EuTuCHe, CERN 2007

Turbulence in Superfluid ^{4}He in the *T*~0 Limit

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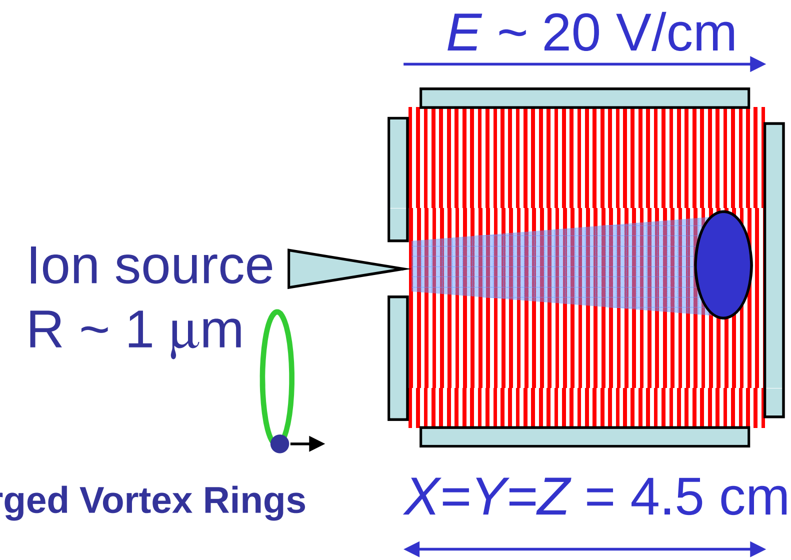
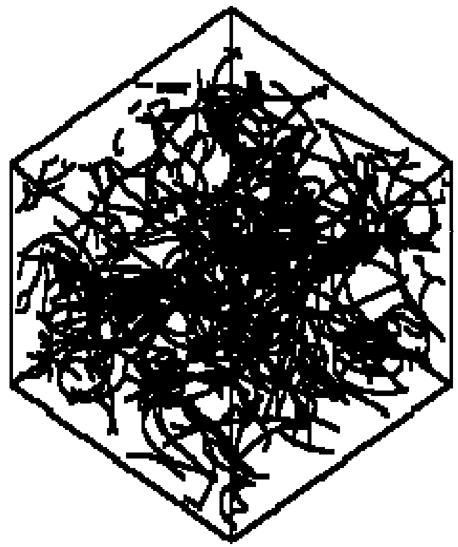


Charged Vortex Rings

Rotating Cryostat

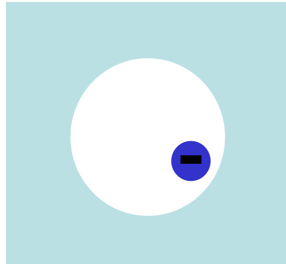


Vortex tangle

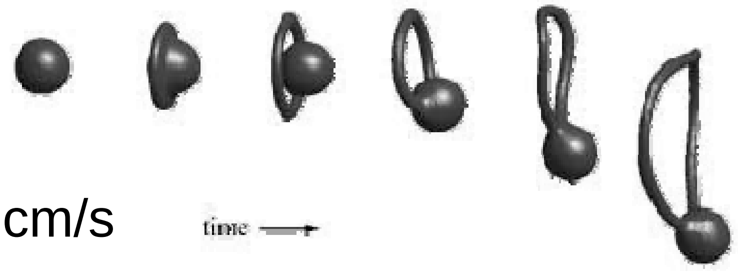
T ~ 0.1 K
^{4}He, *p* = 0

Ions in helium

In liquid helium, an injected electron creates a bubble of radius ~ 20 A



Vortex rings are nucleated by such ions at $T < 1$ K



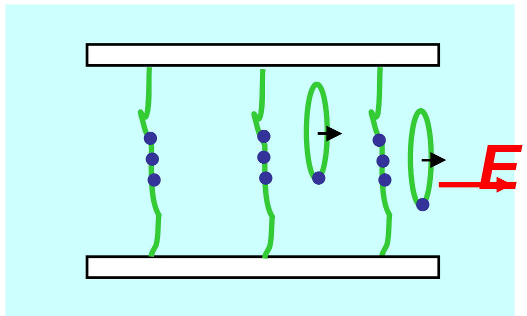
Ring dynamics: $KE \sim R$, $v \sim 1/R$

Initial rings: $KE_0 = 34$ eV, $R_0 = 0.8$ µm, $v = 10.6$ cm/s

After gaining another 90eV, $KE_f = 124$ eV, $R_f = 2.7$ µm
$\langle R \rangle = 2$ µm, $\langle v \rangle = 5$ cm/s

Ions are attracted to vortex lines (binding energy ~ 50 K)

Charged rings have large capture diameter ~ $2R = 4$ µm
(c.f. typical inter-vortex spacing of ~1000 µm)



Manchester facilities:

Rotating millikelvin cryostat ($T > 0.5$ mK, $\Omega < 1$ rev/s)

At the moment, we study 4He at T~0.1K, Cell volume: $(5\ \text{cm})^3$

Two turbulence generation techniques:

- Injection of ions
- Starting/stopping rotation

Hence, we can have both isotropic and polarised tangle; either neutral or charged

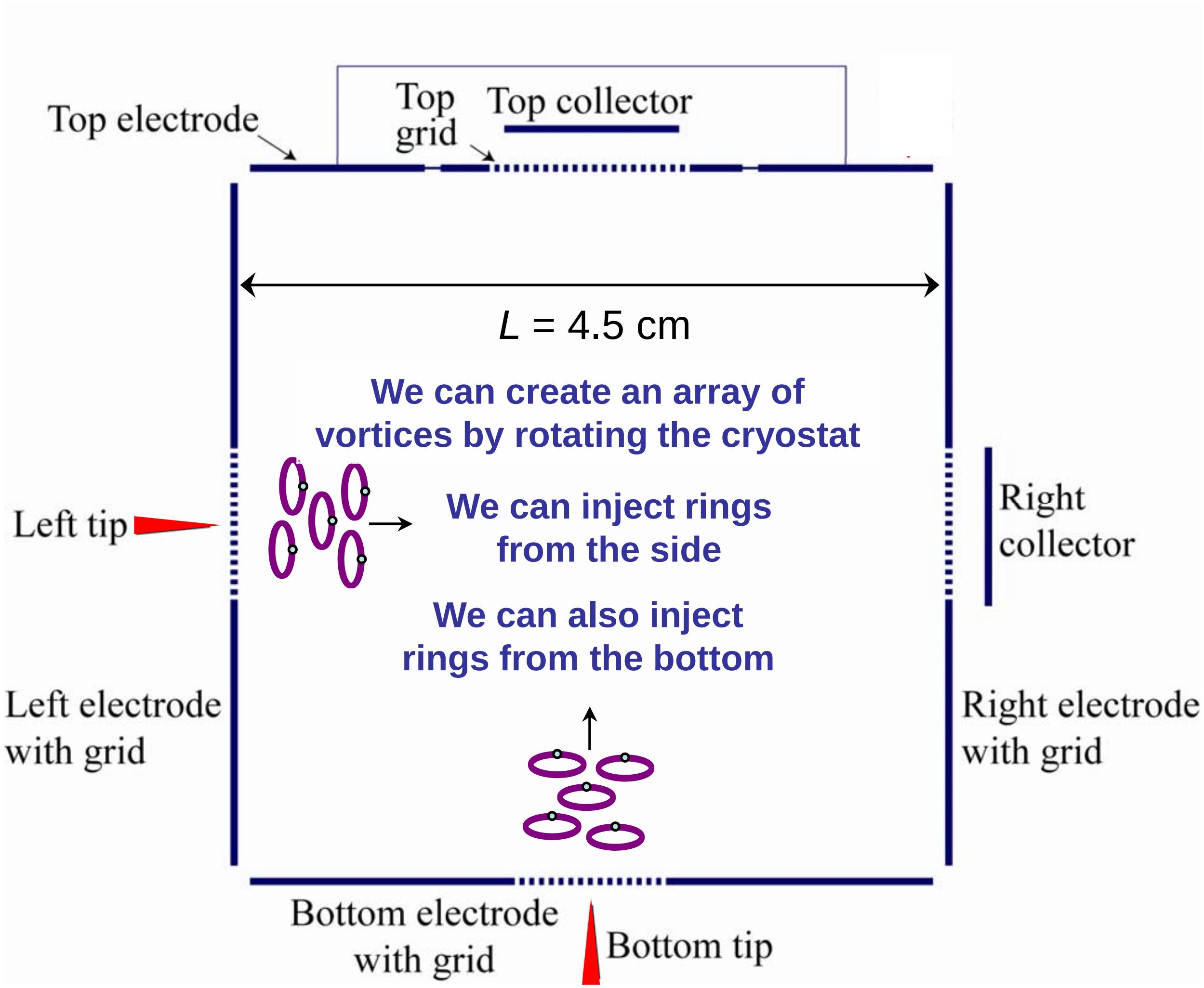
Detection technique: scattering (trapping) of ballistic charged vortex rings of R ~ 1 μm;

