Saclay 2015, Sept .15th

The T1 transition in counterflow
Numerical study with 2-way coupling

The superfluid entrance length

Based on the
PhD thesis work of :

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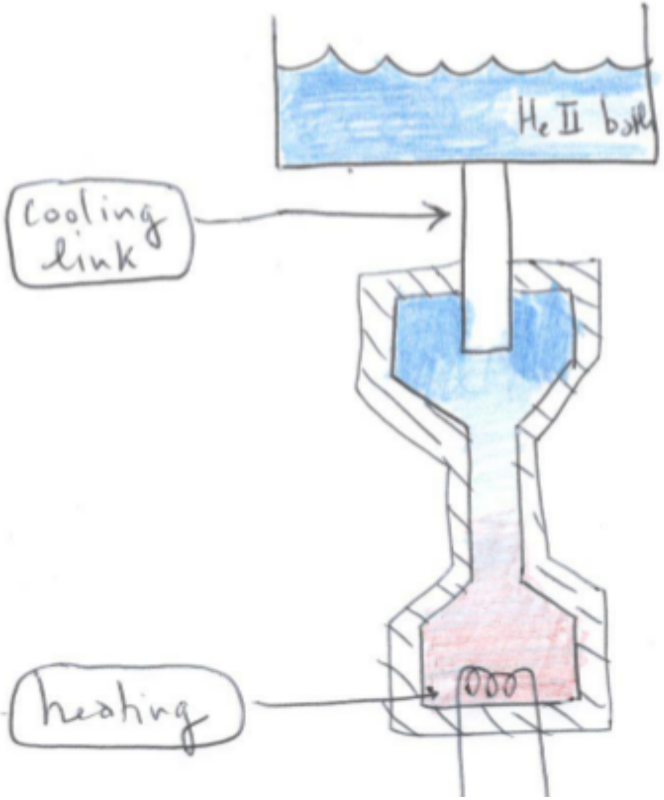
Mis en place et soutenu par Région RhôneAlpes

(*) PhD grant from Région Rhône-Alpes, Arc Energies program

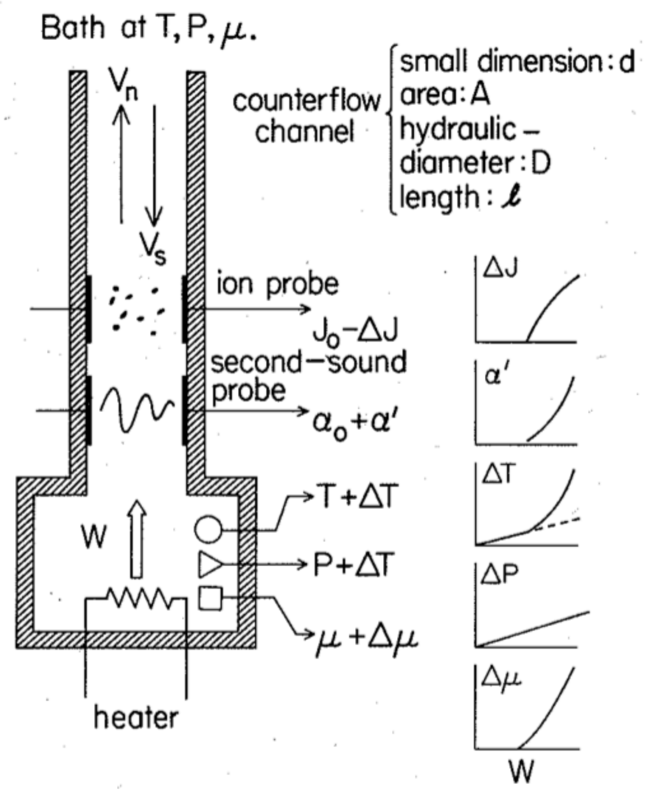
The T1 transition in pipe counterflow

a typical counterflow geometry



The T1 transition in pipe counterflow

signatures of transitions



Tough 1982

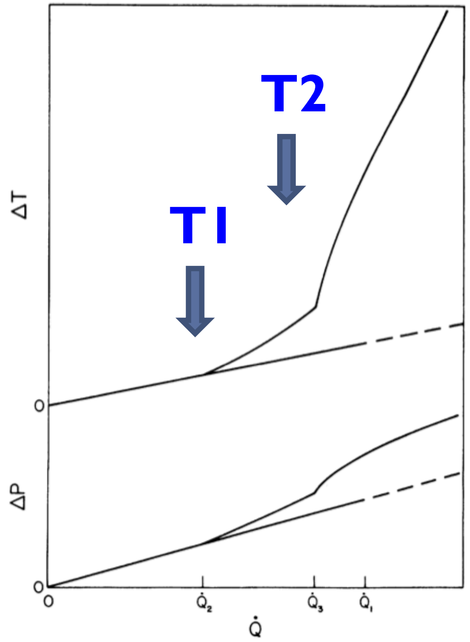
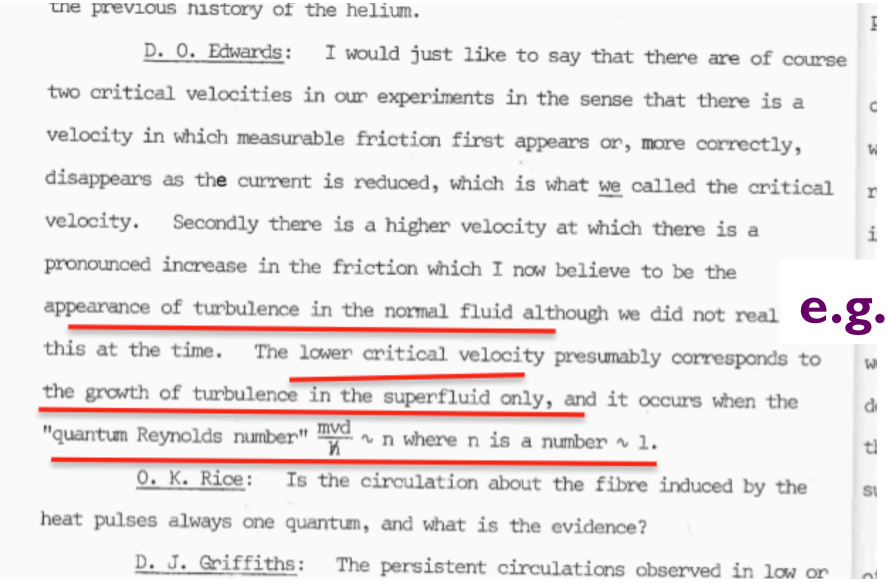


FIG. 2. Form of the temperature- and pressure-difference data ΔT and ΔP as a function of heat current $\dot{Q}$.

Childers & Tough1976
(schematics representation)

The T1 transition in pipe counterflow

Phenomenological interpretation of T1 and T2



the previous history of the helium.

D. O. Edwards: I would just like to say that there are of course two critical velocities in our experiments in the sense that there is a velocity in which measurable friction first appears or, more correctly, disappears as the current is reduced, which is what we called the critical velocity. Secondly there is a higher velocity at which there is a pronounced increase in the friction which I now believe to be the appearance of turbulence in the normal fluid although we did not real this at the time. The lower critical velocity presumably corresponds to the growth of turbulence in the superfluid only, and it occurs when the "quantum Reynolds number" $\frac{mvd}{\hbar} \sim n$ where n is a number ~ 1.

