FERMIONS ACROSS DIMENSIONS

Julien Barrat

28.09.2023

DESY Theory Workshop

RTG 2575:
Rethinking Quantum Field Theory

TO APPEAR

Scalar-fermion correlators in Yukawa CFTs across dimensions,

JB, I. Burić, V. Schomerus, P. van Vliet.

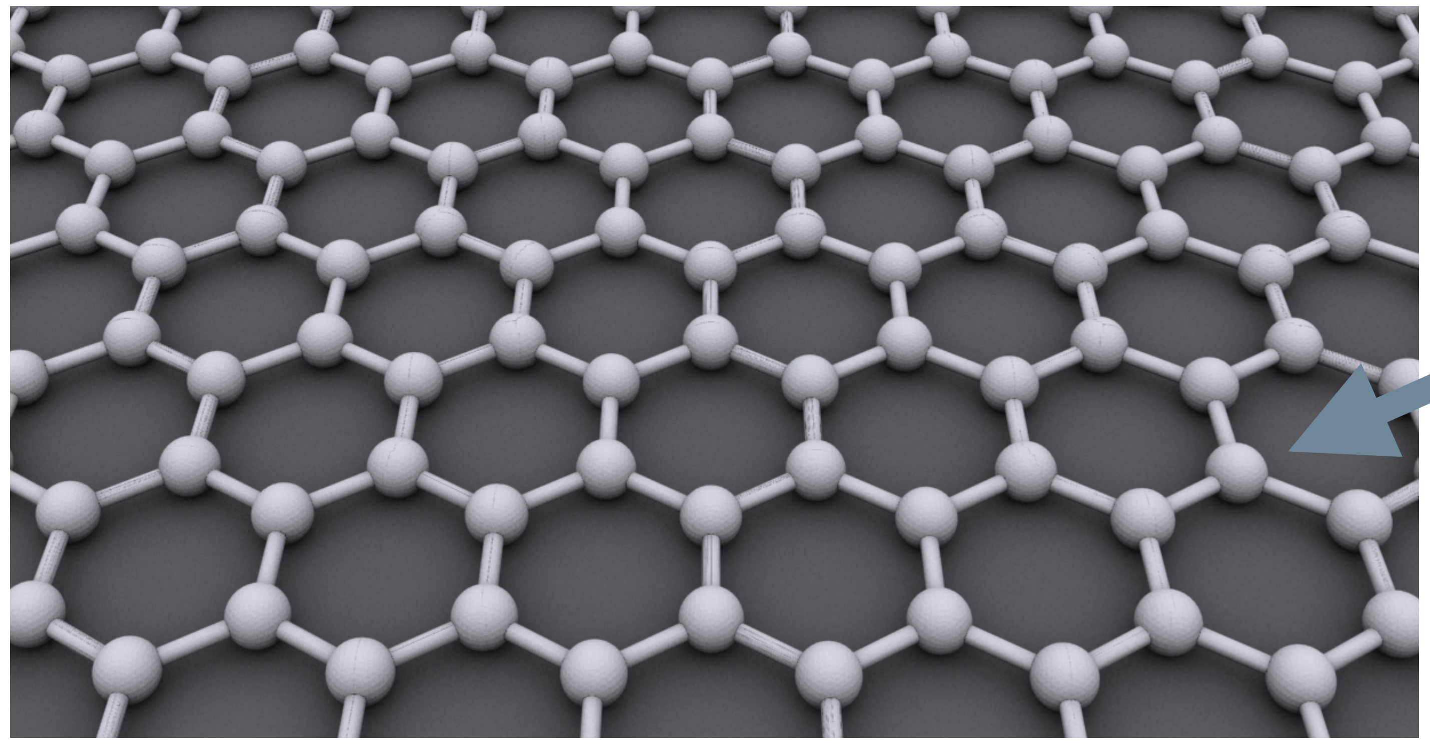
1. YUKAWA CFT

2. SCALAR-FERMION CORRELATORS

1.

