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Decay at Low Temperatures in 4He

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Dynamics of charged vortex rings and tangles in the zero temperature limit

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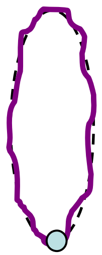
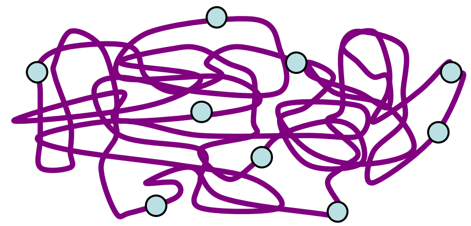
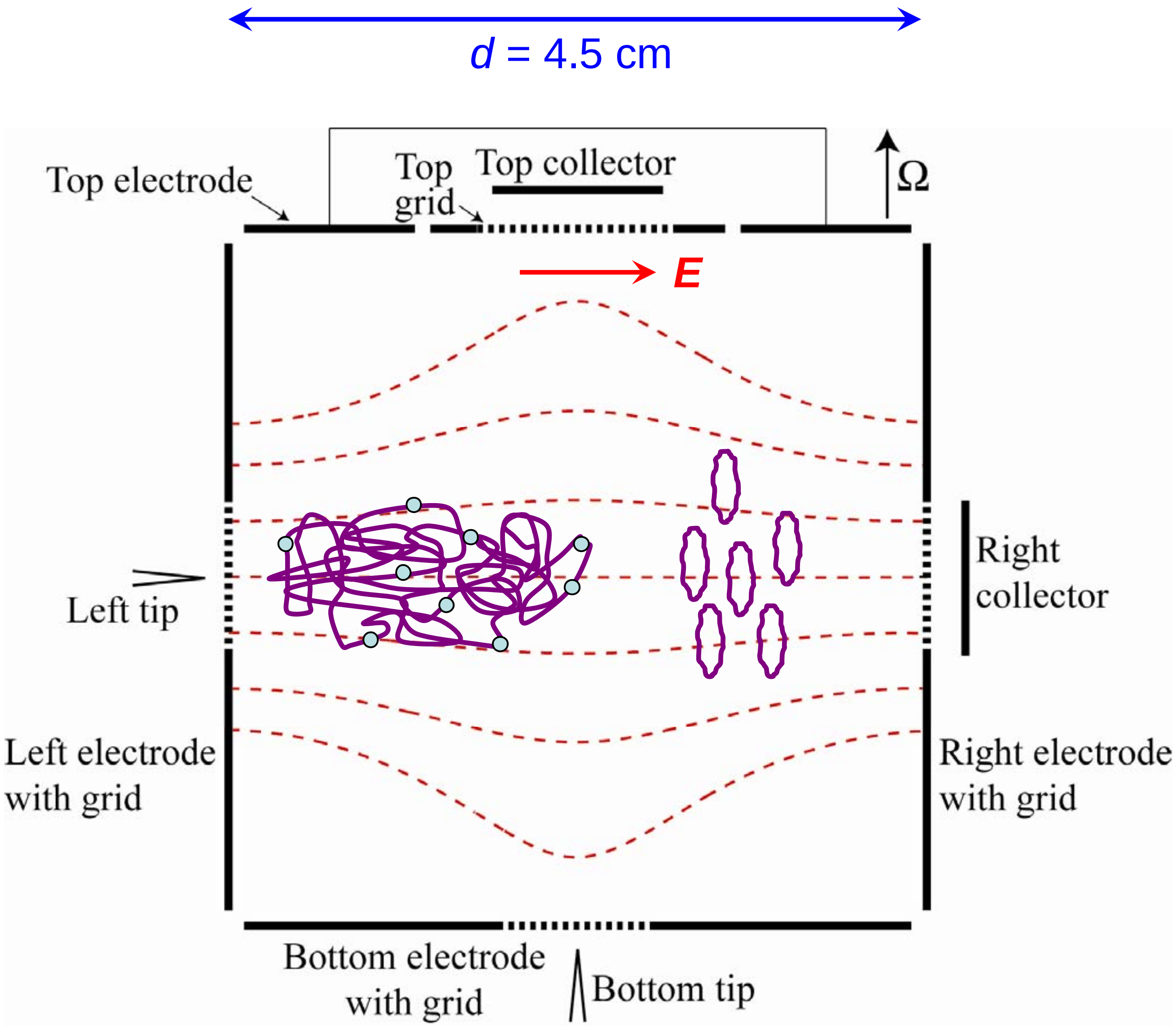


1) Charged vortex rings



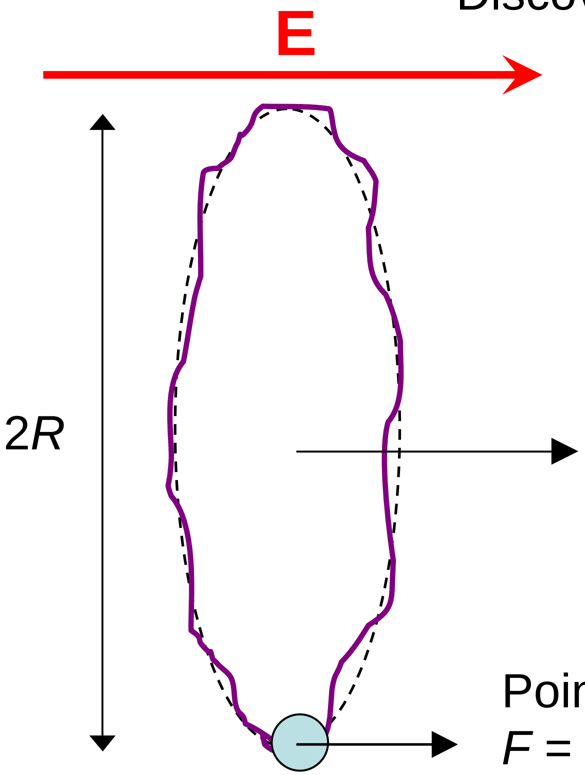
2) Charged vortex tangle

Experimental Cell



Characteristics of Charged Vortex Rings

Discovered by Rayfield and Reif in 1964.



Pulling on the ring with an electric field increases the energy and radius but decreases the velocity of the ring.

Energy: $H_0 = ½\, \rho\kappa^2\, (\Lambda\text{-}3/2)\, R$

Velocity: $v = \kappa\,(\Lambda\text{-}1/2)/(4\pi\, R)$

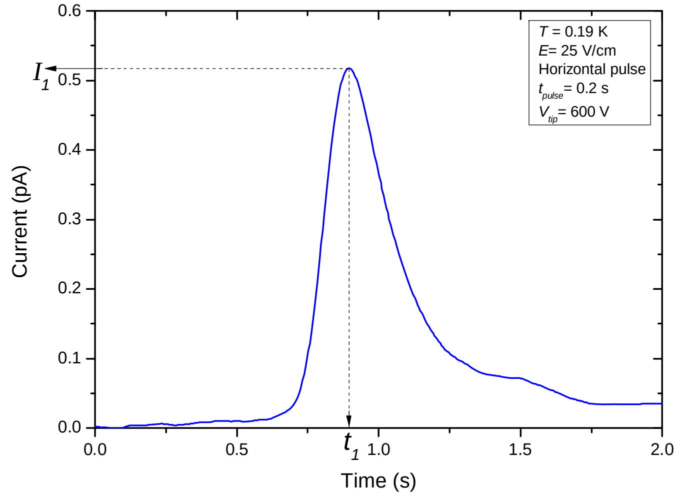
$\Lambda = \ln\,(8R/a_0) \approx 13$

Point force applied via a trapped ion:
$F = eE$

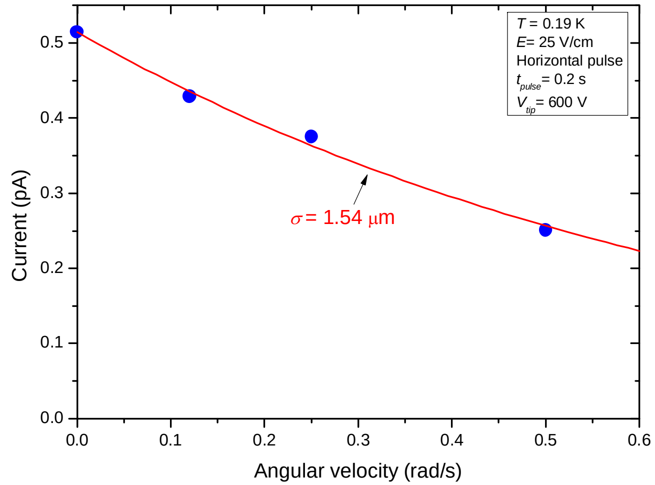
Schwarz and Donnelly (1966) showed that the trapping diameter, σ, could found from the attenuation of a beam of CVR's during steady rotation.

