Superfluid turbulence in rotating ^{3}He-B

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Overview

- Introduction to the experiment
- Experimental observations on:
  - Criteria for turbulence
  - Sequence of events

^{3}He compared to ^{4}He:

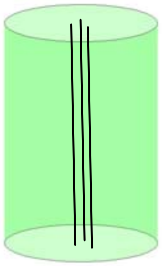
- High viscosity of normal component
- NMR
- Range of mutual friction
- Vortex formation different

Vortex states

vortex-free rotation

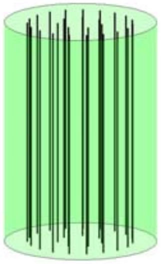
- maximum energy state
- normal component in corotation with the bucket
- superfluid stationary in laboratory frame

intermediate



- $0<N<N_{max}$

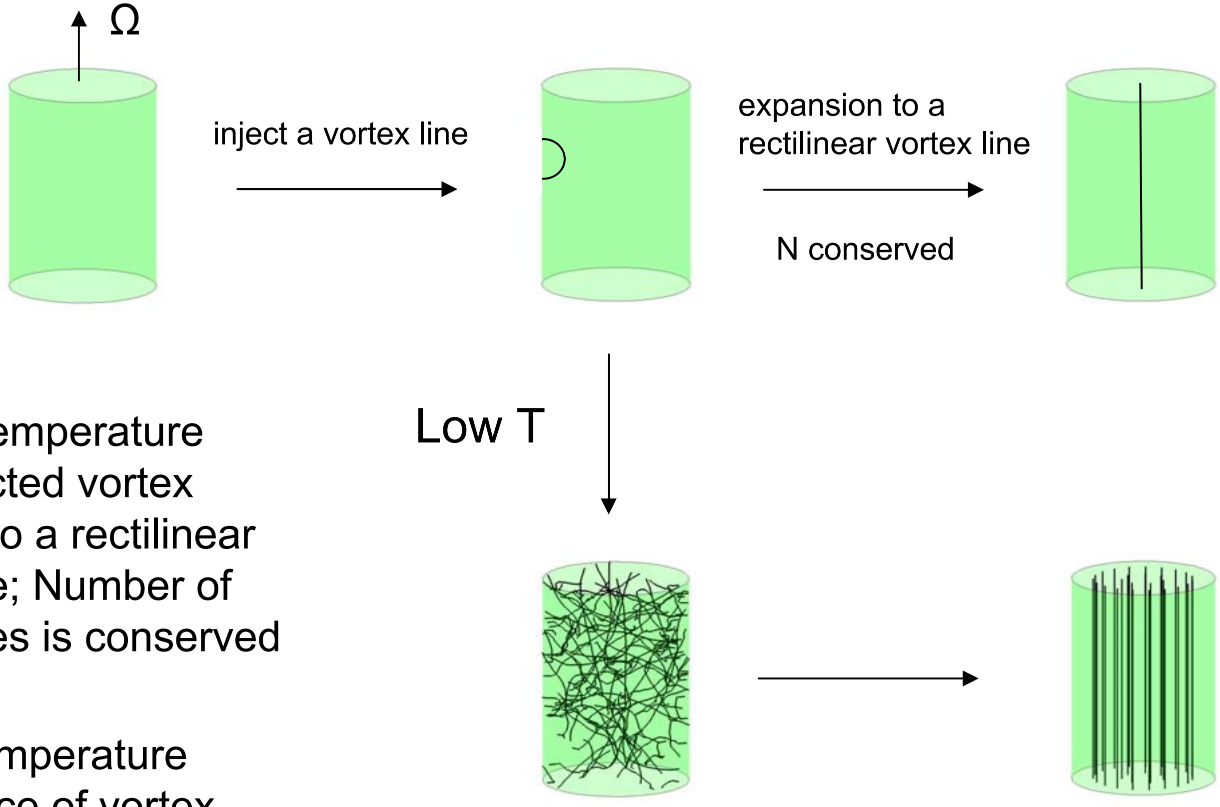
solid-body rotation



- minimum energy state
- superfluid mimics solid-body rotation
- total number of vortex lines:

$$N = \pi R^2 \frac{2\Omega}{\kappa}$$

Overview of the Experiment



High T

Ω

inject a vortex line

expansion to a rectilinear vortex line

N conserved

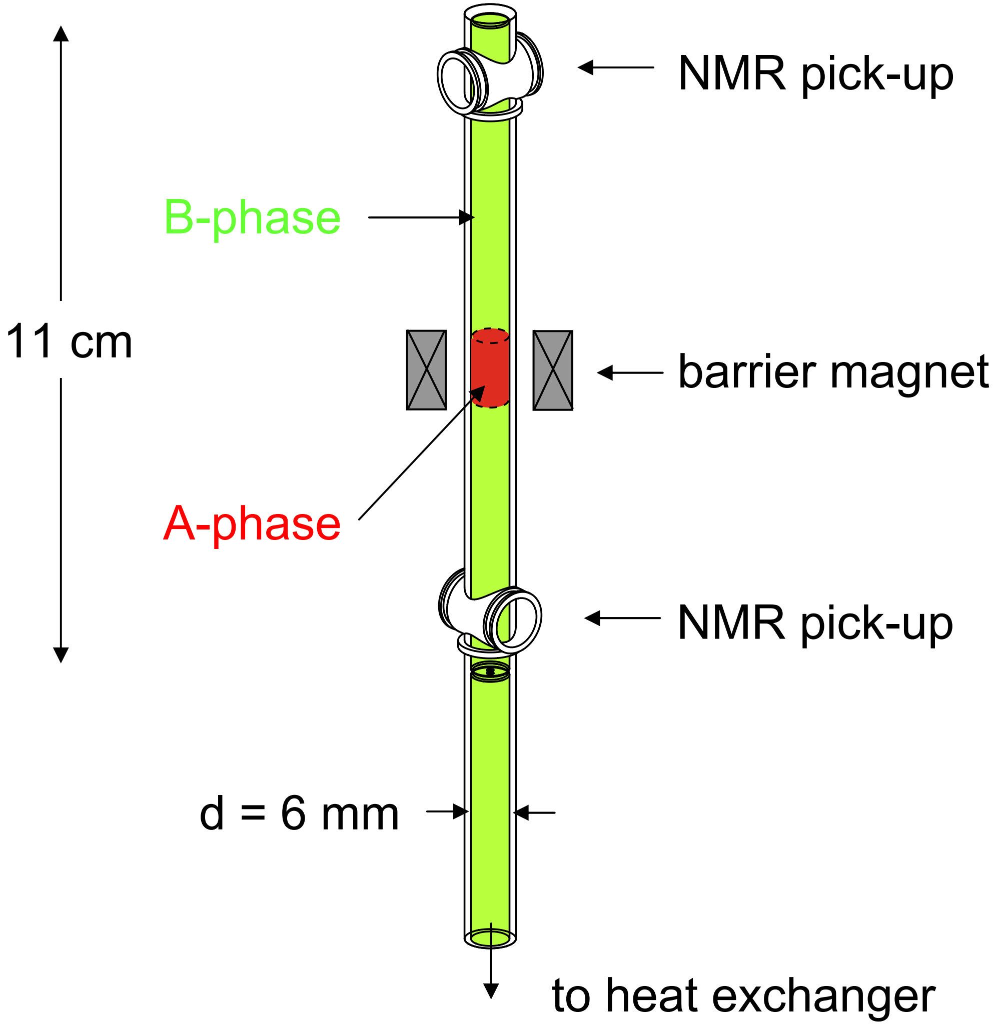
Low T

Equilibrium amount of vortex lines

- At high temperature each injected vortex expands to a rectilinear vortex line; Number of vortex lines is conserved