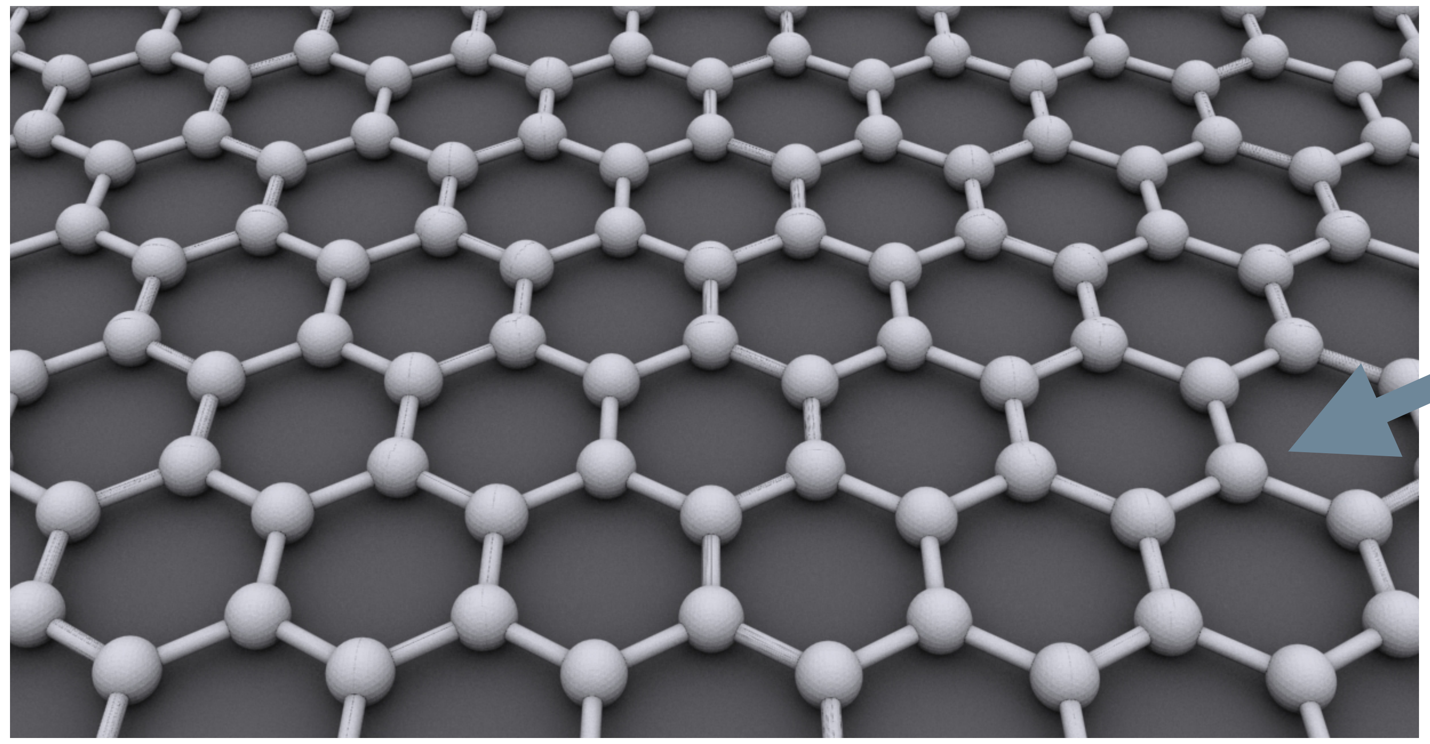
YUKAWA CFT

GRAPHENE



carbon atoms

GRAPHENE



carbon atoms

$2d$ material

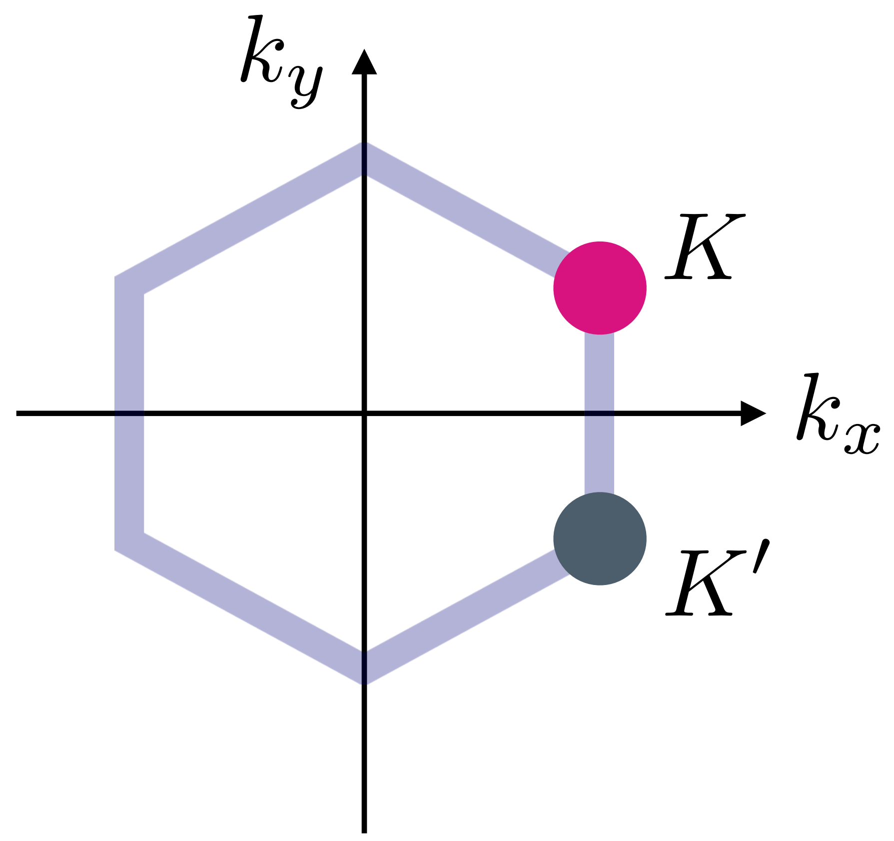
Excellent conductor

Robust, flexible, light

Lorentz symmetry

GRAPHENE $\longrightarrow$ QFT

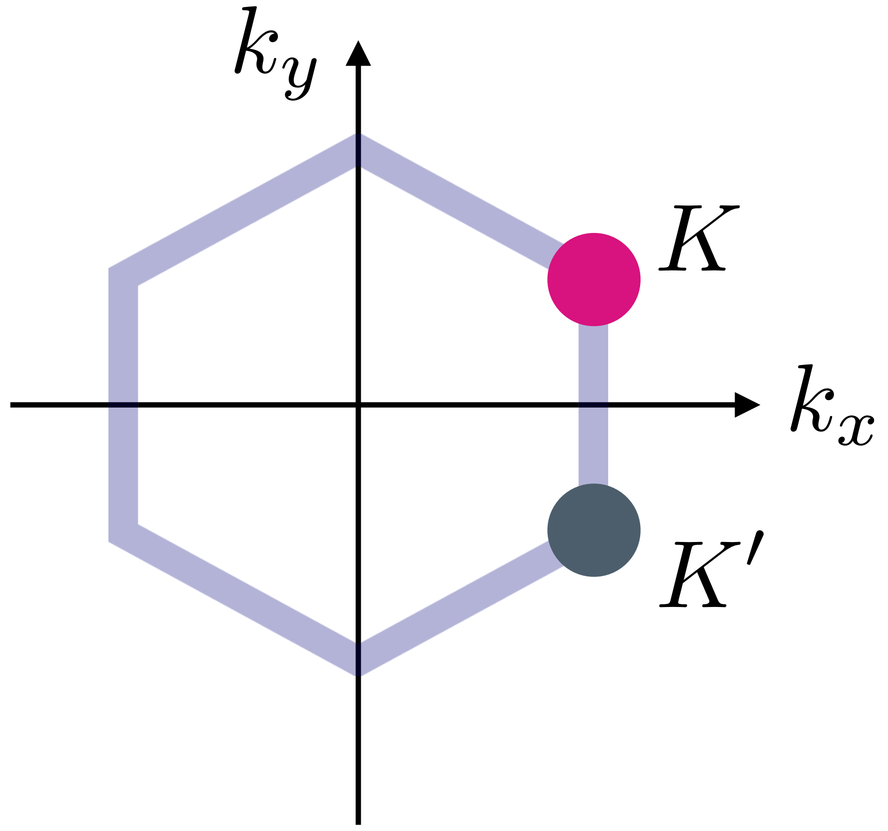
Reciprocal lattice



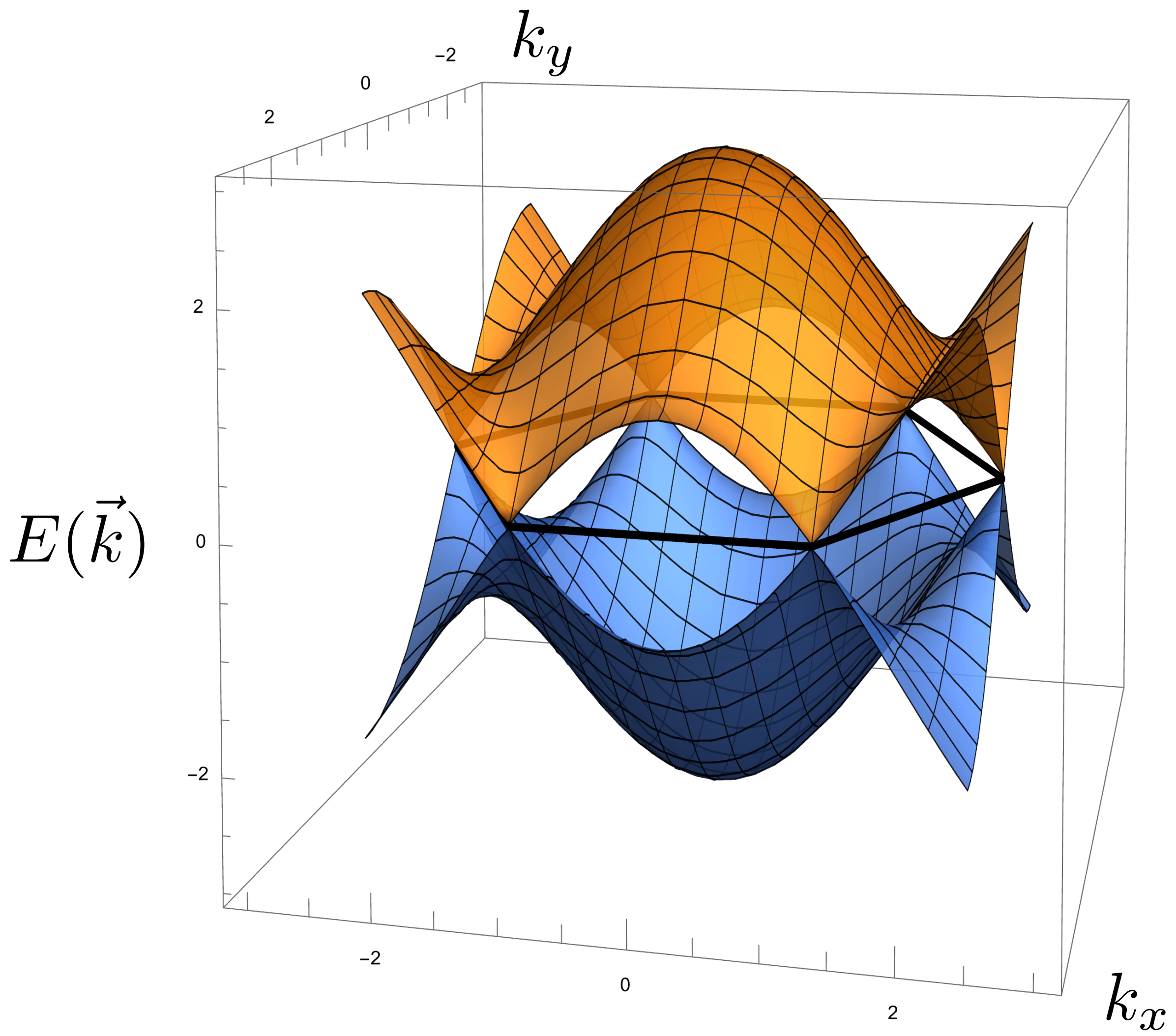
$$\mathcal{H} = -t \sum_{\text{sites, spin}} \left(a^{\dagger}_{\sigma,i} b_{\sigma,j} + \text{h.c.} \right)$$