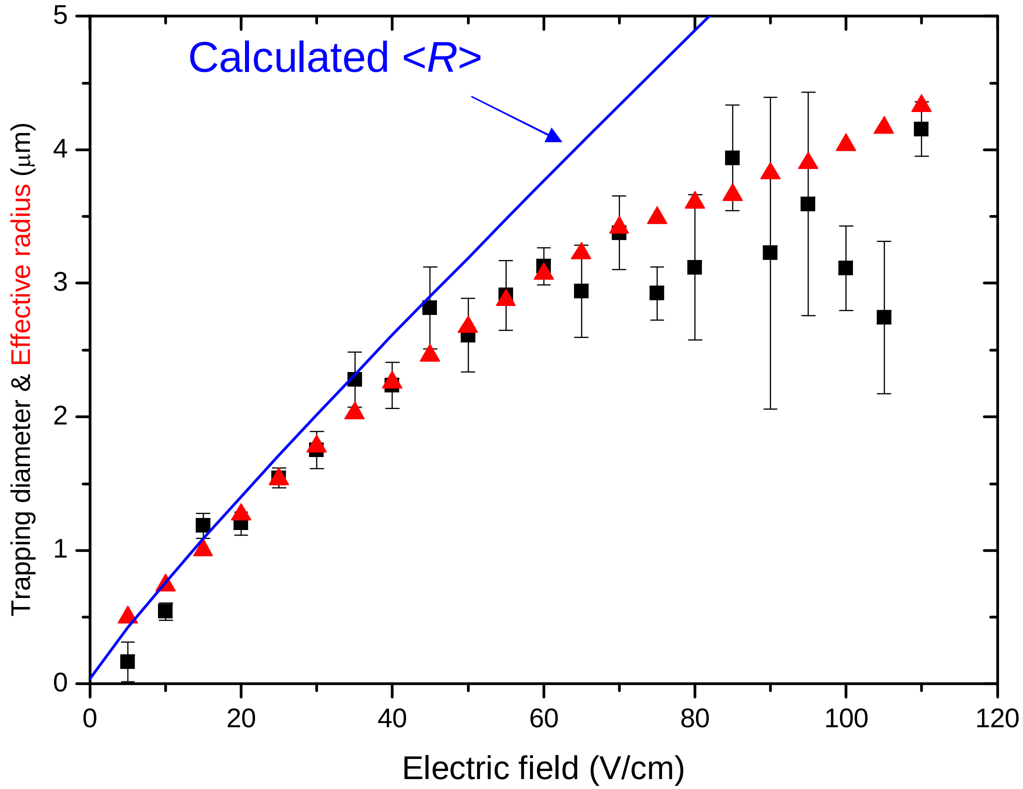
$$I = I_0 \exp\,(-2\Omega\sigma d/\kappa) \quad \text{where } \sigma \sim R.$$

Typical pulse (E=25 V/cm):

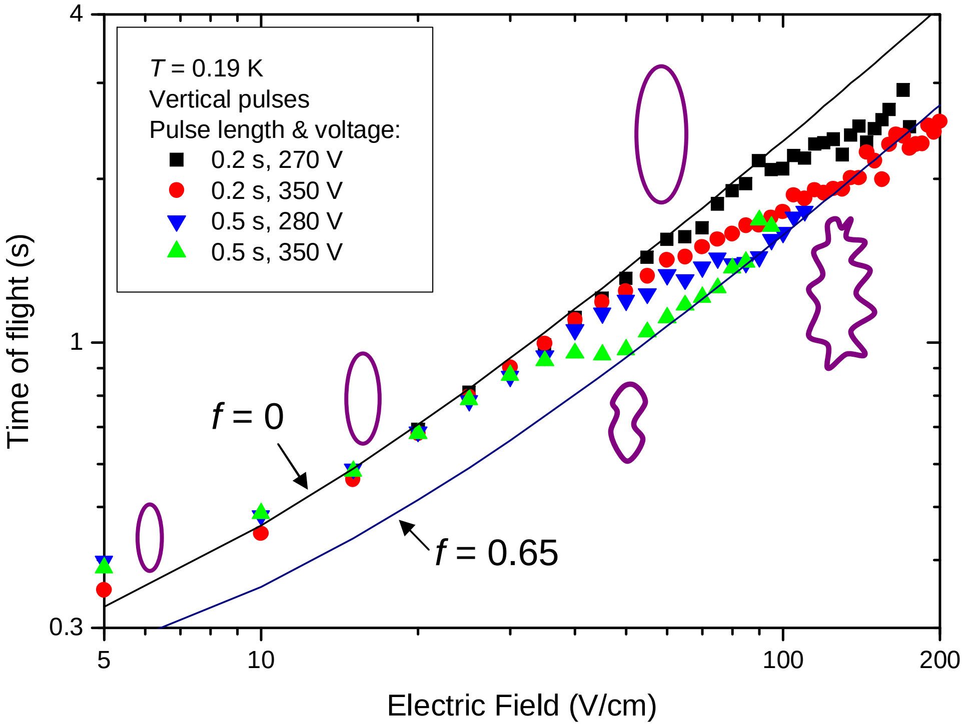


Example of σ measurement (E=25 V/cm):





Time of flight vs. Electric field



CVR's arrive faster than expected at high fields, implies losses.

Possible explanations:

- non-linear cascade?
- pinching off of rings?
- accumulation of energy in Kelvin waves (distorted rings)?

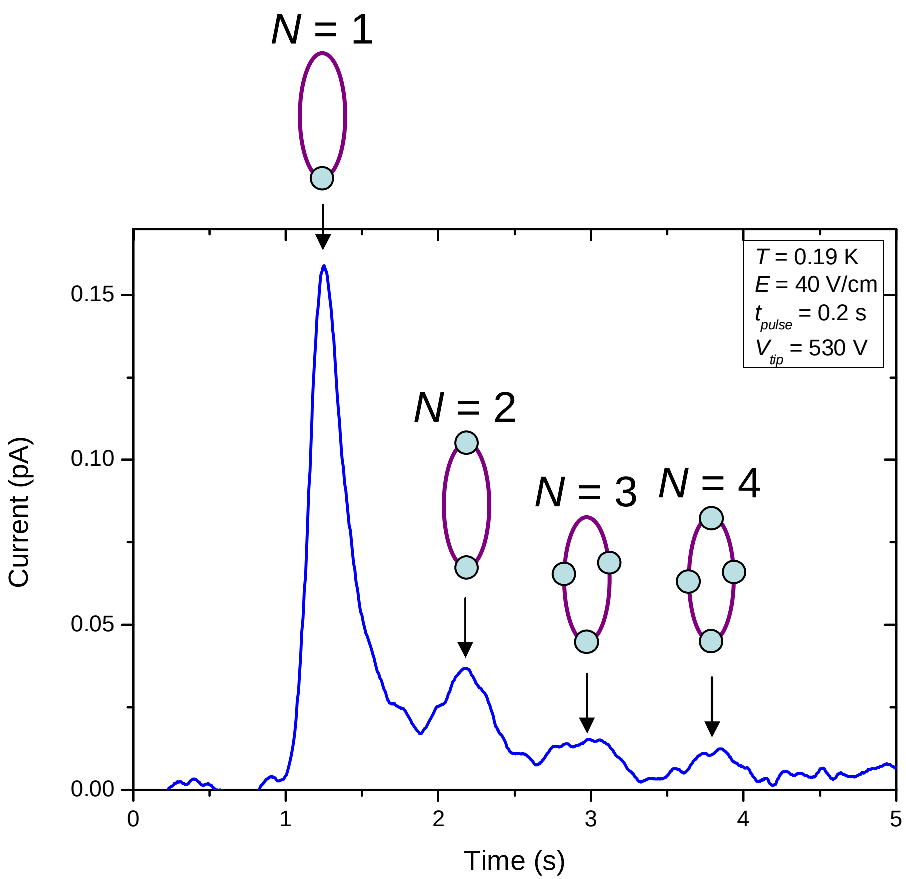
Simple model: some energy goes into Kelvin waves

