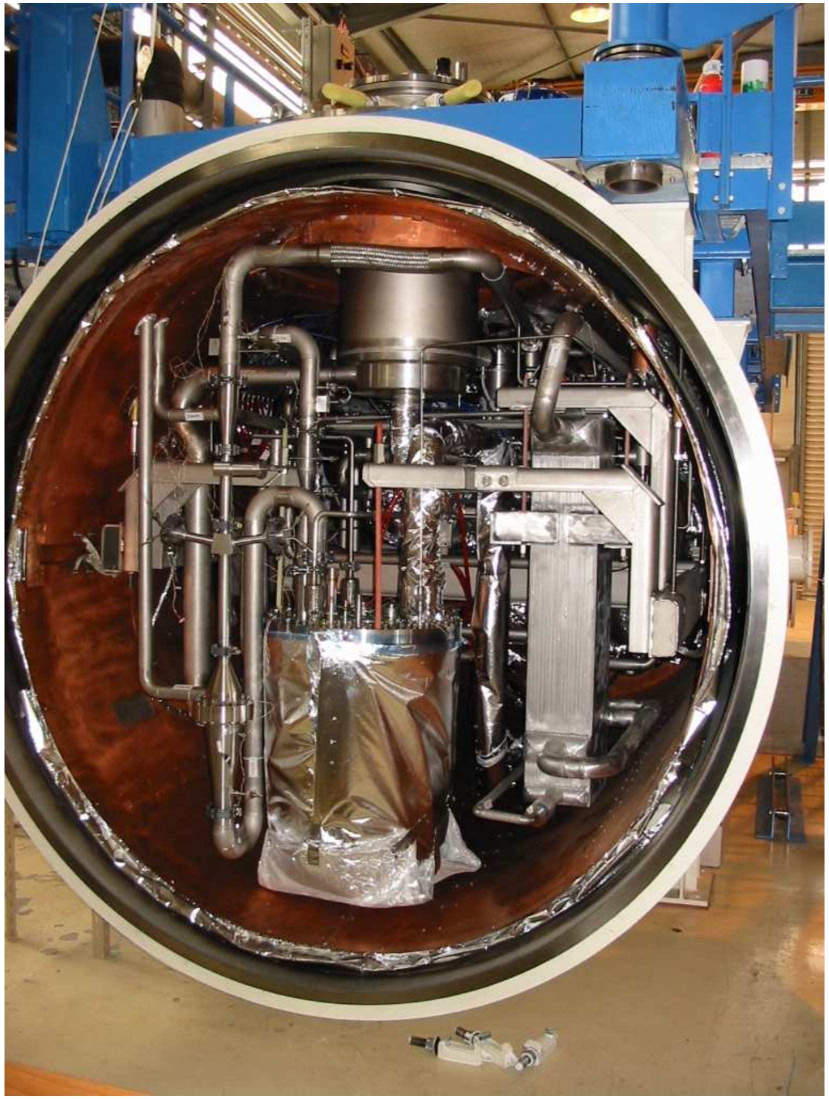
-The proportion of superfluid will be varied continuously from 0 to 80% (2.2 to 1.64 K).

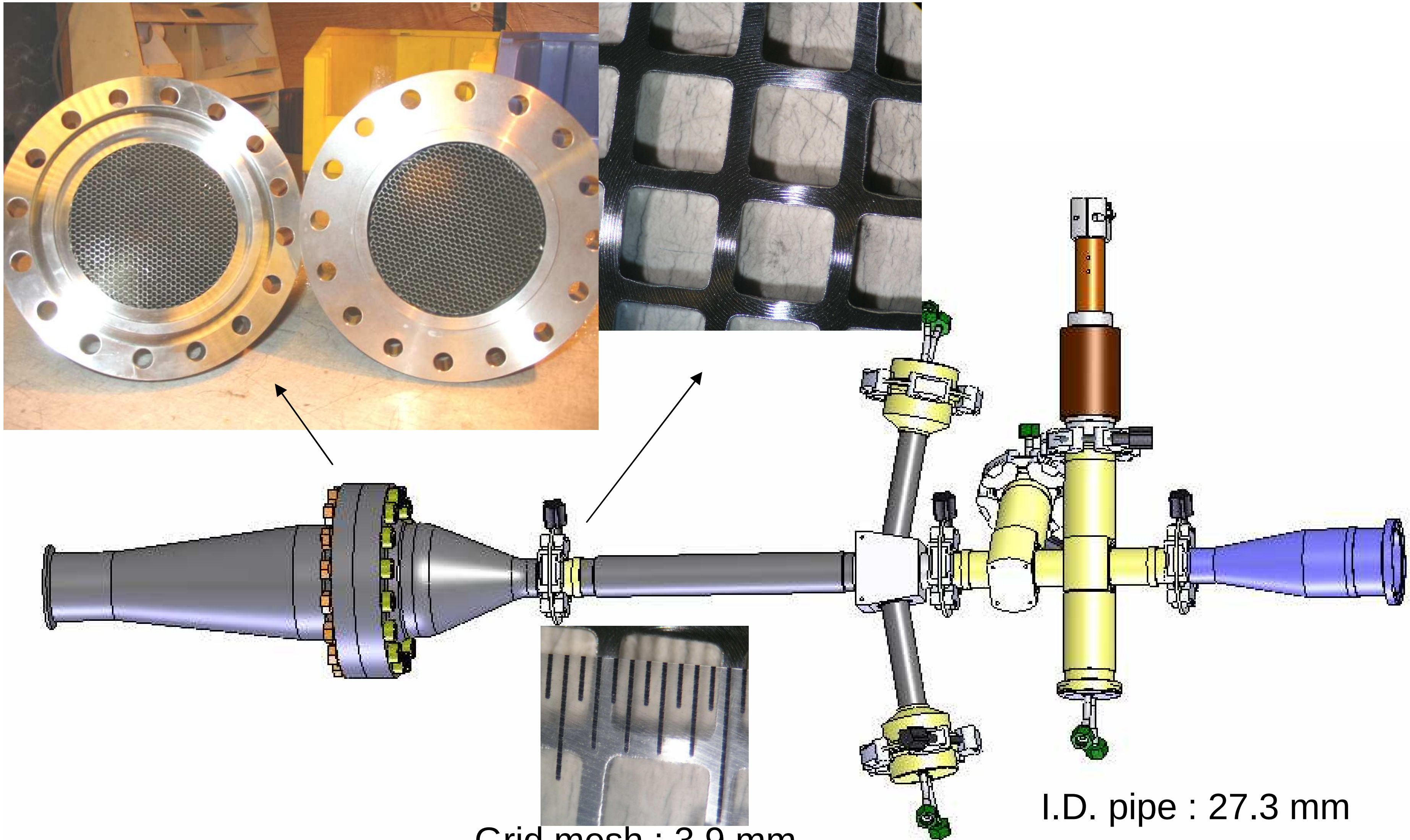
Even when the proportion of normal fluid is negligible, dissipation is observed : **quantized vortices** are generated from turbulence. The mechanism of dissipation is related to the interaction between these vortex lines. A signature of that mechanism is expected at a length scale comparable with inter vortex spacing.


