Searching holographic superconductor

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Introduction of Holography Theory

Holography theory emerged as a powerful tool to understand superconductor theory by providing insights into strongly correlated electron systems.

By utilizing holography theory, we can explore the complex phase transitions and non-perturbative phenomena in superconductors.

Unlike conventional approaches, holography theory provides a unique framework to understand the universal properties of superconductors, facilitating breakthroughs in our comprehension of high-temperature superconductivity.

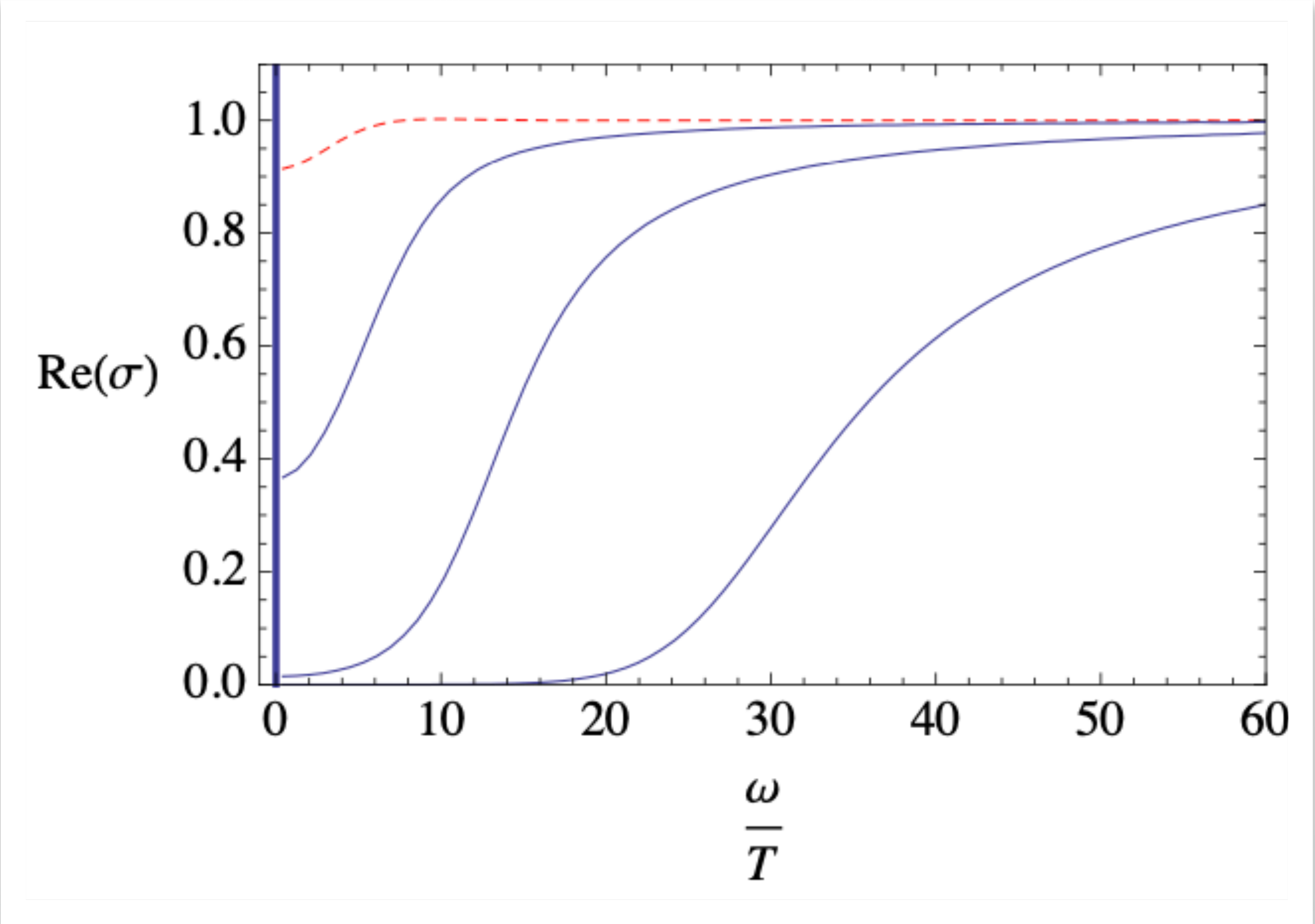
Conductivity of Holographic Superconductors

- Introduced the concept of using holography to model superconductivity.
  [Hartnoll, Herzog, Horowitz 08]

- Holographic superconductor is described a gravity theory involving a black hole in AdS4 with a U(1) gauge field and a charged scalar field.

- Provided initial calculations showing how the conductivity behaves in this holographic setup.

$$\boxed{\mathscr{L} = R + \frac{6}{L^2} - \left|D_\mu \psi\right|^2 - \frac{1}{4}F^2 - m^2\psi^2}$$



Initial Model Limitations

The initial model was too simplistic, lacking the complexity needed to describe real-world superconductors accurately.

Did not provide a comprehensive phase diagram, which is crucial for understanding the behavior of superconductors under various conditions.

Holographic Superconductors with Superconducting Dome

- The axion scalar field ϕ is essential for modeling realistic superconductors where momentum is not infinitely relaxed due to impurities. [Andrade, Withers 13]

- Introduced interactions M between complex scalar fields and gauge fields, allowing superconductor dome shape. [Seo, Kim, Kim 23]

- Depending on the values of γ_2, γ_4, and m, there will be a variety of areas that break the BF condition.