- At low temperature appearance of vortex loops usually leeds to equilibrium number of vortex lines

Experimental setup



11 cm

B-phase

A-phase

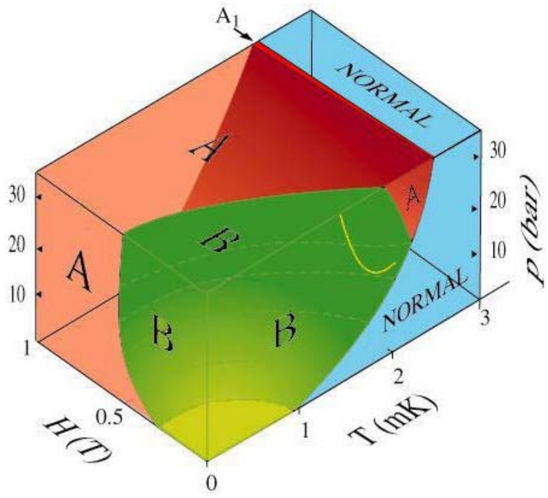
d = 6 mm

NMR pick-up

barrier magnet

NMR pick-up

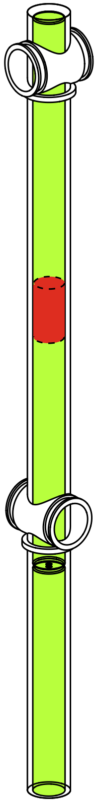
to heat exchanger



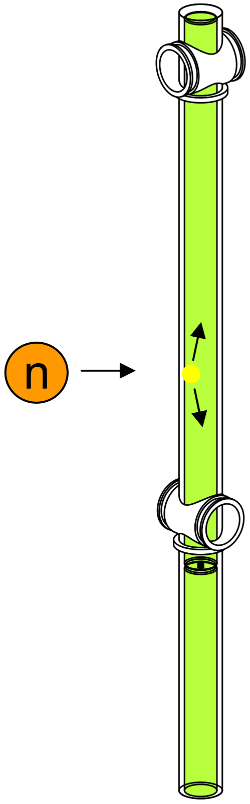
- Rotation up to 4 rad/s
- Magnetically stabilized AB phase boundary for vortex line injection