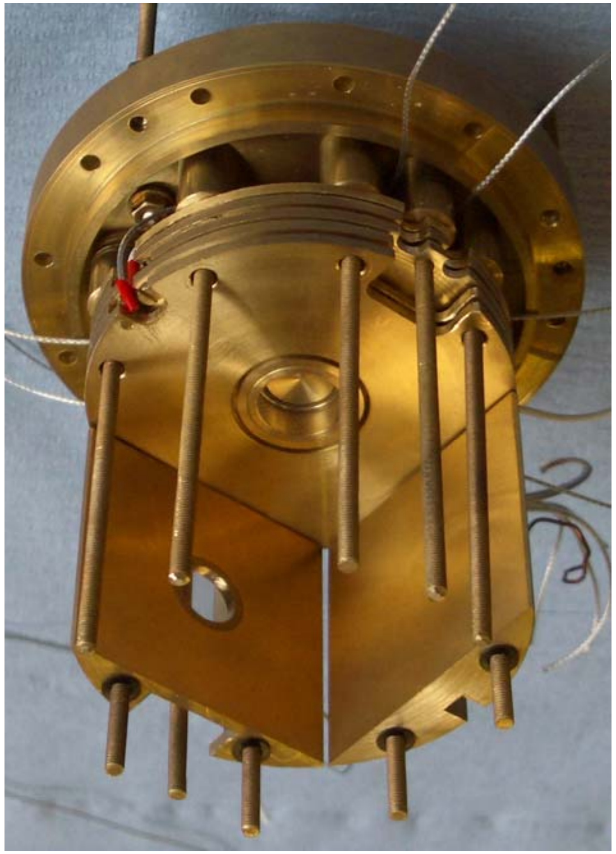
Convenient for tangles with $l = 1000 - 100$ μm ($L = 10^2 - 10^4$ cm^{-2}; $\omega = 0.1 - 10$ s^{-1})

Experimental Cell

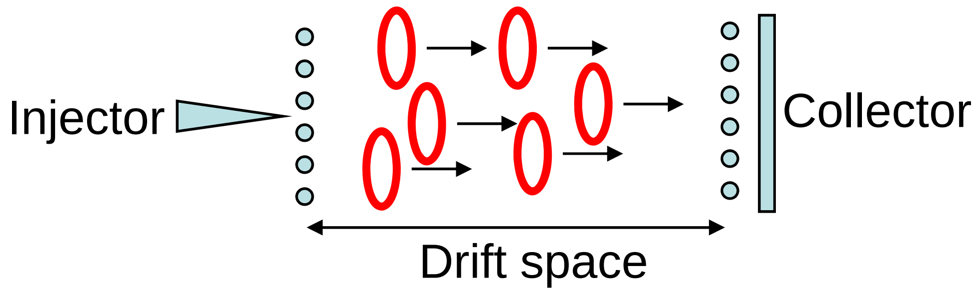
The experiment is a cube with sides of length 4.5 cm containing ^{4}He (P=0, T<0.2 K).

We can create a variety of electric fields to pull on the charged rings.