GRAPHENE $\longrightarrow$ QFT

Reciprocal lattice



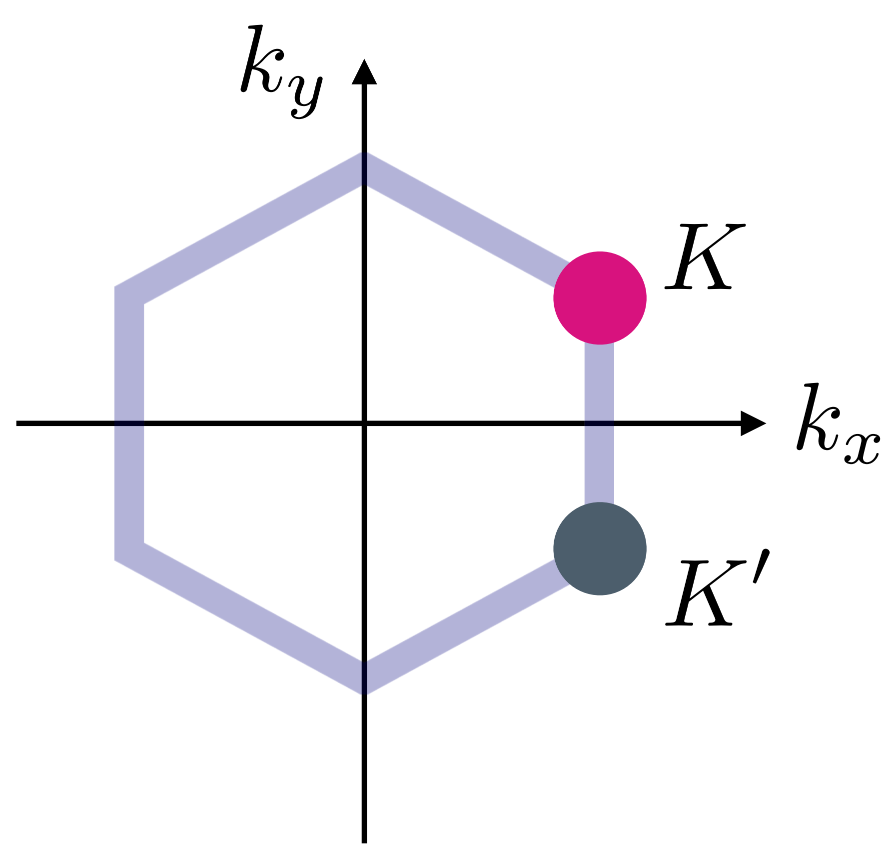
Energy bands



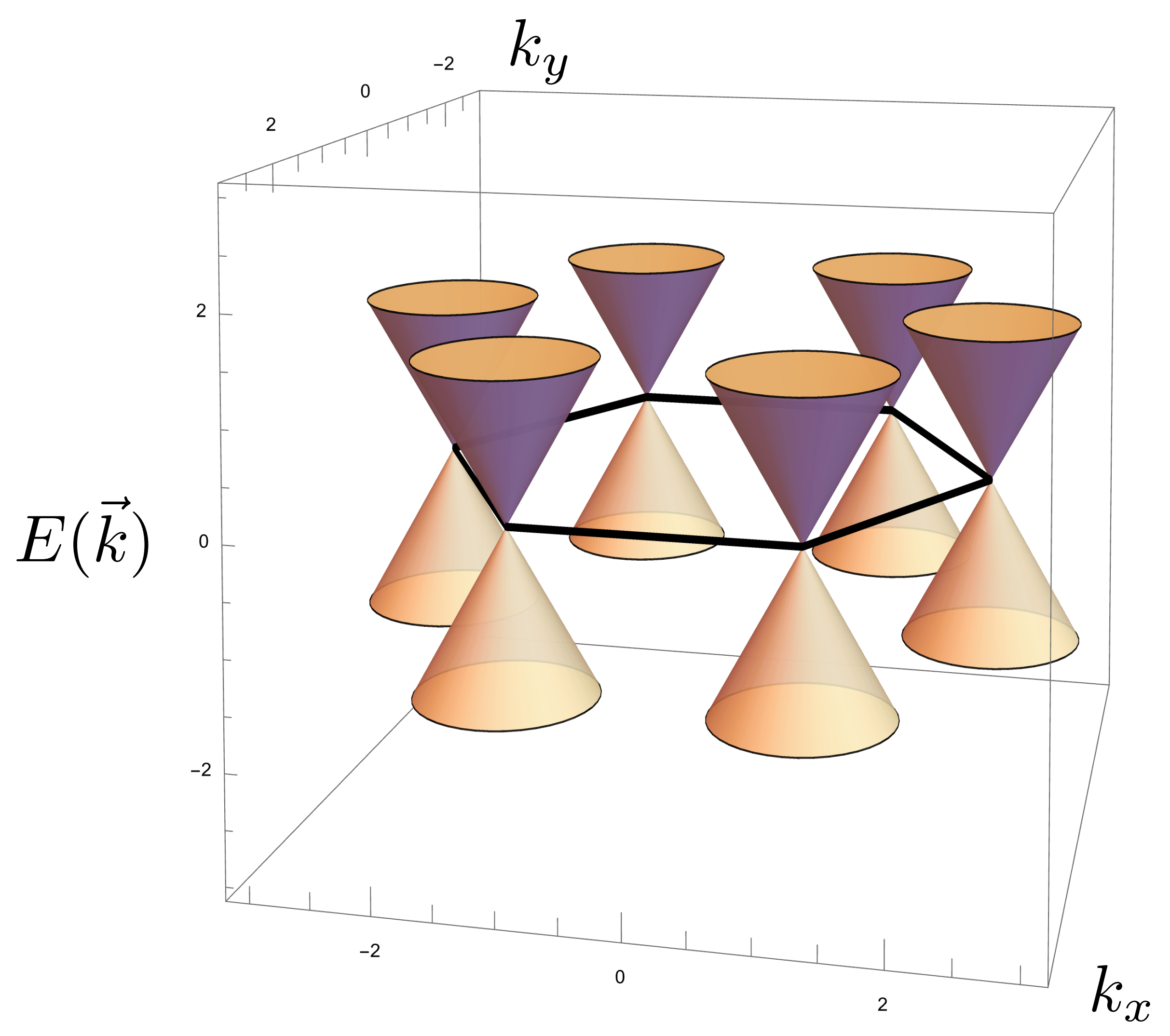
$$\mathcal{H} = -t \sum_{\text{sites, spin}} \left(a^\dagger_{\sigma,i} b_{\sigma,j} + \text{h.c.} \right)$$

GRAPHENE $\longrightarrow$ QFT

Reciprocal lattice



Energy bands



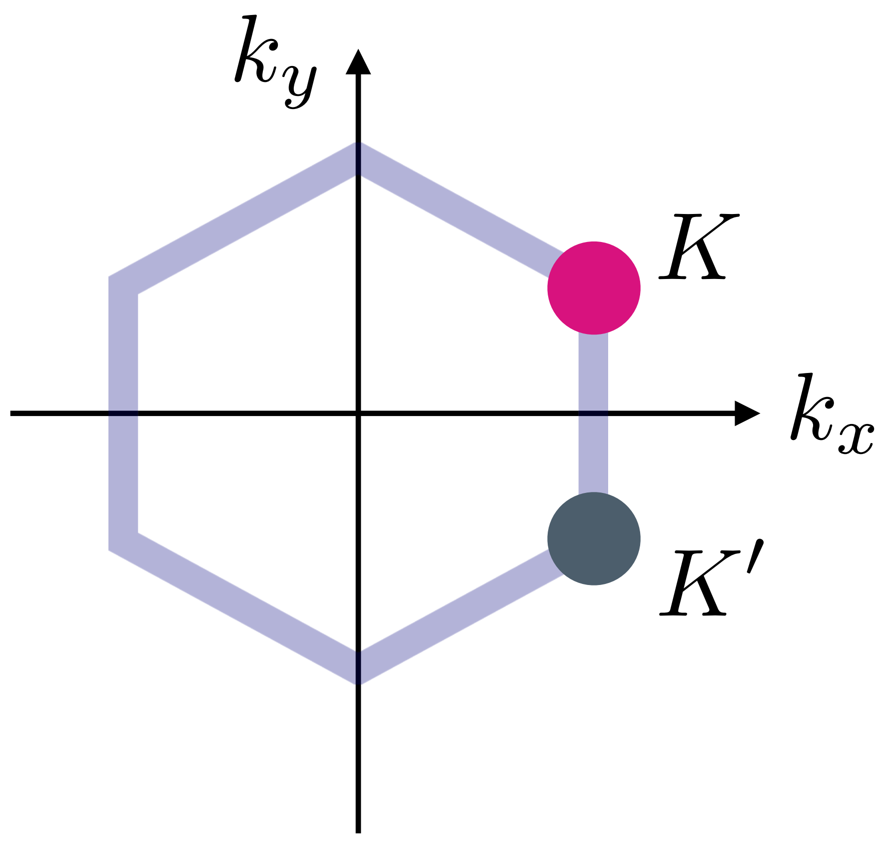
$$E_{\pm}(\vec{k}) = \pm v_F |\vec{k}|$$

(relativistic!)