Mechanisms for vortex formation

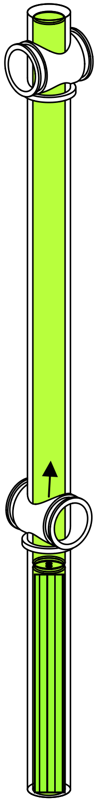
Shear-flow instability of AB interface



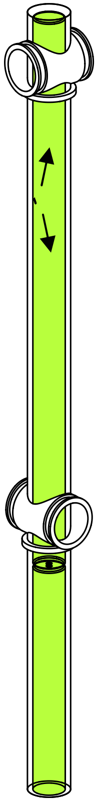
Kibble-Zurek after neutron capture



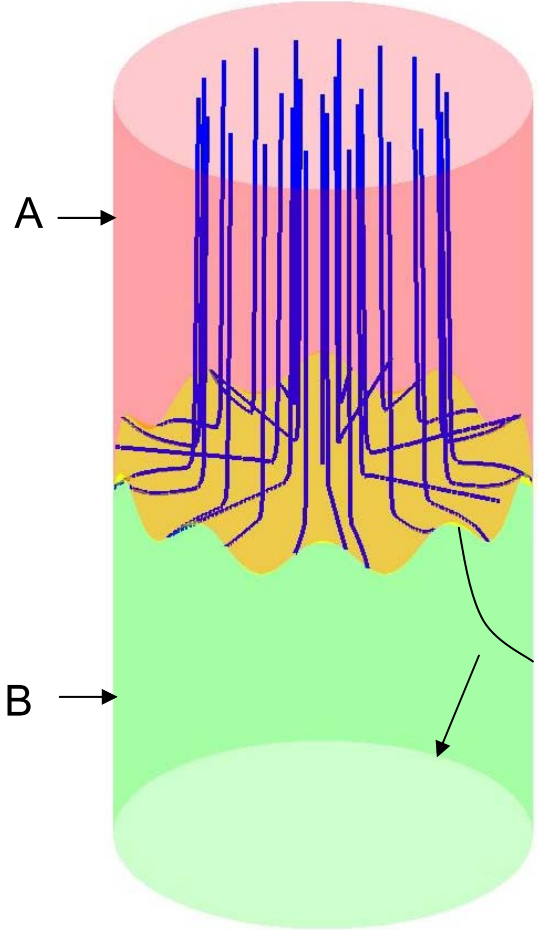
Flow through orifice



Wall defect

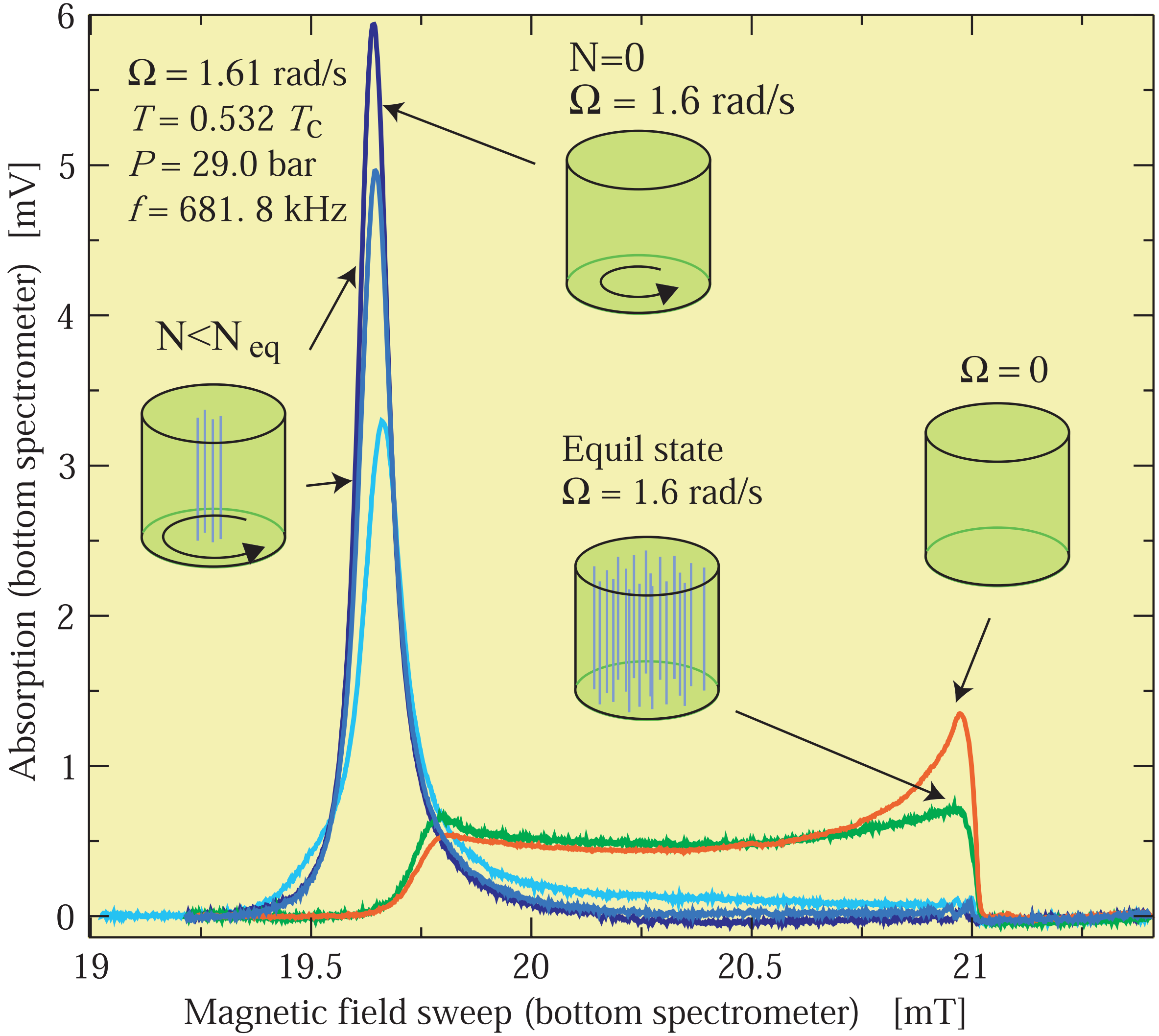


Shear-flow instability of the AB phase boundary



- A phase has low Ω_c and B phase high Ω_c
  - A mimics solid body rotation
  - B does not move
- Under rotation a velocity difference between the superfluids form, ”wind”
- Phase boundary becomes unstable and vortex lines are injected to the B phase
- Number of vortex lines injected N~10
- Velocity where vortex lines are injected can be tuned with magnetic field

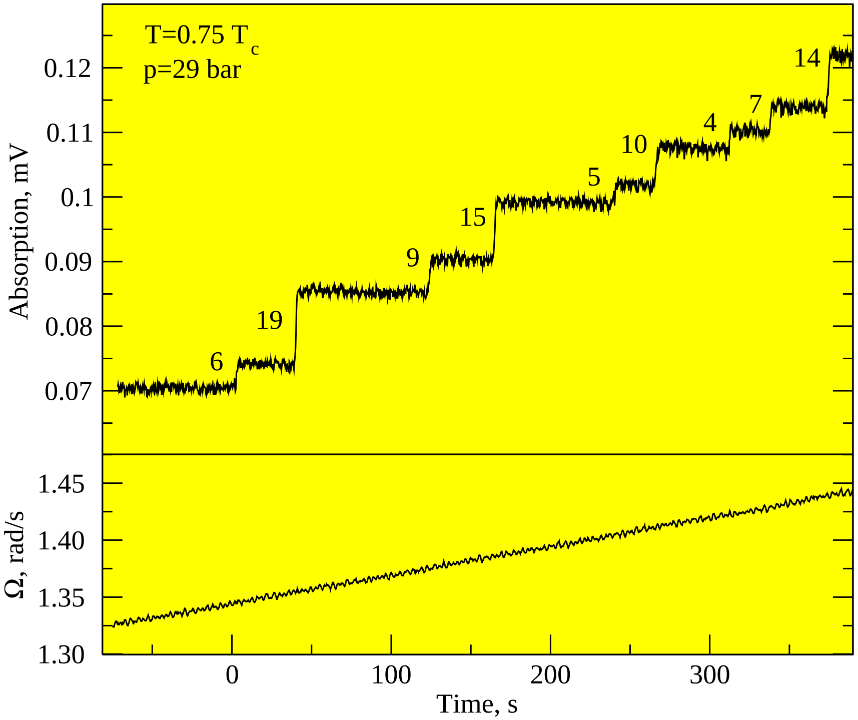
NMR on ^{3}He-B



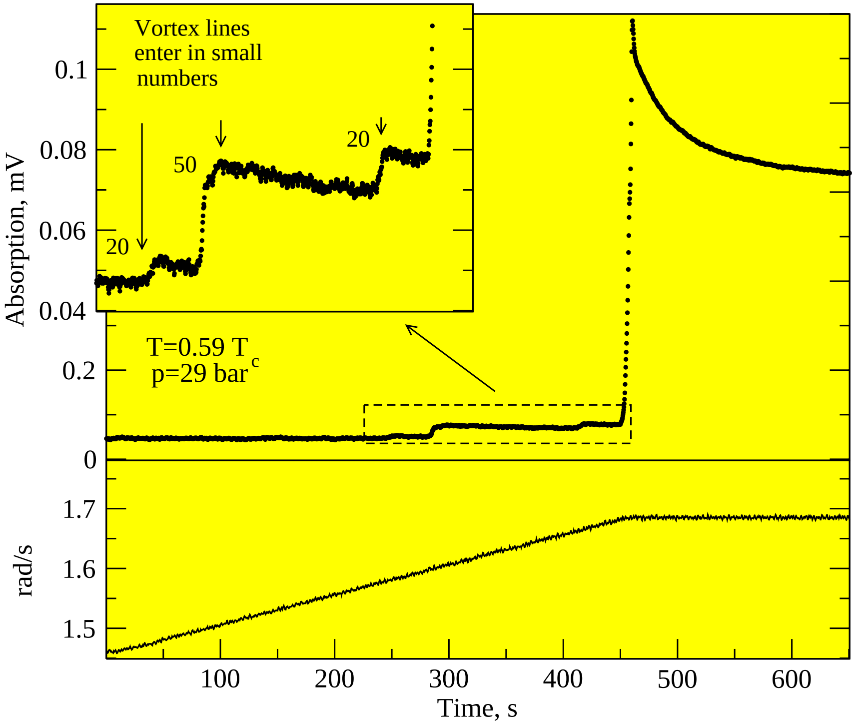
Ω = 1.61 rad/s
T = 0.532 Tc
P = 29.0 bar
f = 681. 8 kHz
N=0
Ω = 1.6 rad/s
N<N eq
Ω = 0
Equil state
Ω = 1.6 rad/s
0
1
2
3
4
5
6
19
19.5
20
20.5
21
Absorption (bottom spectrometer) [mV]
Magnetic field sweep (bottom spectrometer) [mT]