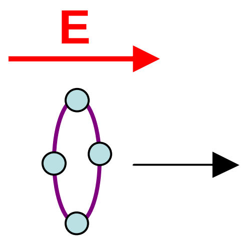
$$e\, E\, v = d/dt\,(H_0) + d/dt\,(H_{KW}) \qquad H_{KW} = f\, H_0$$

Transition to distorted ring state depends upon charge density, then follows f=0.65

Multi-charged Rings: *T*=0

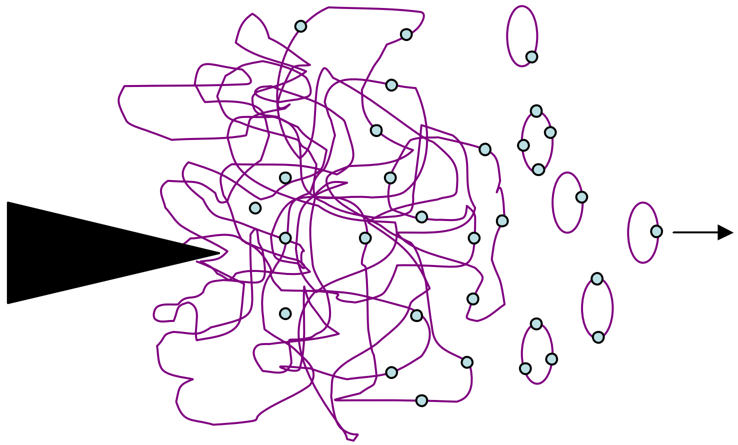
We can observe multi-charged rings with *N* =1 - 4 ions per ring at low temperatures.





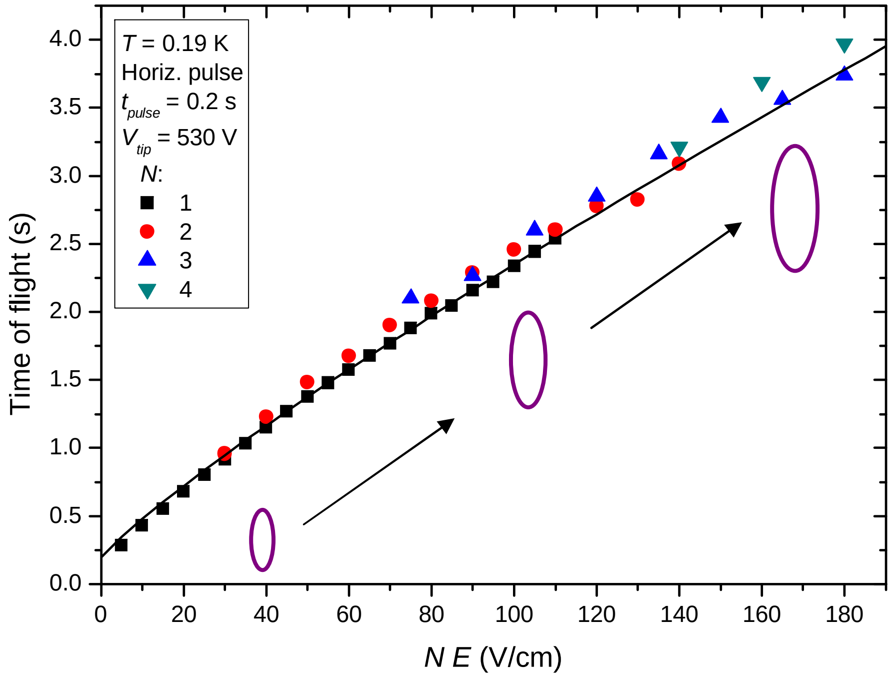
Force: $F = e\,N\,E$
- applied more homogeneously to ring

The multi-charged rings are probably produced from the breakup of a dense vortex tangle near the field emission tip.

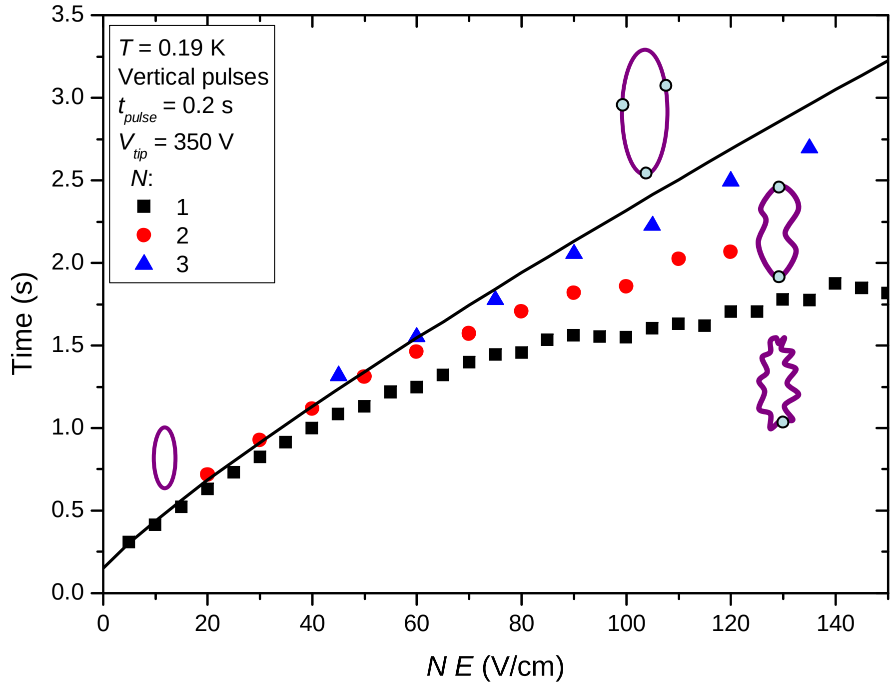


Dependence on charge density

Low CVR densities: good agreement with theory for smooth rings.