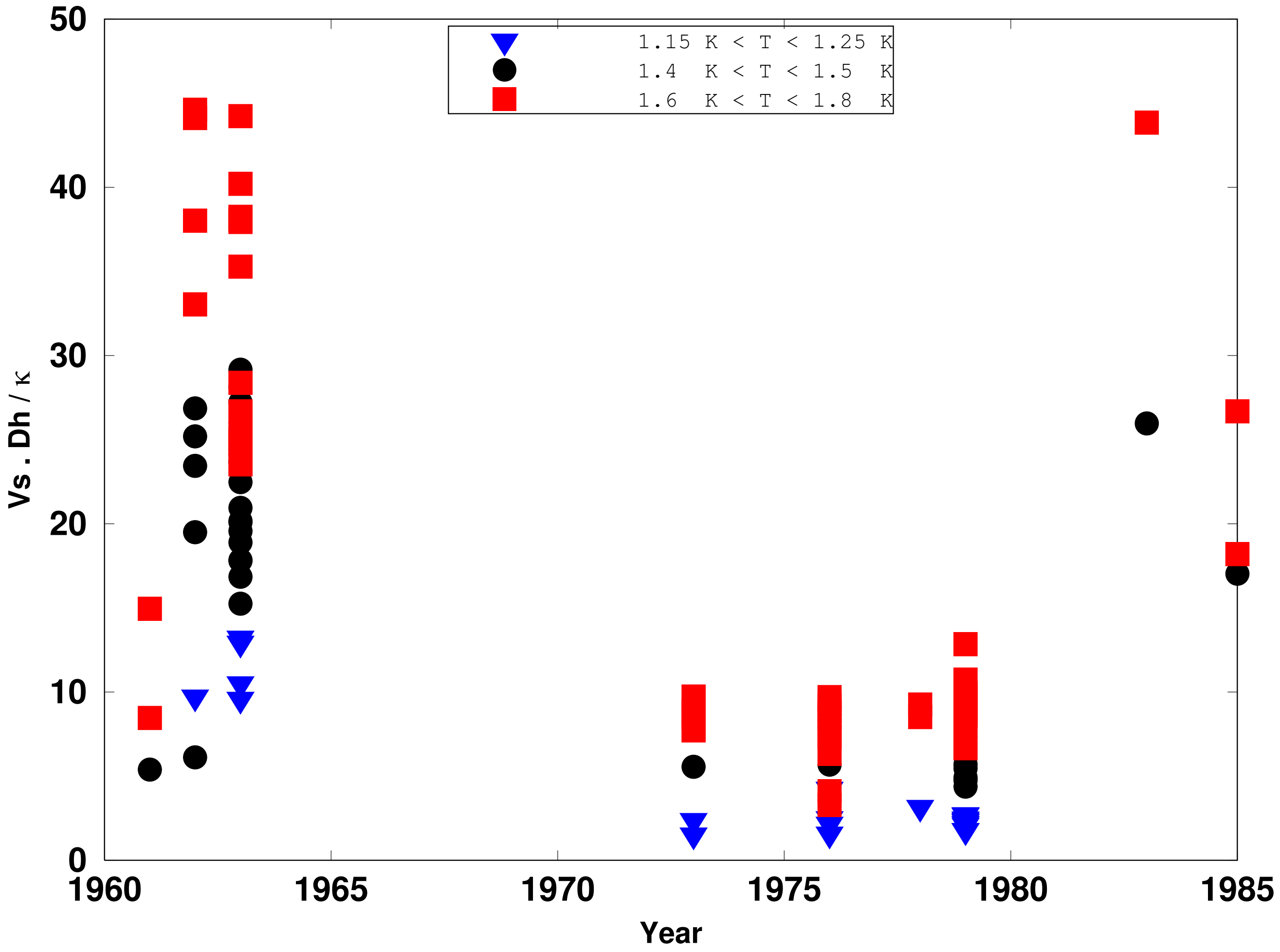
O. K. Rice: Is the circulation about the fibre induced by the heat pulses always one quantum, and what is the evidence?

D. J. Griffiths: The persistent circulations observed in low or

e.g.: Edwards 1965

- T1 : superfluid tangle appears (normal fluid remains laminar)
- T2 : normal fluid instability

TI threshold : 50 years of measurements



T1 threshold : 50 years of modelling

- *Example :* *critical velocity* ***v_c*** *versus Diameter* ***d***

v_c independent of d	[Landau 41, Iordanskii 65, Langer et al. 67]
$v_c \sim d^{-1/4}$	[Kruglov 2011]
$v_c \sim d^{-1/3}$ w/ or without log corr.	[Craig 66] [Jones 69]
$v_c \sim d^{-1}$ with log corr	[Feynman 55, Peshkov 61, Fineman et al.63, Glaberson et al. 66, Swanson et al. 85, Schwarz 88, Barenghi et al. 97]
$v_c \sim d^{-1}$	[Mongiovi and Jou 2005, Fetter 1963, Childers and Tough 1976]

50 years of modelling

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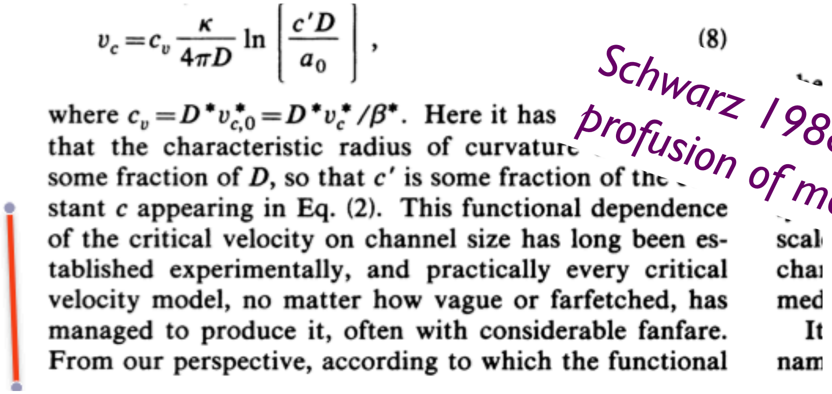

$$v_c = c_v \frac{\kappa}{4\pi D} \ln\left[\frac{c'D}{a_0}\right], \qquad (8)$$

where $c_v = D^* v^*_{c,0} = D^* v^*_c / \beta^*$. Here it has that the characteristic radius of curvature some fraction of D, so that c' is some fraction of the stant c appearing in Eq. (2). This functional dependence of the critical velocity on channel size has long been established experimentally, and practically every critical velocity model, no matter how vague or farfetched, has managed to produce it, often with considerable fanfare. From our perspective, according to which the functional

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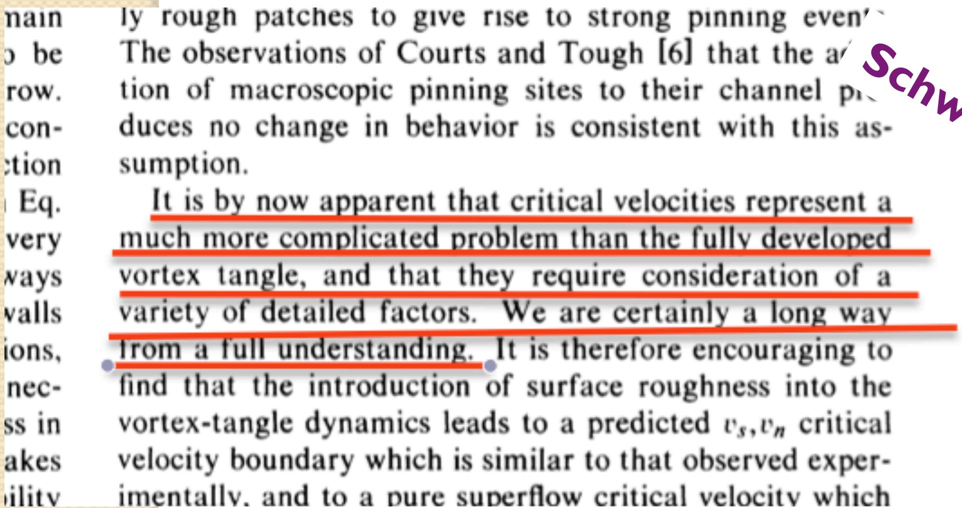
Schwarz 1988 sarcasms about profusion of models