CEA
SBT



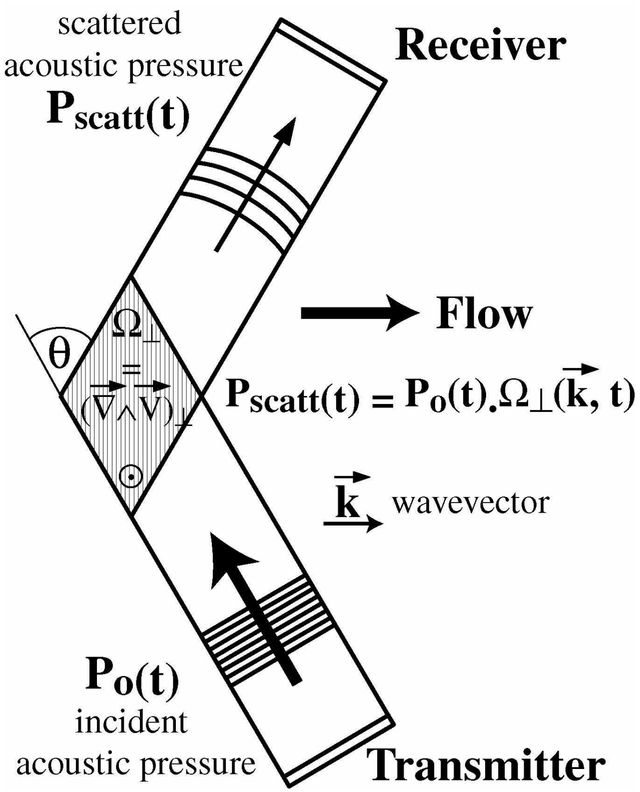


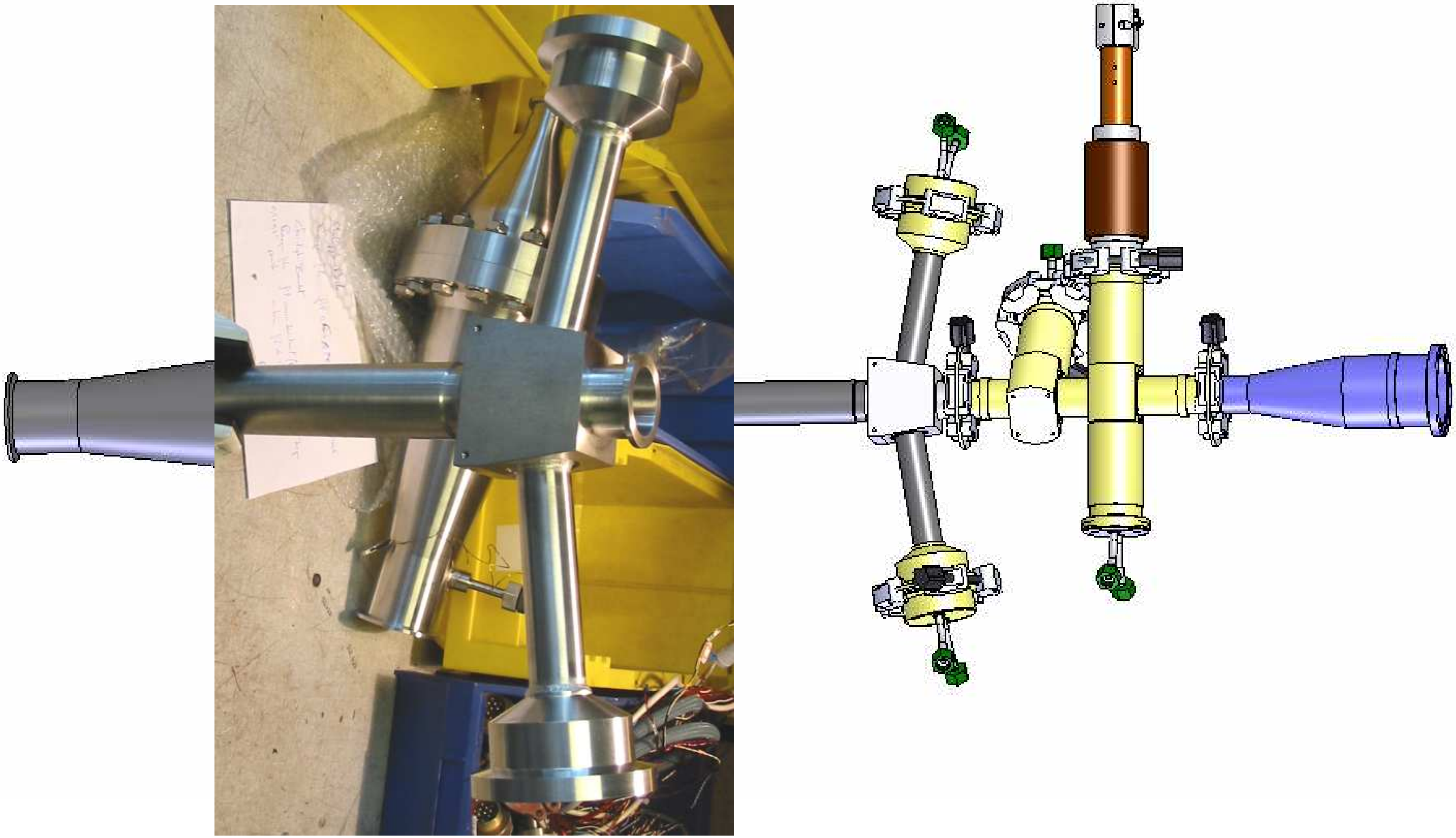




Grid mesh : 3.9 mm

I.D. pipe : 27.3 mm


scattered
acoustic pressure
Pscatt(t)
Receiver
Flow
θ
Ω⊥ = (∇∧V)⊥
Pscatt(t) = Po(t).Ω⊥(k, t)
k wavevector
Po(t)
incident
acoustic pressure
Transmitter