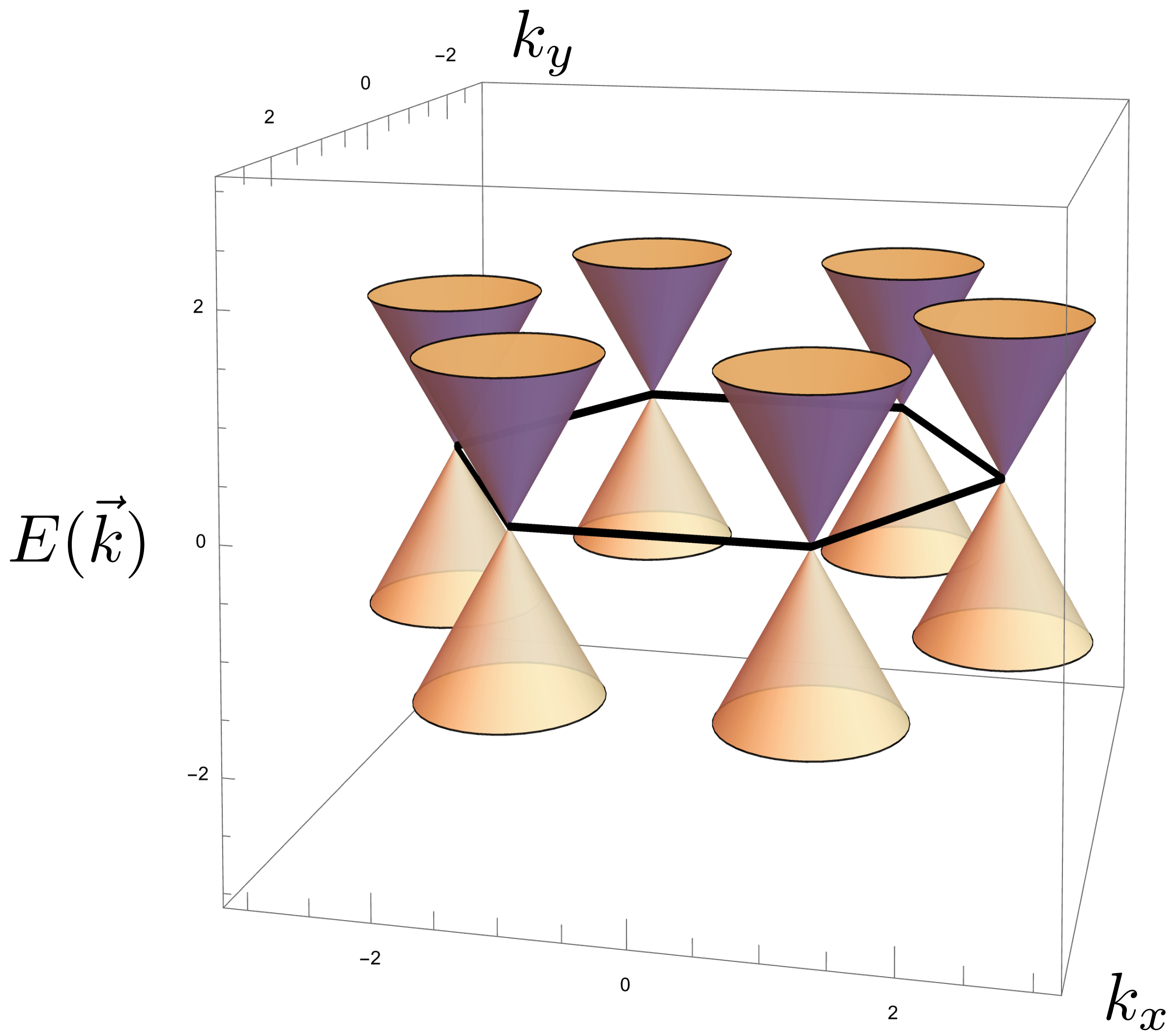
1. YUKAWA CFT

GRAPHENE $\longrightarrow$ QFT

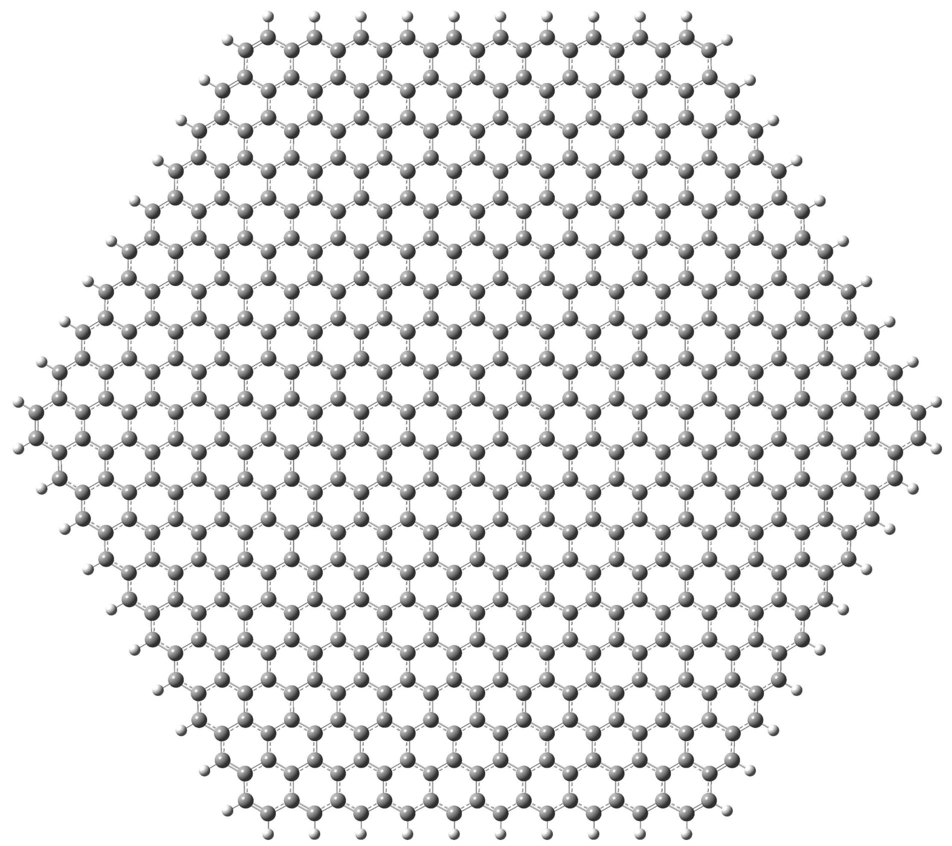
Reciprocal lattice



Energy bands



Continuum limit

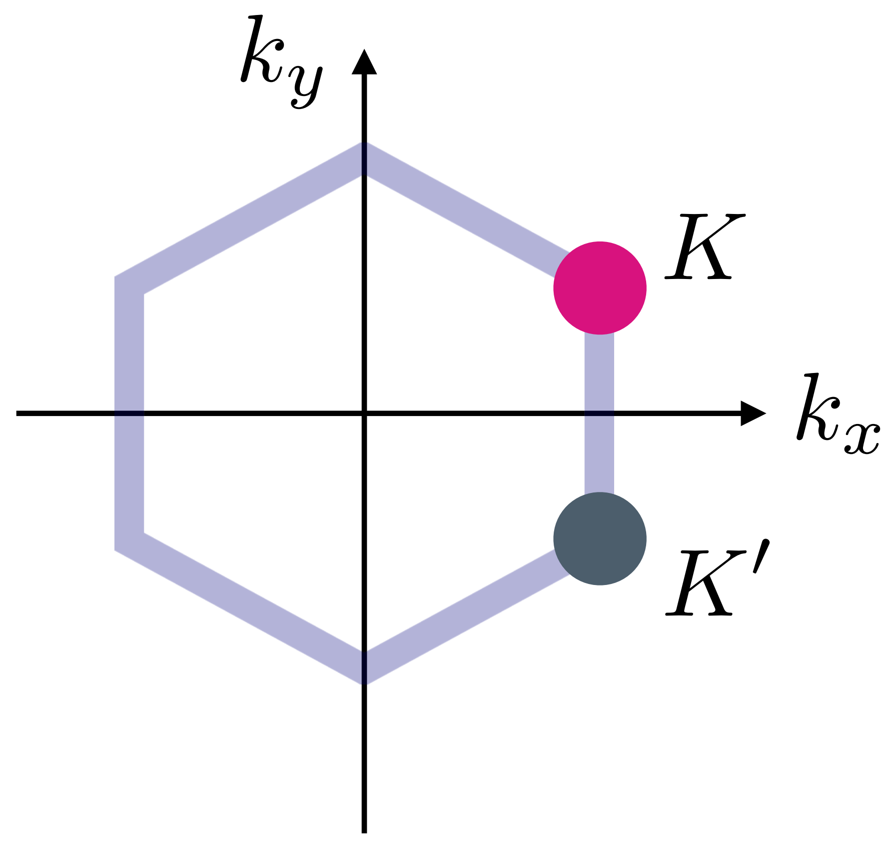


$$S_{\text{free}} = \int d^3x\, i\, \bar{\psi}^a\, \sigma \cdot \nabla\, \psi^a \qquad a = 1, 2$$

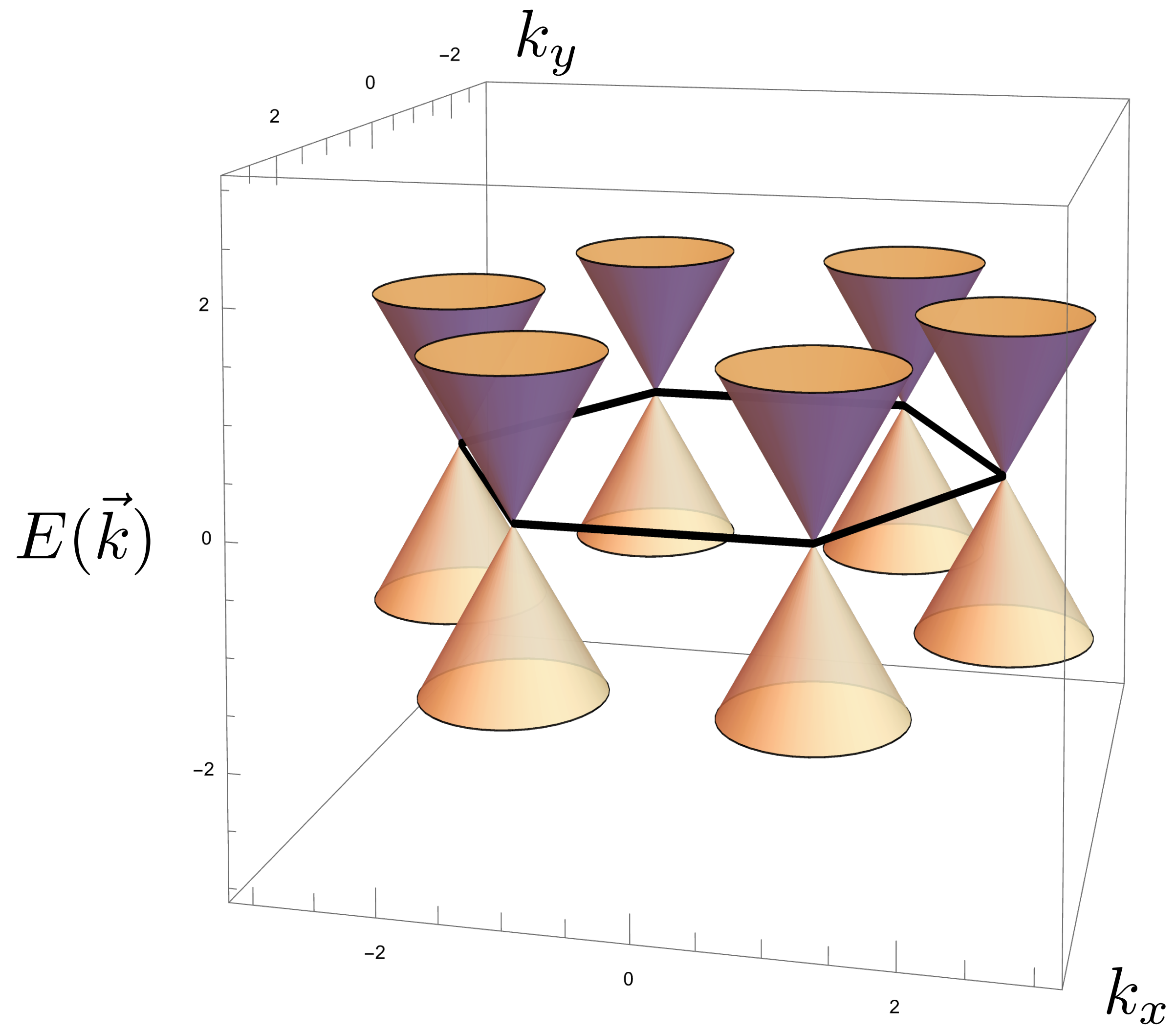
[Semenoff, '84]

GRAPHENE $\longrightarrow$ QFT

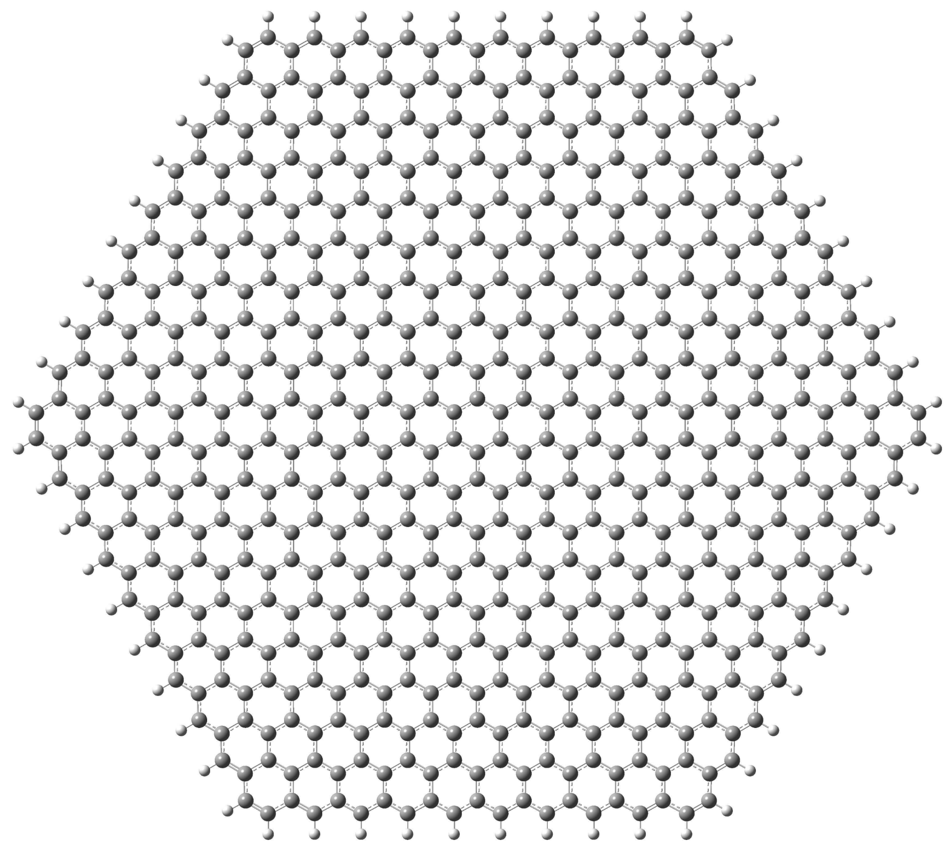
Reciprocal lattice



Energy bands



Continuum limit



$$S = \int d^3x \left(i\bar{\psi}^a \partial\!\!\!/ \psi^a + \frac{g^2}{2} (\bar{\psi}^a \psi^a)(\bar{\psi}^b \psi^b) \right) \qquad a = 1, 2$$