Vortex formation at high T

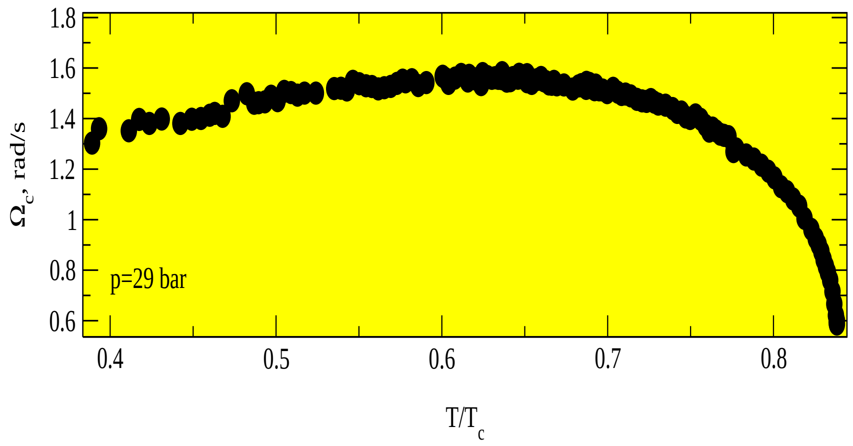
High T

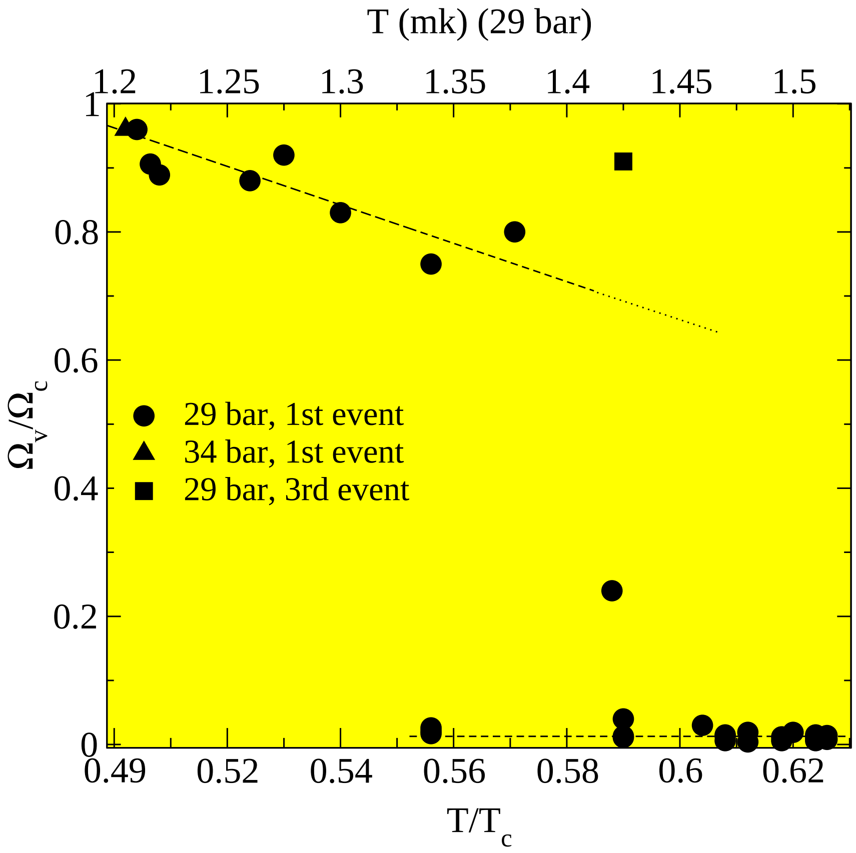


Low T

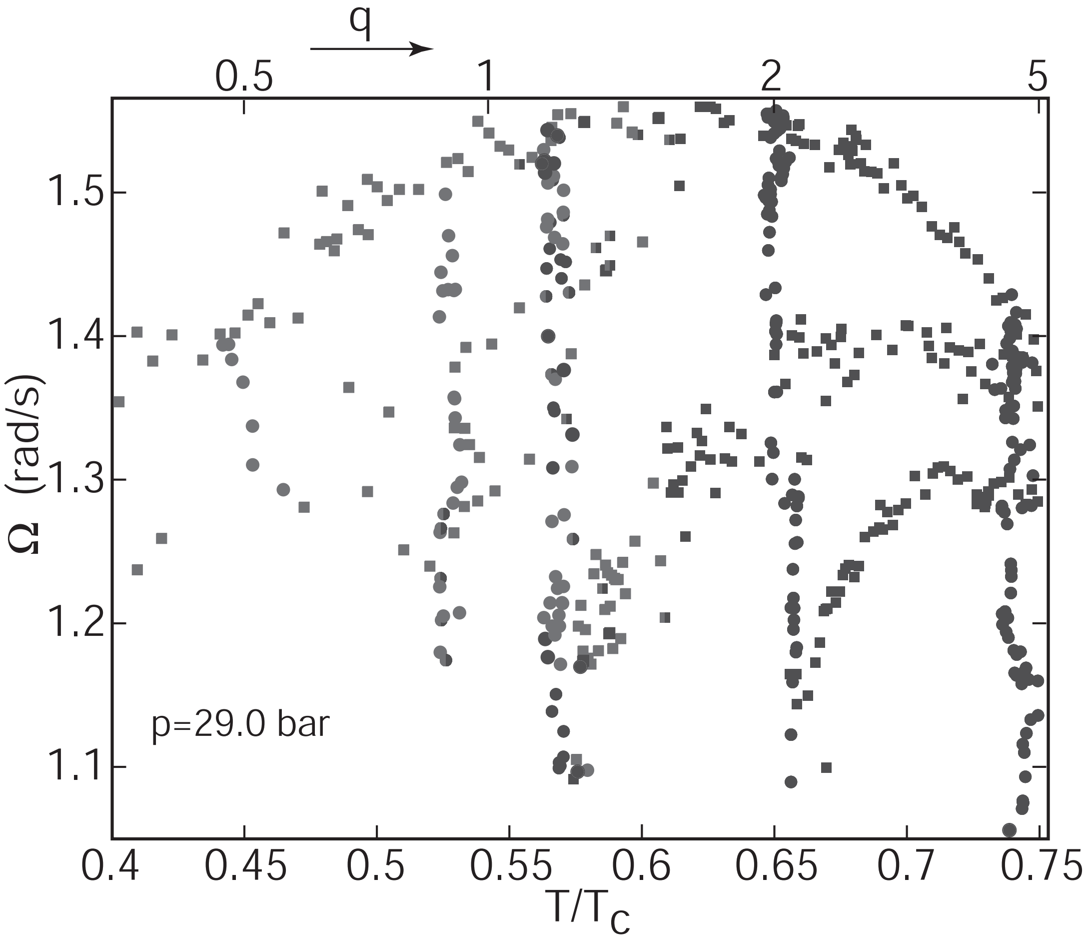


Number of vortex lines per event as a function of T

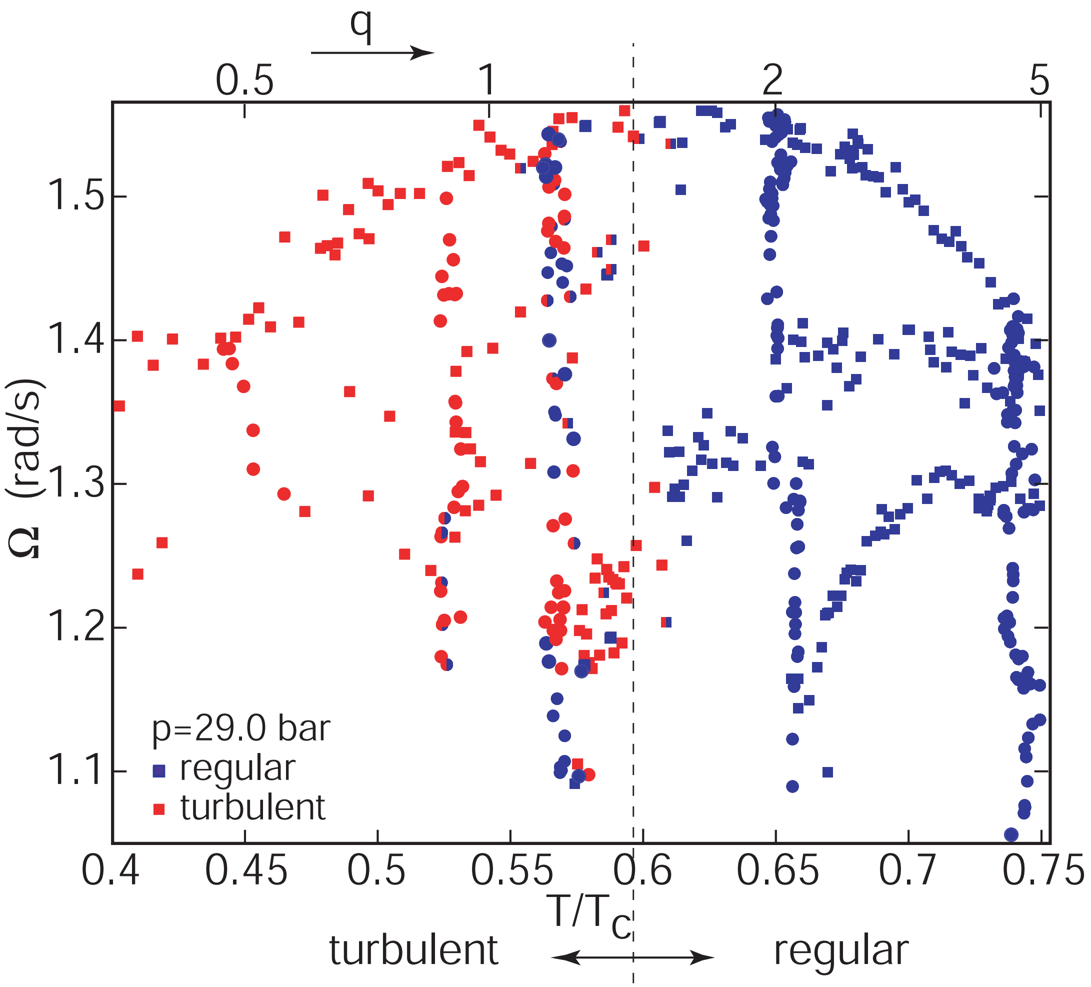




Transition to turbulence



Transition to turbulence



Discussion