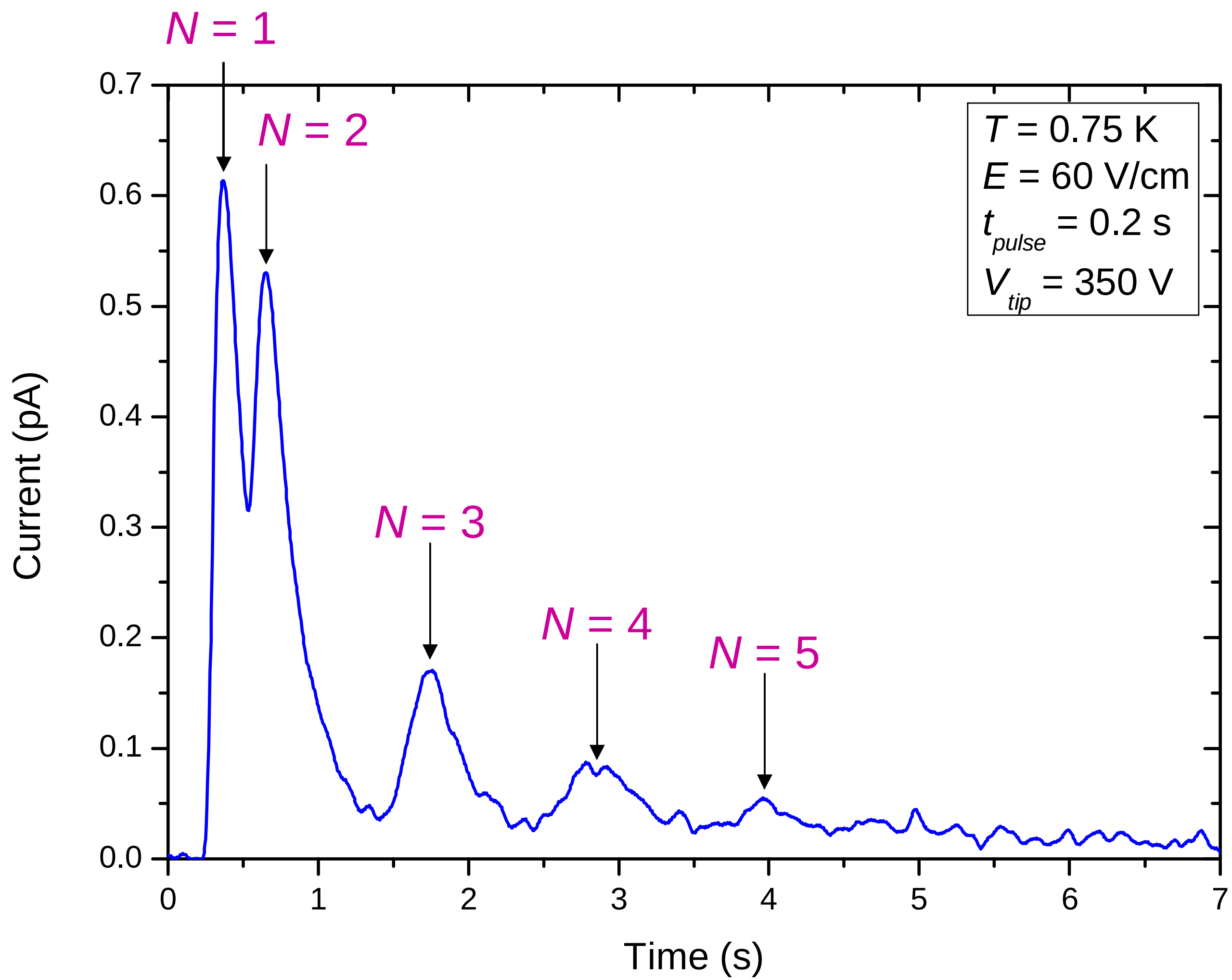
High CVR densities: losses.



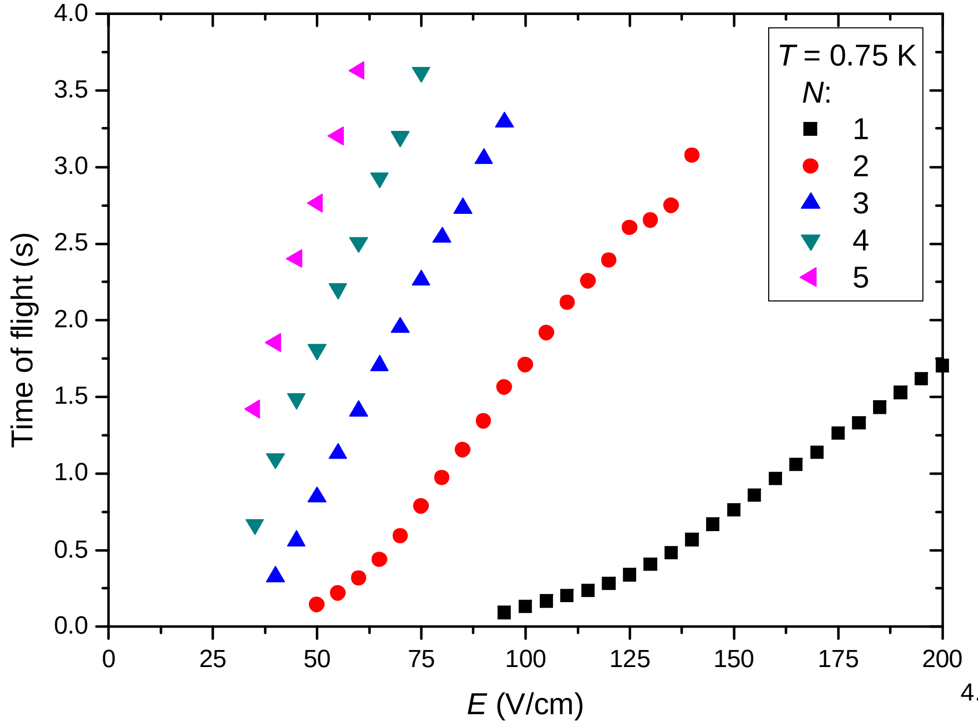
The more ions there are on the ring the less the losses to Kelvin waves etc. Probably because the force is applied more evenly.

Multi-charged rings: *T*>0

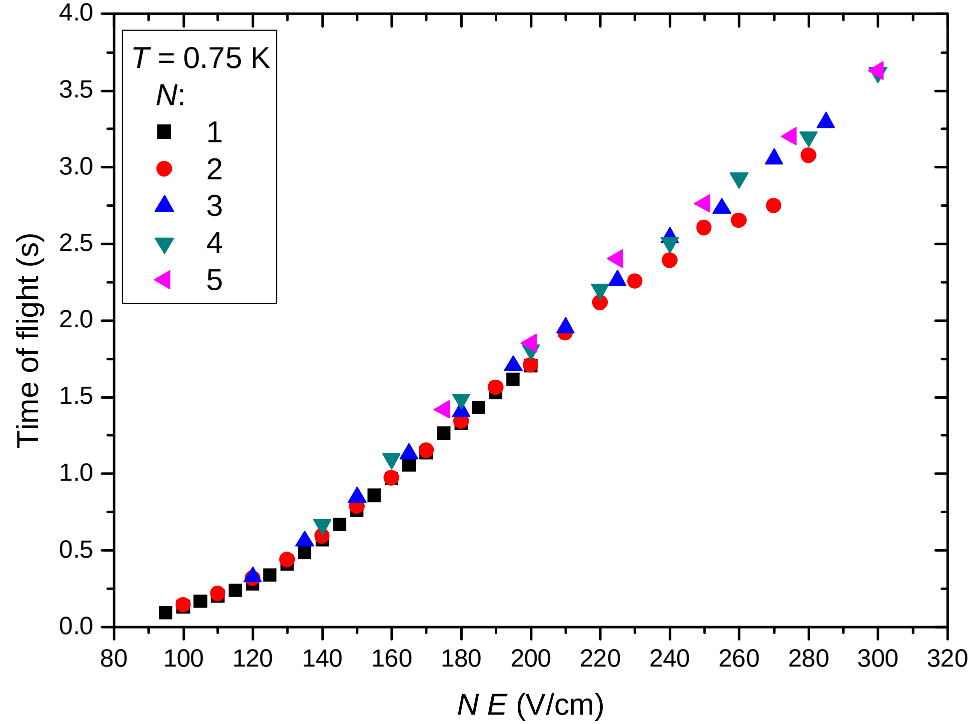
At higher *T* we observe rings with up to 11 ions attached.