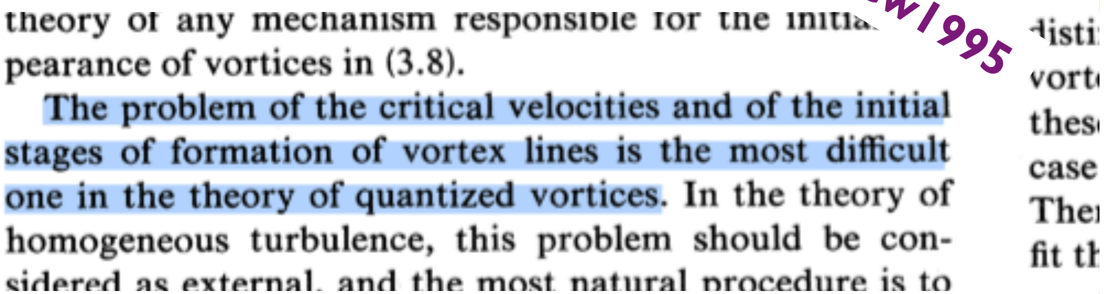
The puzzle of T1 transition



ly rough patches to give rise to strong pinning even The observations of Courts and Tough [6] that the a tion of macroscopic pinning sites to their channel p duces no change in behavior is consistent with this assumption.

It is by now apparent that critical velocities represent a much more complicated problem than the fully developed vortex tangle, and that they require consideration of a variety of detailed factors. We are certainly a long way from a full understanding. It is therefore encouraging to find that the introduction of surface roughness into the vortex-tangle dynamics leads to a predicted v_s,v_n critical velocity boundary which is similar to that observed experimentally, and to a pure superflow critical velocity which

Schwarz 1992



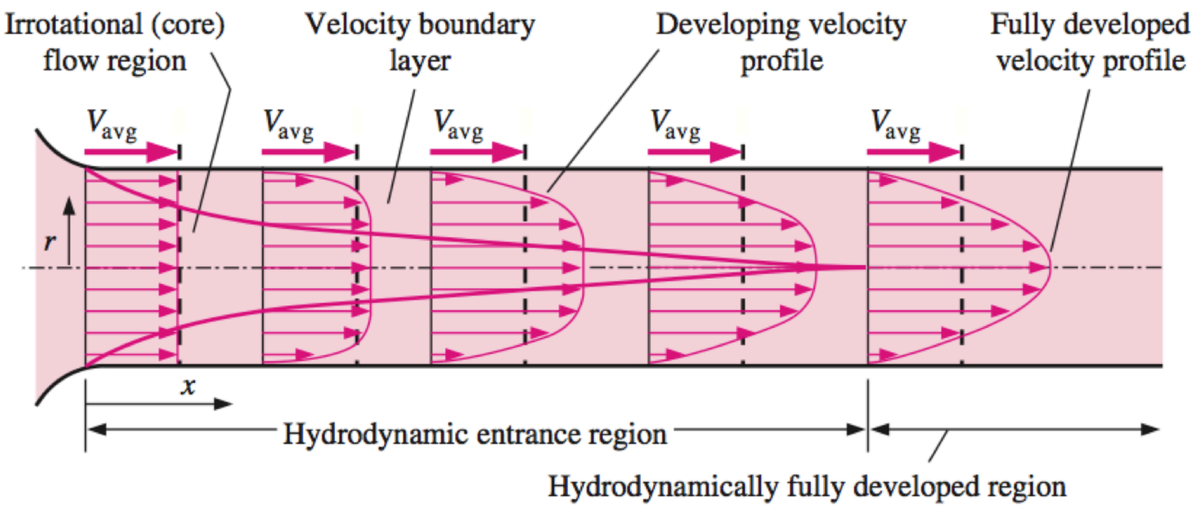
theory of any mechanism responsible for the initia pearance of vortices in (3.8).

The problem of the critical velocities and of the initial stages of formation of vortex lines is the most difficult one in the theory of quantized vortices. In the theory of homogeneous turbulence, this problem should be considered as external, and the most natural procedure is to

Nemirovski review1995

Do we have a measurement interpretation problem ?

Idea and Motivation : entry effect

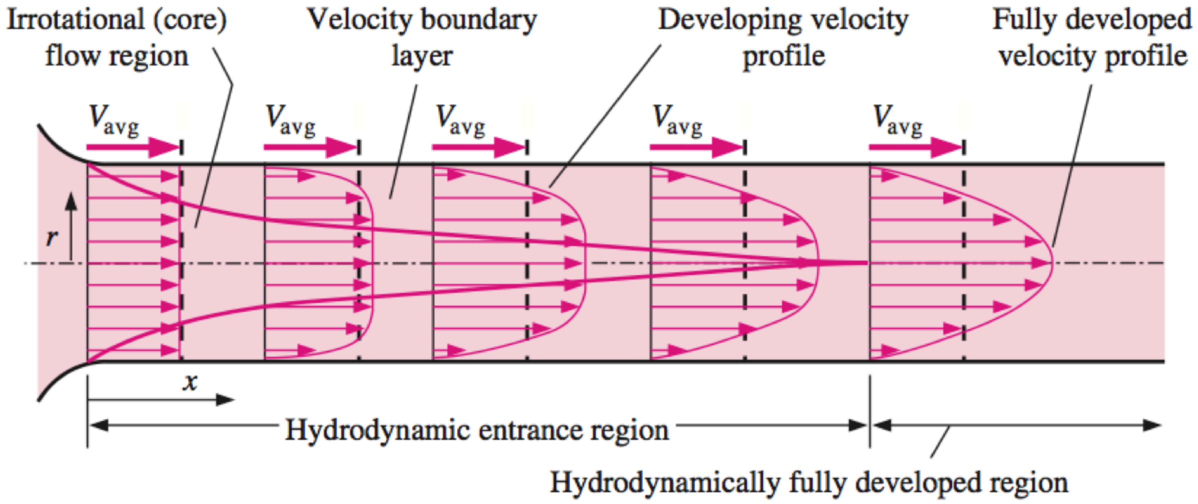


Cenjel et al.
JFM 2006

$$L_e \sim V \frac{(D/2)^2}{\nu}$$

- Classical laminar hydrodynamics :
  - Viscous diffusion time Vs. Advection time
  - Entry profile forgotten after few tens of diameters

