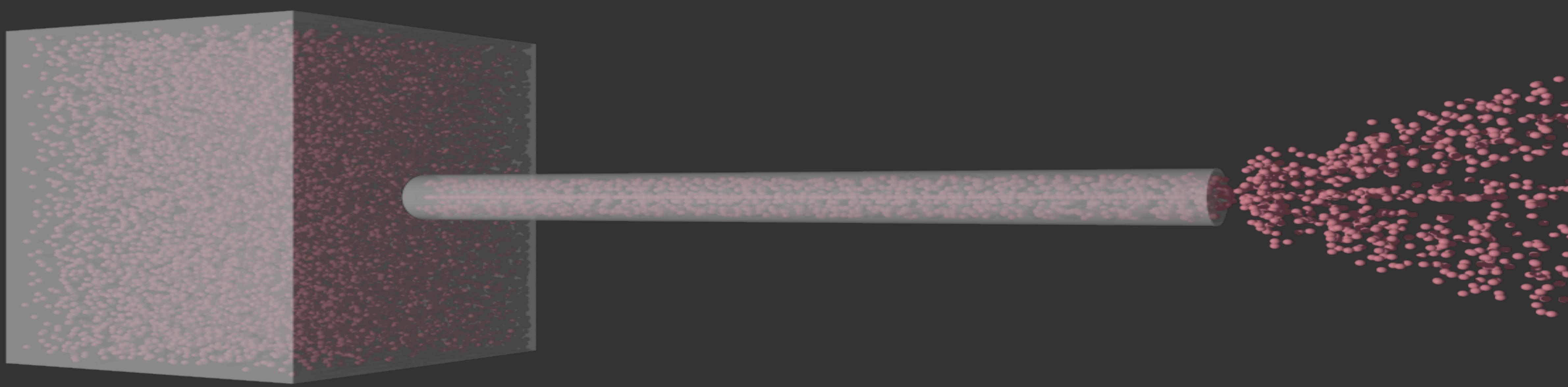
1D Helium Systems

Grand Challenges in Quantum Fluids and Solids





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Classical Fluid Flow

Hagen-Poiseuille Law

$$Q = \frac{\pi \rho R^4}{8 \eta L} \Delta P$$

for a viscous fluid: Q ⟶ 0 as R ⟶ 0

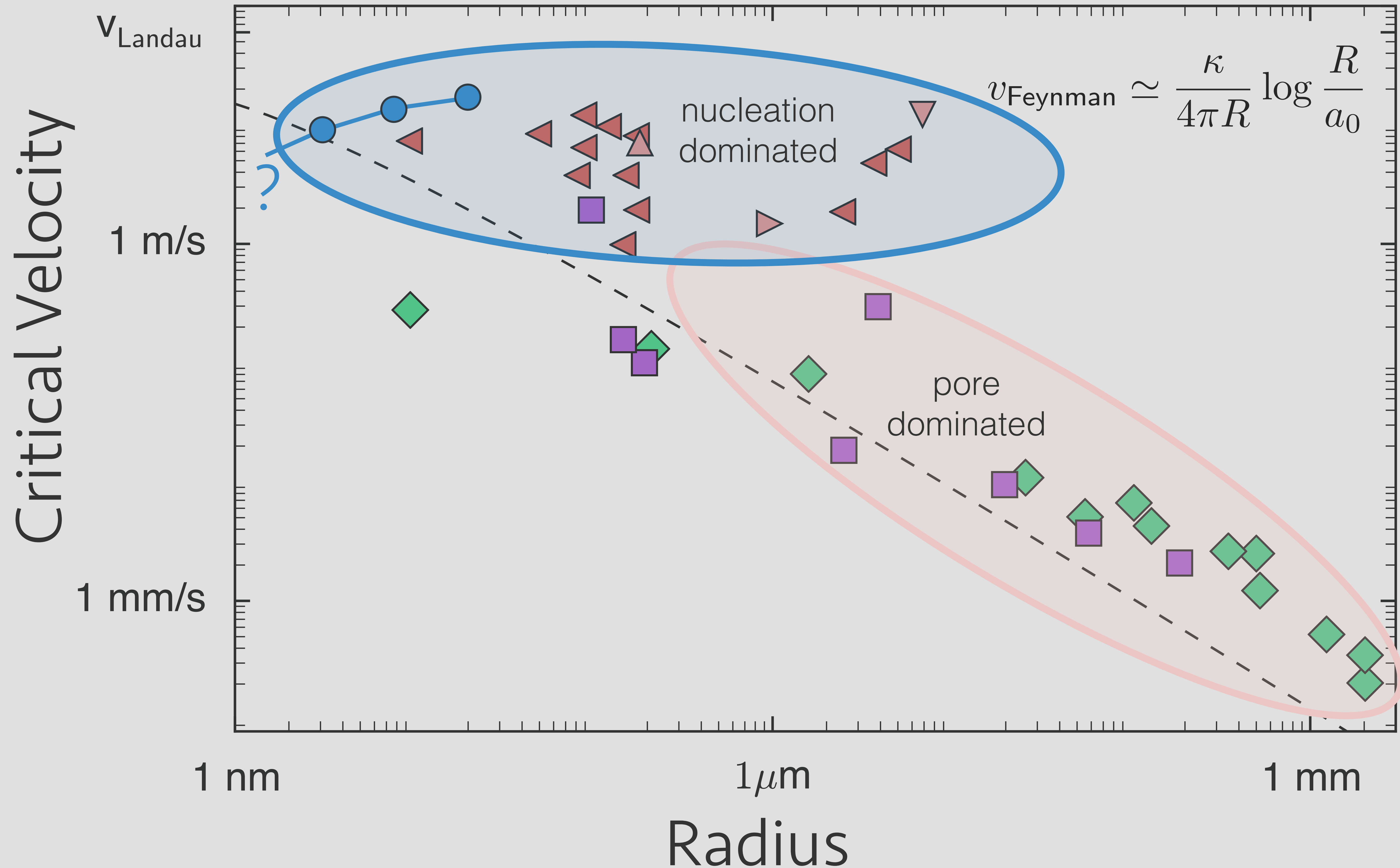
In the 1D Euler limit:

$$\frac{\partial v}{\partial t} + v \frac{\partial v}{\partial x} + \frac{1}{\rho} \frac{dP}{dx} = 0 \quad \Rightarrow \quad v = \sqrt{\frac{2 \Delta P}{\rho}}$$