For classical liquids, taking $\omega = \nabla \times v$

$$\frac{\partial \omega}{\partial t} = \underbrace{\nabla \times [v \times \omega]}_{\text{inertial} \sim U\omega/R} + \underbrace{v \nabla \omega}_{\text{viscous} \sim v\omega/R^2}$$

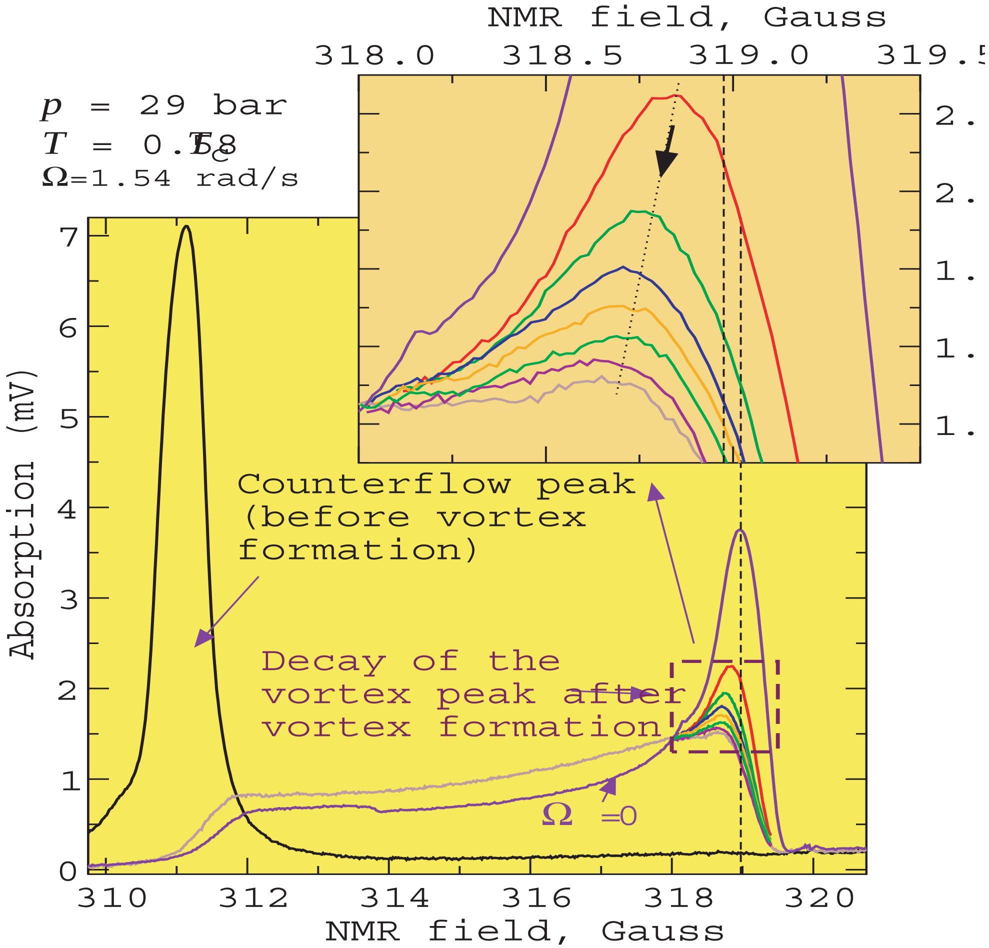
$$\frac{\text{inertial}}{\text{viscous}} = Re = UR/v > 1 \longrightarrow \text{turbulence}$$