Time of flight vs. E for N = 1 to 5

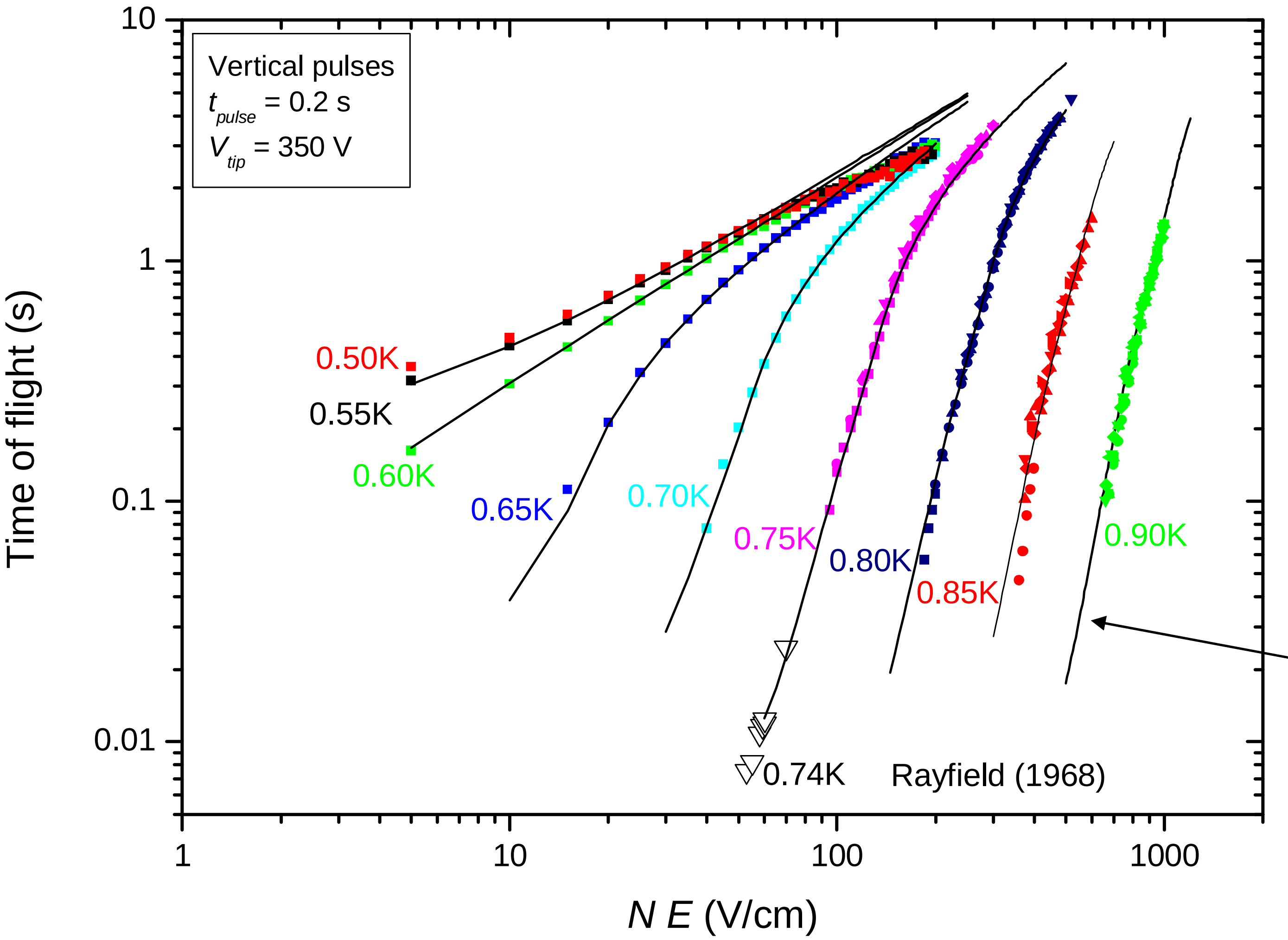


Time of flight vs. scaled field (N E)



Temperature dependence

Follow Rayfield and Reif: $F = N\,e\,E - F_{drag}$ $F_{drag} \sim \alpha(T)\Lambda$



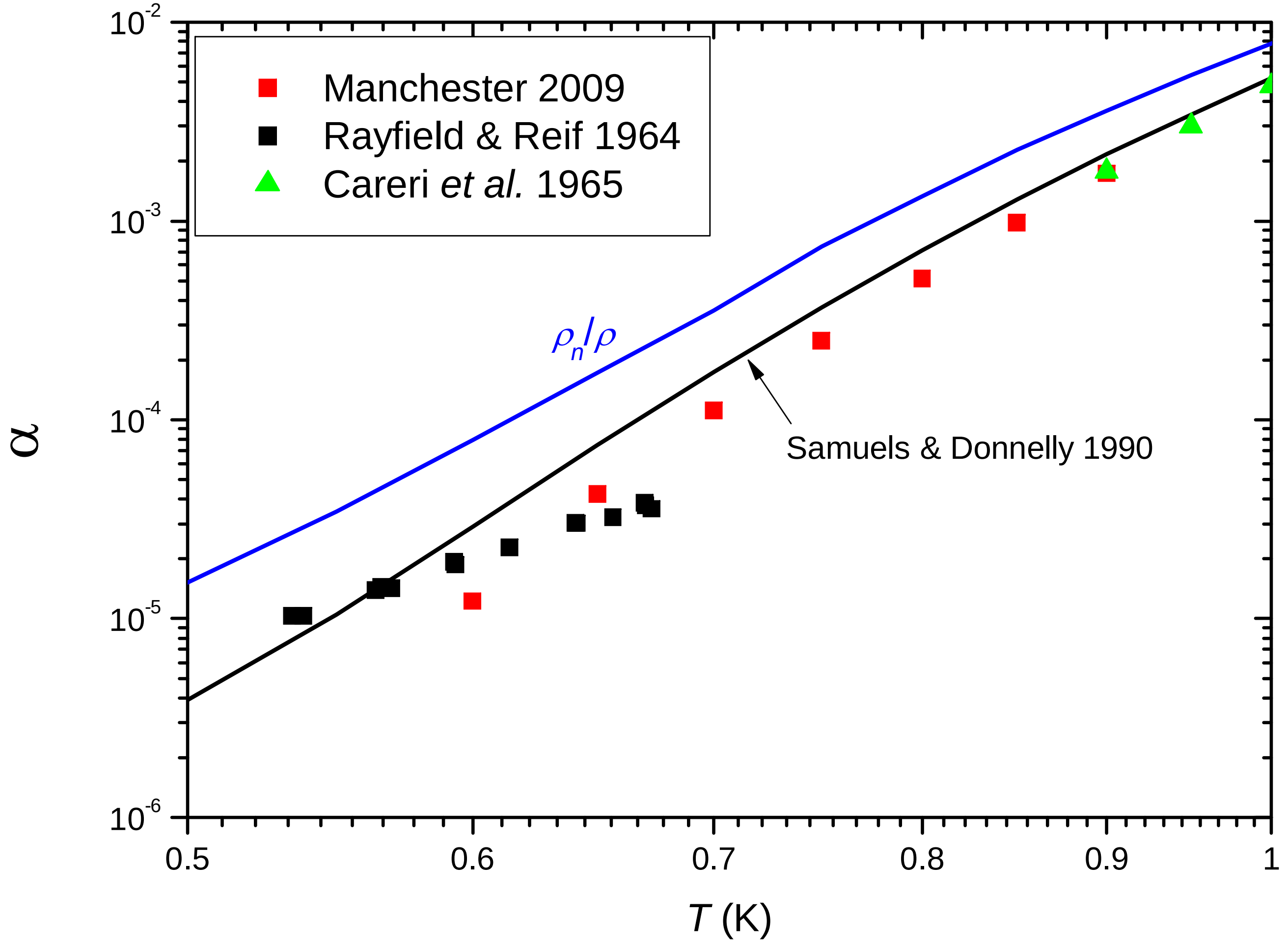
Observe N = 11 at 0.90 K. Behaviour is independent of N at high temperatures.

Calculated behaviour

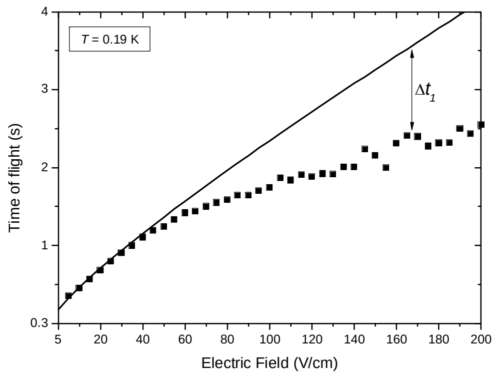
Deviation from calculated behaviour at high E for T < 0.70 K

Mutual Friction

Obtained values of α agree well with previous measurements.