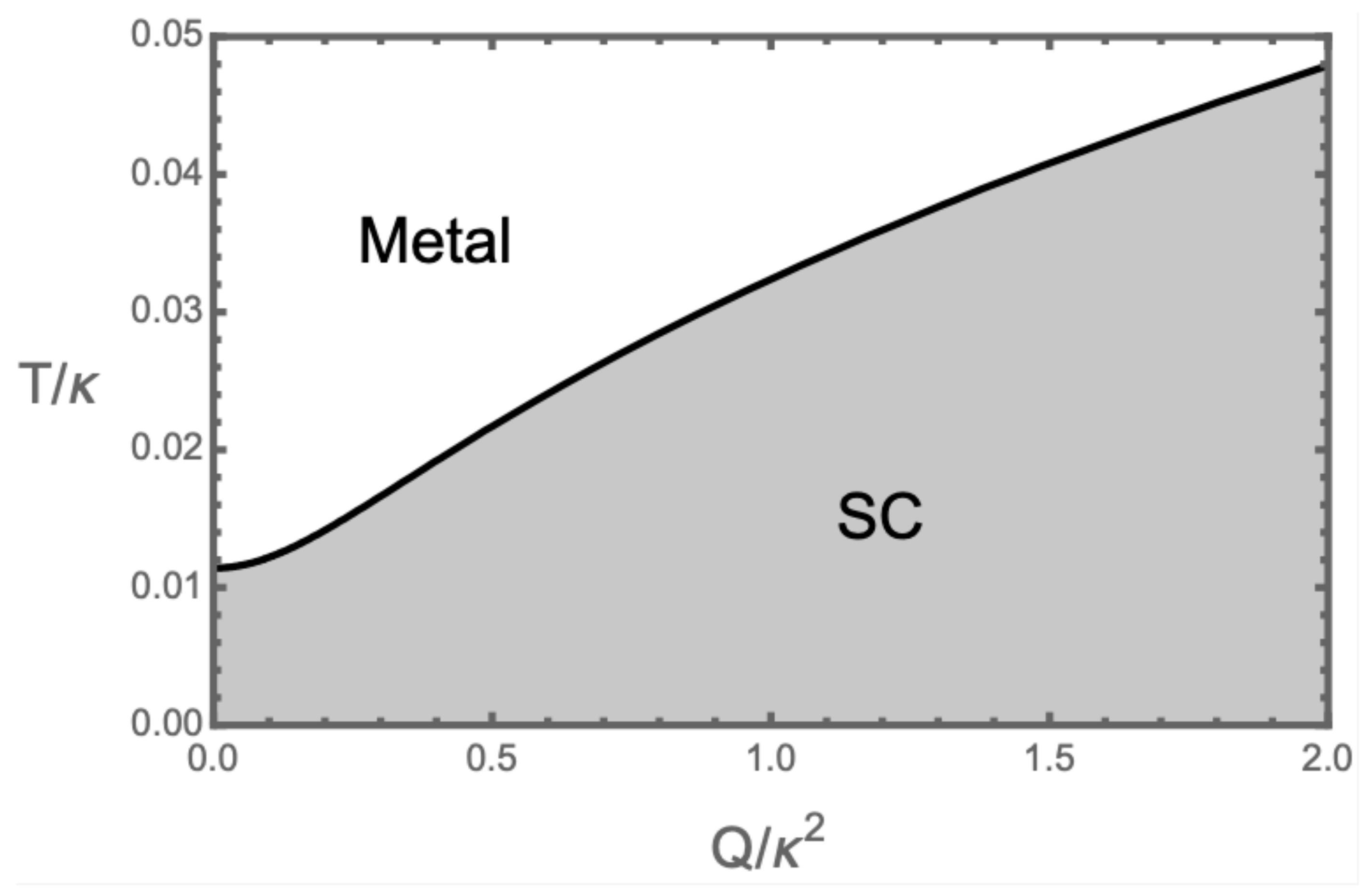
$$\boxed{\mathscr{L} = R + \frac{6}{L^2} - \left| D_\mu \psi \right|^2 - \frac{1}{4}F^2 - M(F^2)\psi^2 - \frac{1}{2}\left(\partial \phi^I\right)^2}$$

$$\boxed{\begin{aligned} &M(F^2) = m^2 + \gamma_2 F^2 + \gamma_4 F^4 \\ &\phi^I = \{\kappa x, \kappa y\} \end{aligned}}$$