max velocity for classical inviscid flow

Quantum Fluid Flow

E. Varoquaux, arXiv:1406.5629



Why do we want to get smaller?

1 Entering previously inaccessible physical regimes can lead to the discovery of new and useful phenomena.

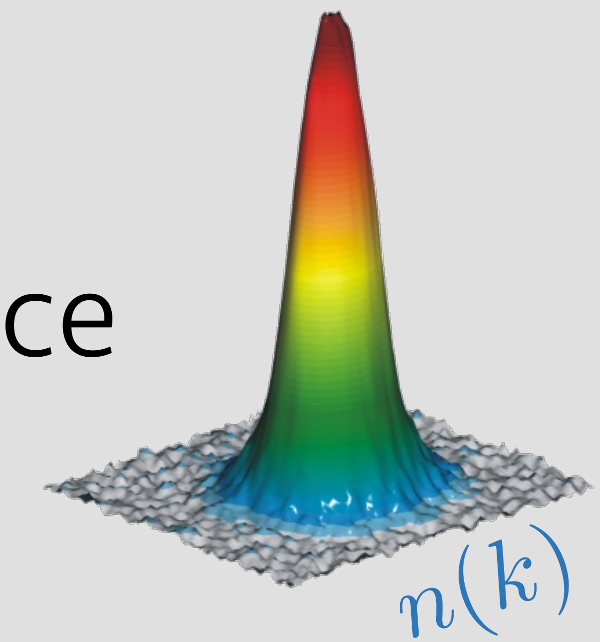
2 Need more data to construct a theory for the pore ➠ nucleation dominated dissipative crossover as $R \to 0$.