Idea and Motivation : entry effect

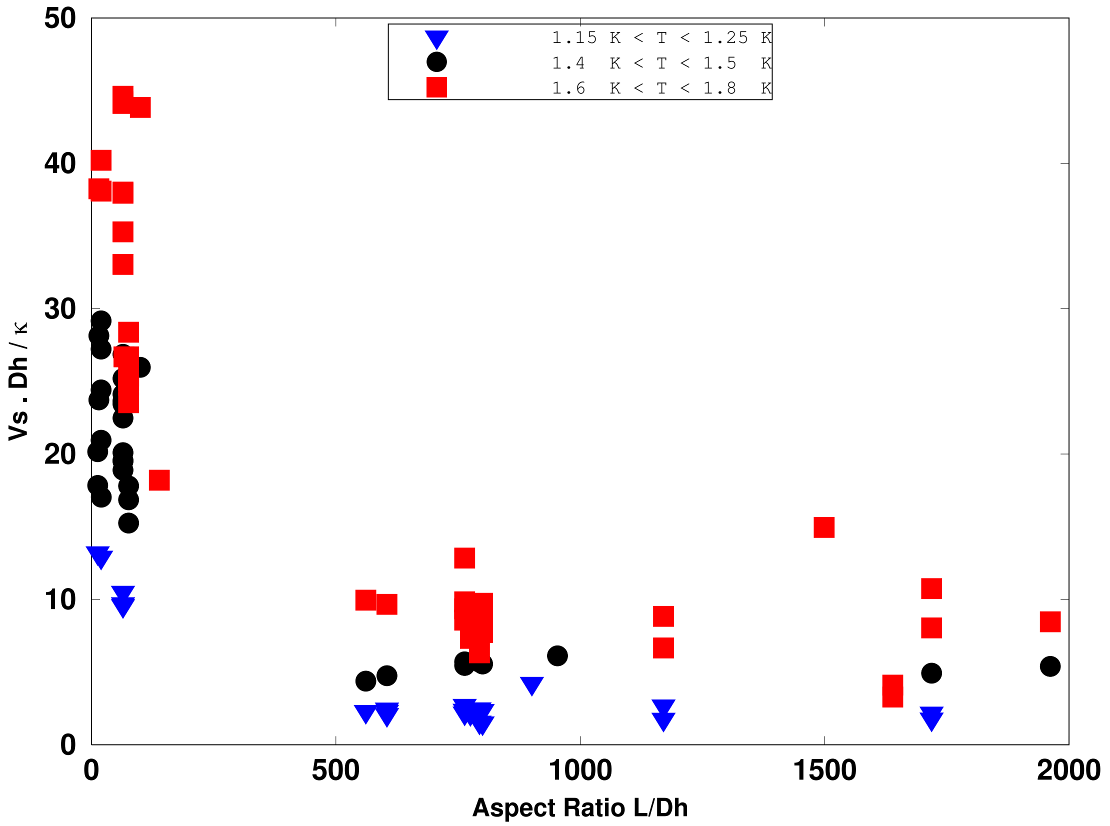


Cenjel et al.
JFM 2006

$$L_e \sim V \frac{(D/2)^2}{\xcancel{\nu}}$$

- What happens in a superfluid ?
  Does the flow ever forget the entry profile ?

A first encouraging result



- The pipe's aspect ratio seems a relevant parameter
- Insufficient aspect-ratio in some datasets ?
- Lack of data within 100 < L/Dh < 500

Main result of this talk :

« The superfluid entry length »
can greatly exceed the
classical, viscous entry length

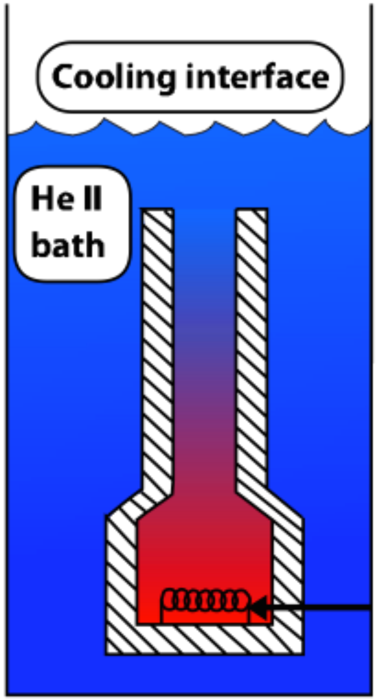
Rule of thumbs :
pipe aspect ratio should be one decade larger
than suggested by classical hydrodyanmics

The physical effects studied

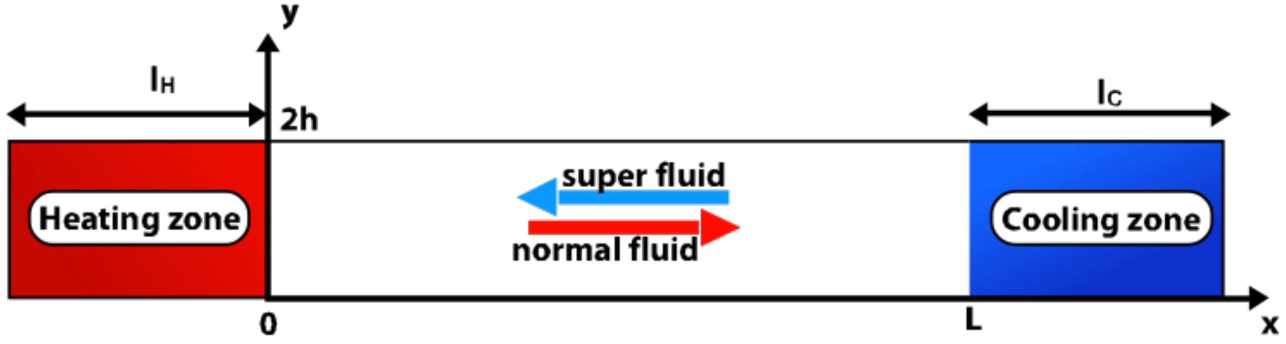
- Superfluid vorticity is carried into the pipe

Physical origin of this vorticity

- ◦ Reservoirs vortices
- ◦ Flow recirculation near the heater/cooler
- ◦ Geometrical discontinuities at pipe's entry



Simulation model 1/2



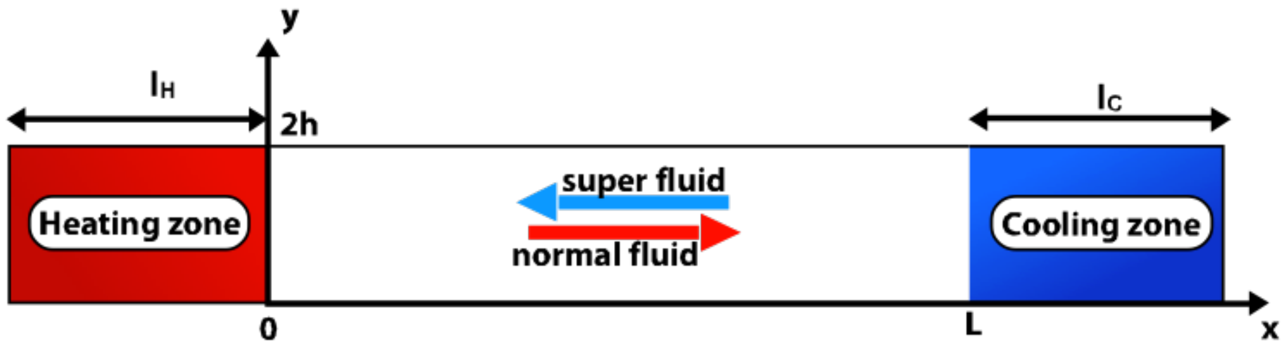
- Model for reservoirs :

  spatially-distributed heating /cooling zone

  no geometrical discontinuity

  symmetric heating / cooling reservoirs (for direct comparison)