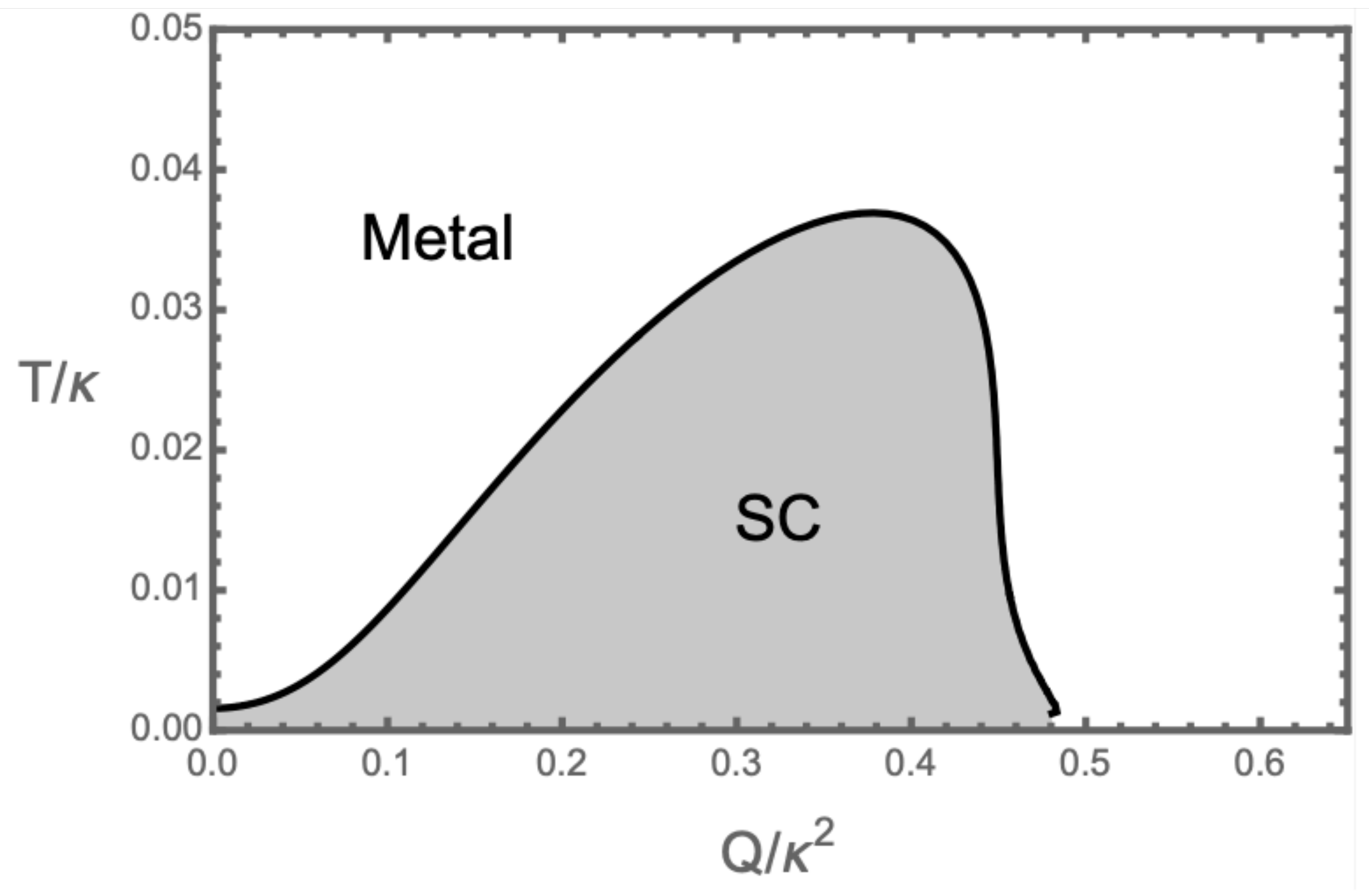
Improved Result of Phase Diagram

- Depending on the values of γ_2, γ_4, and m, phase diagram now includes a dome-shaped region indicating the superconducting phase.

- This phase diagram aligns more closely with experimental observations of superconductors, especially high-temperature superconductors



(a) $m^2 = -2, \ \gamma_2 = \gamma_4 = 0$



(c) $m^2 = -1.5, \ \gamma_2 = 6, \ \gamma_4 = 1.5$

Summary of Key Developments

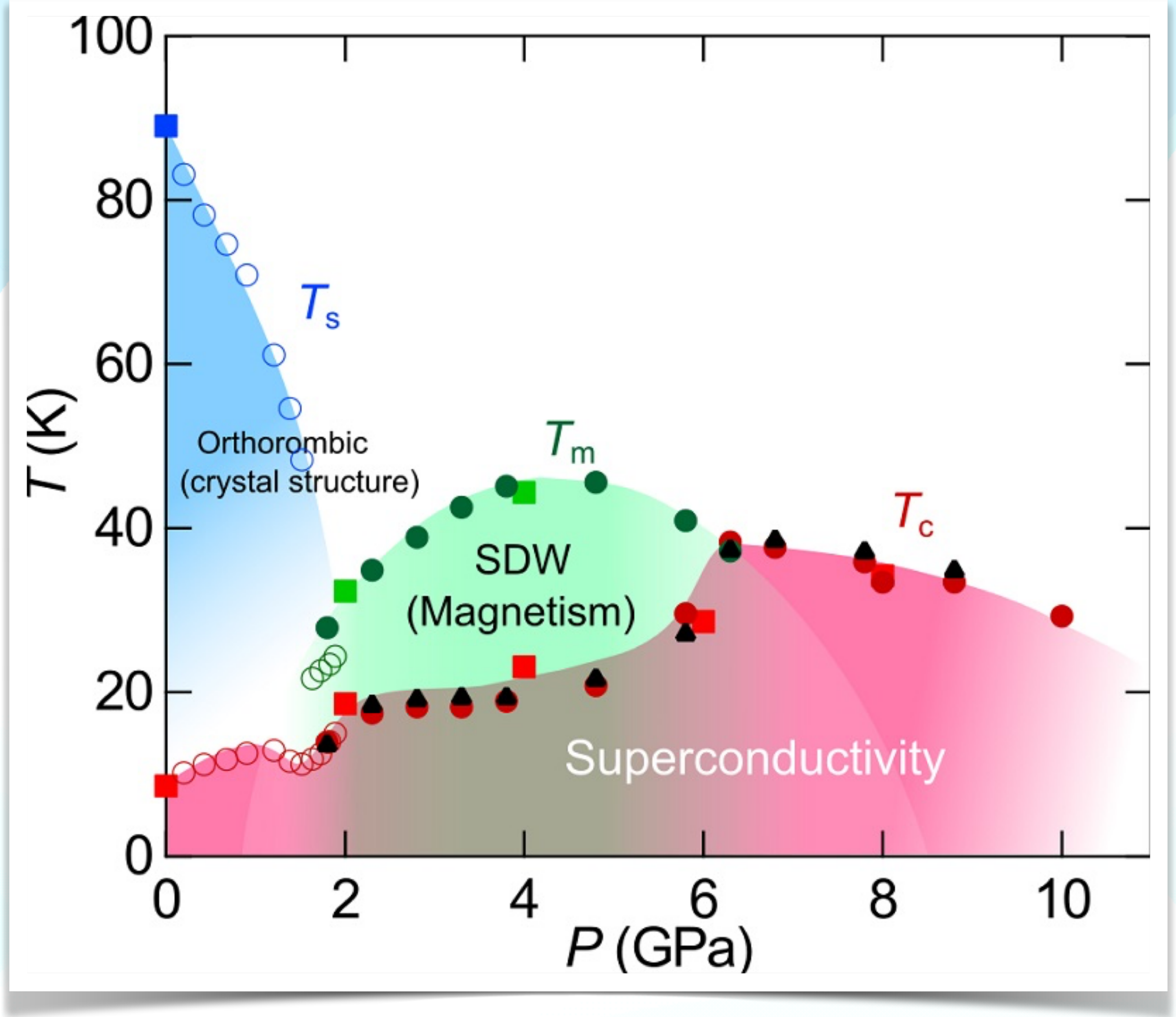
The theory evolved from a simplistic model to one incorporating non linear interactions M and realistic features.