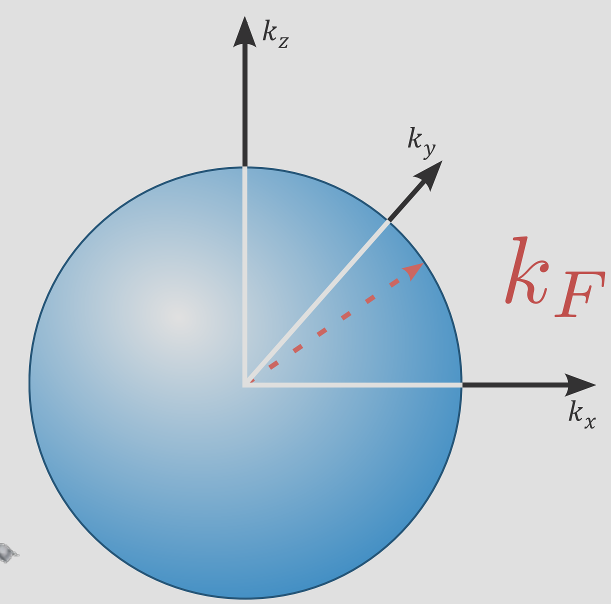
3 Experimental discovery of a high density & strongly interacting Tomonaga-Luttinger liquid

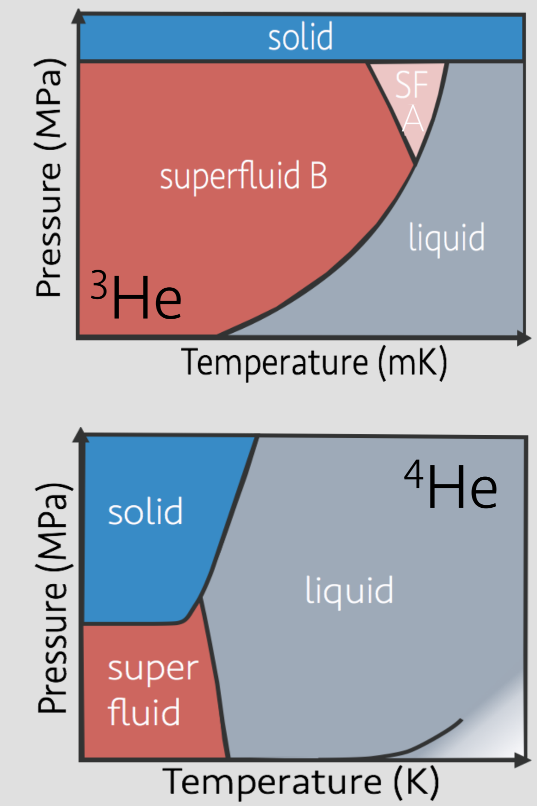
Universal Physics in 1D

All excitations are collective ⇒ no quasiparticle description.

Bose-Fermi correspondance







no long range order ⇒ correlations are algebraic

$$H_{\mathsf{TLL}} \sim \int dx \left[\frac{1}{K} \left(\partial_x \phi\right)^2 + K \left(\partial_x \theta - \rho_0\right)^2 \right]$$