[Herbut, '09]

YUKAWA QFT

UV completion

$$S = \int d^3x \left(i\bar{\psi}^a \partial\!\!\!/ \psi^a + \frac{1}{2}\partial_\mu \phi^I \partial_\mu \phi^I + g\bar{\psi}^a \Sigma^I \phi^I \psi^a + \frac{\lambda}{4!} \phi^I \phi^I \phi^J \phi^J \right)$$

[Hubbard, Stratonovich, '57]

[Gross-Neveu, '74]

YUKAWA QFT

UV completion

$$S = \int d^3x \left(i\bar{\psi}^a \not{\partial} \psi^a + \frac{1}{2}\partial_\mu \phi^I \partial_\mu \phi^I + g\bar{\psi}^a \Sigma^I \phi^I \psi^a + \frac{\lambda}{4!}\phi^I \phi^I \phi^J \phi^J \right)$$

$$(a = 1, \ldots, N_f, \ I = 1, \ldots, N)$$

[Hubbard, Stratonovich, ’57]
[Gross-Neveu, ‘74]

YUKAWA QFT

UV completion

$$S = \int d^3x \left(i\bar{\psi}^a \partial\!\!\!/ \psi^a + \frac{1}{2}\partial_\mu \phi^I \partial_\mu \phi^I + g\bar{\psi}^a \Sigma^I \phi^I \psi^a + \frac{\lambda}{4!}\phi^I \phi^I \phi^J \phi^J \right)$$

$$(a = 1, \ldots, N_f, \ I = 1, \ldots, N)$$

[Hubbard, Stratonovich, '57]
[Gross-Neveu, '74]

Fixed points: $\beta_g(g_\star) = \beta_\lambda(\lambda_\star) = 0$

YUKAWA QFT

UV completion

$$S = \int d^3x \left(i\bar{\psi}^a \partial\!\!\!/ \psi^a + \frac{1}{2}\partial_\mu \phi^I \partial_\mu \phi^I + g\bar{\psi}^a \Sigma^I \phi^I \psi^a + \frac{\lambda}{4!}\phi^I \phi^I \phi^J \phi^J \right)$$

$$(a = 1, \ldots, N_f,\ I = 1, \ldots, N)$$

[Hubbard, Stratonovich, '57]
[Gross-Neveu, '74]

Fixed points: $\beta_g(g_\star) = \beta_\lambda(\lambda_\star) = 0$

$\boxed{\text{Conformal bootstrap}}$ don't use action, assume fixed points exist $\longrightarrow$ many results!

[Alday, Bissi, Gimenez-Grau, Gromov, Henriksson, Kaviraj, Kravchuk, Liendo, Paulos, Poland,Rong, Rychkov, Schomerus, v. Vliet, Zhiboedov, ...]

YUKAWA QFT

UV completion

$$S = \int d^3x \left(i\bar{\psi}^a \partial\!\!\!/ \psi^a + \frac{1}{2}\partial_\mu \phi^I \partial_\mu \phi^I + g\bar{\psi}^a \Sigma^I \phi^I \psi^a + \frac{\lambda}{4!}\phi^I \phi^I \phi^J \phi^J \right)$$

$$(a = 1, \dots, N_f, \ I = 1, \dots, N)$$

[Hubbard, Stratonovich, '57]
[Gross-Neveu, '74]

Fixed points: $\beta_g(g_\star) = \beta_\lambda(\lambda_\star) = 0$

Conformal bootstrap — don't use action, assume fixed points exist $\longrightarrow$ many results!

[Alday, Bissi, Gimenez-Grau, Gromov, Henriksson, Kaviraj, Kravchuk, Liendo, Paulos, Poland,Rong, Rychkov, Schomerus, v. Vliet, Zhiboedov, ...]

ε-expansion — $d = 4 - \varepsilon$

[Wilson, Fisher, '74]

$d = 4$ free theory

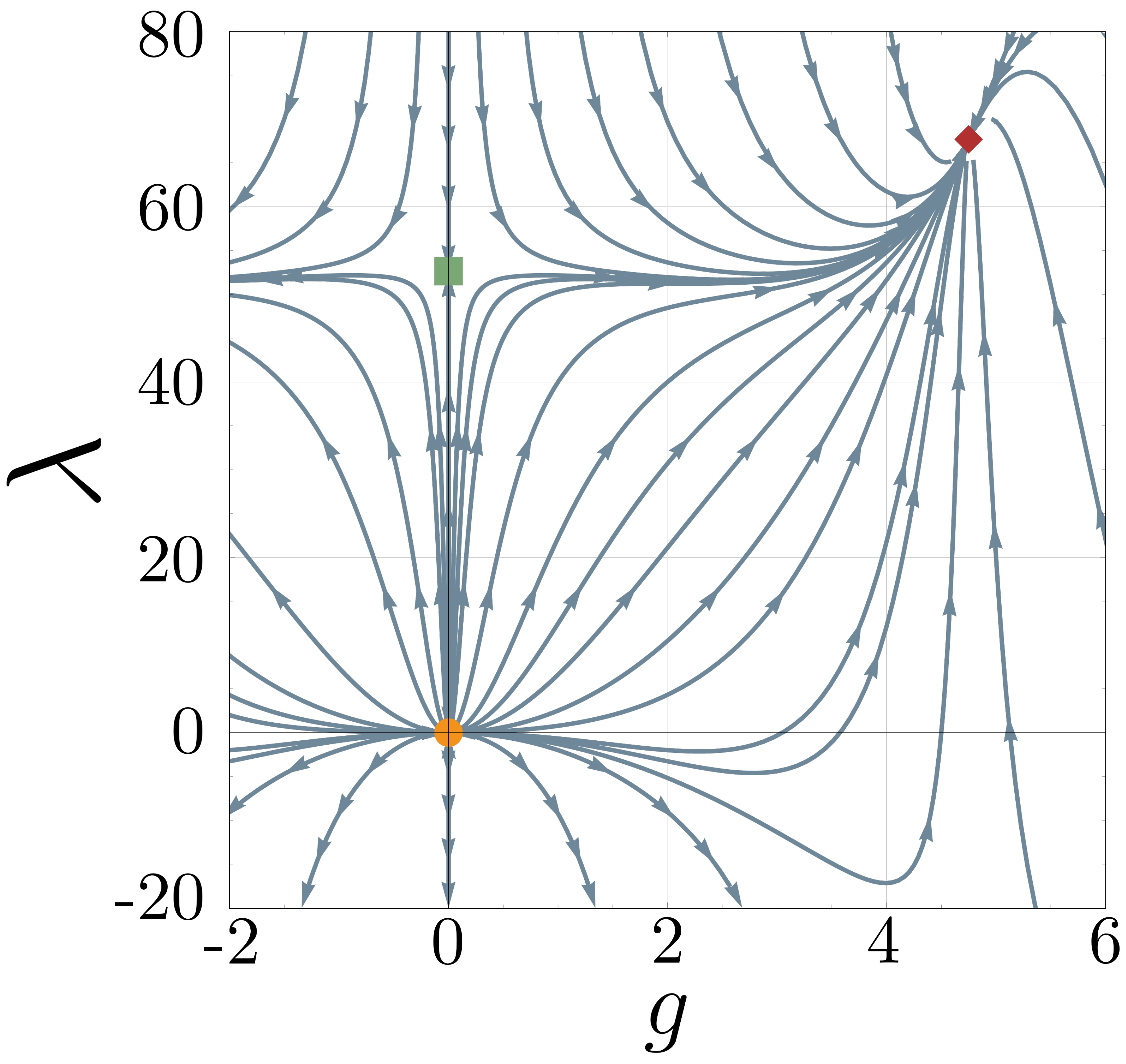
$\Big\downarrow \varepsilon \to 1$

$d = 3$ interacting theory

[Cuomo, Gimenez-Grau, Giombi, Henriksson, Komargodski, Liendo, Raviv-Moshe, v. Vliet, ...]