The interaction M between the complex scalar field and the gauge field causes variations in the phase diagram of holographic superconductors.

Problem of Holographic Superconductor

- By considering arbitrary of M, a holographic superconductor model can have a dome-shaped phase diagram similar to the phase diagram of a real superconductor.

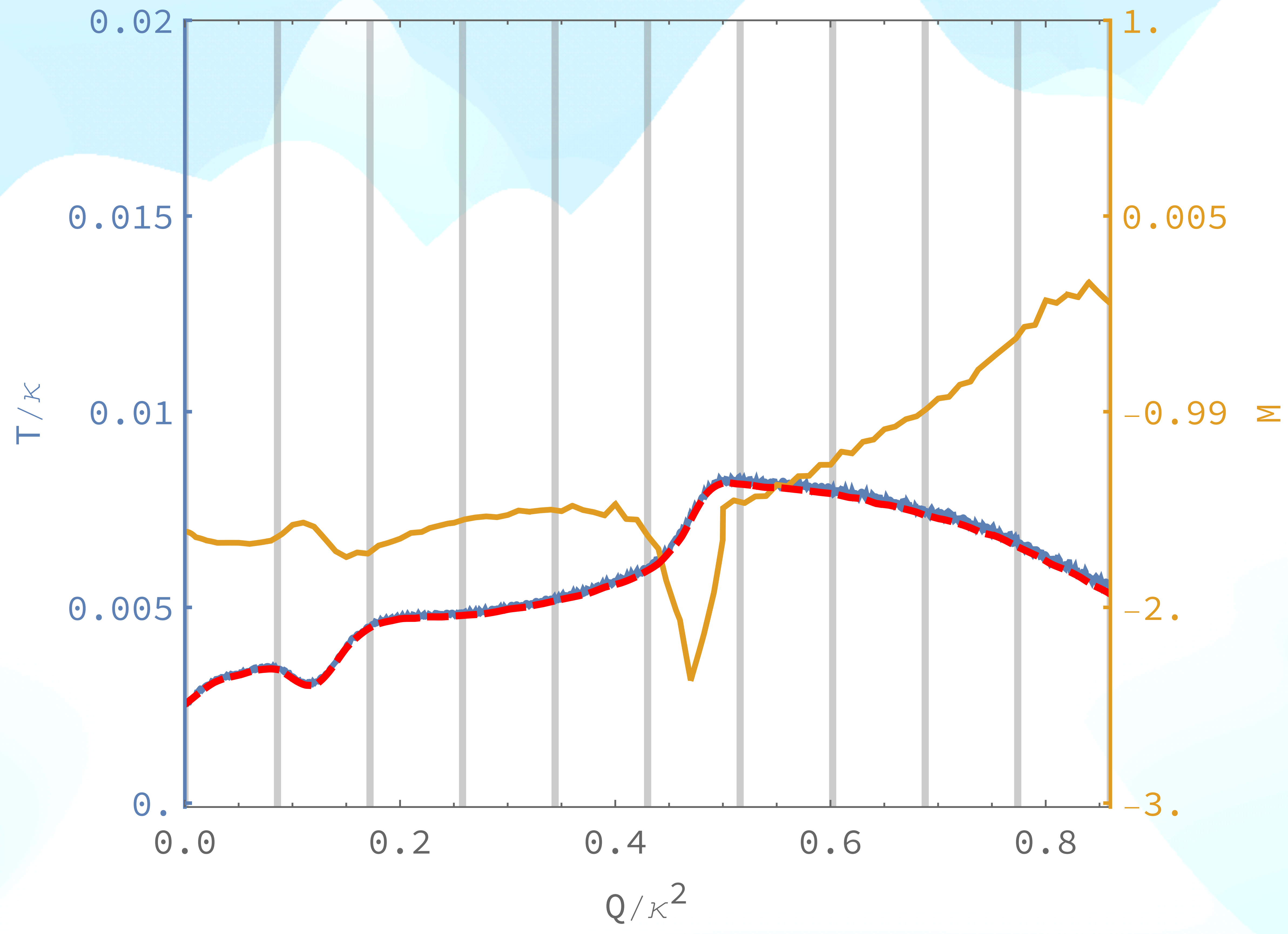
- Our goal is to find a M function that can fit the actual data. However, this study involves solving the inverse problem in gravity theory.