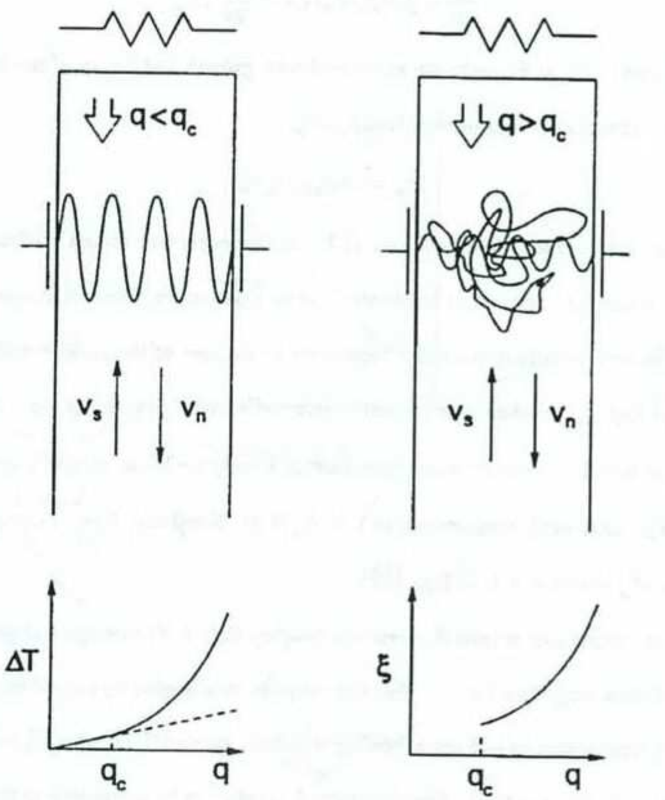
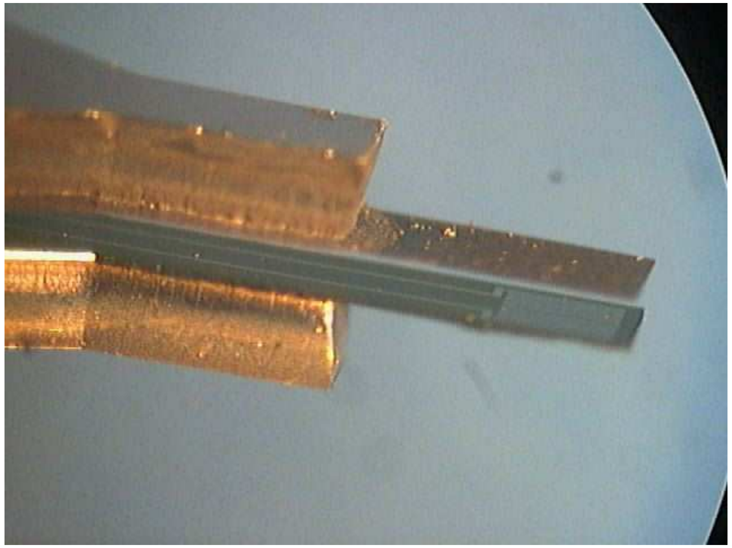
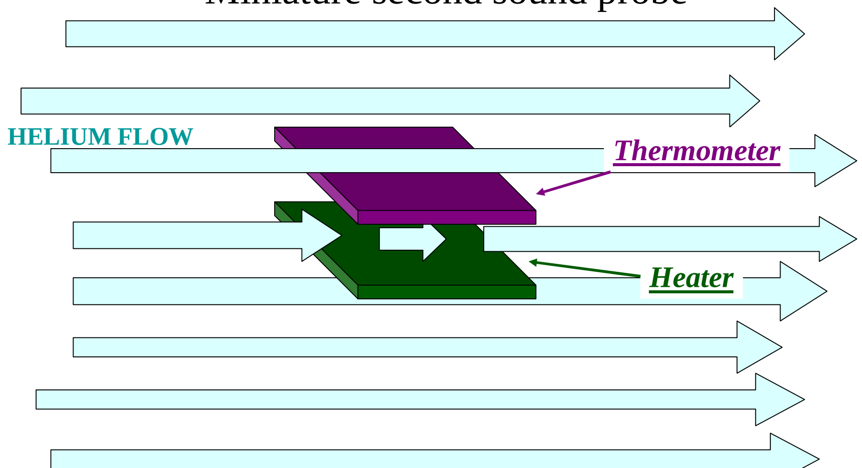


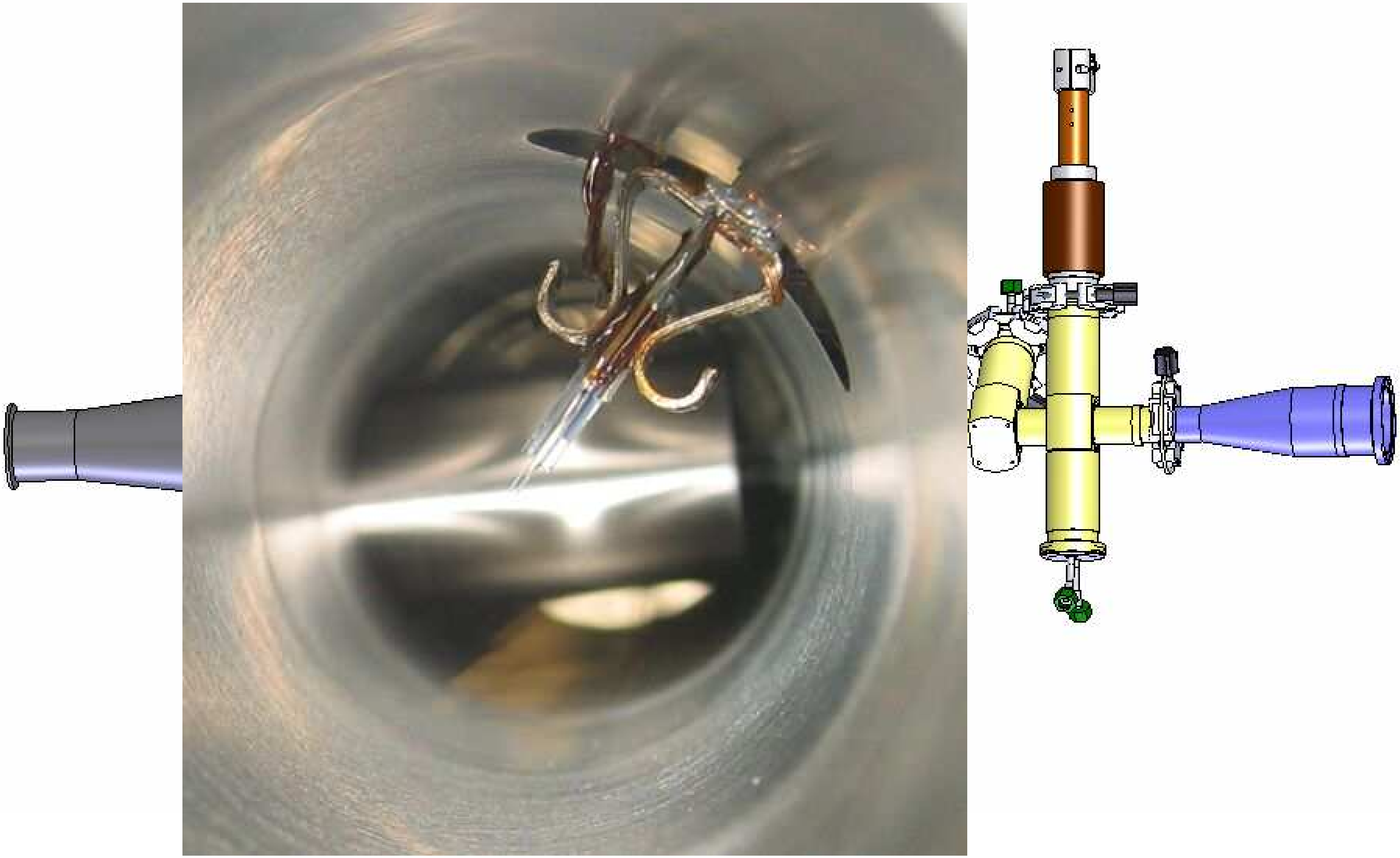
FIGURE 2 Illustration of counterflow turbulence. Below the critical heat flux, no vortex lines are created and the temperature gradient is linear in q as in left hand diagram. Above the critical heat flux, vortex lines are created as shown in the right, so that grad $T \sim q^3$, accompanied by a sudden increase in the measured attenuation, ξ.