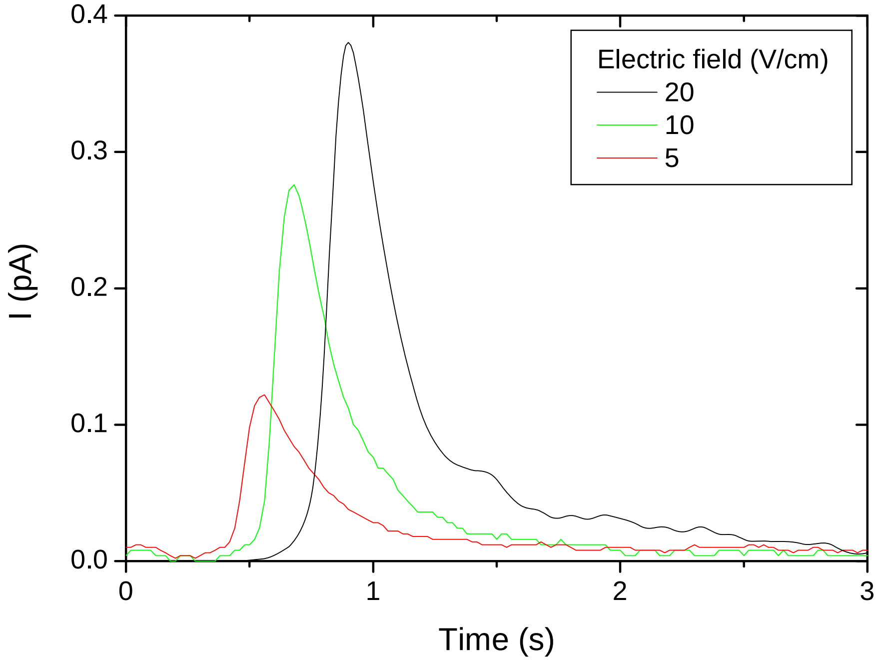




Properties of rings – short pulses

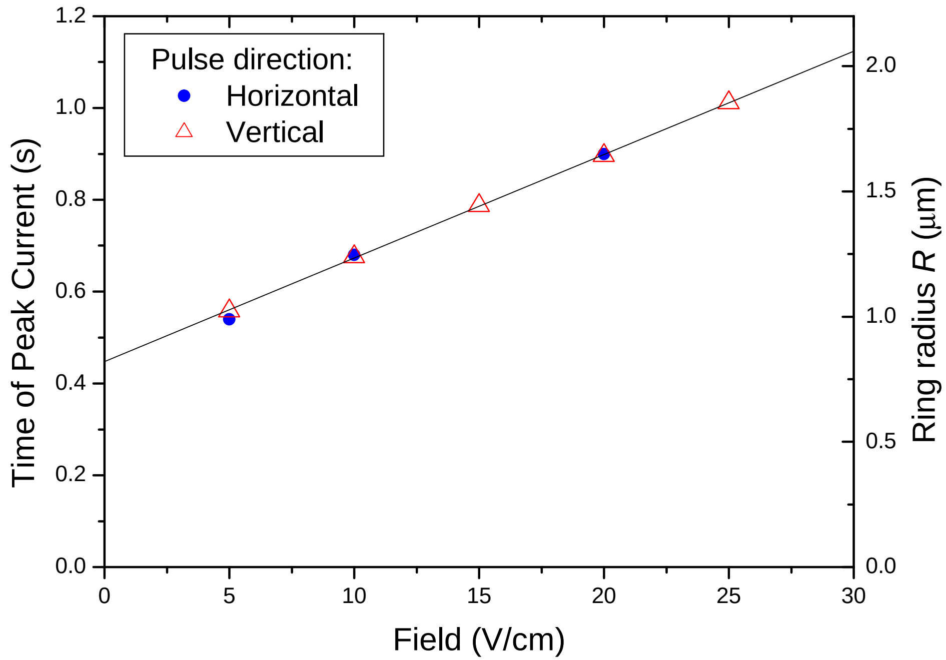


Current v electric field



Sharp peak indicates all rings have the same radius

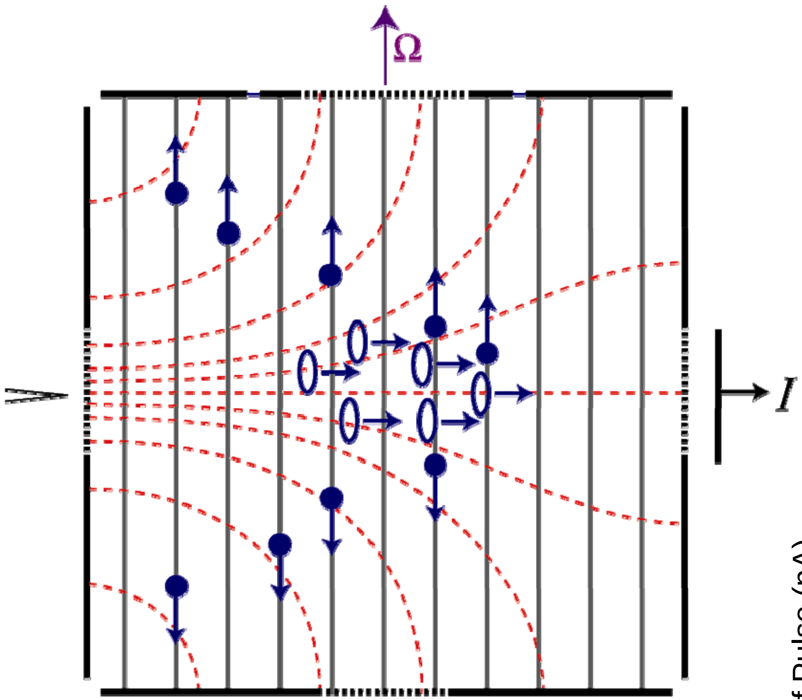
Arrival time v electric field



Rings have same radius whether emitted from the left or bottom tips

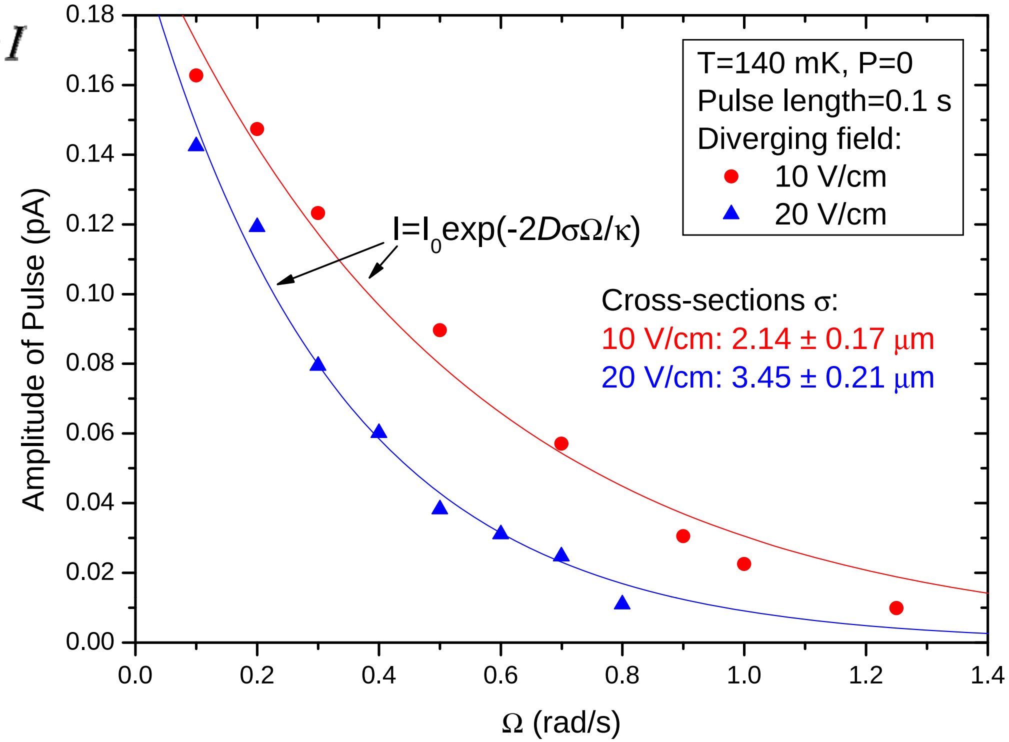
Interaction cross-section

Rotating the cryostat allows measurement of the ring-line interaction diameter, σ