Interpolation Method

- In ordinary research, the trial and error method is used to find an analytic M function to solve this problem, but it requires a lot of time and effort.

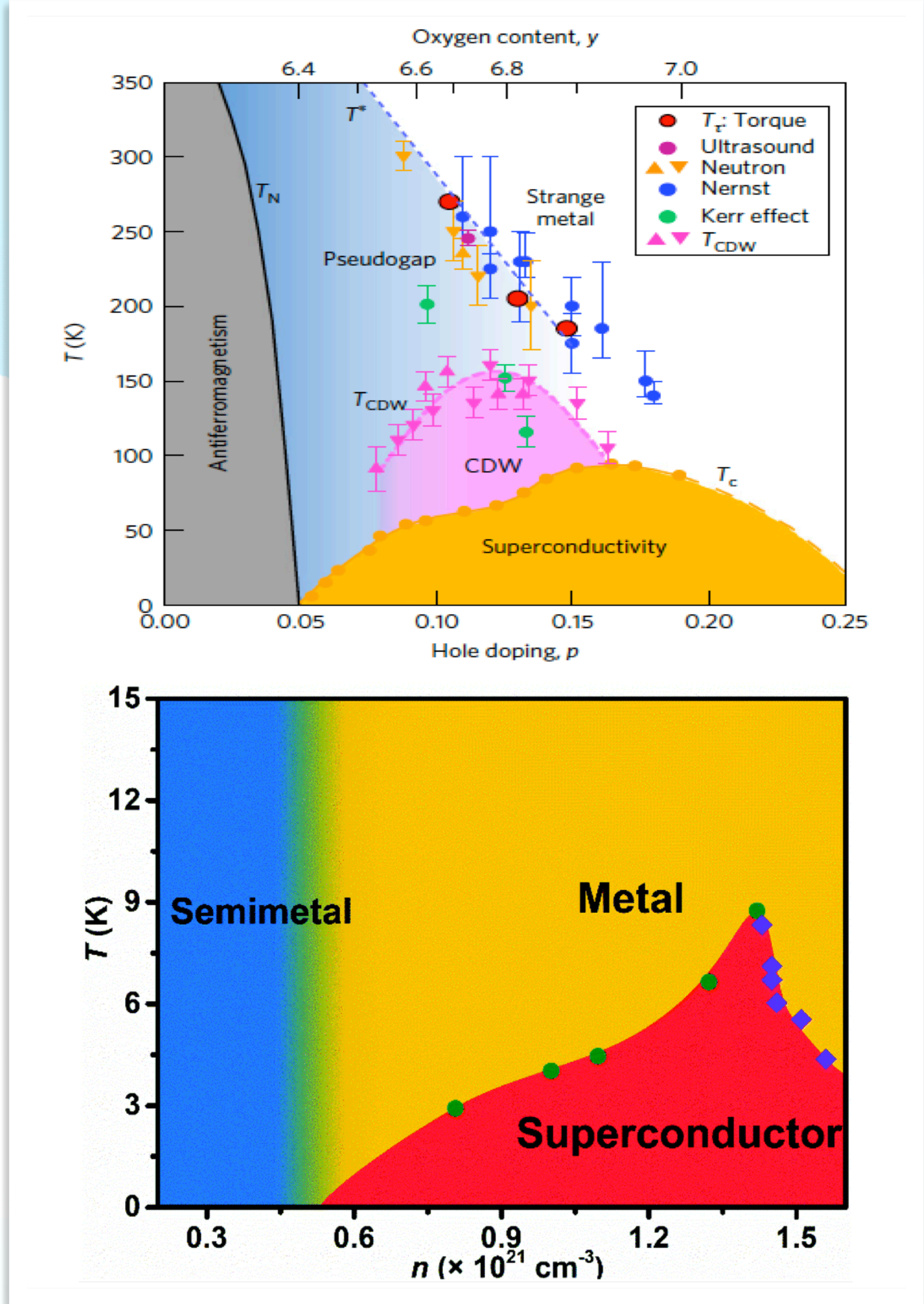
- Another approach is to numerically find the value of $M(F^2)$ by interpolation according to each value of F^2.



Difficulty of Inverse Problem

- We cannot determine the value of $M(F^2 = 0)$ if the critical temperature of the superconductor has no y-intercept.

- In these cases, we apply deep learning techniques and specifically modeled the function M as a neural network ansatz.



Solution for Holography Theory (Neural Network)

- We apply machine learning techniques to model the M function as a neural network.

- In this study, the loss function is defined as the summation of the source zero condition for horizon values, charge, and temperature, which is evaluated using the shooting method.

- When the loss approaches zero, the holographic superconductor theory, modeled by the trained neural network M, satisfies the given phase diagram.