Simulation model 2/2

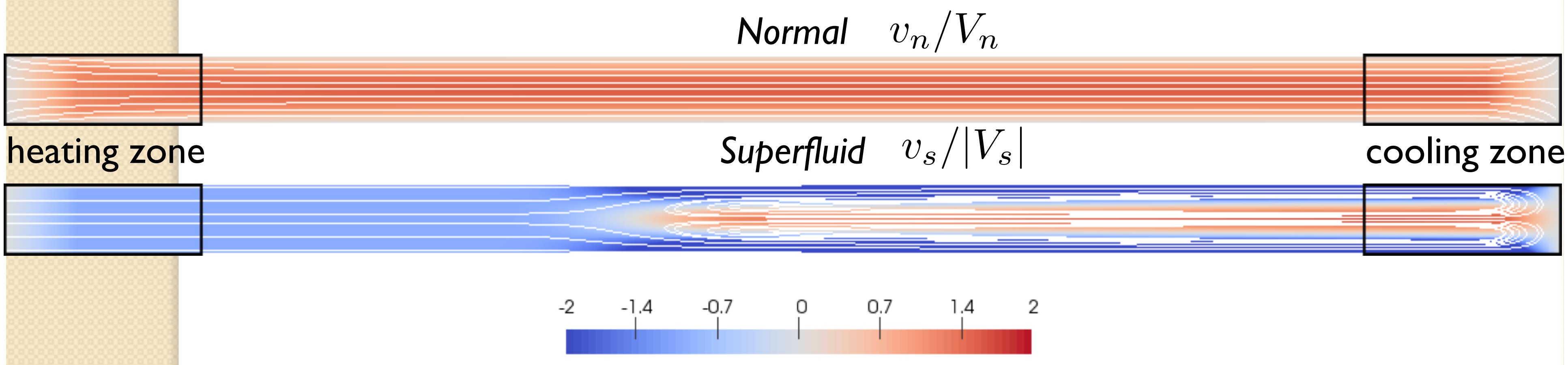


- Full mutual coupling (two-way simulation) : HVBK model, no vortex tension
  Artificial superfluid viscosity : $\nu_s / \nu_n = 1/25$ (validations at 1/50, 1/100)
- Side-wall boundary conditions : Normal = no-slip , Superfluid = slip
- Boussinesq-type approximation Incompressible isothermal fluid
- Lattice-Boltzmann numerical schemes, 2D (3D not presented here)
- Code validations : conservation of population, impulsion, mass flux, single-fluid flow special case,…

- $T = 1.5$ K
- $Re_N = 146.7$

Mutual coupling turned OFF

Normalized VELOCITY field



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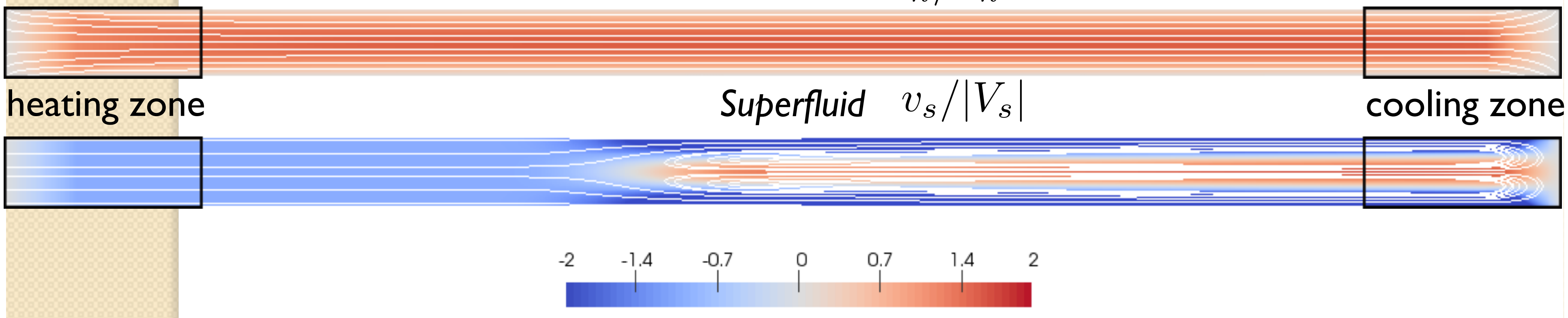
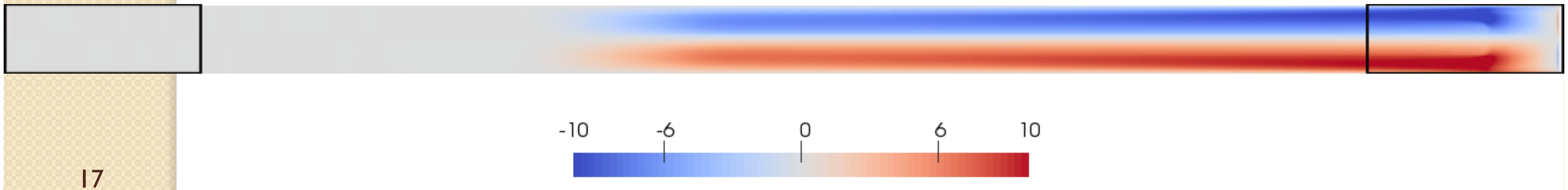
Normalized VELOCITY field



