Towards a semi-holographic superfluid

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MOTIVATION

Goal: using holography describe bosonic *single-particle* spectra in a strongly interacting superfluid!

What do we mean by single particles?
- Creation/annihilation operators in Fock space
- Obey canonical commutation relations and the sum rule

$$[\psi_\alpha(\mathbf{x},t),\psi^\dagger_{\alpha'}(\mathbf{x}',t)]_\pm=\delta(\mathbf{x}-\mathbf{x}')\delta_{\alpha,\alpha'} \qquad \frac{-1}{\pi}\int \mathrm{d}\omega \mathrm{Im} G_{R_{\alpha,\alpha'}}(\omega,\mathbf{k})=\delta_{\alpha,\alpha'}$$

Why are they interesting?
Their spectral functions can be experimentally observed!

FROM 'STANDARD' HOLOGRAPHY...

- Add a scalar field ϕ to the bulk
- EOM near the boundary yields

$$\phi\sim\phi_s r^{-\Delta_-}+\phi_O r^{-\Delta_+}$$

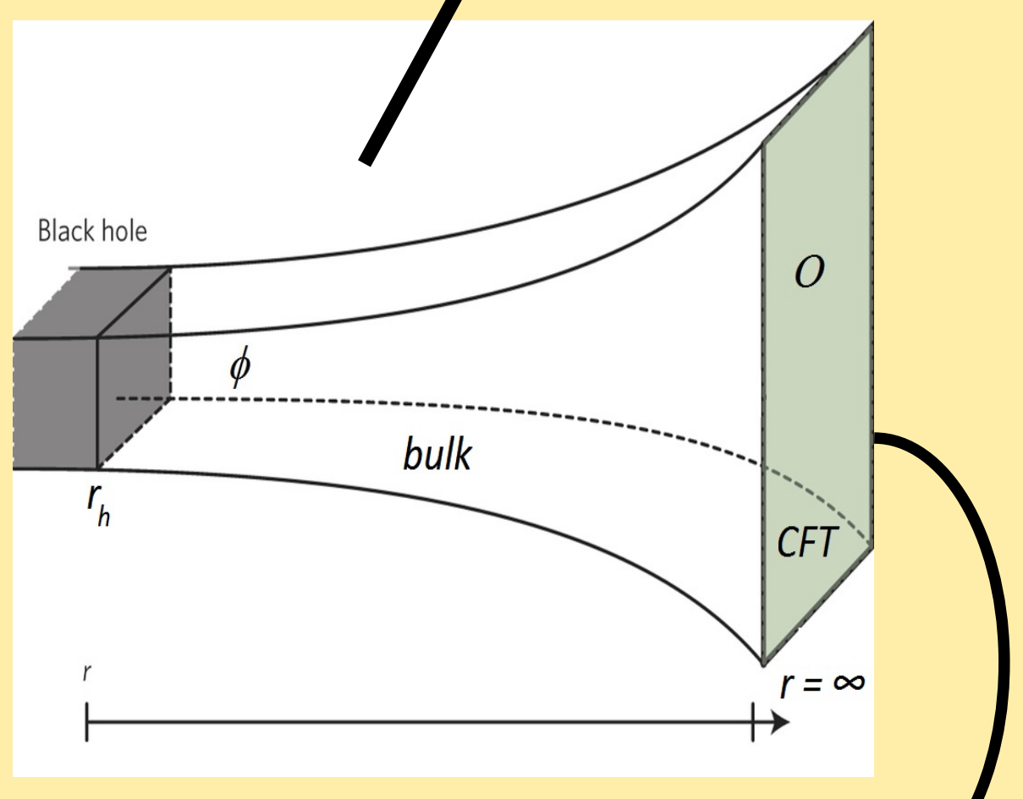
source   *~ vev of operator O*

- Retarded Green's function of *O* behaves as

$$G_{R,O}=\left(-\omega^2+k^2c^2\right)^{\frac{1}{2}(\Delta_+-\Delta_-)}$$

which violates the sum rule. Hence ϕ is not an elementary scalar field!

d+1-dimensional theory with gravity



d-dimensional CFT

...TO SEMI-HOLOGRAPHY!