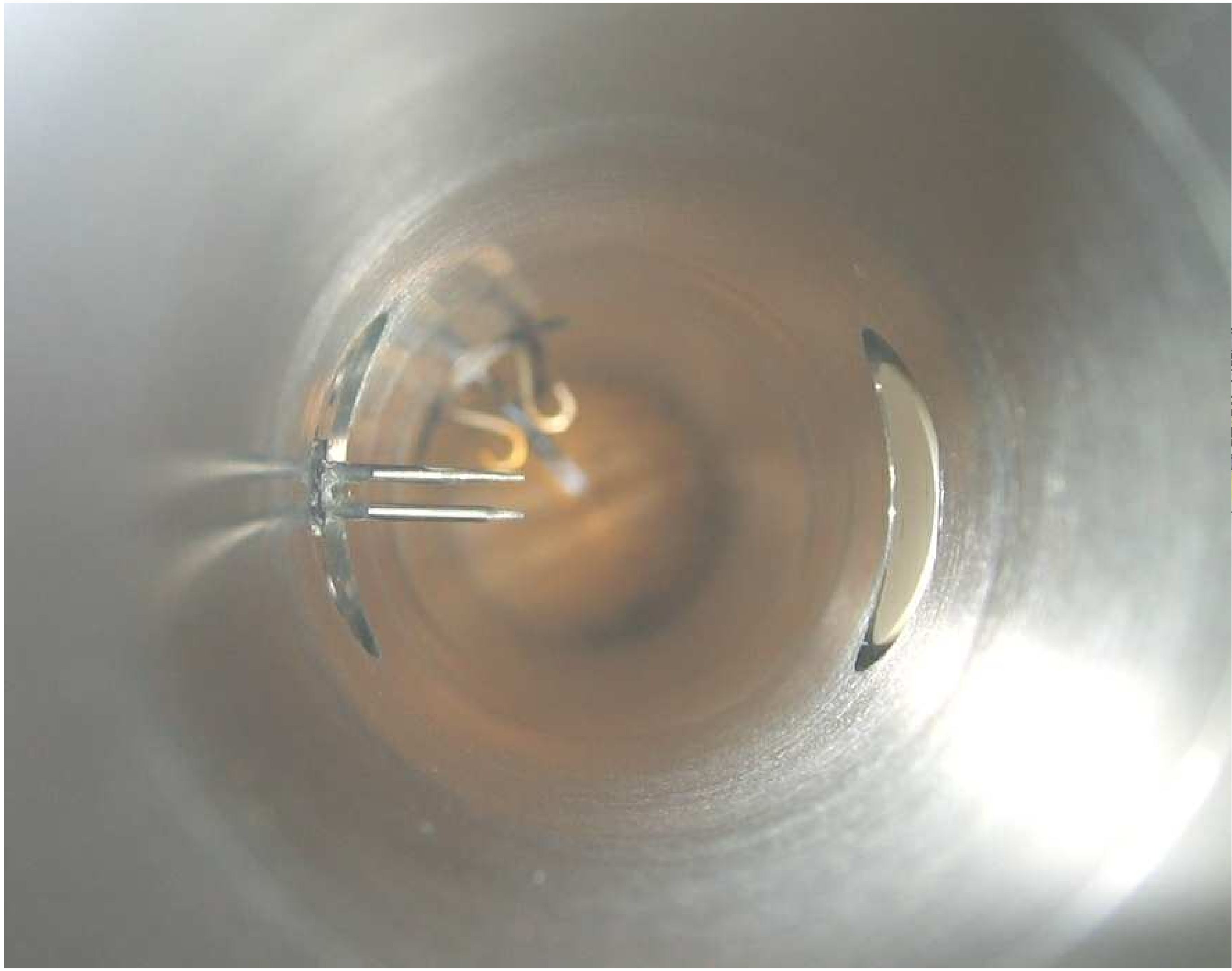


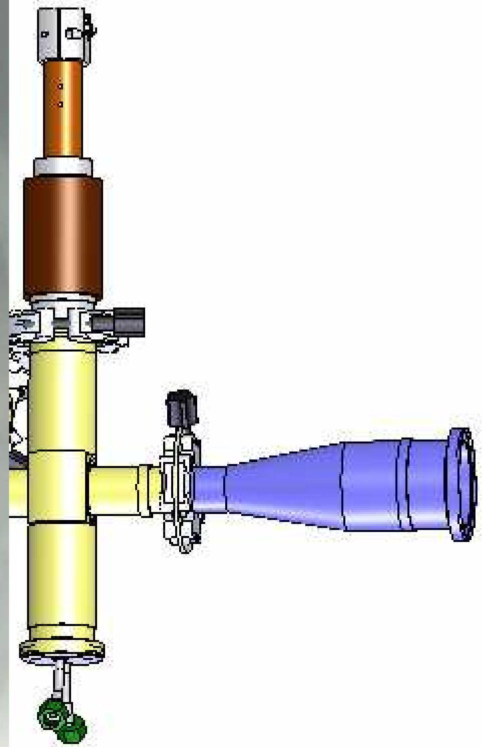
Miniature second sound probe

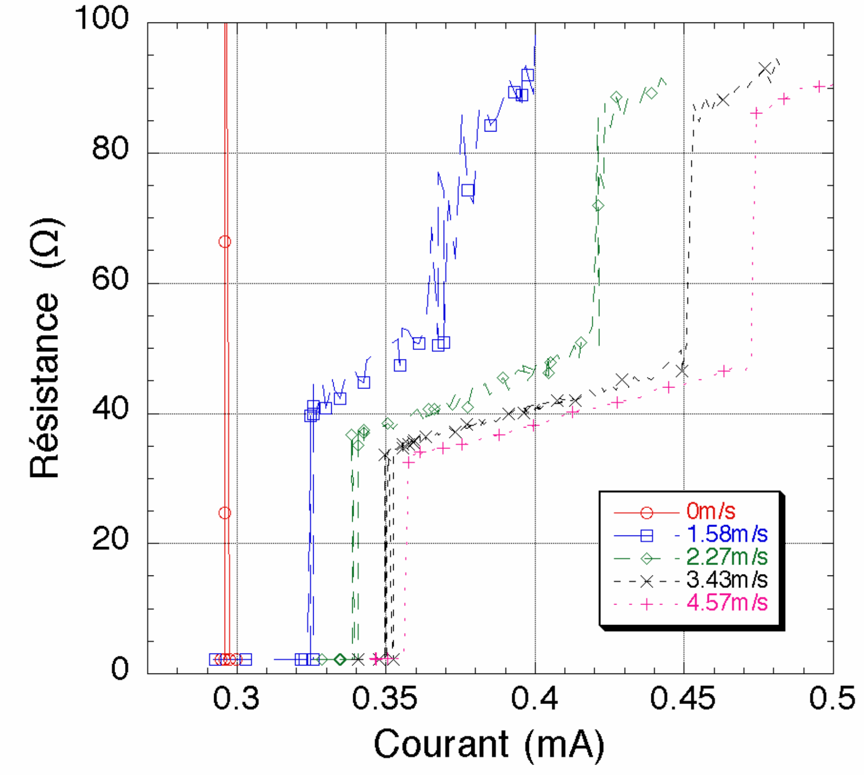


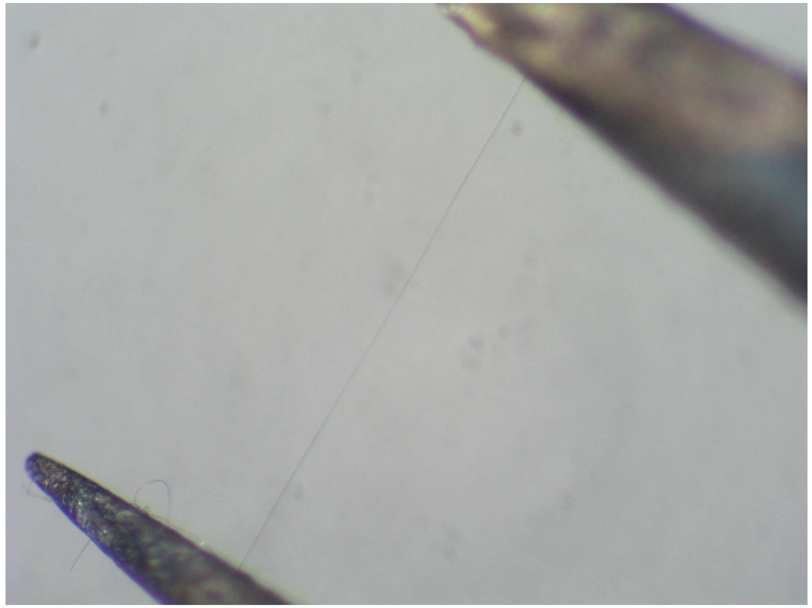
- Attenuation ~ Vortex line density ~ (inter-vortex spacing) $^{-2}$