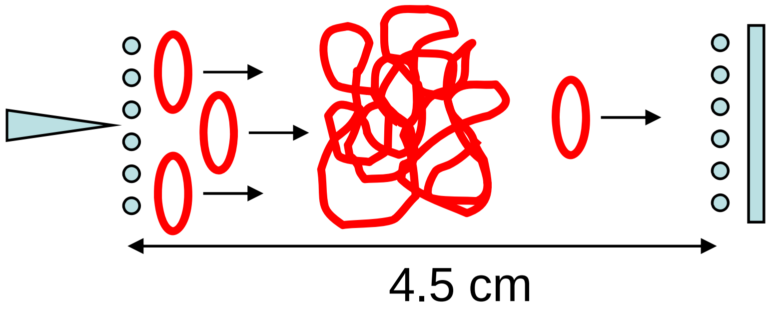


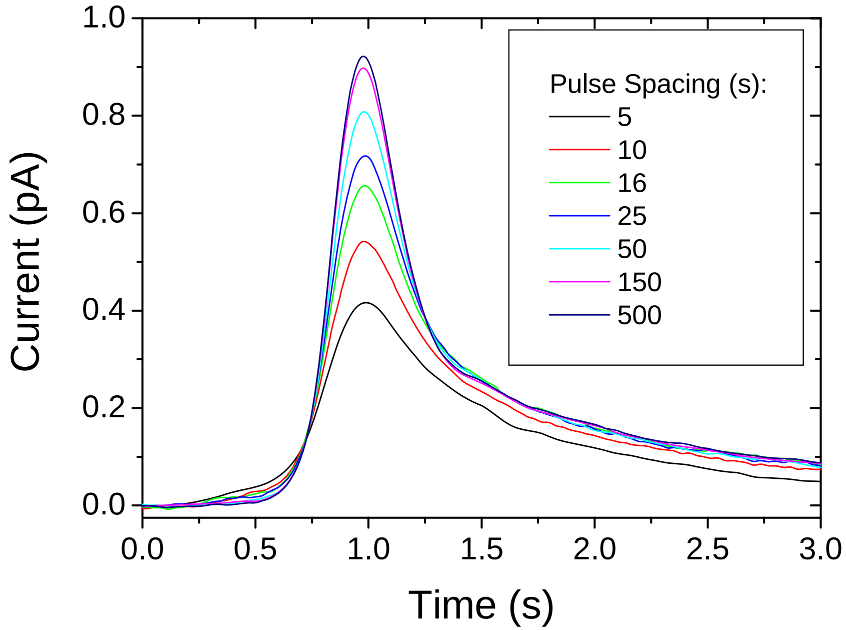
Schwarz and Donnelly (1966):

$$\sigma \sim 2R$$



Vortex Tangles

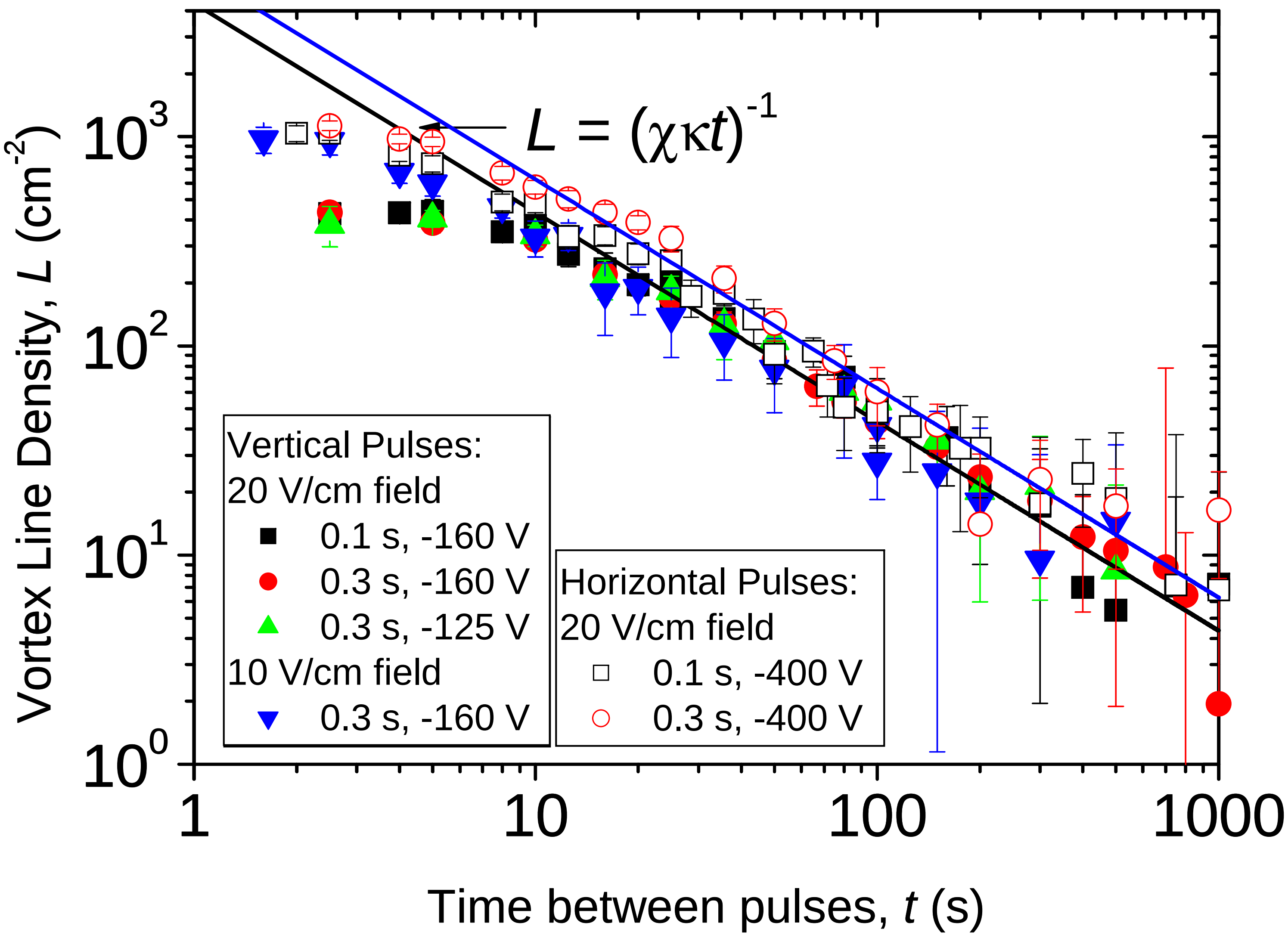




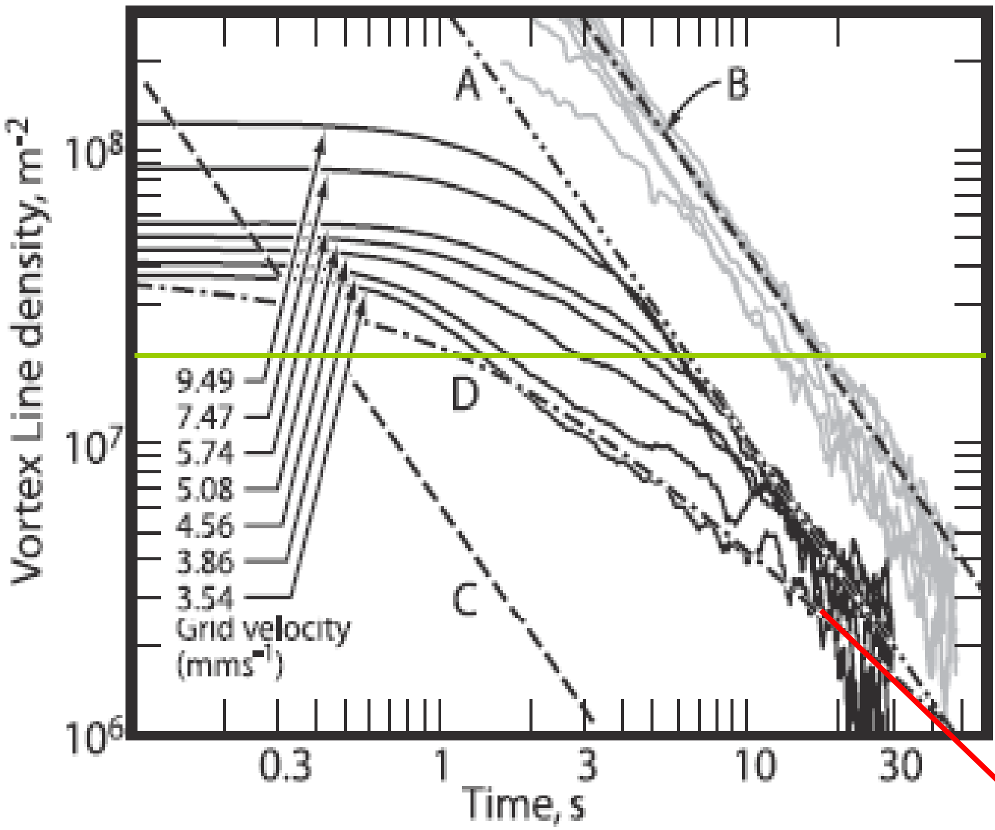
We can convert current into vortex line density *L*, $I = I_0 \exp(-L\sigma D)$