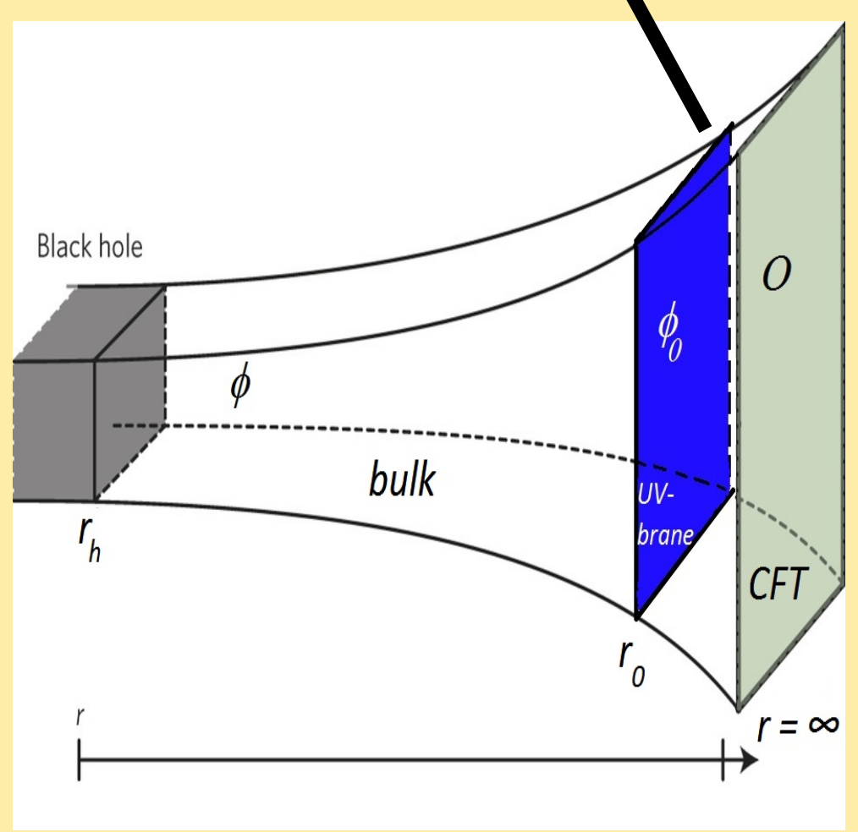
- Introduce a UV brane $r=r_0$
- Make the source dynamical on this brane [1]!