For superfluids with v_n=0, Re_s=UR/κ >1 and $\omega_s = \langle \nabla \times v_s \rangle$ averaged over vortex lines

$$\frac{\partial \omega_s}{\partial t} = \underbrace{(1-\alpha')\nabla \times [v_s \times \omega_s]}_{\text{inertial} \sim (1-\alpha')U\omega/R} + \underbrace{\alpha \nabla \times [\hat{\omega}_s \times (\omega_s \times v_s)]}_{\text{viscous} \sim \alpha U\omega/R}$$

$$\frac{\text{inertial}}{\text{viscous}} = \frac{1-\alpha'}{\alpha}$$

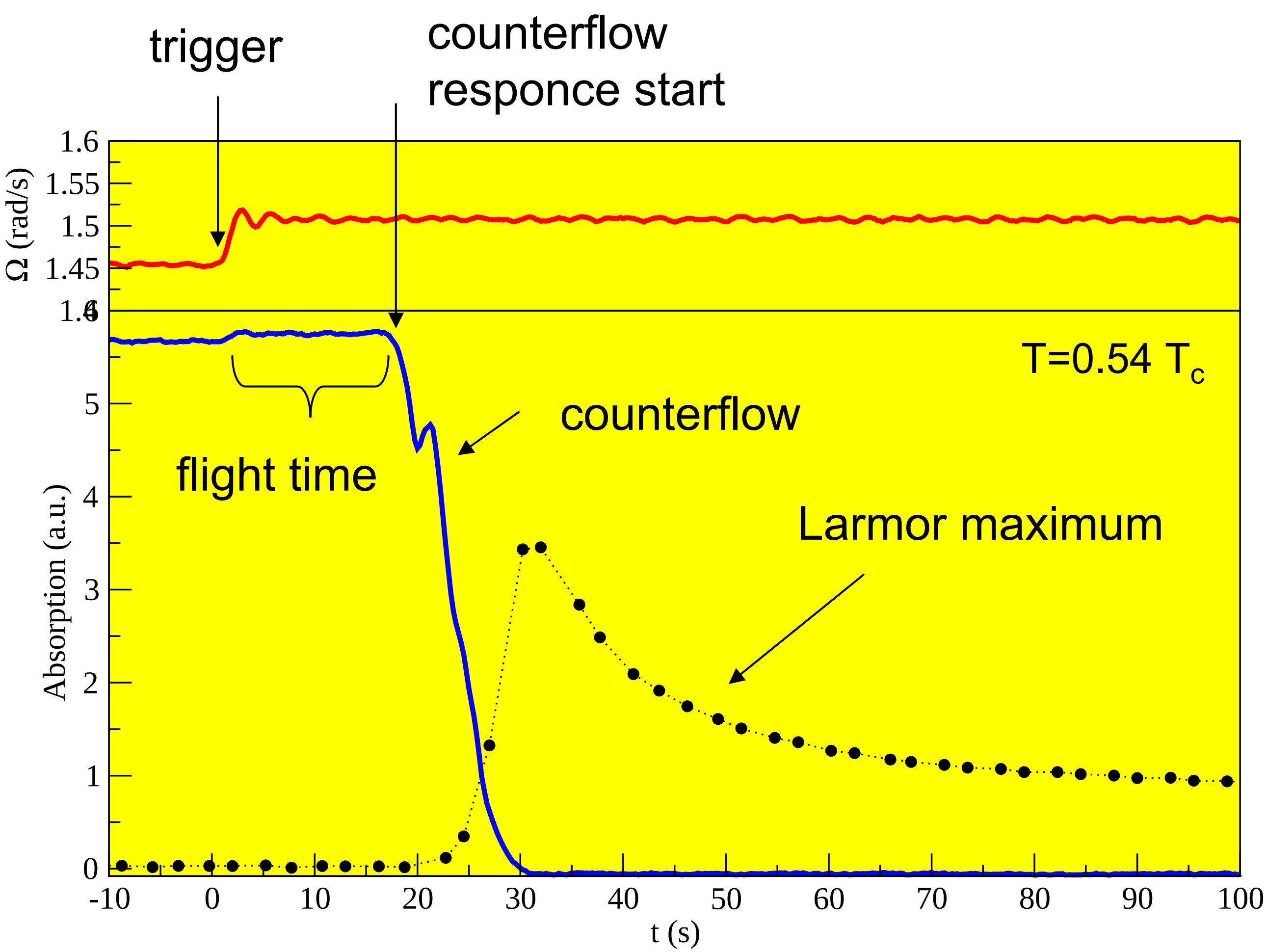
Spectra of turbulent events



Counterflow peak (before vortex formation)