The decay appears to follow the Vinen's equation:

$dL/dt = -\chi\kappa L^2$, meaning that **$L = (\chi\kappa t)^{-1}$** - χ contains details of the decay mechanism



Comparison with 3He-B experments



D.I.Bradley *et al*., PRL 96, 035301 (2006)

[^{3}He-B, $T \sim 0.15\ T_c$]

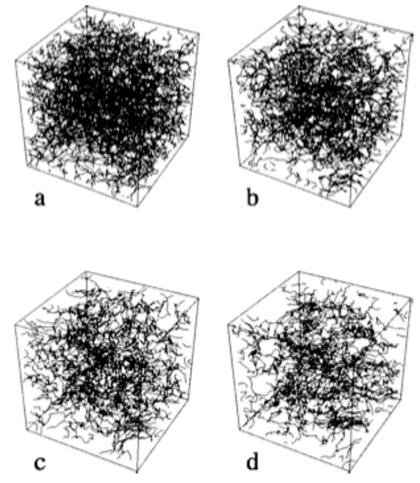


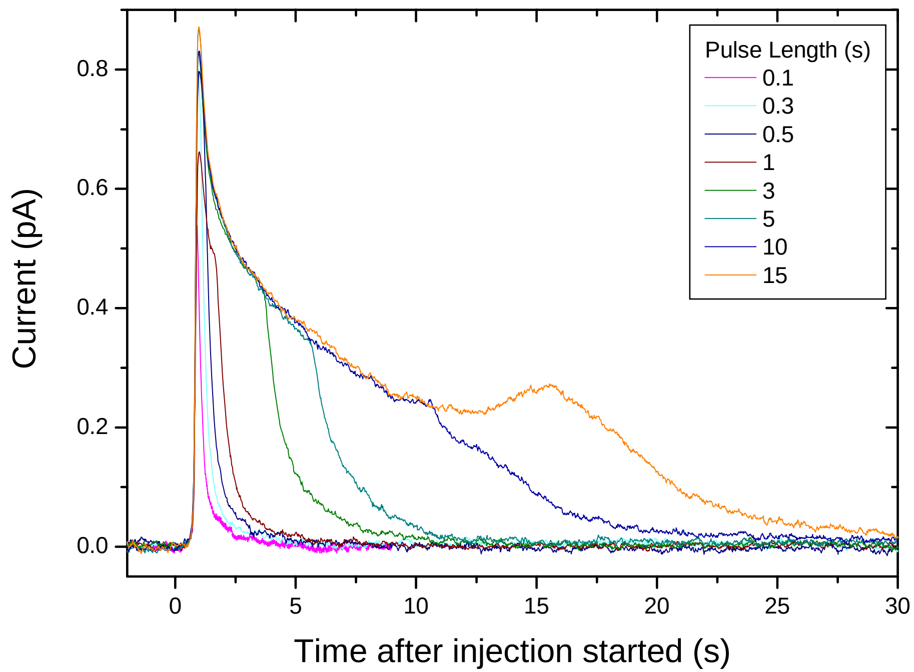
FIG. 9. Decay of a dense VT by the LIA calculation without the mutual friction. The system is a 1-cm^3 cube. A periodic boundary condition is used only along the vertical direction in these figures, while the other sets of faces are treated as smooth, rigid walls. The time is $t=0$ sec (a), 30 sec (b), 60 sec (c), and 90 sec (d).

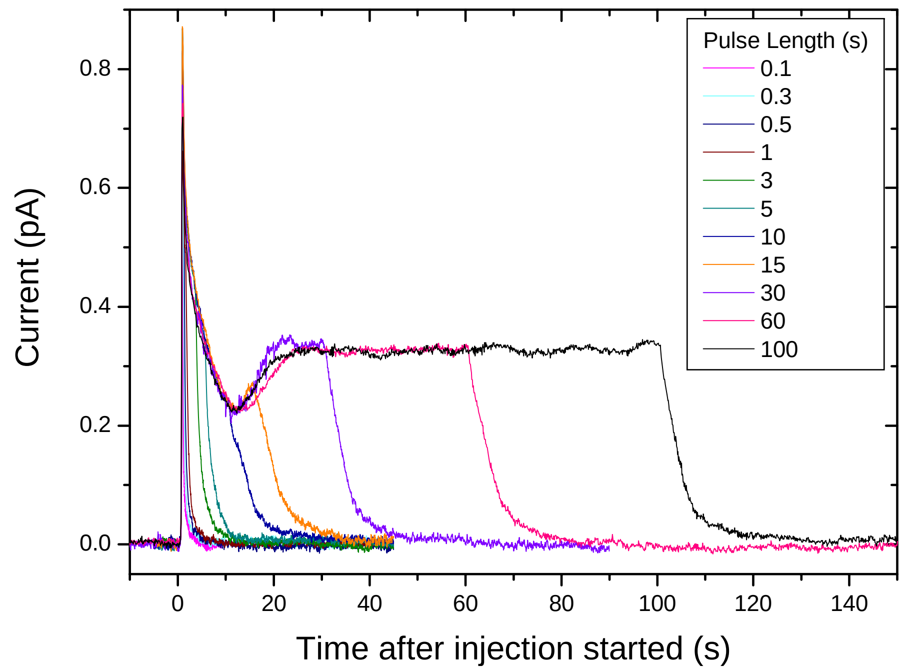
Walmsley et al. [^{4}He, $T \sim 0.1$ K]