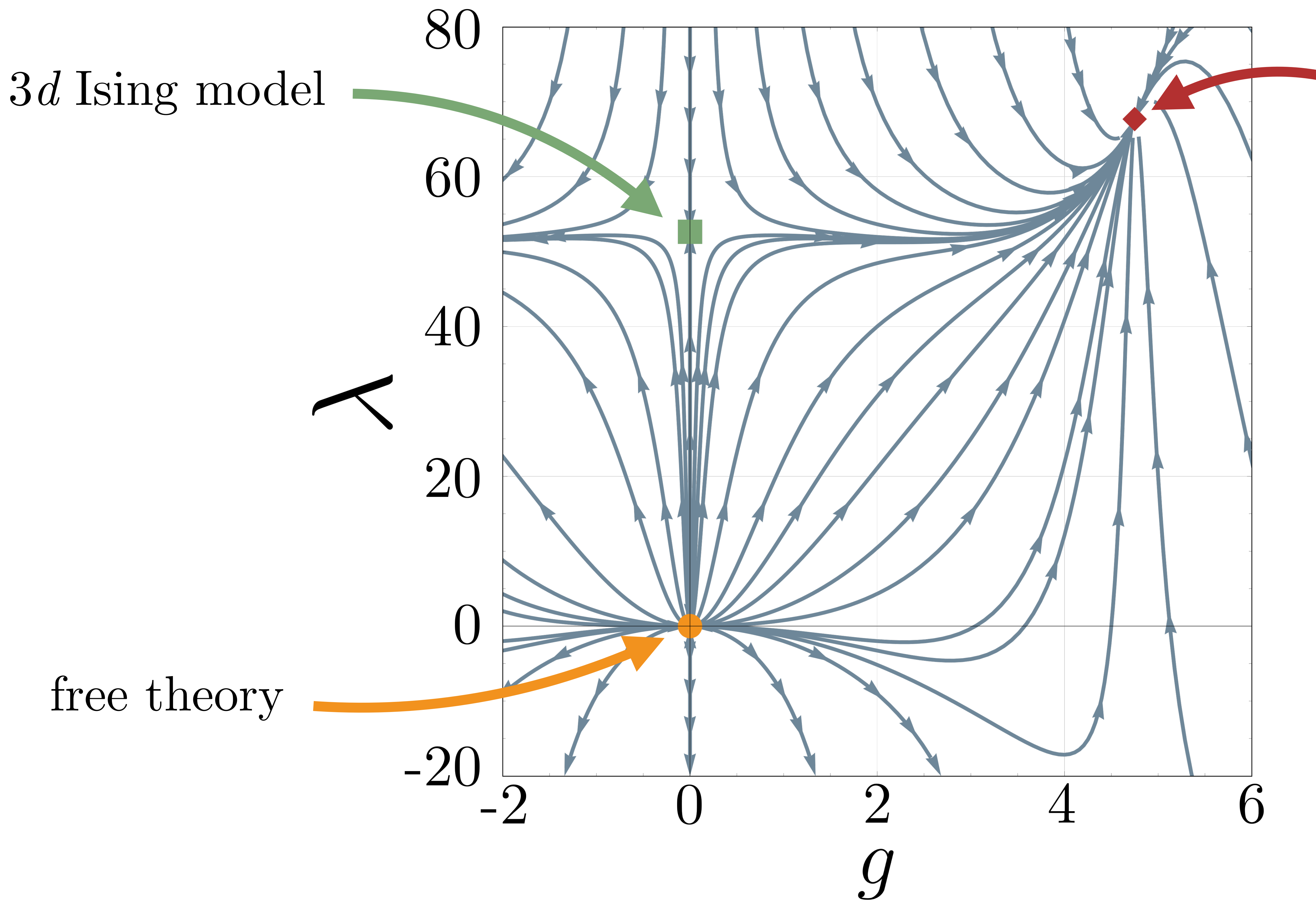
PHASE TRANSITIONS

RG flow $(N = 1, N_f = 1/4)$



PHASE TRANSITIONS

RG flow $(N = 1, N_f = 1/4)$



WFY fixed point

$(\mathcal{N} = 1$ SUSY$)$

$$\beta_g(g_\star) = \beta_\lambda(\lambda_\star) = 0$$

$$g_\star^2 = \frac{64\pi^2}{7}\varepsilon + \dots$$

$$\lambda_\star = \frac{8\pi^2}{21}(5 + \sqrt{1705})\varepsilon + \dots$$

[Karkkainen, Lacaze, Lacock, Petersson, ‘94]
[Rosenstein, Yu, Kovner, ’93]

2.

SCALAR-FERMION CORRELATORS

AN INTERESTING CORRELATOR

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

AN INTERESTING CORRELATOR

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

OPE

$$\overbracket{\phi\phi} \sim \mathbb{1} + \phi^2 + \ldots \qquad\qquad \overbracket{\phi\bar{\psi}} \sim \bar{\psi} + \ldots$$

AN INTERESTING CORRELATOR

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

OPE

$$\overbracket{\phi\phi} \sim \mathbb{1} + \phi^2 + \dots \qquad\qquad \overbracket{\phi\bar{\psi}} \sim \bar{\psi} + \dots$$

Tensor structure

$$\mathbb{T}_1 := \frac{\bar{s}\,\not{x}_{34}\,s}{x_{12}^2 x_{34}^4}$$ [Cuomo, Karateev, Kravchuk, '17]

$d = 4$ $$\langle\, \phi\phi\bar{\psi}\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})$$

$$\mathbb{T}_2 := \frac{\bar{s}\,\not{x}_{31}\not{x}_{12}\not{x}_{24}\,s}{|x_{12}|^3|x_{34}|^3|x_{13}||x_{24}|}$$

$d = 3$ $$\langle\, \phi\phi\bar{\psi}\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z}) + \mathbb{T}_3\, f_3(z,\bar{z}) + \mathbb{T}_4\, f_4(z,\bar{z})$$

AN INTERESTING CORRELATOR

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

OPE

$$\overbrace{\phi\phi} \sim \mathbb{1} + \phi^2 + \dots \qquad\qquad \overbrace{\phi\bar{\psi}} \sim \bar{\psi} + \dots$$

Tensor structure

$$\mathbb{T}_1 := \frac{\bar{s}\, \not{x}_{34}\, s}{x_{12}^2 x_{34}^4}$$

[Cuomo, Karateev, Kravchuk, '17]

$$\mathbb{T}_2 := \frac{\bar{s}\, \not{x}_{31} \not{x}_{12} \not{x}_{24}\, s}{|x_{12}|^3 |x_{34}|^3 |x_{13}||x_{24}|}$$

$d = 4$

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle = \underbrace{\mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})}_{\text{parity-even}}$$

$d = 3$

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle = \underbrace{\mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})}_{\text{parity-even}} + \underbrace{\mathbb{T}_3\, f_3(z,\bar{z}) + \mathbb{T}_4\, f_4(z,\bar{z})}_{\text{parity-odd}}$$

AN INTERESTING CORRELATOR

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

OPE

$$\overbracket{\phi\phi} \sim \mathbb{1} + \phi^2 + \dots \qquad\qquad \overbracket{\phi\bar{\psi}} \sim \bar{\psi} + \dots$$

Tensor structure

$$\mathbb{T}_1 := \frac{\bar{s}\,\not{x}_{34}\,s}{x_{12}^2 x_{34}^4}$$

[Cuomo, Karateev, Kravchuk, '17]

$$\mathbb{T}_2 := \frac{\bar{s}\,\not{x}_{31}\not{x}_{12}\not{x}_{24}\,s}{|x_{12}|^3|x_{34}|^3|x_{13}||x_{24}|}$$

$$d = 4 \qquad \langle\, \phi\phi\bar{\psi}\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})$$

$$d = 3 \qquad \langle\, \phi\phi\bar{\psi}\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z}) + \cancel{\mathbb{T}_3\, f_3(z,\bar{z}) + \mathbb{T}_4\, f_4(z,\bar{z})}$$

2. SCALAR-FERMION CORRELATORS

CONFORMAL BLOCKS

$$\langle \, \phi\phi\bar{\psi}\psi \, \rangle$$

CONFORMAL BLOCKS

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

Calogero-Sutherland
Hamiltonian

$d = 4$

$$C_2^{d=4} = \begin{pmatrix} H_0^{(6)} + 8 & 0 \\ 0 & H_0^{(4)} \end{pmatrix}$$

$d = 3$

$$C_2^{d=3} = \begin{pmatrix} H_0^{(5)} + 6 & 0 \\ 0 & H_0^{(3)} \end{pmatrix}$$

2. SCALAR-FERMION CORRELATORS

CONFORMAL BLOCKS

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

Calogero-Sutherland Hamiltonian

$$d = 4 \qquad C_2^{d=4} = \begin{pmatrix} H_0^{(6)} + 8 & 0 \\ 0 & H_0^{(4)} \end{pmatrix}$$

$$d = 3 \qquad C_2^{d=3} = \begin{pmatrix} H_0^{(5)} + 6 & 0 \\ 0 & H_0^{(3)} \end{pmatrix}$$

$$\longrightarrow \quad C_2^{d} = \begin{pmatrix} H_0^{(d+2)} + 2d & 0 \\ 0 & H_0^{(d)} \end{pmatrix}$$

2. SCALAR–FERMION CORRELATORS

CONFORMAL BLOCKS

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

Calogero-Sutherland Hamiltonian

$$d = 4 \qquad C_2^{d=4} = \begin{pmatrix} H_0^{(6)} + 8 & 0 \\ 0 & H_0^{(4)} \end{pmatrix}$$

$$d = 3 \qquad C_2^{d=3} = \begin{pmatrix} H_0^{(5)} + 6 & 0 \\ 0 & H_0^{(3)} \end{pmatrix}$$

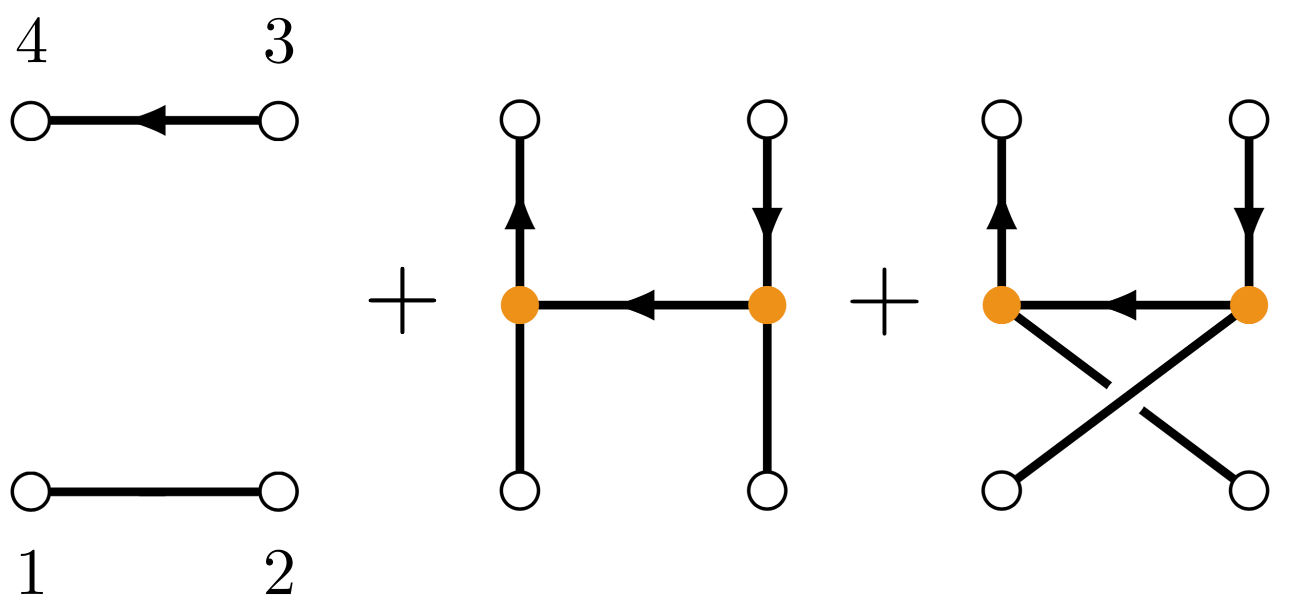
$$C_2^{d} = \begin{pmatrix} H_0^{(d+2)} + 2d & 0 \\ 0 & H_0^{(d)} \end{pmatrix}$$