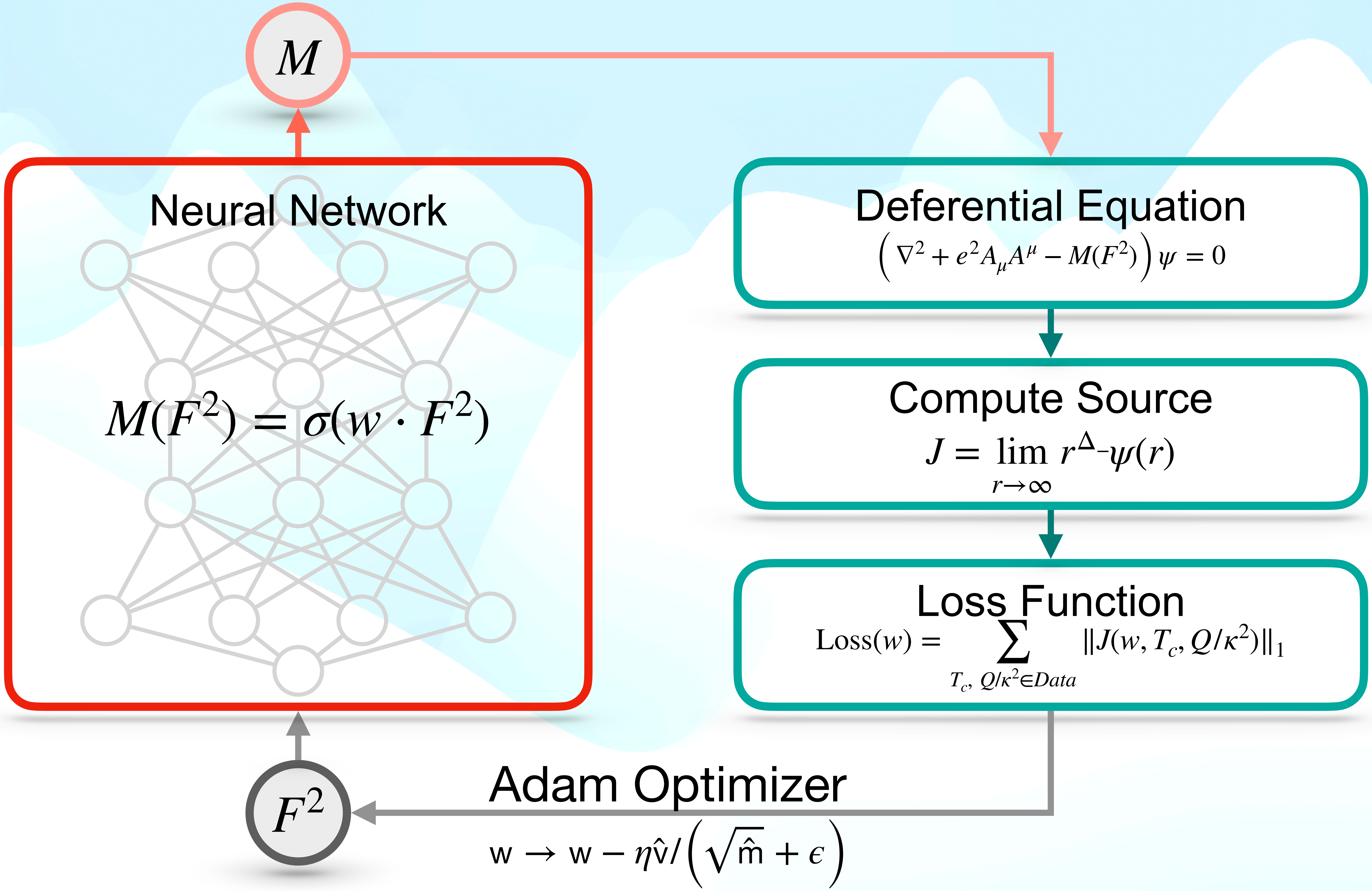
$$\boxed{\mathscr{L} = R + \frac{6}{L^2} - \left|D_\mu \psi\right|^2 - \frac{1}{4}F^2 - M(F^2)\psi^2 - \frac{1}{2}\left(\partial\phi^I\right)^2}$$

$$\boxed{M = \mathrm{NN}(F^2; W)}$$

$$\psi \approx \frac{J}{r^{\Delta_-}} + \frac{\langle O \rangle}{r^{\Delta_+}} + \cdots$$