Curve D: Vinen equation with $\chi = 0.3$

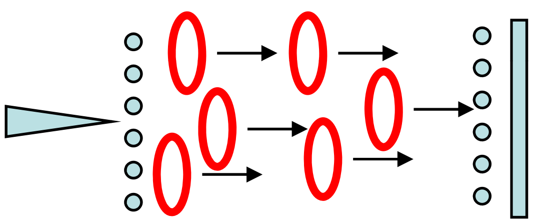
Creating Vortex Tangles

Pulse length = 0.1 – 15 s

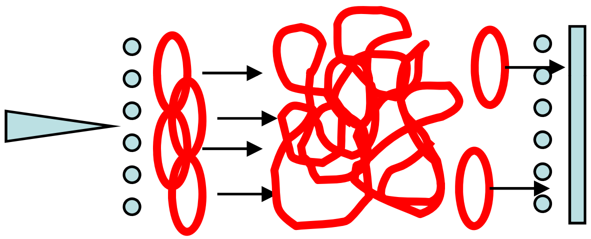




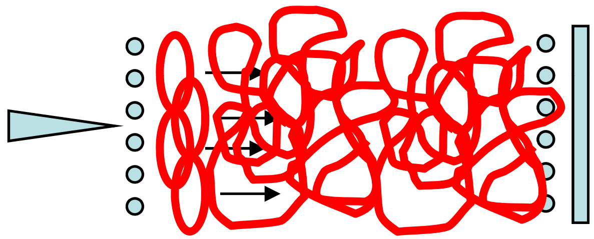
Short pulses (< 1 s):
Most rings propagate independently



Long pulses (3 - 5 s):
Rings collide and form tangle

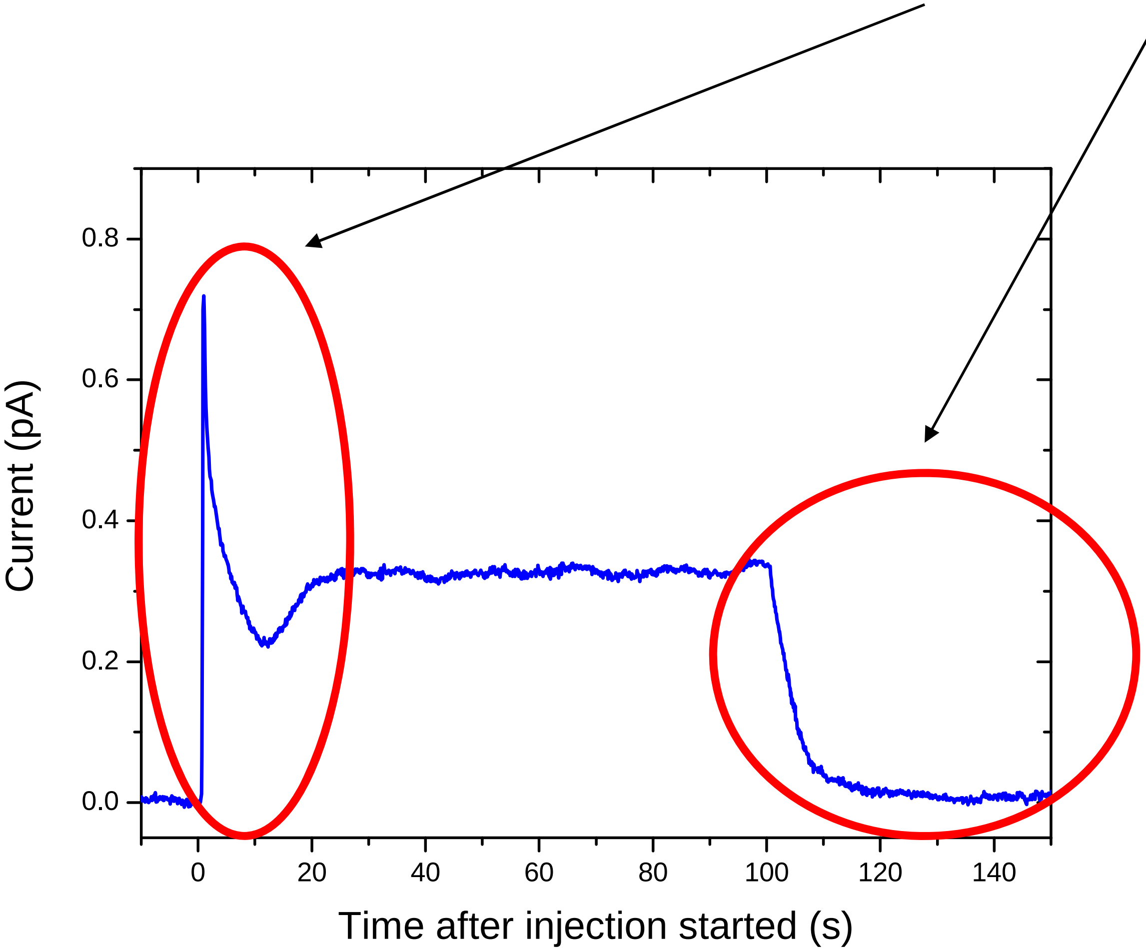


Longer pulses (>10 s):
Tangle reaches collector (occupies all drift spaces)



How does current relate to vortex line density?

What happens in the transient regions where the tangle grows and decays.