scalar blocks

$$\boxed{\begin{bmatrix} f_1(z,\bar{z}) \\ f_2(z,\bar{z}) \end{bmatrix} = \sum_{\Delta} \lambda_{\phi\phi\mathcal{O}_\Delta} \lambda_{\mathcal{O}_\Delta\bar{\psi}\psi} \begin{bmatrix} c & \frac{z+\bar{z}}{z\bar{z}} \\ 0 & 2 \end{bmatrix} \begin{bmatrix} g^{(d)}_{\Delta,\ell}(z,\bar{z}) \\ g^{(d+2)}_{\Delta+1,\ell-1}(z,\bar{z}) \end{bmatrix}}$$

PERTURBATIVE CALCULATION

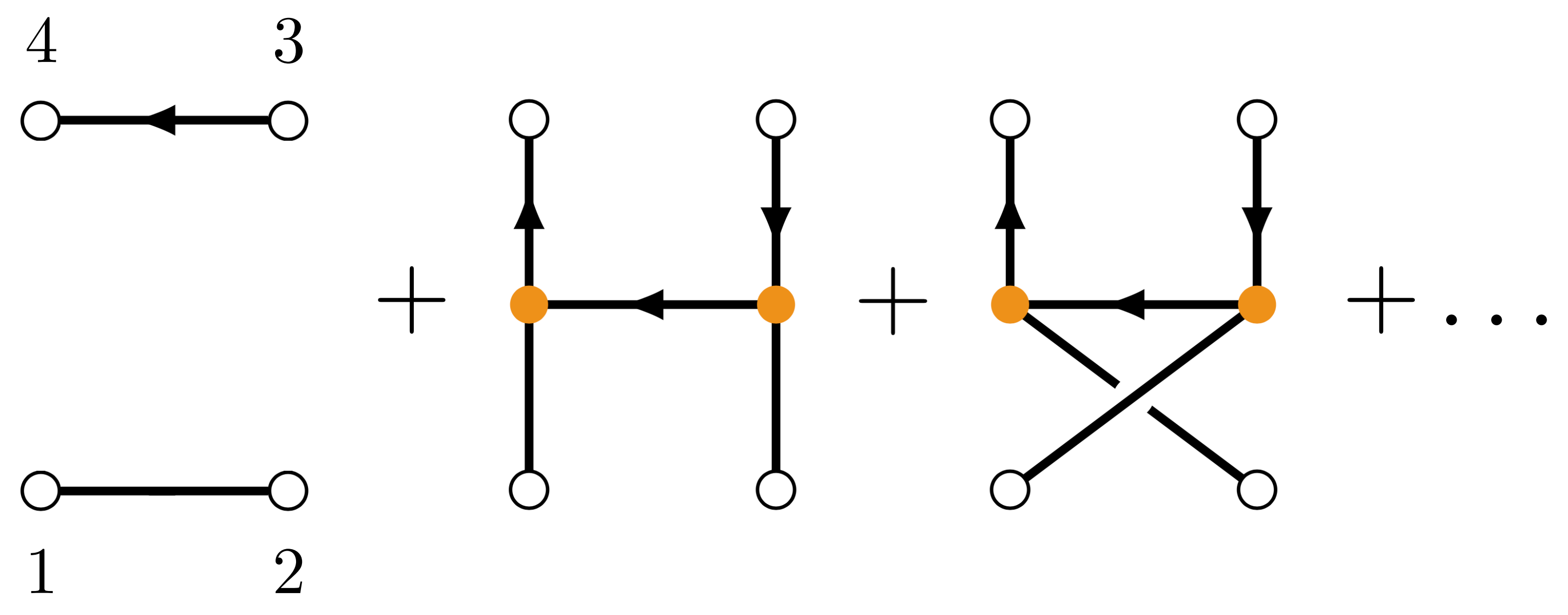
$$\langle \phi\phi\bar{\psi}\psi \rangle = \quad + \quad + \quad + \ldots$$



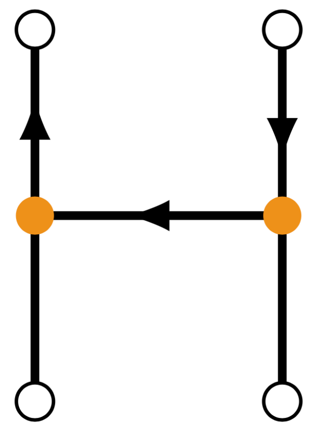
2. SCALAR–FERMION CORRELATORS

PERTURBATIVE CALCULATION

$\langle \phi\phi\bar{\psi}\psi \rangle =$



Integral:



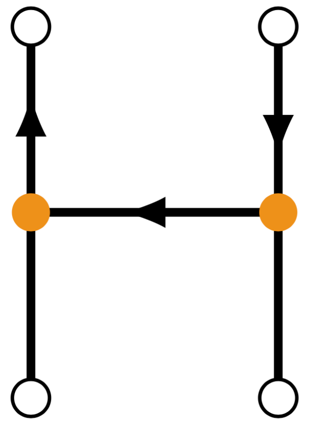
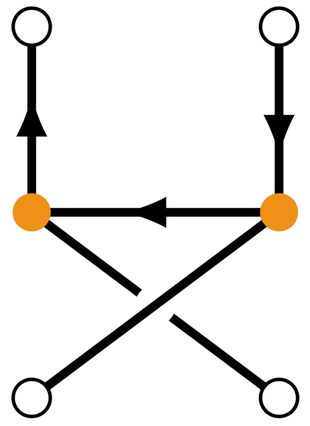
$$\sim \varepsilon \int d^4x_5 \int d^4x_6 \, I_{15} I_{26} \, \not{\partial}_3 I_{36} \, \not{\partial}_6 I_{56} \, \not{\partial}_5 I_{45} + \mathcal{O}(\varepsilon^2)$$

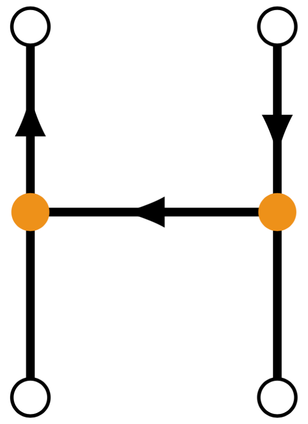
$$I_{ij} := \frac{1}{4\pi^2 x_{ij}^2}$$

2. SCALAR-FERMION CORRELATORS

PERTURBATIVE CALCULATION

$\langle\, \phi\phi\bar{\psi}\psi \,\rangle =$ 

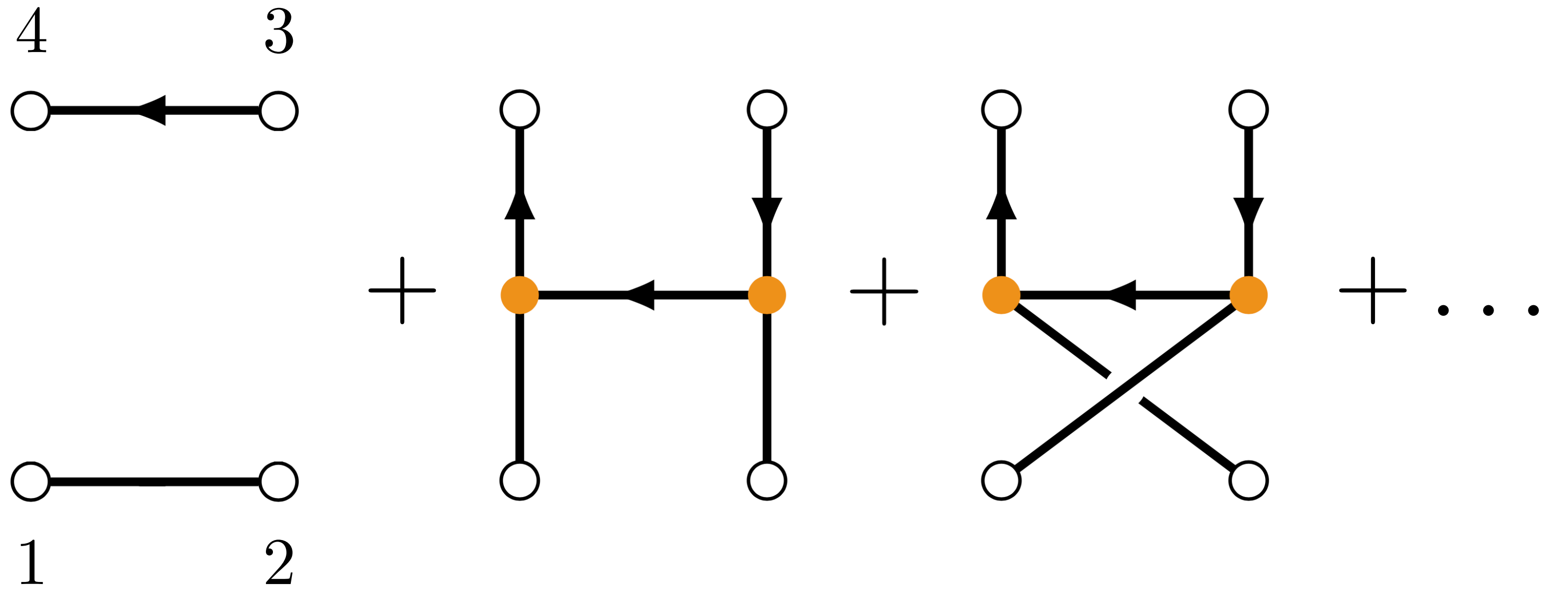
$+$  $+$  $+ \dots$

Integral:  $\sim 4\pi^2 \varepsilon\, \not{x}_{23} \gamma^\mu \gamma^\nu\, I_{23} \partial_4^\nu \int d^4x_5\, x_{25}^\mu I_{15} I_{25} I_{35} I_{45} + \mathcal{O}(\varepsilon^2)$ $\qquad I_{ij} := \dfrac{1}{4\pi^2 x_{ij}^2}$