- Anisotropic sensor

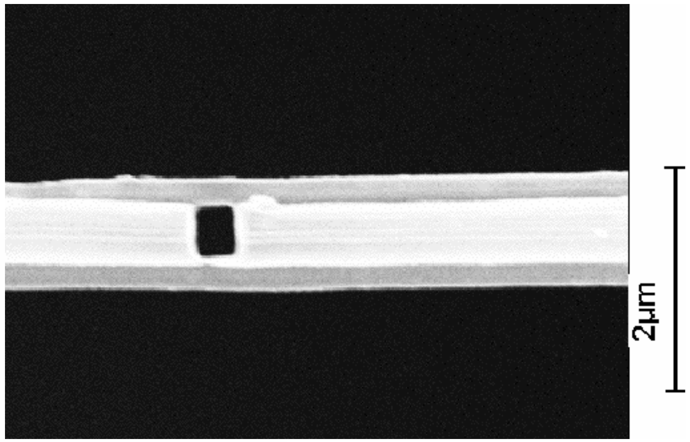


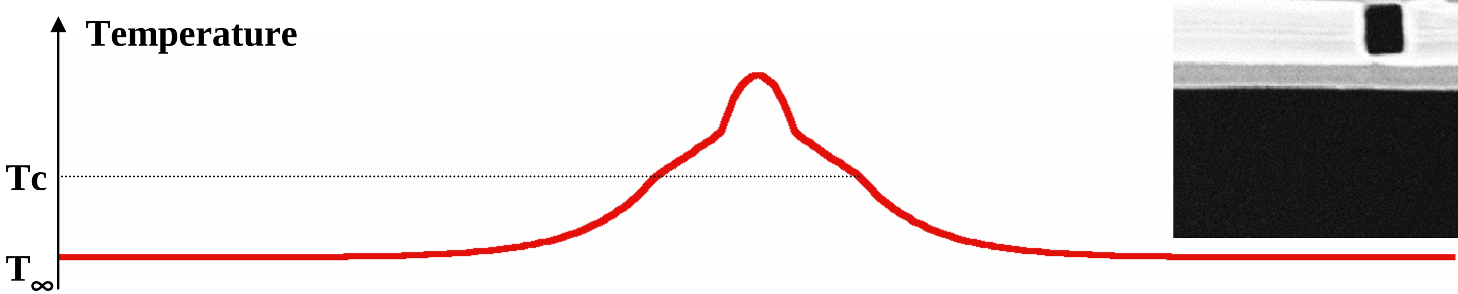





Résistance (Ω)
Courant (mA)
100
80
60
40
20
0
0.3
0.35
0.4
0.45
0.5
0m/s
1.58m/s
2.27m/s
3.43m/s
4.57m/s




2µm


Temperature
Tc
T∞

Most impressive figures :