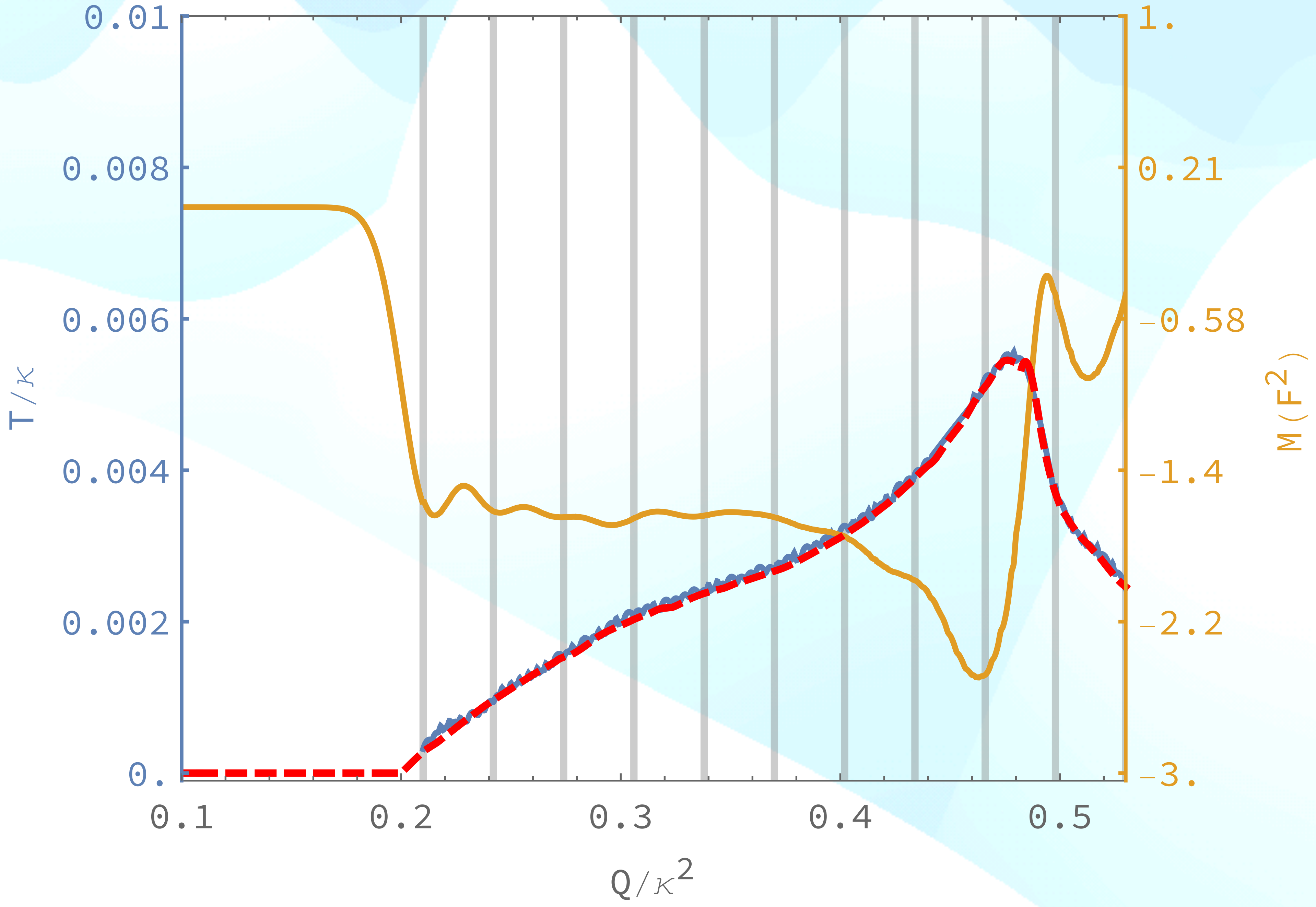
$$Loss(W) = \sum_{T,Q} \| J_{\langle O \rangle}(W, T, Q) \|_1$$