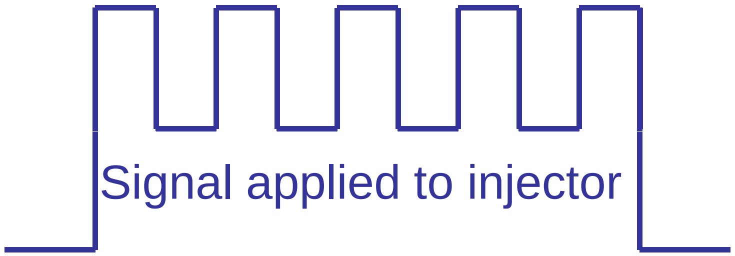


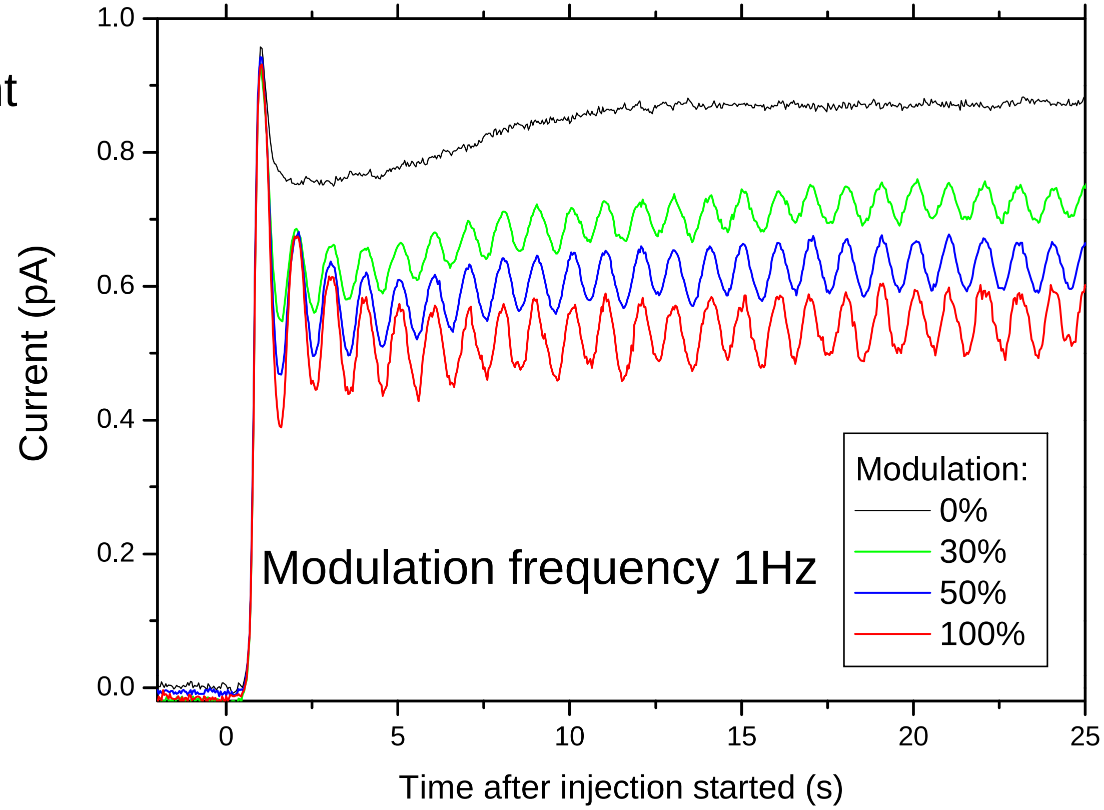
Tangle Growth

We can monitor the growth of vortex line density by adding an AC modulation to the pulse.

Some rings will contribute to the growth of the tangle and then help to sustain it.

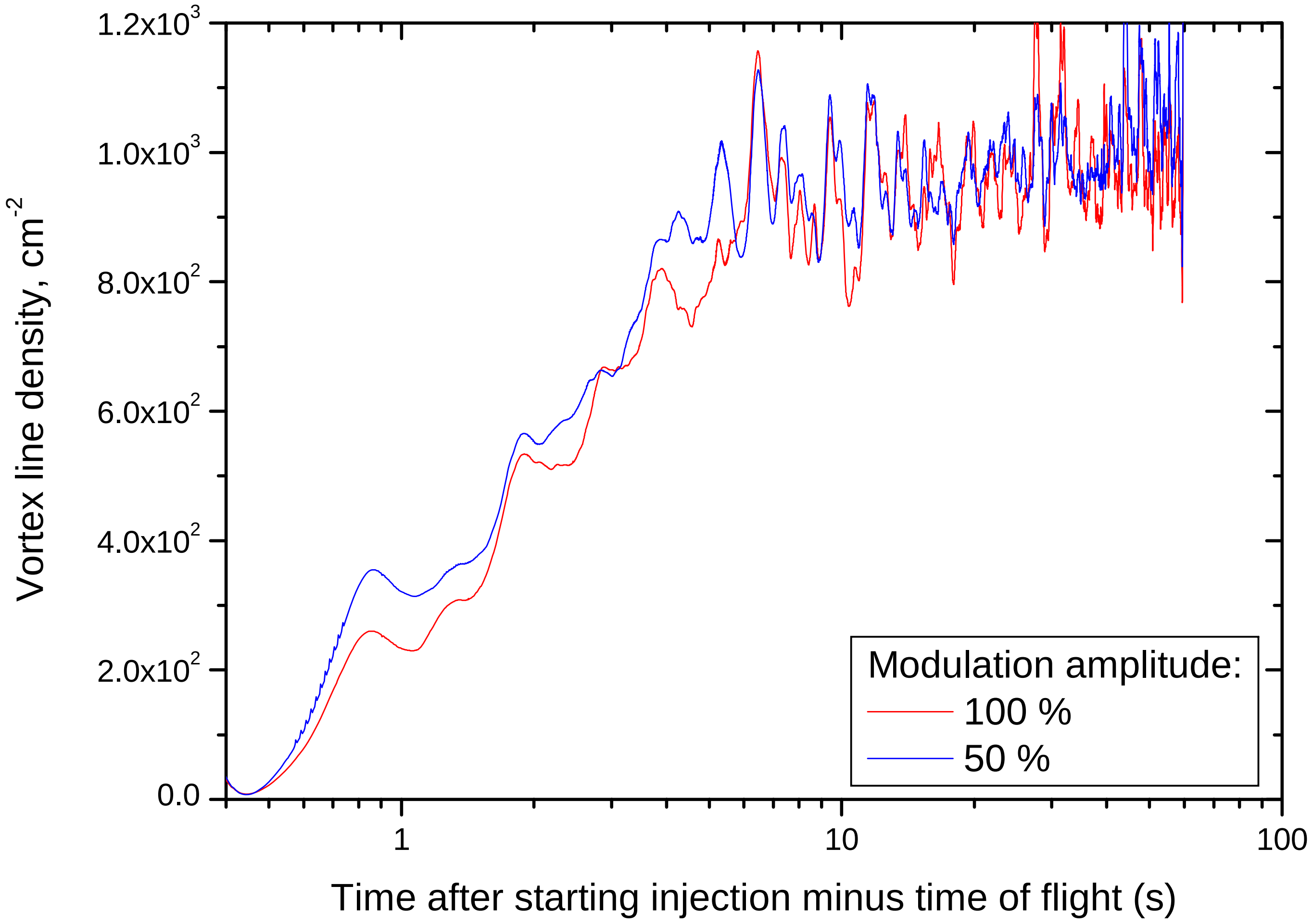
Other rings will travel straight through to the other side.





We can extract the signal at the modulation frequency and then obtain the vortex line density.

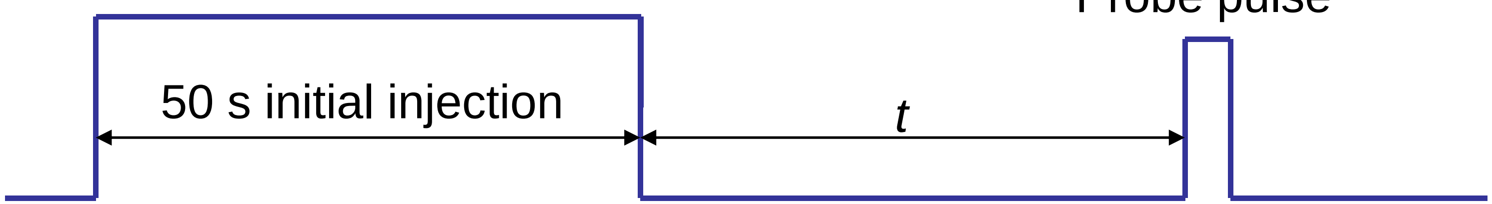
The vortex line density grows to 10^3 cm^{-2} in around 10 seconds.