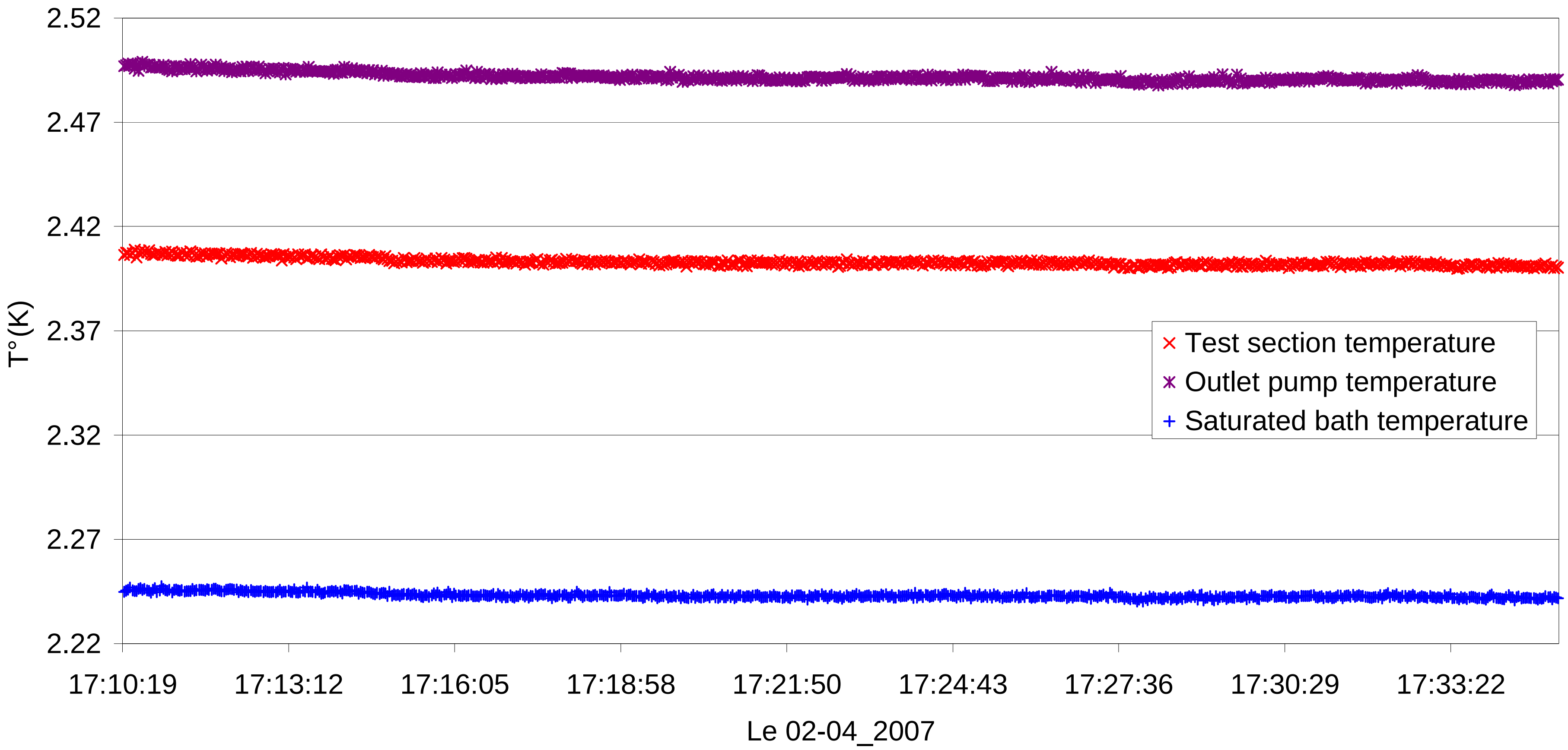
- 750 g/s achieved at a temperature of 1.9 K

- a maximum **pipe Re number of 2.5 10^7** on the test line and 2.3 10^7 in the 15 m long 30 mm I.D. heat exchanger with a mean flow velocity of 8 m/s (far from sound velocity : 230 m/s)

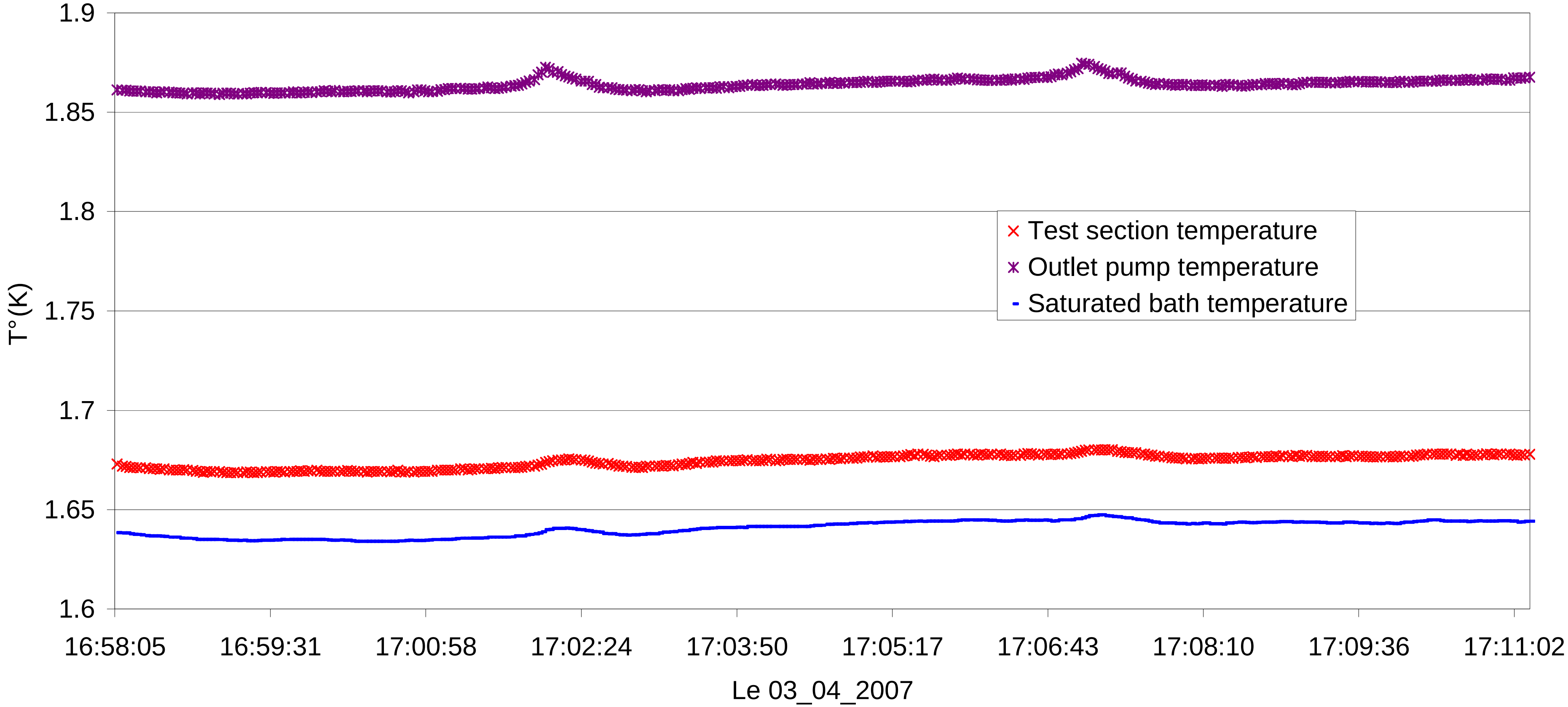
- which corresponds to a mesh Reynolds number $\boldsymbol{Re_M}$ of **3.6 10^6** in HeII and **1.5 10^6** in normal helium