Mechanism of NN Learning

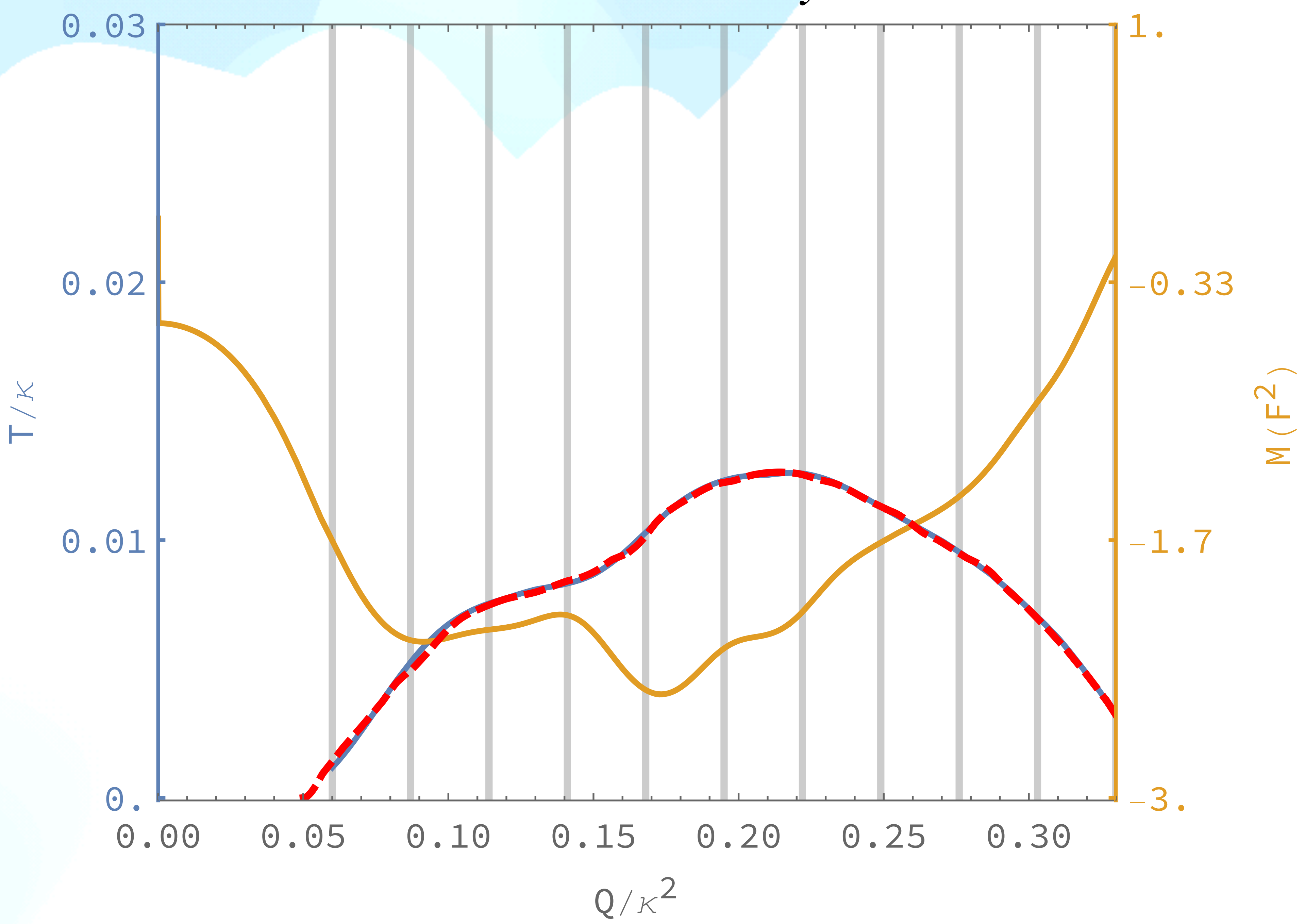


Result of Superconductor

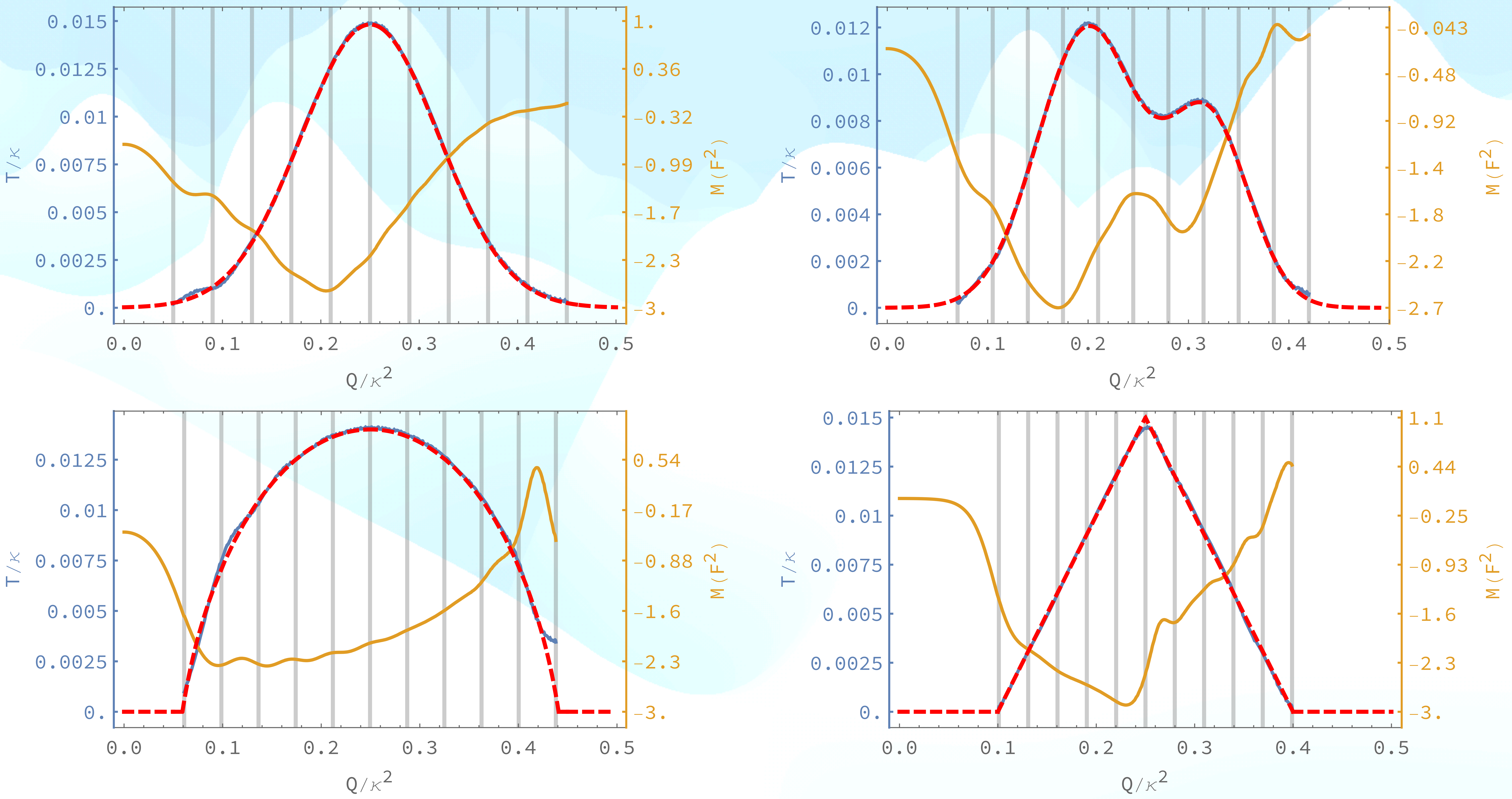
$W_{1-x}Mo_xS_2$



$YBa_2Cu_3O_y$



Result of Artificial Diagram



Conclusion

By applying a neural network and interpolation approach, we can find a holographic superconductor theory that satisfies the phase diagram with the non-linear interaction M.

The interpolation method can determine an unique function M. However, the neural network method is not unique even if the initial value of M was chosen naturally.

For future work, we will consider other matters to model a more simplistic holographic superconductor that satisfies the phase diagram data.

Thanks for your attention

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