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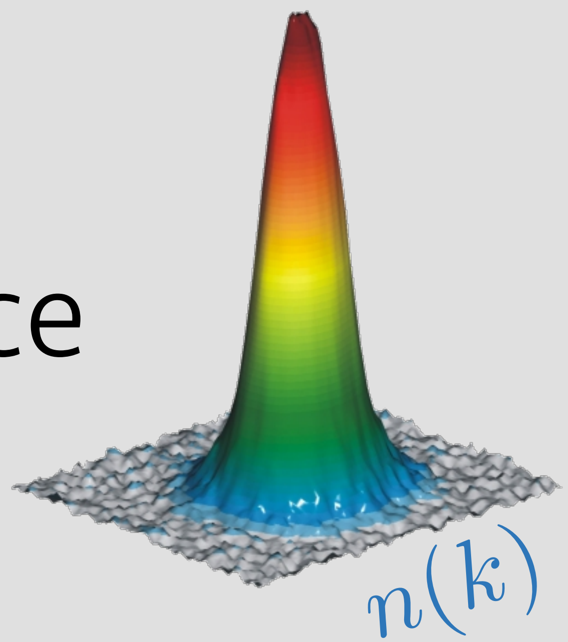
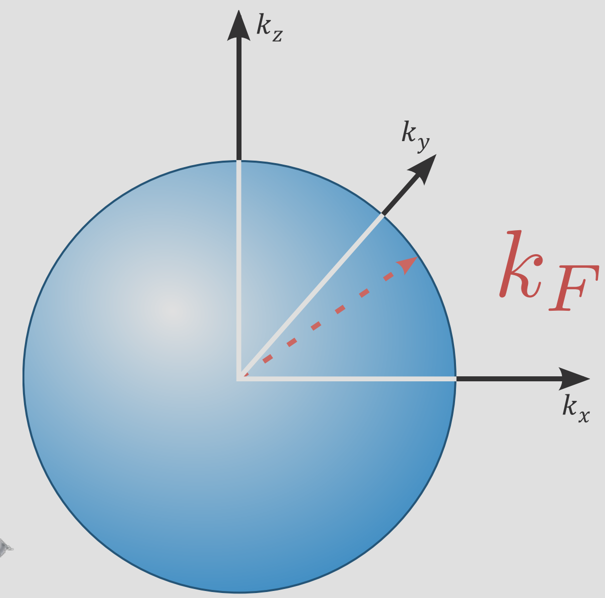
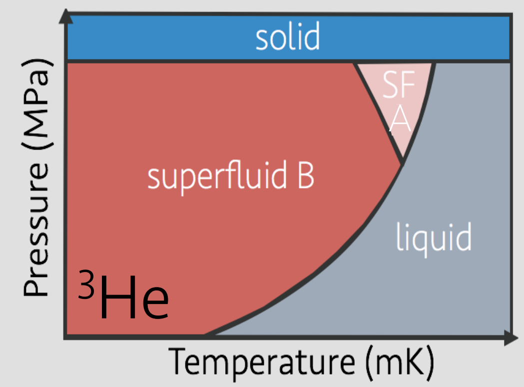
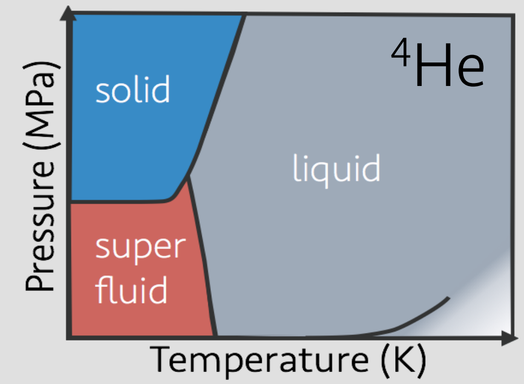
Bose-Fermi correspondance