Normal v_n/V_n

Superfluid $v_s/|V_s|$

Normalized VORTICITY field

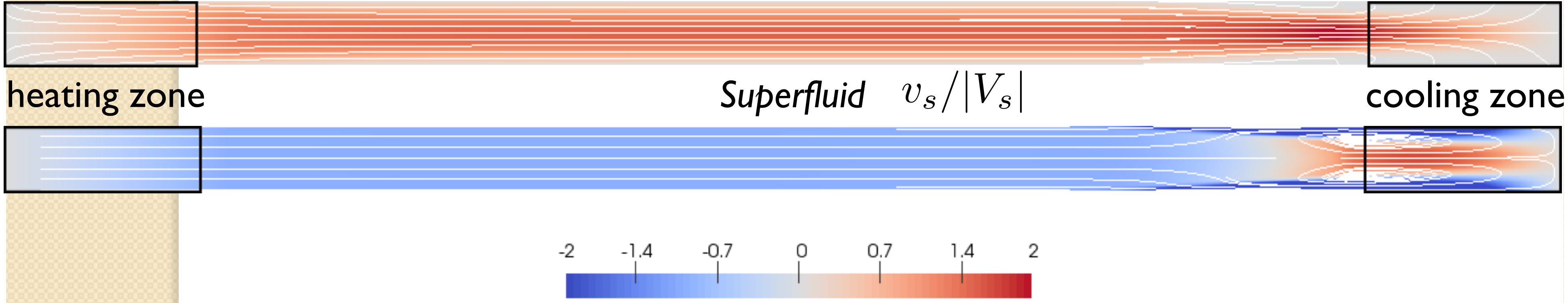


Superfluid $\omega_s h/V_s$

- T = 1.5 K
- $\mathrm{Re}_N = 146.7$

Mutual coupling turned ON

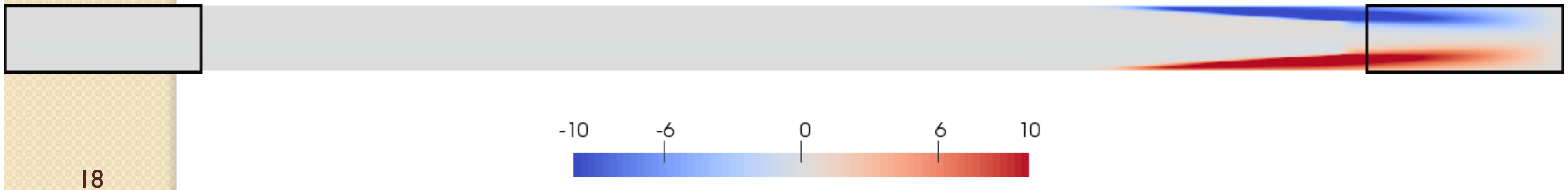
Normalized VELOCITY field



Normal v_n/V_n

Superfluid $v_s/|V_s|$