Decay of the vortex peak after vortex formation

Timings



trigger

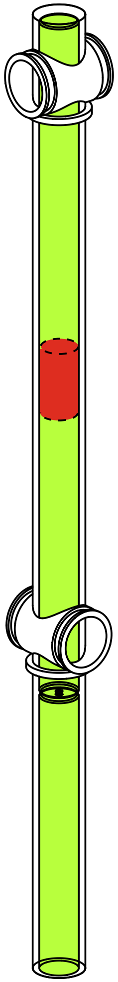
counterflow
responce start

flight time

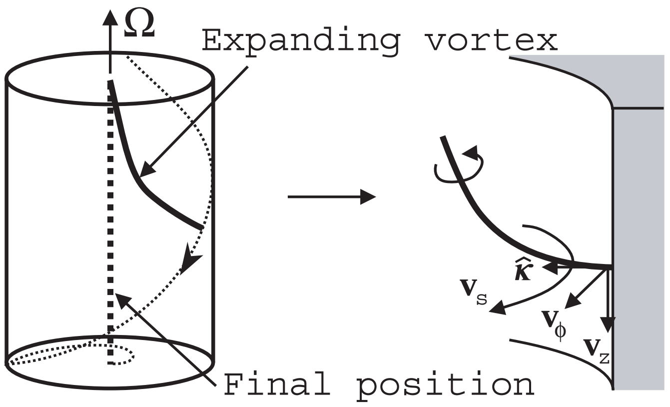
counterflow

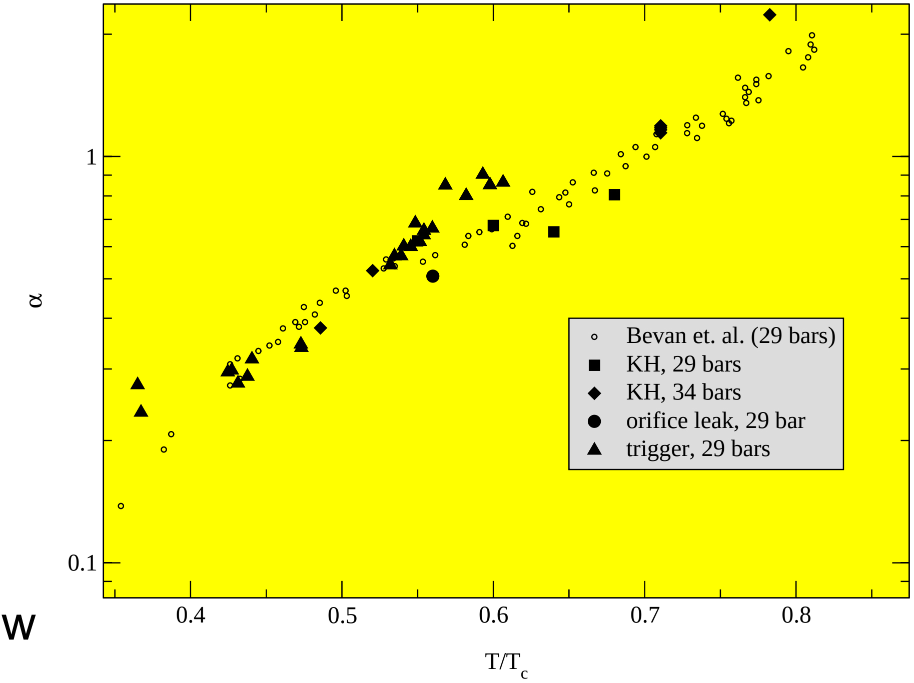
Larmor maximum

T=0.54 T_c



Flight time

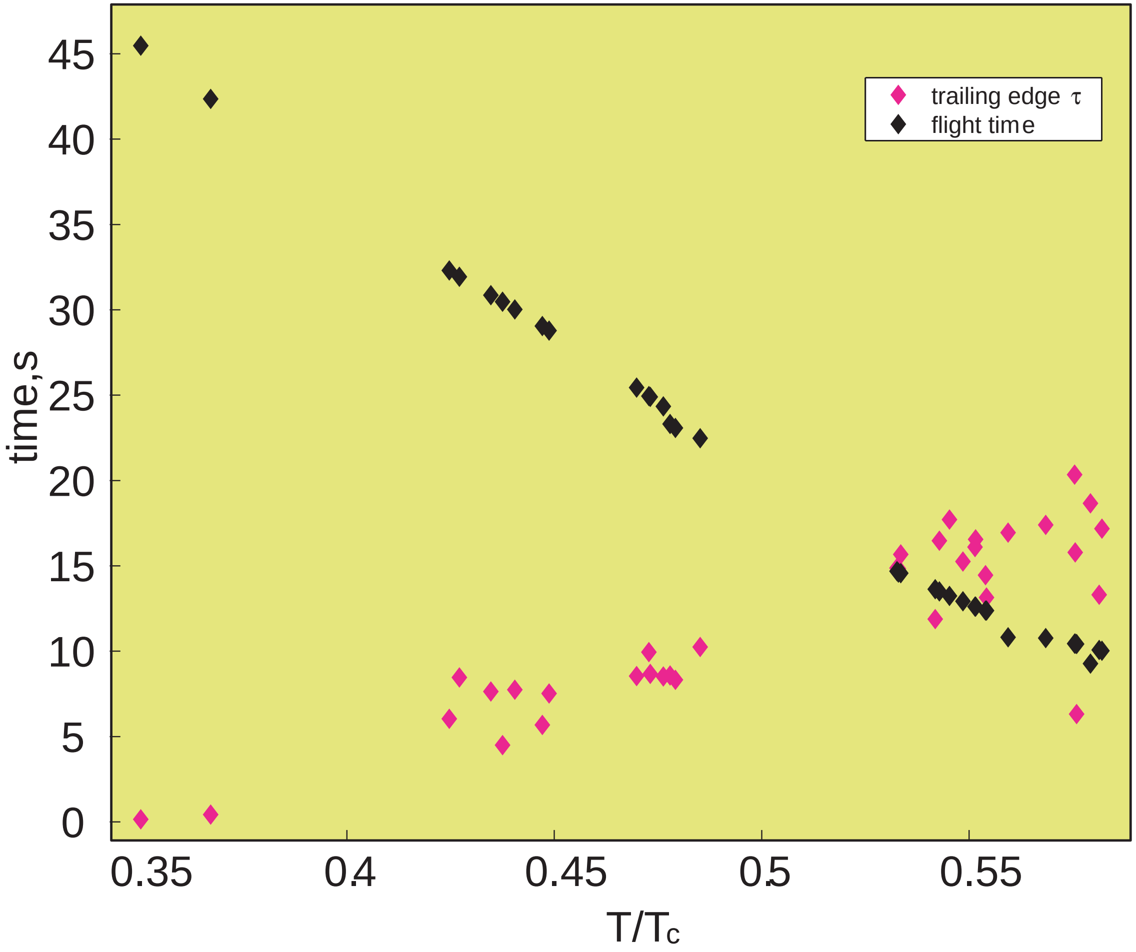




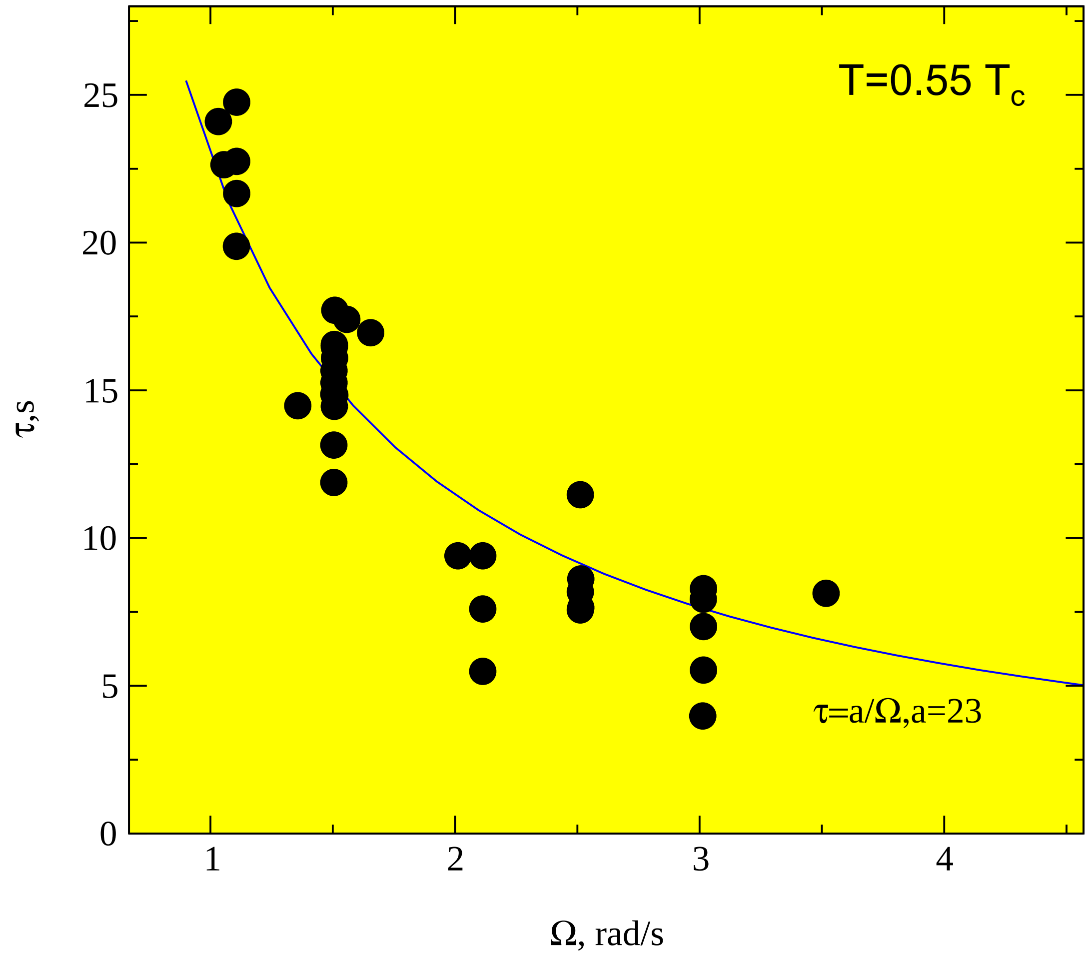
- The speed at which the turbulence expands to the vortex free counterflow