no long range order ⇒ correlations are algebraic

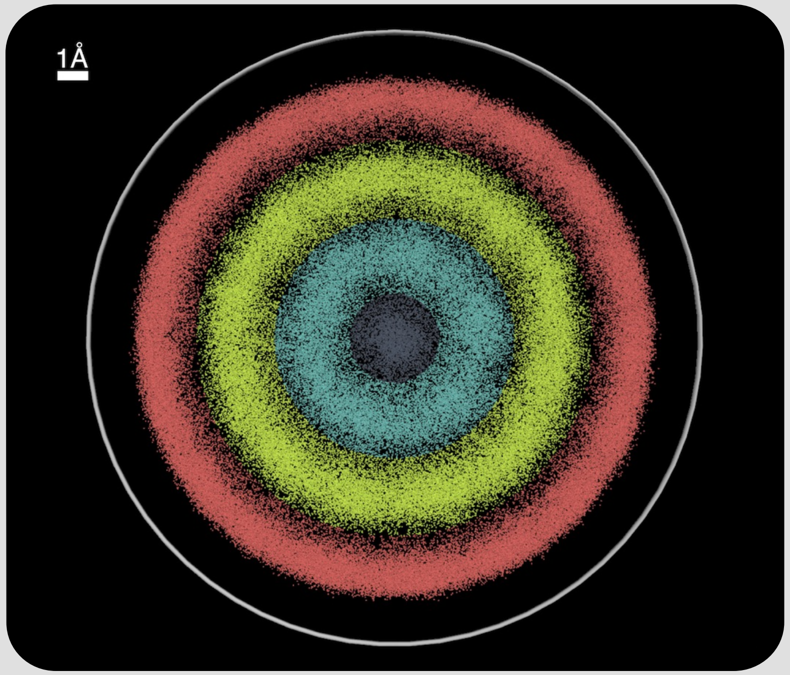
$$n(k) \sim |k|^{K/2-1}$$

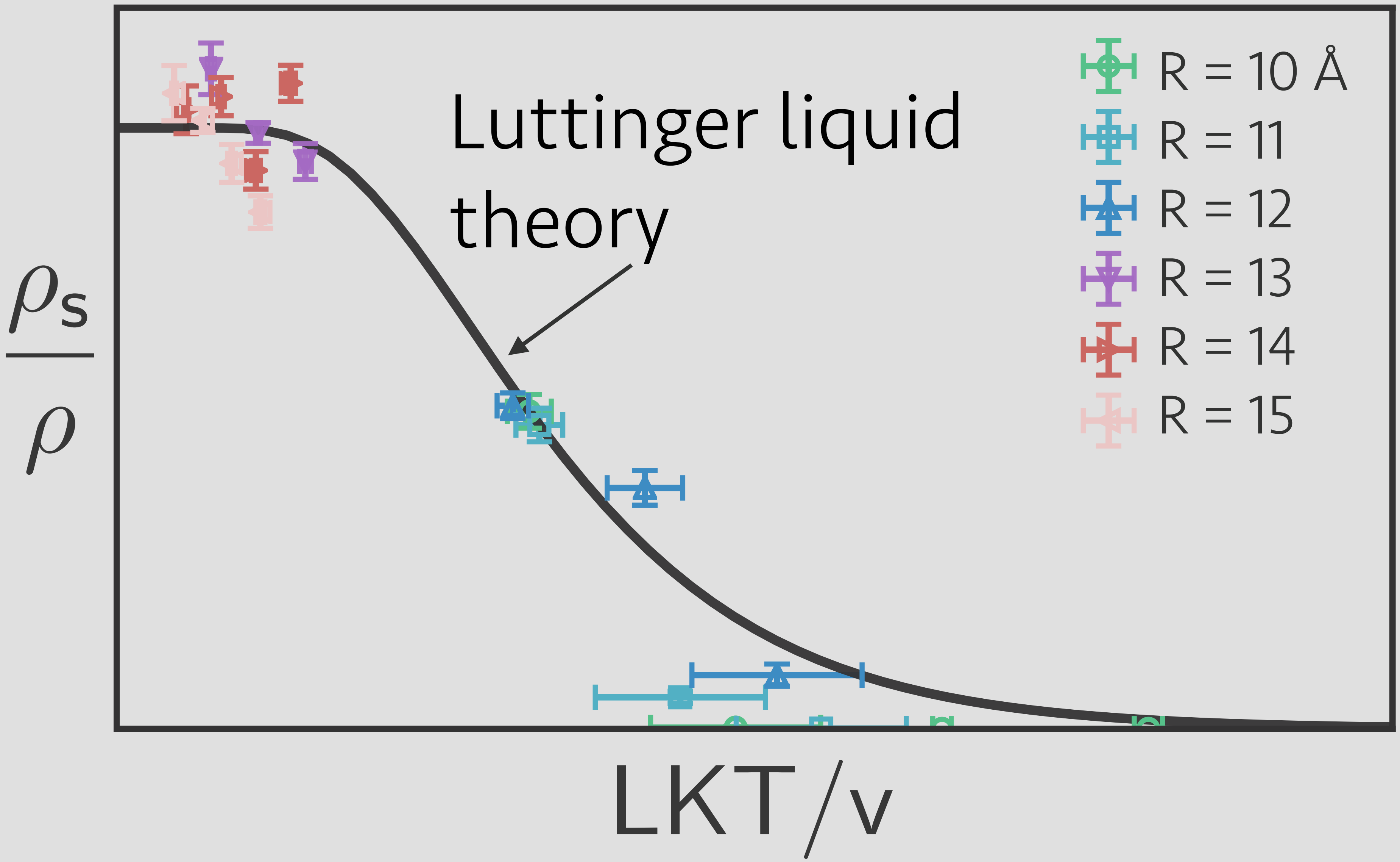
momentum distribution

$$g_2(x) \sim \frac{\cos 2\pi\rho_0 x}{x^{2/K}}$$

pair correlation function

Hints From Simulations



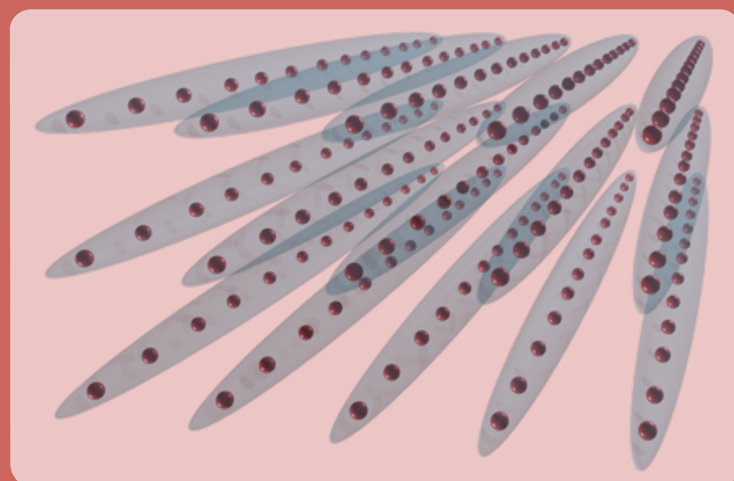


M. Rossi, D. Galli, and L. Reatto, Phys Rev B 72, (2005)
M. Boninsegni, A. Kuklov, L. Pollet, N. Prokof'ev, B. Svistunov, and M. Troyer, PRL 99, 035301 (2007)
B. Kulchytskyy, G. Gervais and A.D., PRB, 88, 064512 (2013)