- an estimated grid **Rλ** of **300** in normal helium and **460** in HeII

Typical temperature stabilities for normal helium operation (Mass flow rate 380g/s)



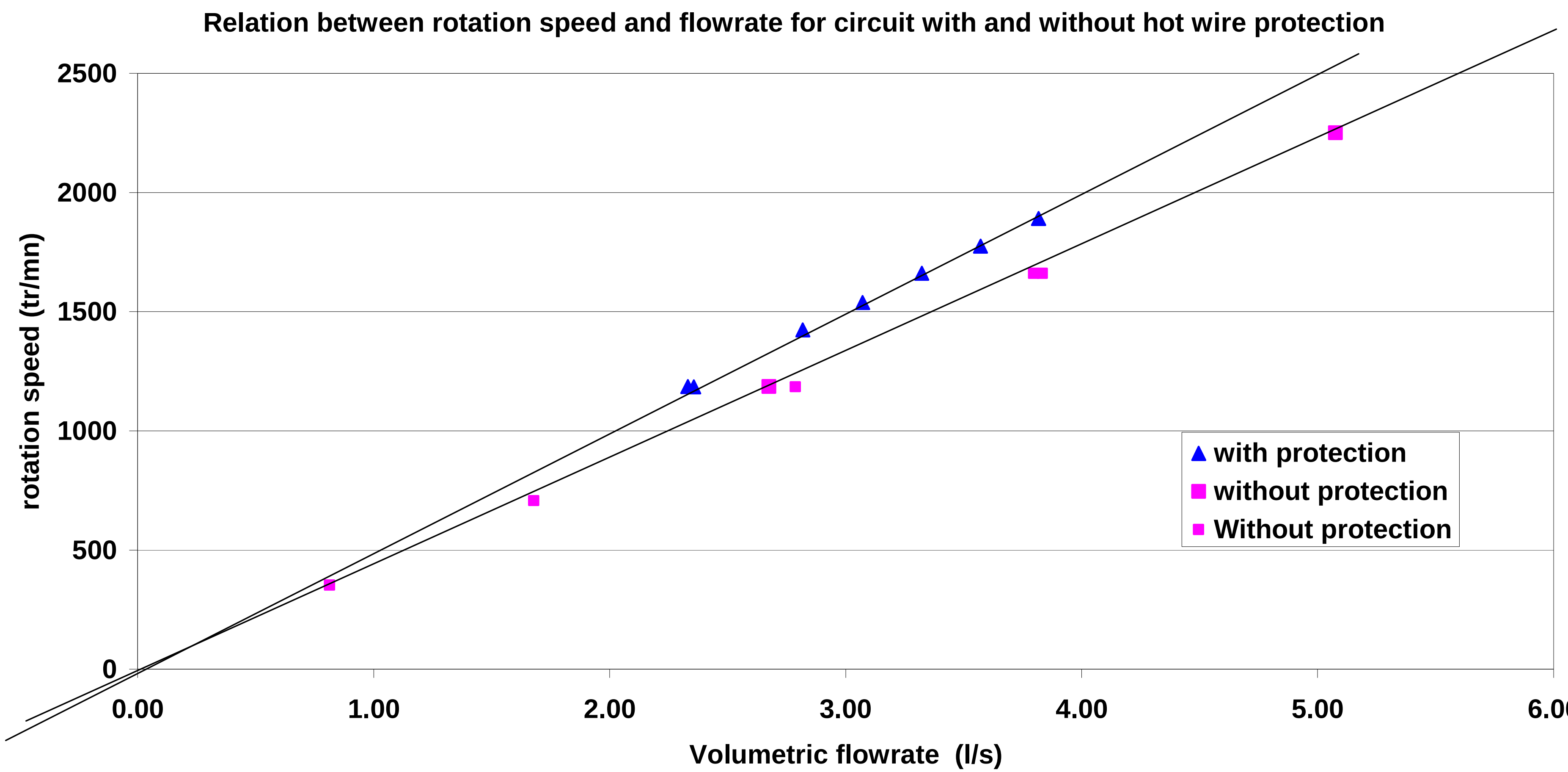
Typical helium temperature stabilities for lowest temperature (mass flow rate 400 g/s)