Normalized VORTICITY field



Superfluid $\omega_s h/V_s$

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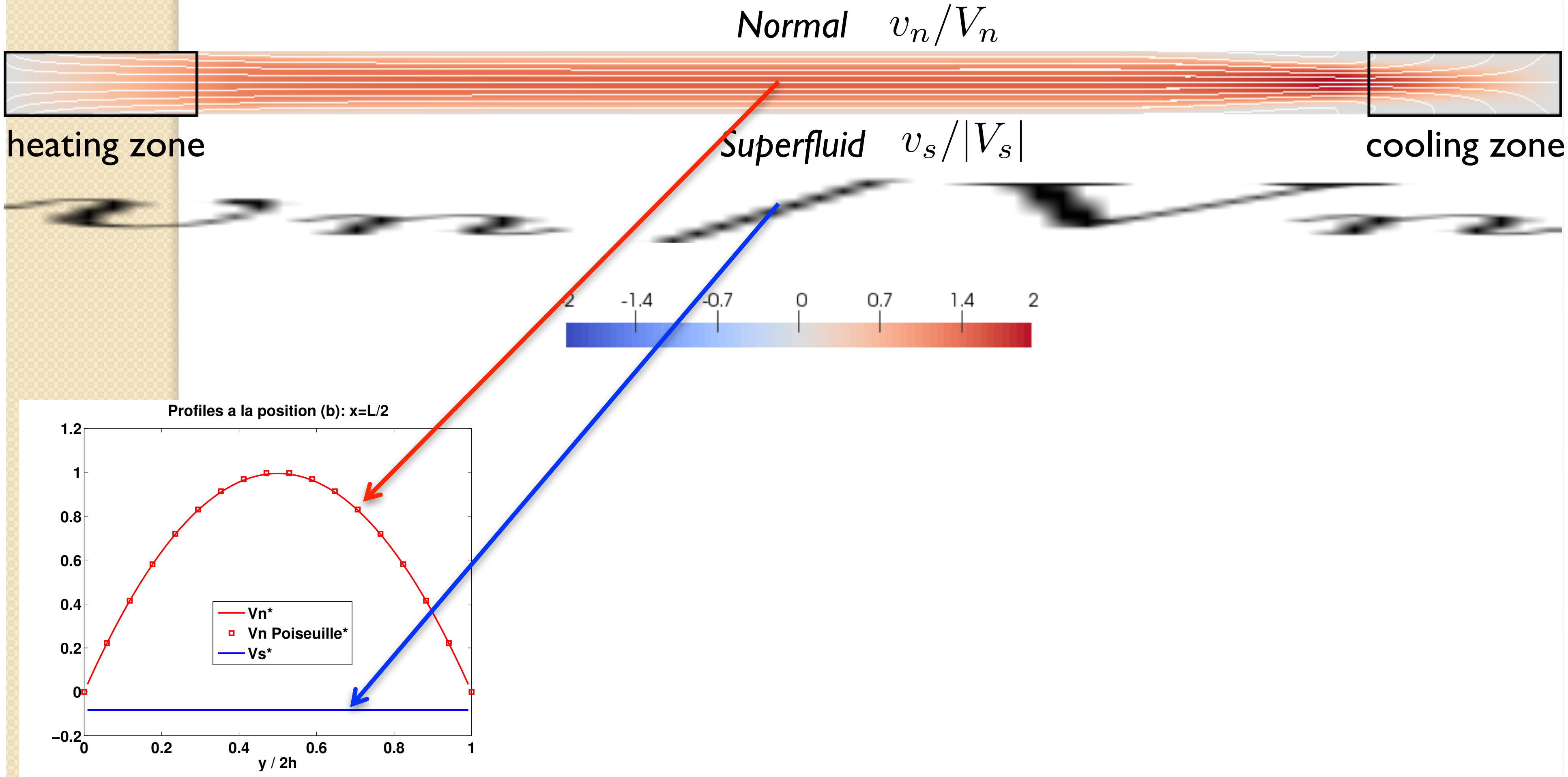

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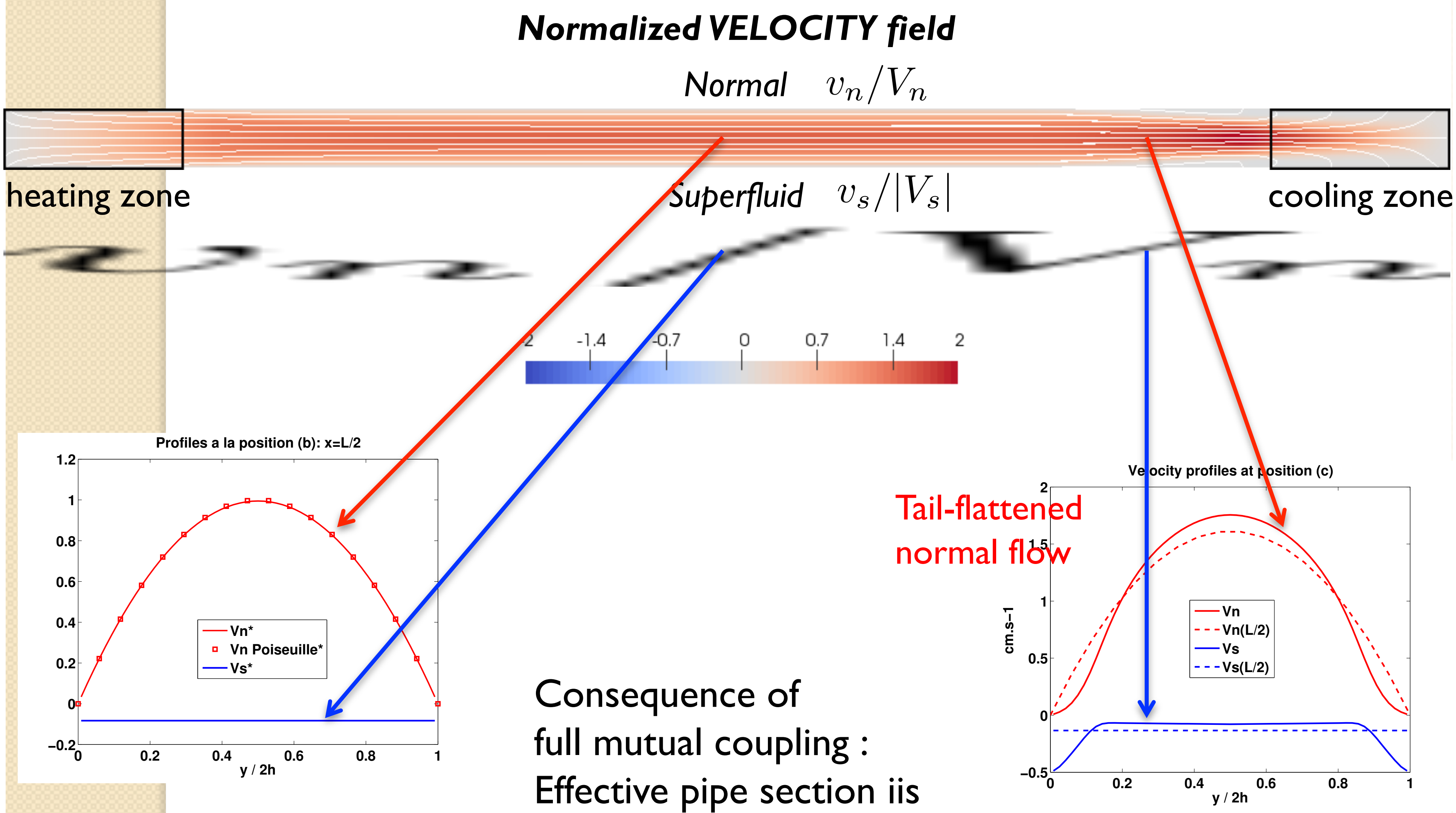
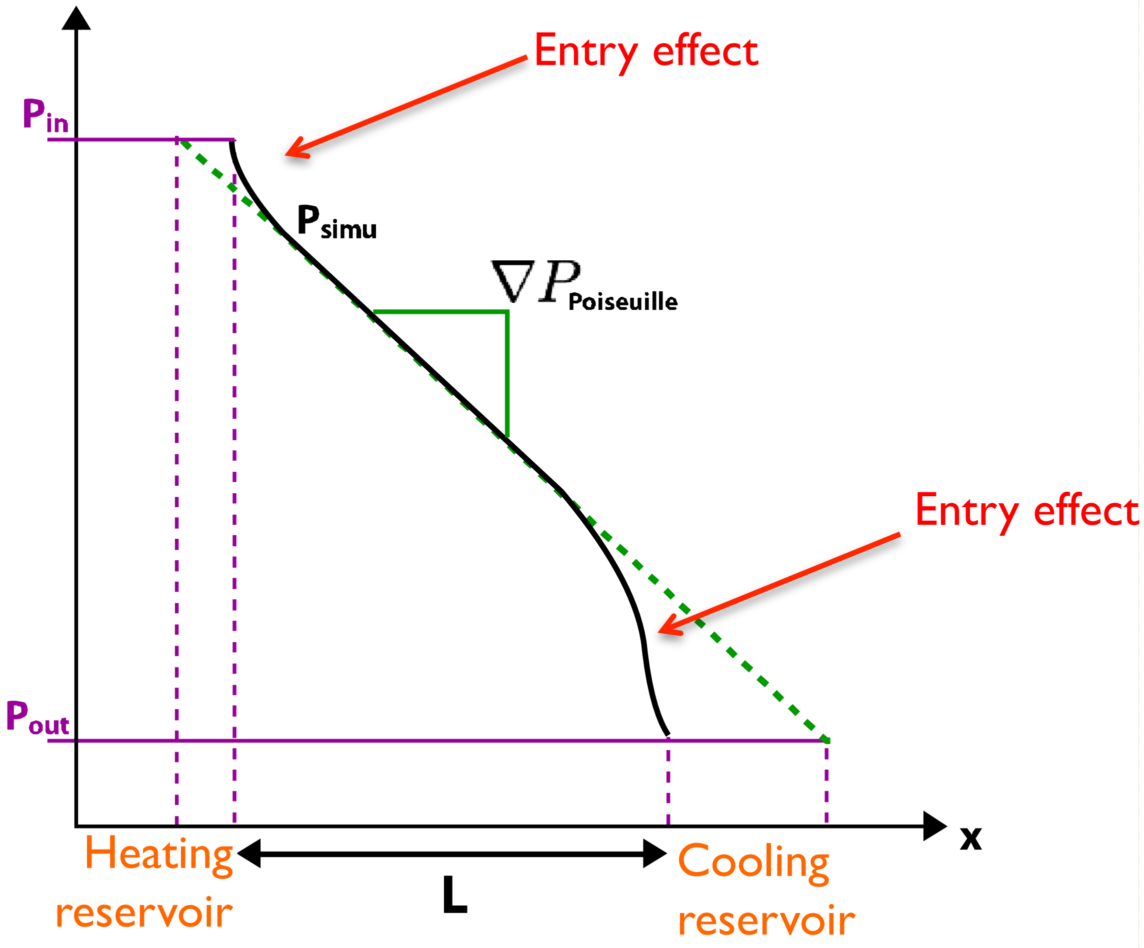
Mutual coupling turned ON