L. Pollet and A. B. Kuklov, PRL 113, 045301 (2014)

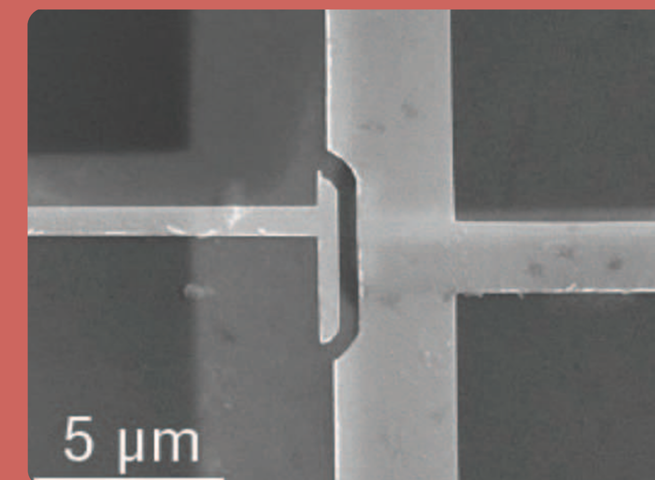
Current experiments within a factor of 2-3 in radius!

BIG challenges in geting *small*

Luttinger liquids can be realized with ultracold atoms



& quantum wires



B. Paredes, *et al.*, Nature **429**, 277 (2004)
T. Kinoshita, *et al.*, Science **305**, 1125 (2004)
E. Haller, *et al.*, Nature **466**, 597 (2010)

O. M. Auslaender, *et al.*, Science **308**, 88 (2005)
Y. Jompol, et al., Science **325**, 597 (2009)
D. Laroche, *et al.*, Science **343**, 631 (2014)