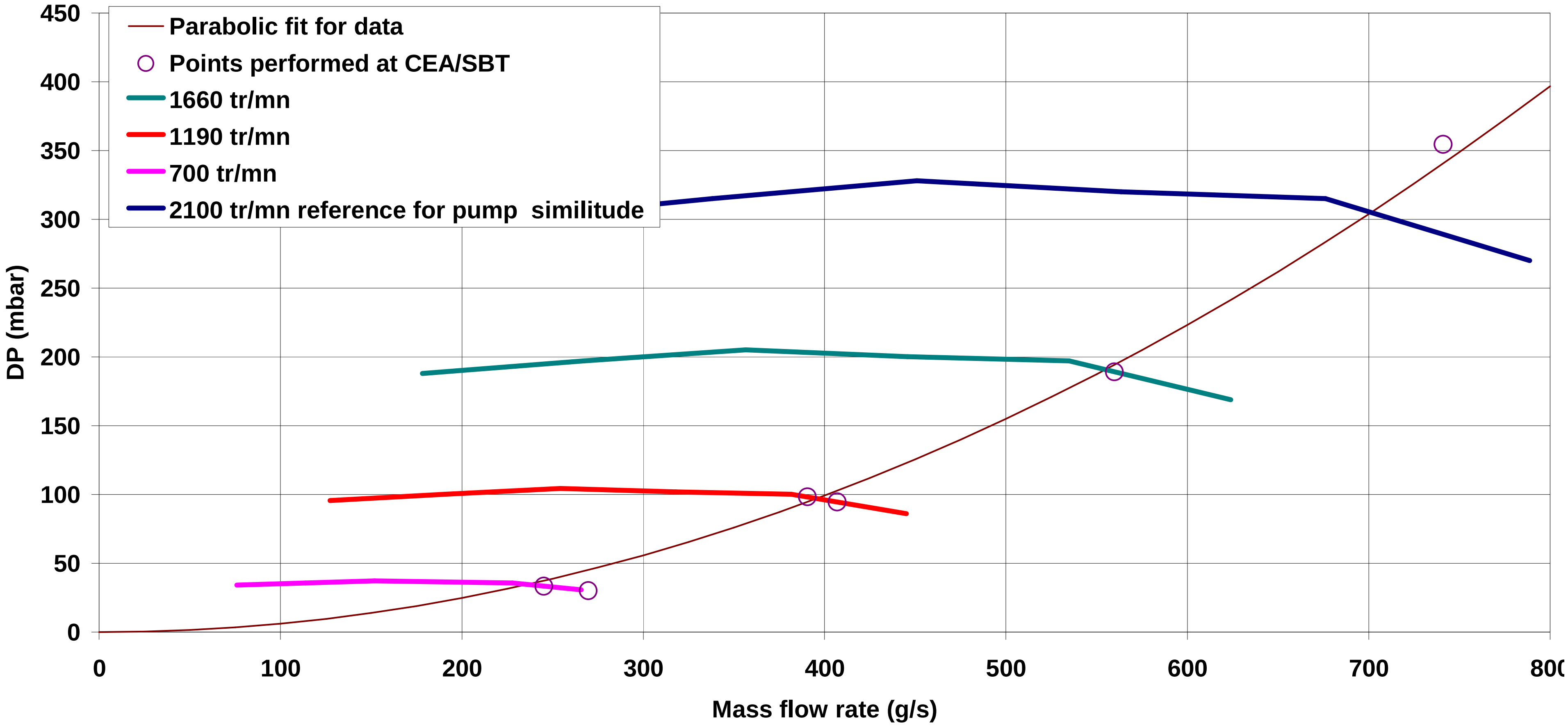


Pump similitude :

$$\left.\begin{aligned} Q_{(\omega)} &= Q_0\left(\frac{\omega}{\omega_0}\right) \\ \Delta P_{(\omega)} &= \Delta P_0\left(\frac{\omega}{\omega_0}\right)^2 \end{aligned}\right\} \Rightarrow \Delta P_{(\omega)} = \Delta P_0\left(\frac{Q_{(\omega)}}{Q_0}\right)^2$$

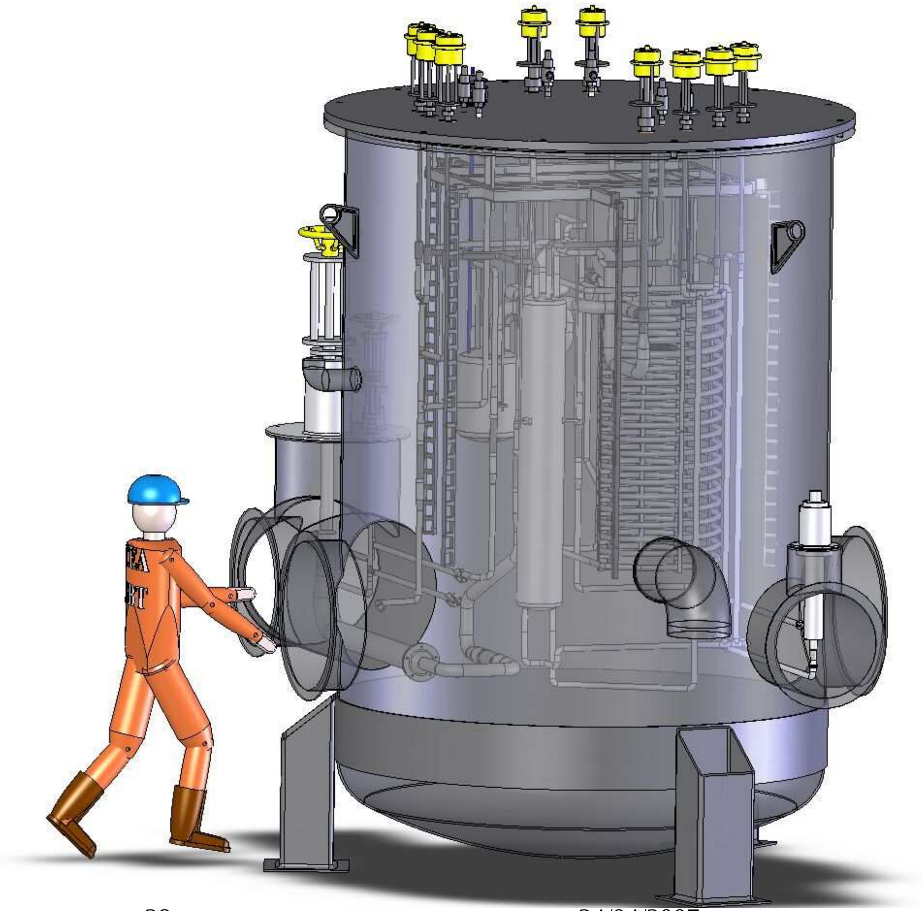
Circuit characteristic (mainly singular pressure losses) : $\Delta P \propto \rho\, Q^2$


Relation between rotation speed and flowrate for circuit with and without hot wire protection
rotation speed (tr/mn)
2500
2000
1500
1000
500
0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Volumetric flowrate (l/s)
with protection
without protection
Without protection


Parabolic fit for data
Points performed at CEA/SBT
1660 tr/mn
1190 tr/mn
700 tr/mn
2100 tr/mn reference for pump similitude
DP (mbar)
Mass flow rate (g/s)
0
50
100
150
200
250
300
350
400
450
500
600
700

And what's planned for the future at CEA/SBT ?

• CEA/SBT plans to built an external cryostat able to accommodate with various hydraulic test sector. We will first move the current grid experiment to this new cryostat and after it will be available for scientists.



Conclusion

The CEA/SBT refrigerator has been adapted to various configuration of helium flow, from pressurized helium II or normal helium to saturated helium, and is ready to accommodate with new ones.

With close contact with our partners (CERN, CNRS), we have implemented various diagnostic to investigate helium two-phase flow and we now focus on turbulence (with CNRS, ENS and UJF) at high Re both in superfluid or normal (or supercritical) helium.

Joining a future IA seems to us a good opportunity to propose as a satellite facility the use of the SBT refrigerator for turbulence studies.

We are also convinced that there are no good experiment without good measurements and that a dedicated JRA on instrumentation is necessary.