$$v_z = \Omega R \alpha$$

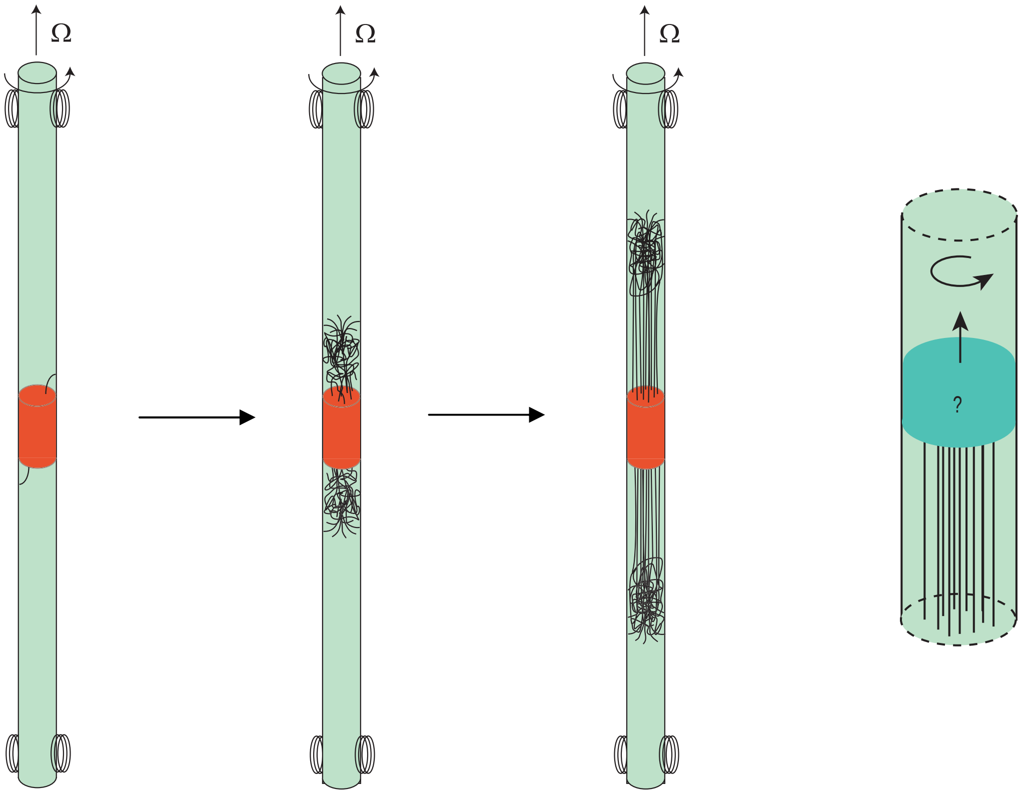
Trailing edge τ as a function of T



Trailing edge τ as a function of Ω



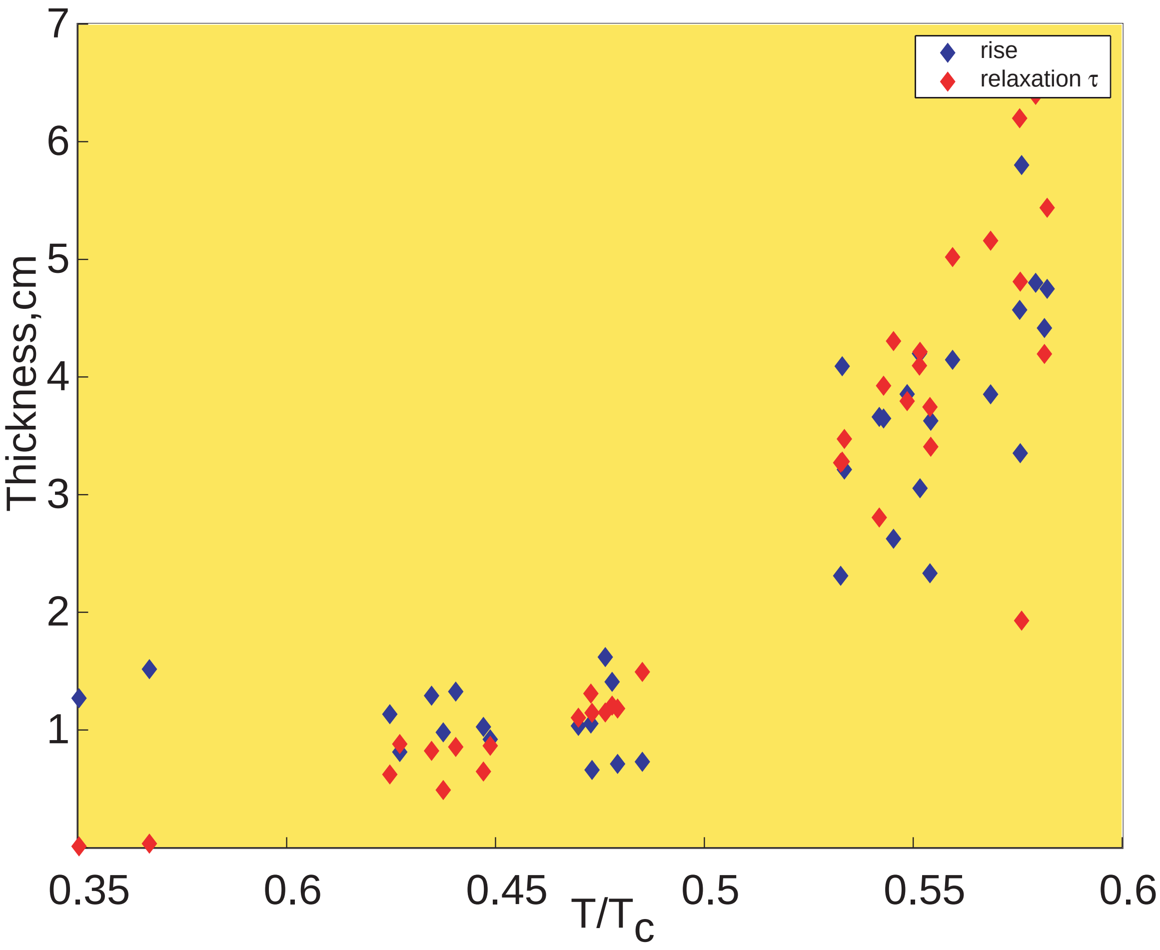
Experiment in scale



Counterflow
-no vortex lines

Equilibrum
vortex state

Layer thickness



Conclusions

- Two clear regimes in ^{3}He-B: laminar and turbulent
- In our experiment we see a ”turbulent layer” propagating through the sample
- Why does the trailing edge τ decrease towards lower T?