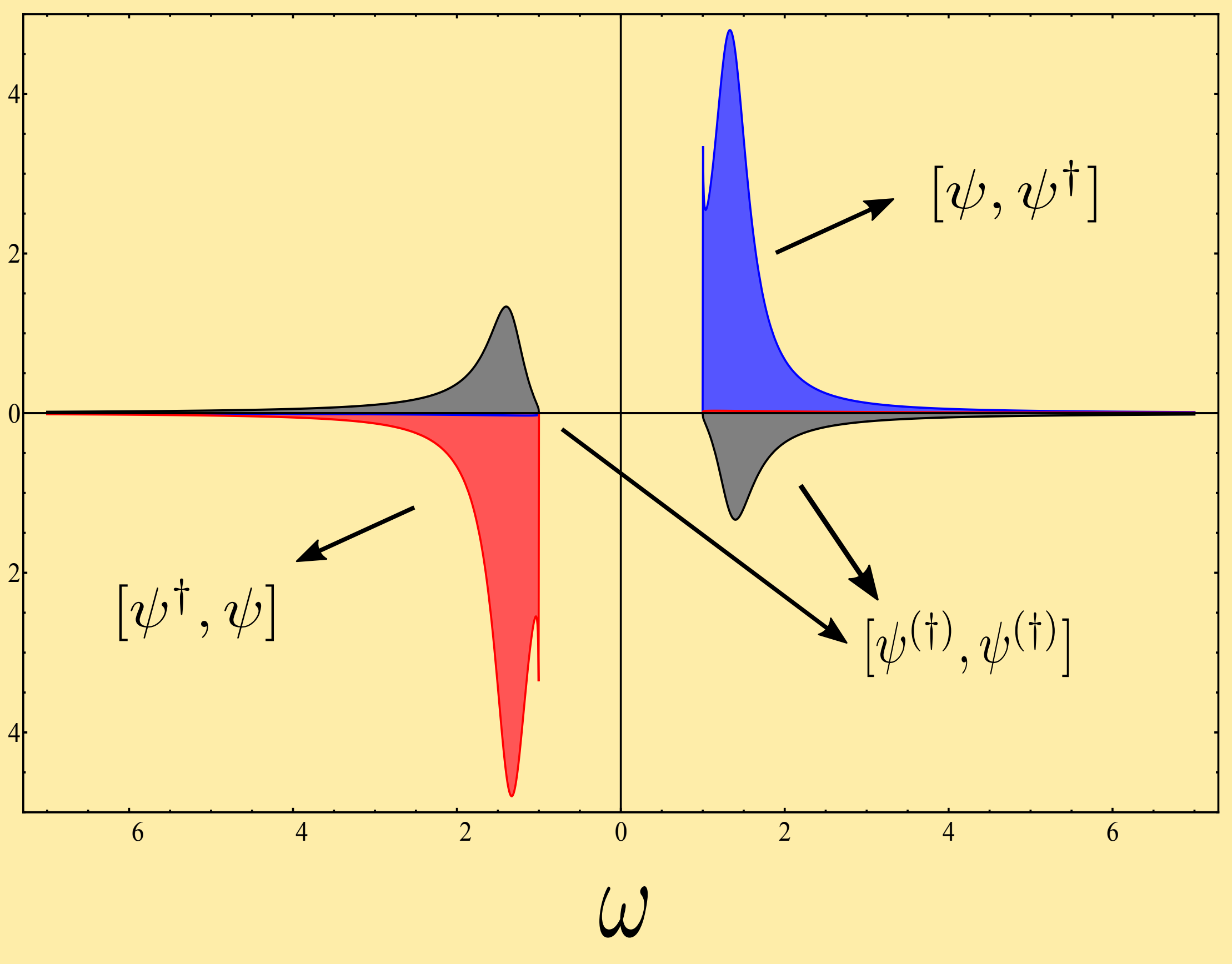
$$S_{UV}=-\hbar Z\int_{r_0}\mathrm{d}^dx\sqrt{-h}\partial_a\phi_s\partial^a\phi_s^*$$

- Retarded Green's function of ϕ_s becomes

$$G_{R,\phi_s}=\frac{-1}{p^2+gG_{R,O}}$$

UV brane with dynamical source





- ϕ_s is an elementary scalar field!
- $G_{R,O}$ now appears as a **self-energy** due to the interaction between ϕ_s the and the CFT!

THE HOLOGRAPHIC SUPERFLUID

The holographic superfluid is a well-known [2] solution to the action

$$S=\int\mathrm{d}^5x\sqrt{-g}\left(\frac{c^3}{16\pi G}(R-\Lambda)-\frac{1}{4\mu_0 c}F_{\mu\nu}F^{\mu\nu}-\hbar g_b\left(D_\mu\phi\left(D^\mu\phi\right)^*+\frac{m^2c^2}{\hbar^2}|\phi|^2\right)\right)$$

Properties:
- Solution consists of metric, temporal gauge field and scalar hair
- Above some temperature T_c, $\phi=0$ only solution => left with a charged black hole
- Below T_c there are solutions with $\phi_s=0$and $\phi_O\neq 0$. On the boundary this yields spontaneous symmetry breaking!

EFFECTIVE ACTION

To find the semi-holographic Green's function, we must first understand the holographic result.