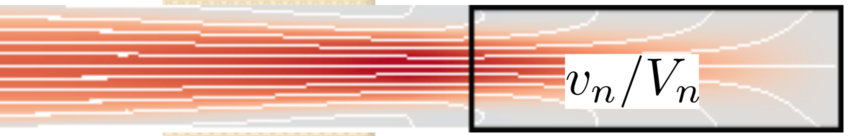
Consequence of
full mutual coupling :
Effective pipe section iis
reduced for normal fluid

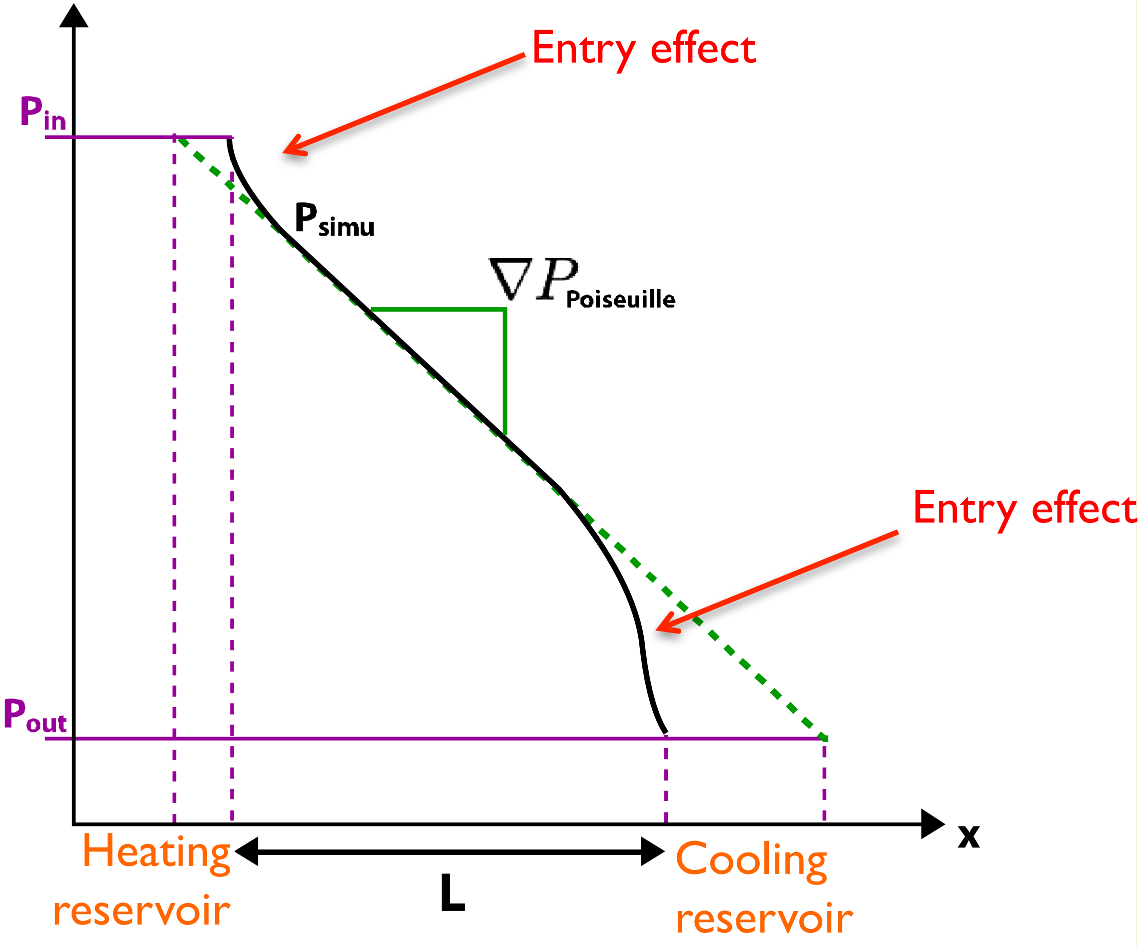
Pressure drop along the pipe



Pressure drop much more pronounced on cold side

Pressure drop along the pipe



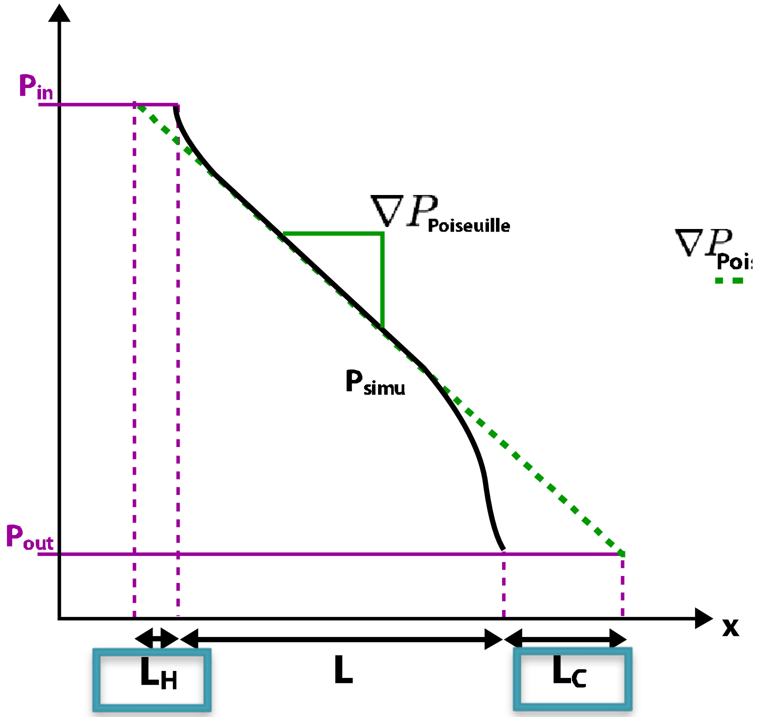


Full reciprocal mutual friction : key ingredient

Comparison of hot and cold entries : definition of entry lengths L_H and L_C

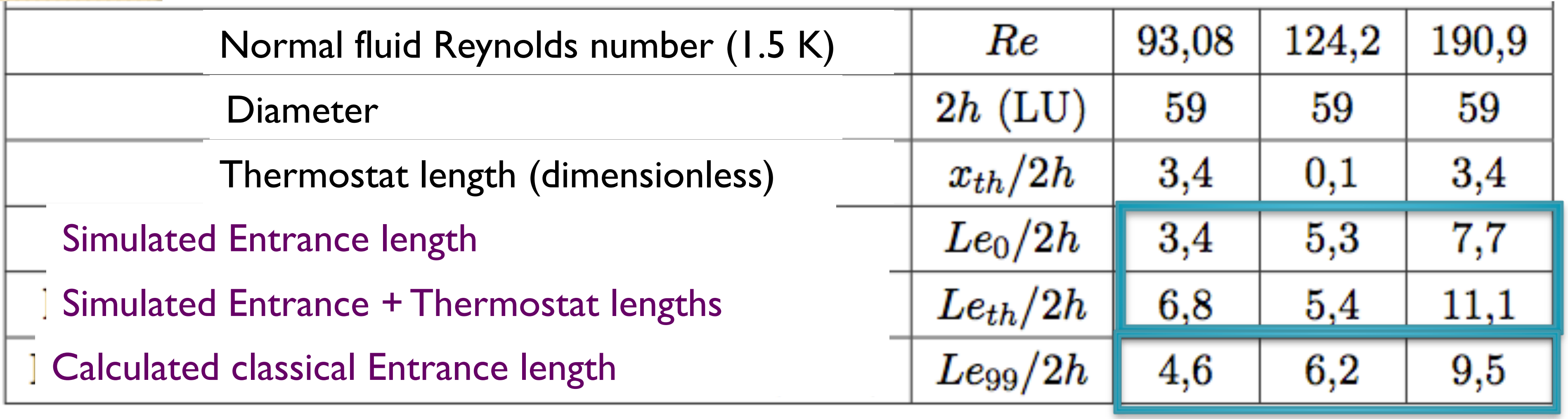
$$L_C = \frac{1}{\nabla p_{pois}} \int_a^L \left(\nabla p(x) - \nabla p_{pois}\right) dx$$

$$L_H = \frac{1}{\nabla p_{pois}} \int_0^a \left(\nabla p(x) - \nabla p_{pois}\right) dx$$



Question #1 : how does L_H compares to classical entry length ?
Question #2 : how does L_C compares to classical entry length ?

Normal fluid entry length : L_H



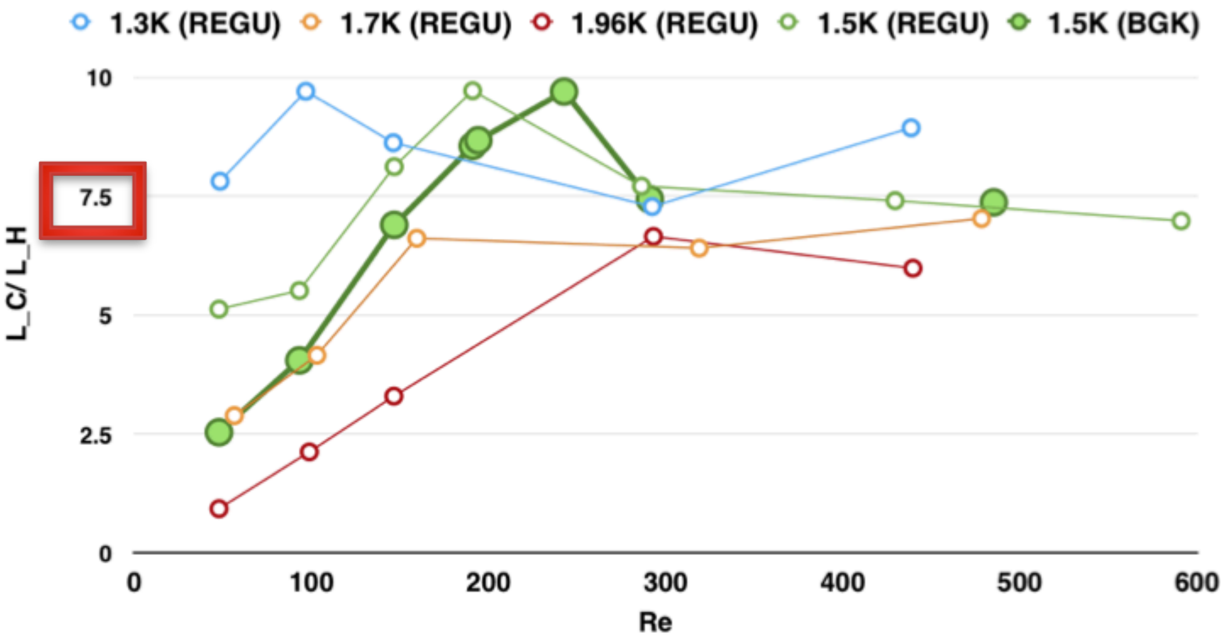
Normal fluid Reynolds number (1.5 K)	Re	93,08	124,2	190,9
Diameter	$2h$ (LU)	59	59	59
Thermostat length (dimensionless)	$x_{th}/2h$	3,4	0,1	3,4
Simulated Entrance length	$Le_0/2h$	3,4	5,3	7,7
Simulated Entrance + Thermostat lengths	$Le_{th}/2h$	6,8	5,4	11,1
Calculated classical Entrance length	$Le_{99}/2h$	4,6	6,2	9,5

Heading side end :

similar to the classical hydrodynamics entry effect

Main quantitative result : Superfluid entry length L_C

RATIO : Superfluid entry L_C / Normal fluid entry L_H



Cooling side end :

The entry effect is nearly one decade larger than in classical hydrodynamics

Consequences and conclusions

- The superfluid entry lengh –defined using excess in pressure drop- can greatly exceed the classical « viscous » entry length. Mutual friction determines the transcient.

Classical criterion (laminar) : $L_e \simeq D\frac{Re}{20}$ $Re = 500 \rightarrow L_e/D = 25$

Counterflow criterion (T1) : $L_e \simeq D\frac{Re}{20} \times (1+7.5) \simeq D\frac{Re}{2.4}$ $Re = 500 \rightarrow L_e/D = 208$

- Special attention needed in counterflow visualisation

  (channel aspect ratio, flow conditionner, …)

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- Special attention needed in counterflow visualisation (channel aspect ratio, flow conditionner, …)

- Perspectives :
  - determination of T1 for aspect ratio 100 < G <500
  - consequences on the T1 « puzzle »
  - extend the analysis from T1 to T2
  - determine LC/L_H for alternative definition of entry lengths