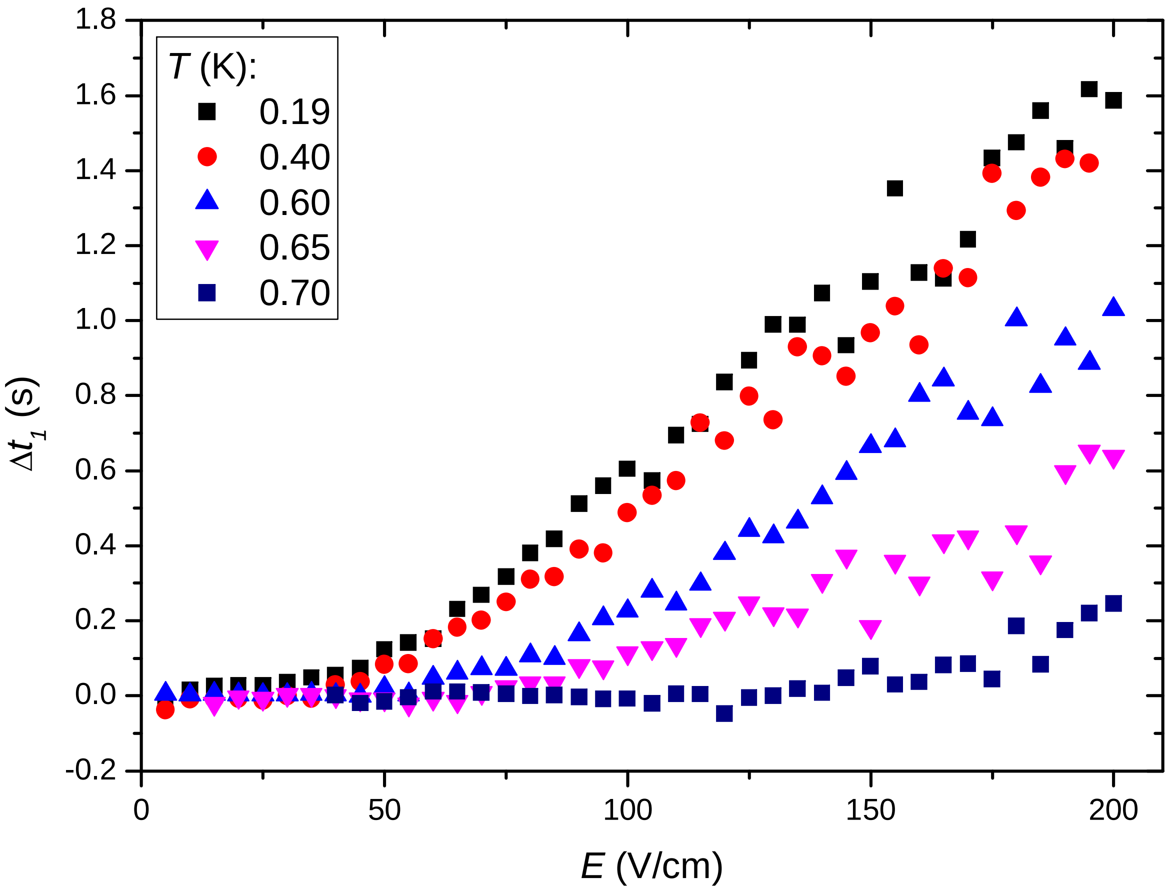


T dependence of deviation



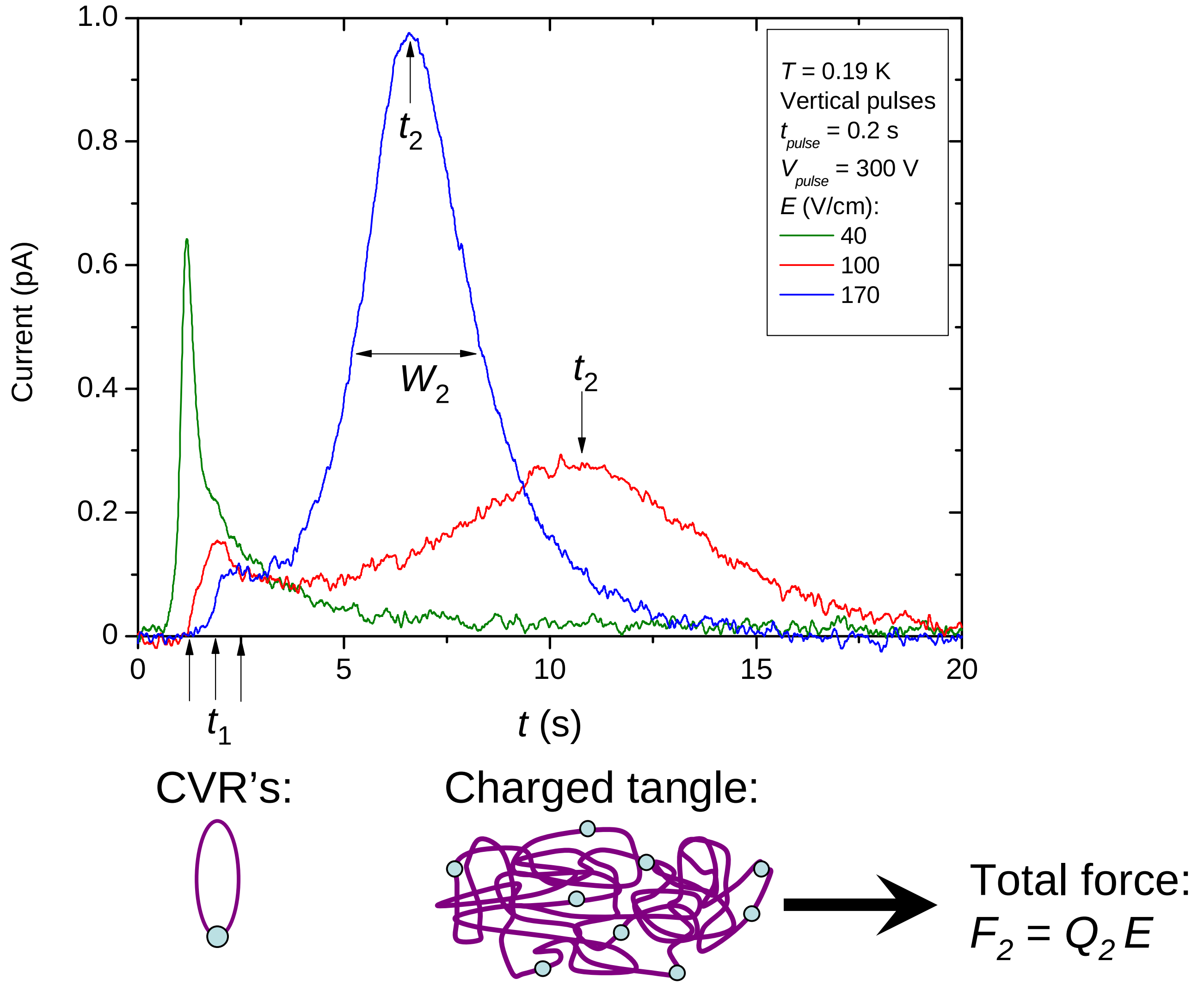
Δt₁ decreases at *T* increases above 0.4 K.

Δt₁ =0 for *T* ≥ 0.75 K.