Near T_c, one can describe a *complex* order parameter Δ with the following effective Landau-Ginzburg action

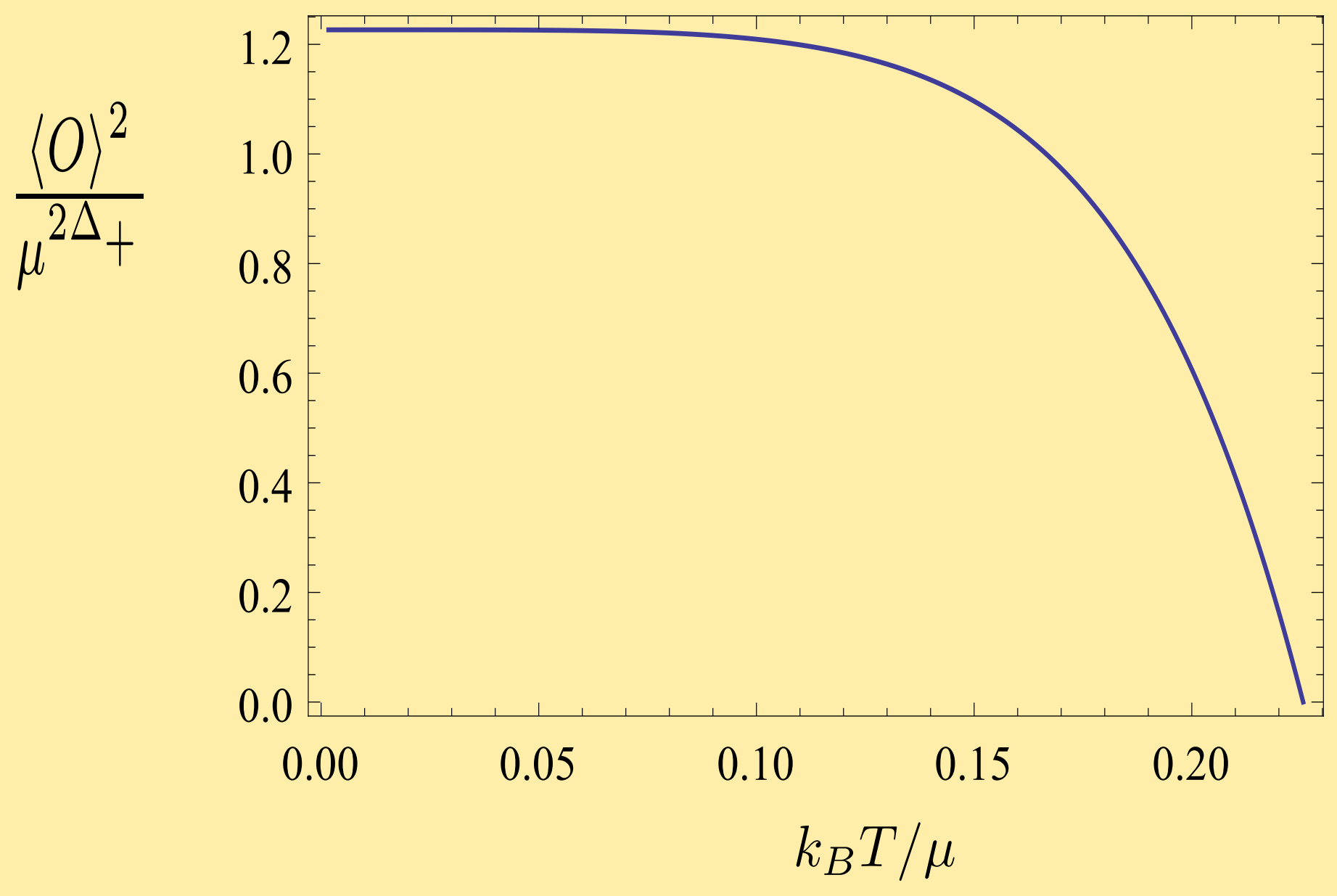
$$S=\int\mathrm{d}^4x\left(-ia\Delta^*\partial_t\Delta+\gamma|\nabla\Delta|^2+\alpha_0(T-T_c)|\Delta|^2+\frac{\beta}{2}|\Delta|^4\right)$$