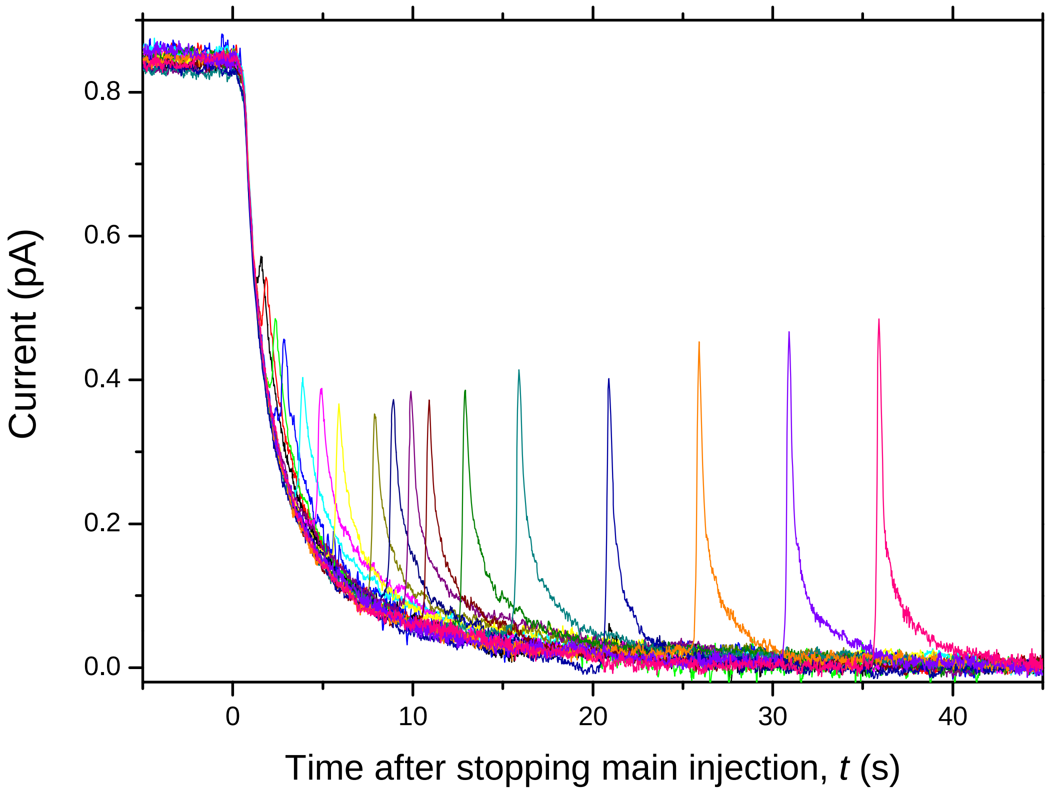


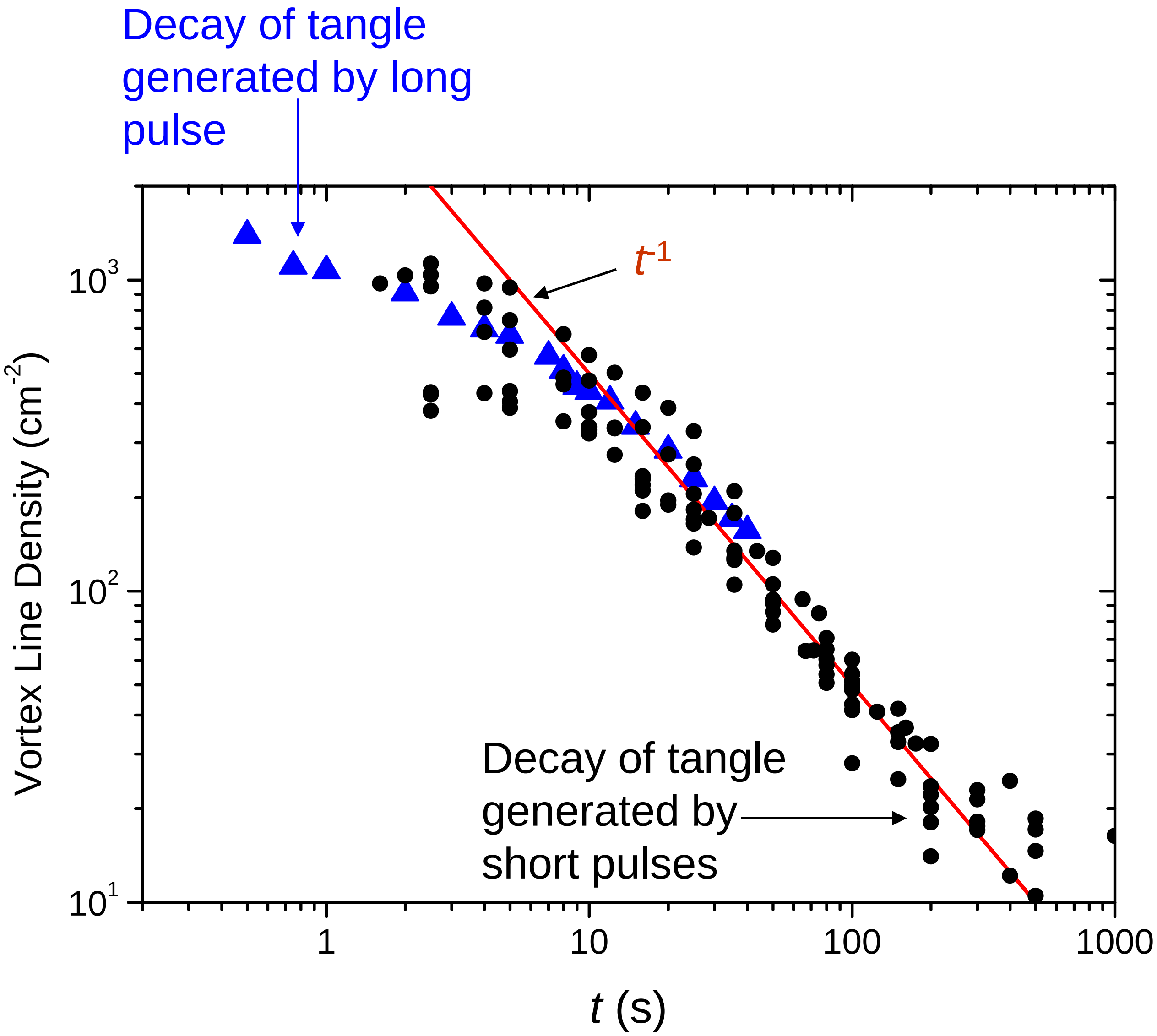
Tangle decay

We probe the decay after a long injection by sending a short pulse a time, *t*, after stopping injection.

Signal applied to injector:







Decay of tangle generated by long pulse
t^{-1}
Decay of tangle generated by short pulses
Vortex Line Density (cm^{-2})
10^3
10^2
10^1
1
10
100
1000
t (s)

Summary

- We have used charged vortex rings to create and probe turbulence in superfluid ^{4}He in the T~0 limit.
- A neutral tangle decays with $L = 1/(0.2\kappa t)$.
- The growth and decay of a charged vortex tangle have been studied.
- The characteristic time scale for growth is ~10 seconds. The time scale for decay is now being studied.

Back in 1966, Schwarz and Donnelly wrote: **"quantized vortex rings are very sensitive vortex-line detectors, making them suitable probes for a number of problems in quantum hydrodynamics."**

Outlook

• The ^4He experiment will be stopped in summer 2007 (because we have to resume ultra-low temperature experiments with vortices in ^3He)

• However, a new rotating facility ($T > 0.02$ K) is being conceived

• Experiments planned with:

- Pipe flow

- Jet flow

- Grid flow