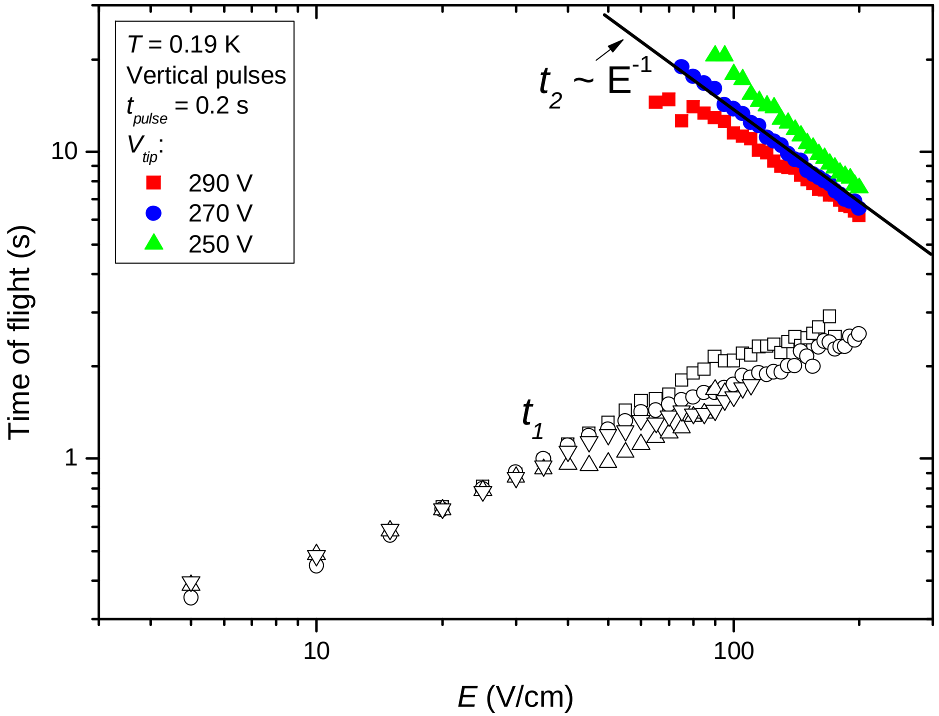


2) Charged Tangle

At high E, we observe a 2nd peak due to a drifting charge vortex tangle.

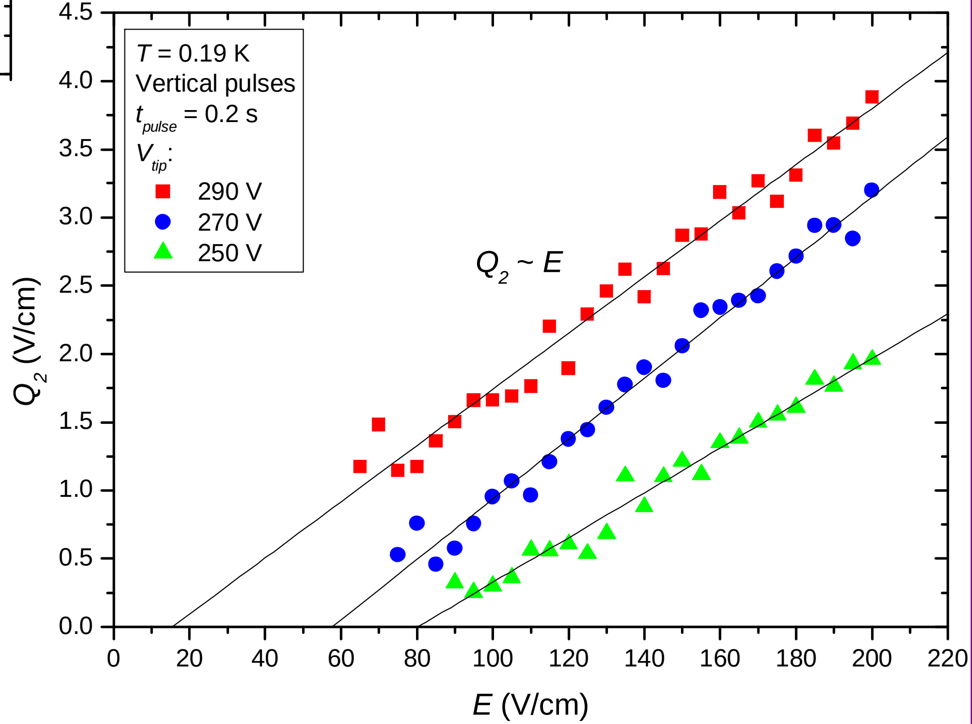


Velocity & Charge

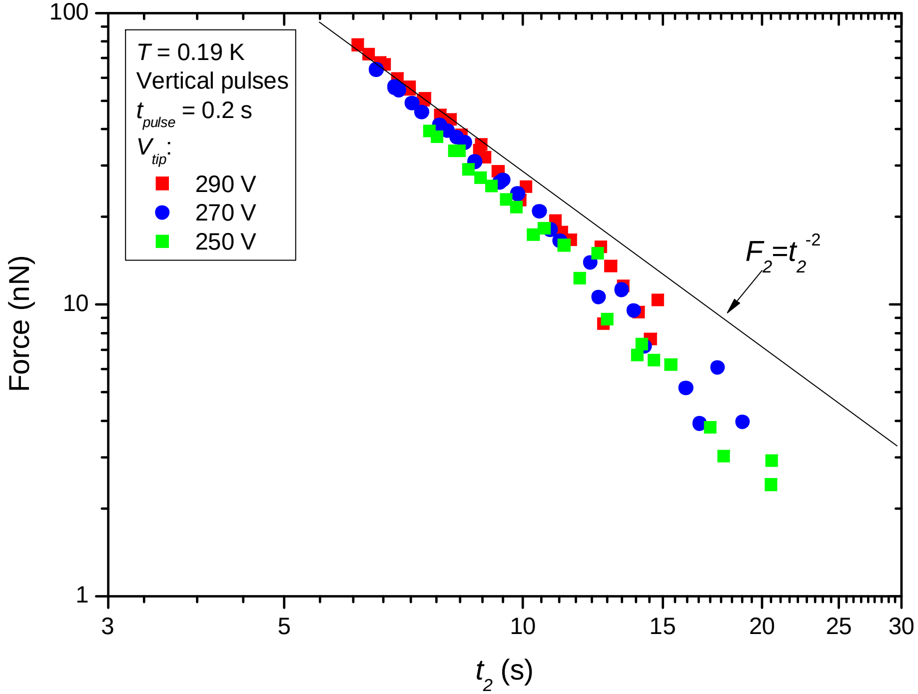


The charged tangle moves faster when pulled harder.

Amount of charge in tangle increases linearly with increasing *E.*



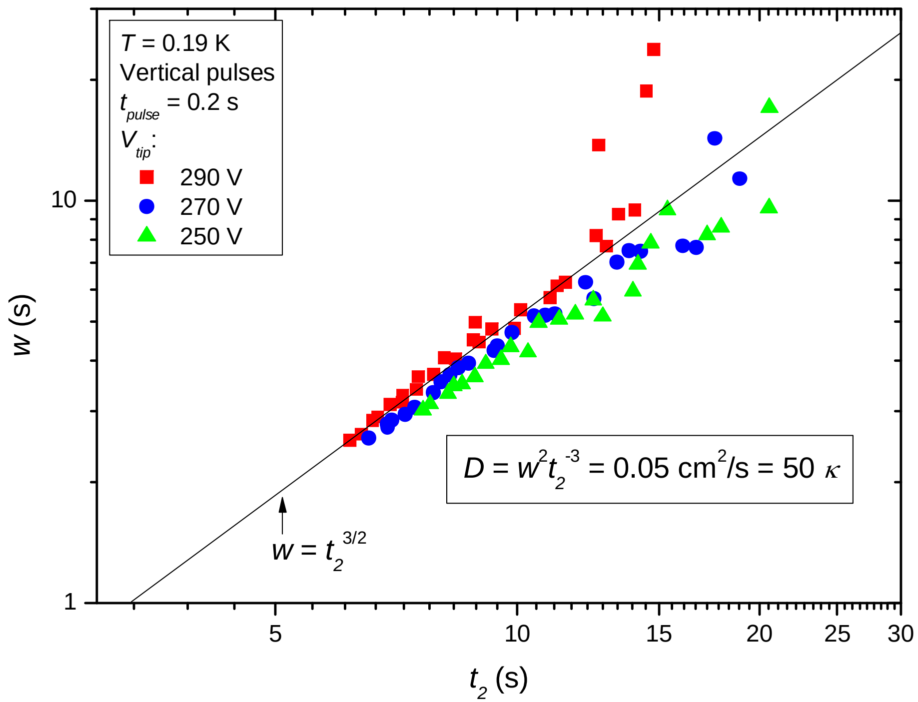
Force



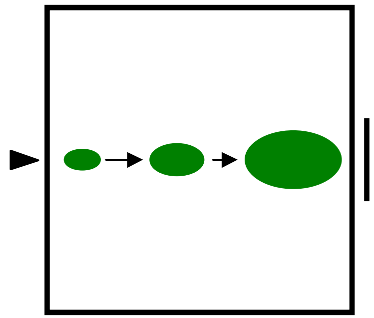
All measurements collapse onto the same curve.