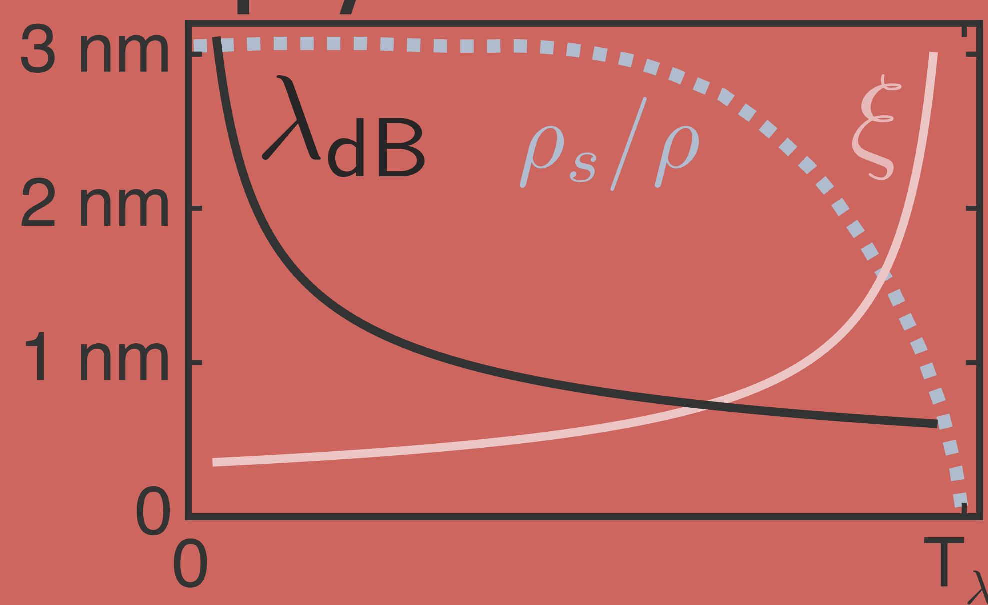
$n_{1D}^{-1} \sim 500$ nm

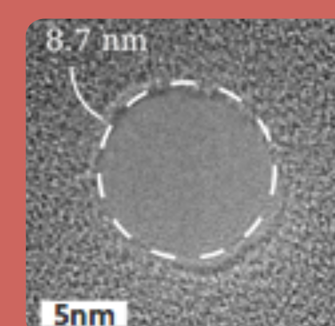
$k_F^{-1} \sim 20 - 50$ nm

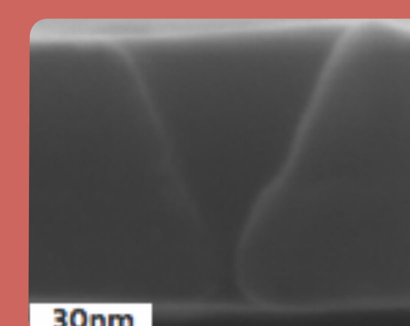
Relevant ^{4}He scales:

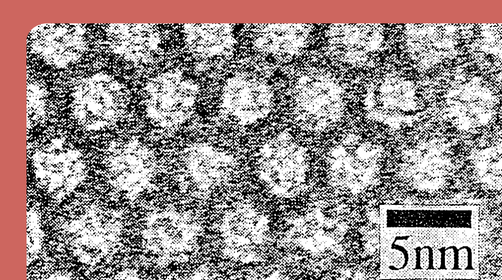
$n_{1D}^{-1} \sim 0.5$ nm
$E_{int} \sim 1$ K

Need physical confinement!









Grand Challenges

1. Theoretical predictions and smoking guns for crossover to Tomonaga-Luttinger liquid regime
2. 1D Boson-Fermion correspondance
3. 1D weak links and Josephson junctions
4. Breakdown of the 2-fluid model
5. Novel quantum phase transitions
6. Entanglement in quantum liquids

Discussion

Helium Community

- What do experimentalists want from theorists?
- What do we really know about the correlation length at low temperature?
- Do we understand how the nature of dissipation mechanisms will change in 1D?
- Can larger pores be created and coated to reduce their size?
- How can we increase the stability of quasi-1D pores?
- What different things can we learn from single channel vs. multi-channel experiments?
- Which types of results be directly compared?

Cold Atoms & Quantum Wires

- What can we learn about 1D in ultracold atom and electronic systems?
- What maximal densities could ever be achieved in those systems?
- How hard is it to “swap-in” fermions in ultracold atoms sytems?