Relationship between Δ and *O*

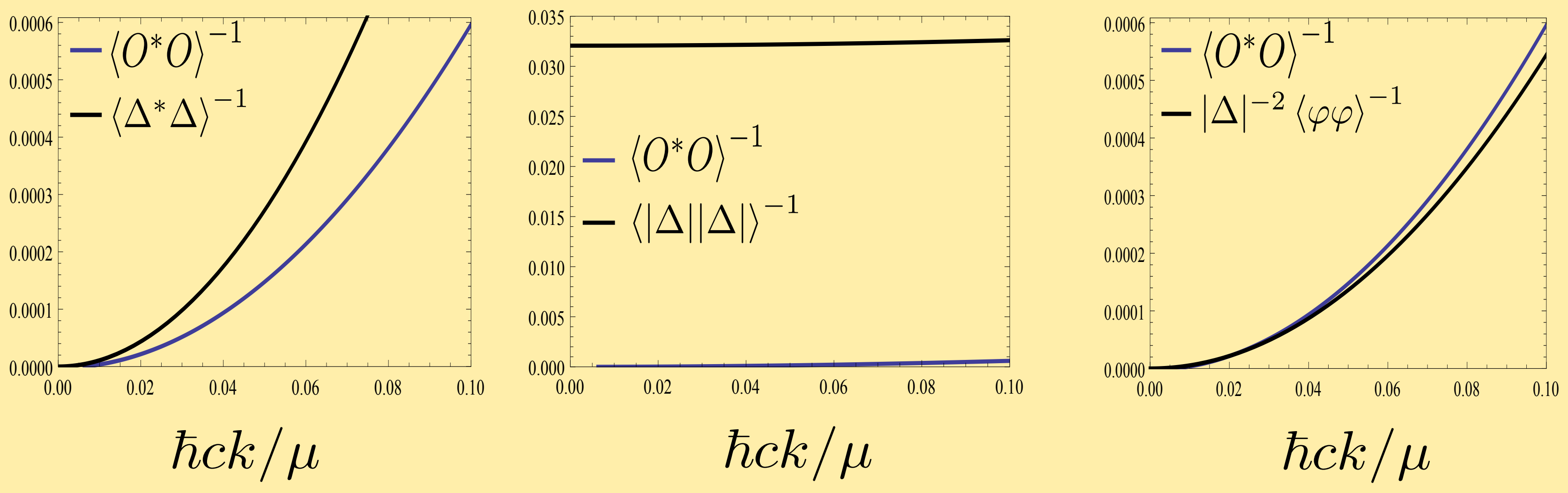
- Below T_c we find

$$\langle\Delta\rangle=\sqrt{\frac{-\alpha_0(T-T_c)}{\beta}}$$

which agrees with $\langle O\rangle(T)$.



- Assuming $O\sim\Delta$ one can determine the above coefficients from the retarded Green's function of *O.* See [3] for $T>T_c$!
- The Green's functions below T_c do not behave as expected from $O\sim\Delta$. Rather, they seem to describe **phase** fluctuations! We believe this is due to large-*N* arguments.



$$(\gamma k^2\ll\alpha_0|T-T_c|\ll\alpha_0T_c)$$

REFERENCES

[1] U. Gürsoy, E. Plauschinn, H. Stoof and S. Vandoren, JHEP 1205, 018 (2012)
[2] S. Hartnoll, C. Herzog and G. Horowitz, JHEP 0812, 015 (2008)
[3] J.-H. She, B. Overbosch, Y.-W. Sun, Y. Liu, K. Schalm, J. Mydosh and J. Zaanen, Phys.Rev. B84, 144527 (2011)