We expect $F \sim t_2^{-2}$ if the charged tangle has a constant acceleration.

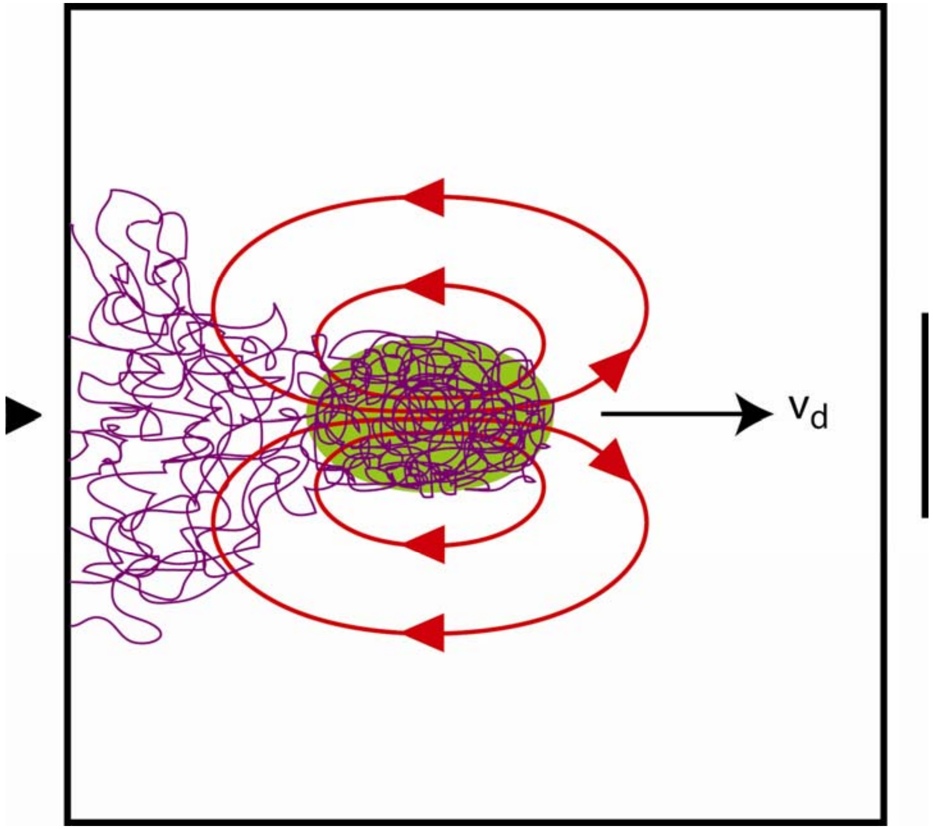
Width of Peak: Diffusion



The width increases with time due to diffusion with $D_{charge} = 50\ \kappa$.

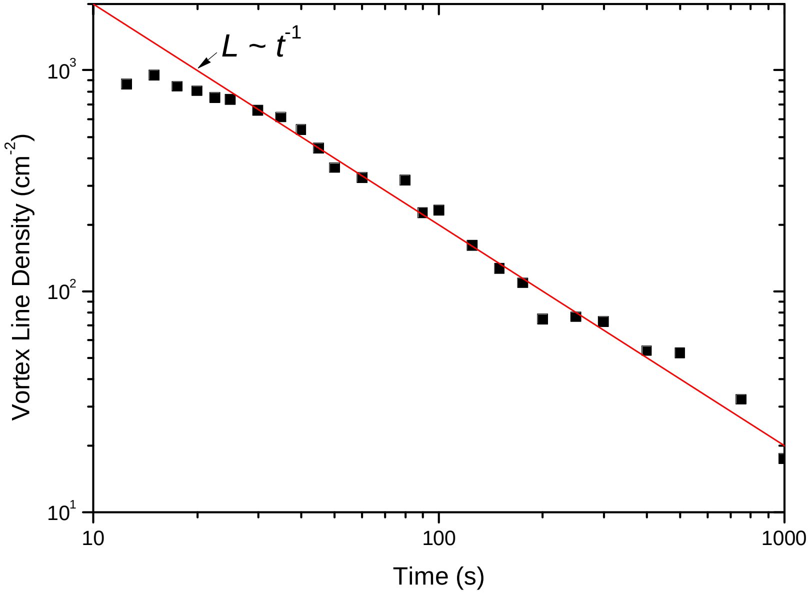


The measurements can be explained by the motion of a polarized charged tangle.



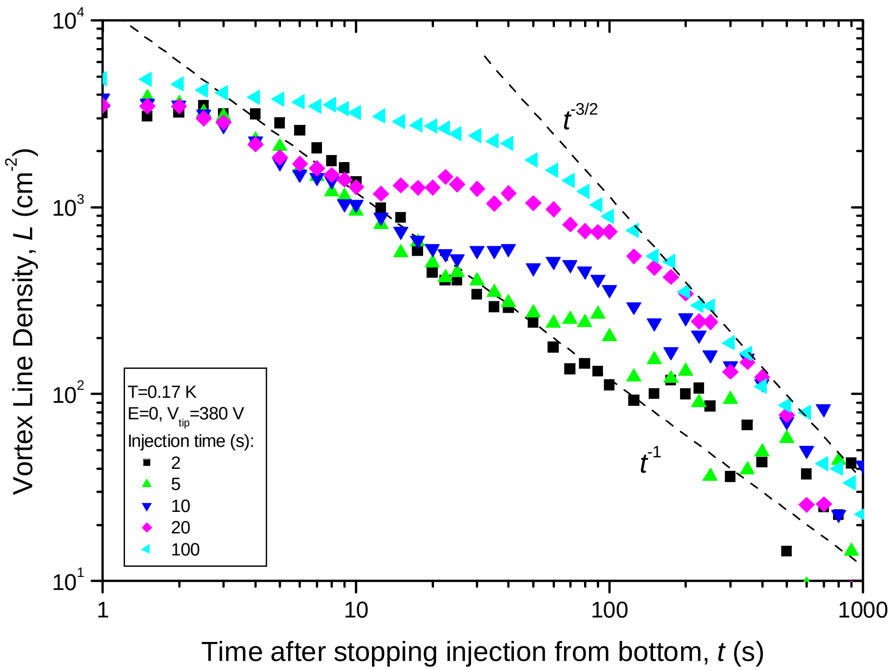
Free Decay

We have measured the vortex line density, *L*, following the passage of a charged tangle across the cell:



$L \sim 1/t$ as expected for a random tangle with $\nu \sim 0.1\ \kappa$.

Injecting current for much longer (~ 100 s) builds up the large scale motion and we see a transition to $L \sim t^{-3/2}$ (even for $E = 0$).



Summary

1) Charged Vortex Rings

- Pulling with a strong force distorts the ring and generates Kelvin waves.
- Multicharged vortex rings have been observed (N_{max} = 11 at T=0.9 K).
- Rings show no distortion above 0.75 K. Independent of T below 0.4 K.

2) Charged Vortex Tangle

- Drifting charged vortex tangle observed.
- Diffusion coefficient for diffusion of charge = 50 κ.
- Leftover tangle decays as $L \sim 1/t$ but long injections lead to $L \sim t^{-3/2}$

Spatial Extent

We can simultaneously measure the current transients to the three components of the top plate.