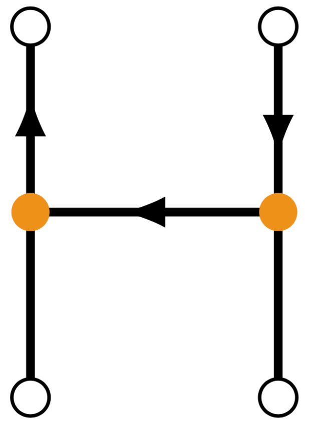
1. Star-triangle relation: $\displaystyle\int d^4x_6\, I_{26} \not{\partial}_3 I_{36} \not{\partial}_6 I_{56} = -4\pi^2\, \not{x}_{23} \not{x}_{25}\, I_{23} I_{25} I_{35}$

PERTURBATIVE CALCULATION

$\langle \phi\phi\bar{\psi}\psi \rangle =$



Integral:



$$\sim 4\pi^2\varepsilon\, \not{x}_{23}\gamma^\mu\gamma^\nu\, I_{23}\partial_4^\nu \int d^4x_5\, x_{25}^\mu I_{15}I_{25}I_{35}I_{45} + \mathcal{O}(\varepsilon^2) \qquad I_{ij} := \frac{1}{4\pi^2 x_{ij}^2}$$

1. Star-triangle relation: $\displaystyle\int d^4x_6\, I_{26}\not{\partial}_3 I_{36}\not{\partial}_6 I_{56} = -4\pi^2\, \not{x}_{23}\not{x}_{25}\, I_{23}I_{25}I_{35}$

2. Tensor decomposition

PERTURBATIVE CALCULATION

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})$$

2. SCALAR-FERMION CORRELATORS

PERTURBATIVE CALCULATION

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})$$

$$\left.\frac{f_i(z,\bar{z})}{\kappa(z,\bar{z})}\right|_{\mathcal{O}(\varepsilon)} = a_i(z,\bar{z})\frac{\log(z\bar{z})}{(1-z)(1-\bar{z})} + b_i(z,\bar{z})\frac{\log((1-z)(1-\bar{z}))}{z\bar{z}} + i\, c_i(z,\bar{z})\ell(z,\bar{z})$$

PERTURBATIVE CALCULATION

$$\langle\, \phi\phi\bar\psi\psi \,\rangle = \mathbb{T}_1\, f_1(z,\bar z) + \mathbb{T}_2\, f_2(z,\bar z)$$

$$\left.\frac{f_i(z,\bar z)}{\kappa(z,\bar z)}\right|_{\mathcal{O}(\varepsilon)} = a_i(z,\bar z)\frac{\log(z\bar z)}{(1-z)(1-\bar z)} + b_i(z,\bar z)\frac{\log((1-z)(1-\bar z))}{z\bar z} + i\, c_i(z,\bar z)\ell(z,\bar z)$$

$$\kappa(z,\bar z) := \frac{(z\bar z)^2}{512\pi^6|z-\bar z|^2}$$

$$i|z-\bar z|\ell(z,\bar z) := \frac{\pi^2}{3} + \log(-x_1)\log(-x_2) + 2(\mathrm{Li}_2(x_1)+\mathrm{Li}_2(x_2)) + \log((1-z)(1-\bar z))\log\left(-\frac{z+\bar z - i|z-\bar z| - 2z\bar z}{z+\bar z+i|z-\bar z|}\right)$$

$$x_1 := \frac{2}{2-z-\bar z-i|z-\bar z|}\,, \qquad x_2 := (1-z)(1-\bar z)\,x_1$$

PERTURBATIVE CALCULATION

$$\langle \phi\phi\bar{\psi}\psi \rangle = \mathbb{T}_1\, f_1(z,\bar{z}) + \mathbb{T}_2\, f_2(z,\bar{z})$$

$$\left.\frac{f_i(z,\bar{z})}{\kappa(z,\bar{z})}\right|_{\mathcal{O}(\varepsilon)} = \boxed{a_i(z,\bar{z})}\,\frac{\log(z\bar{z})}{(1-z)(1-\bar{z})} + \boxed{b_i(z,\bar{z})}\,\frac{\log((1-z)(1-\bar{z}))}{z\bar{z}} + \boxed{i\,c_i(z,\bar{z})}\,\ell(z,\bar{z})$$

$$a_1(z,\bar{z}) = p(z,\bar{z}) - q(z,\bar{z})\,, \qquad b_1(z,\bar{z}) = q(z,\bar{z})\,, \qquad c_1(z,\bar{z}) = p(z,\bar{z})$$

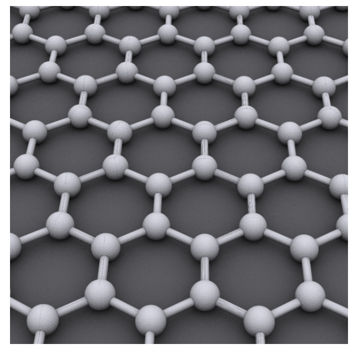
$$a_2(z,\bar{z}) = \frac{1}{2}q(z,\bar{z})(p(z,\bar{z})+2)\,, \qquad b_2(z,\bar{z}) = z\bar{z}\,p(z,\bar{z})\,, \qquad c_2(z,\bar{z}) = q(z,\bar{z})$$

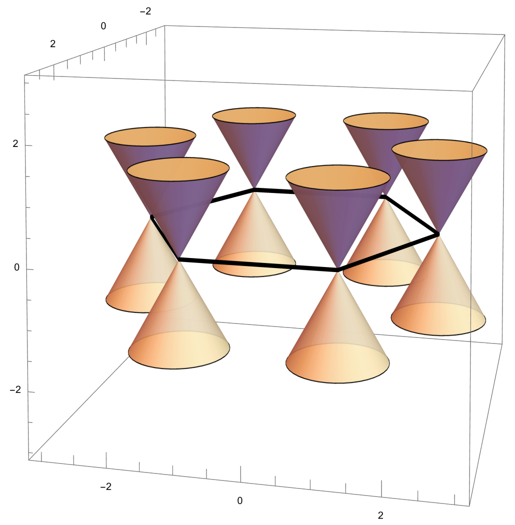
$$p(z,\bar{z}) := z + \bar{z} - 4$$
$$q(z,\bar{z}) := 2(z\bar{z} - z - \bar{z})$$

SUMMARY & OUTLOOK

SUMMARY & OUTLOOK

Phase transitions in graphene

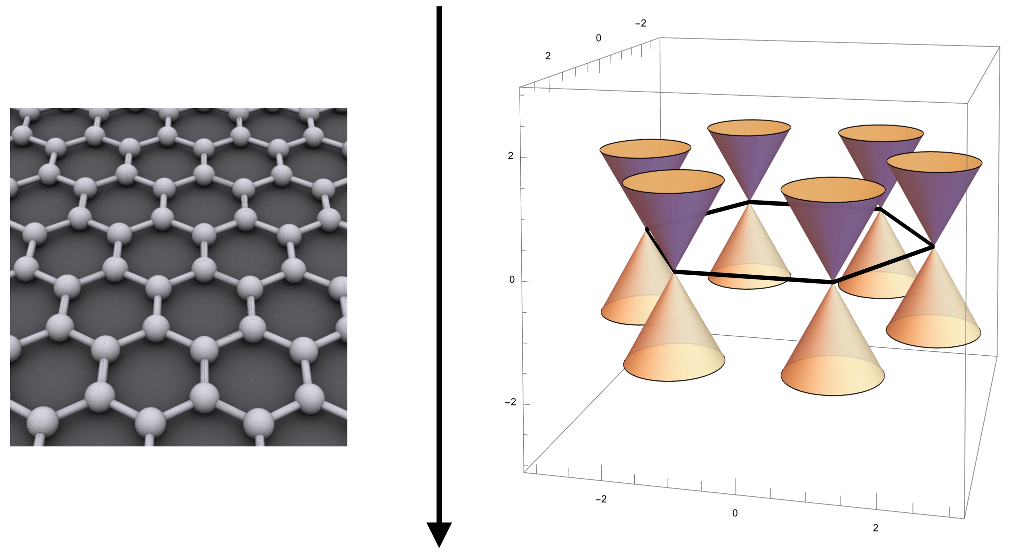




Yukawa CFT

SUMMARY & OUTLOOK

Phase transitions in graphene

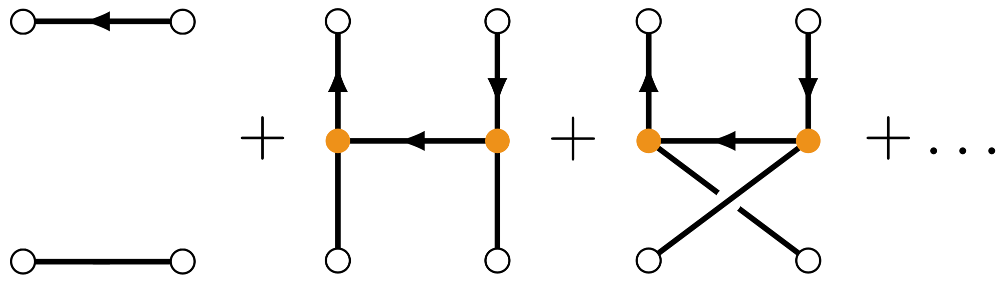


Yukawa CFT

$$\langle\, \phi\phi\bar\psi\psi \,\rangle$$

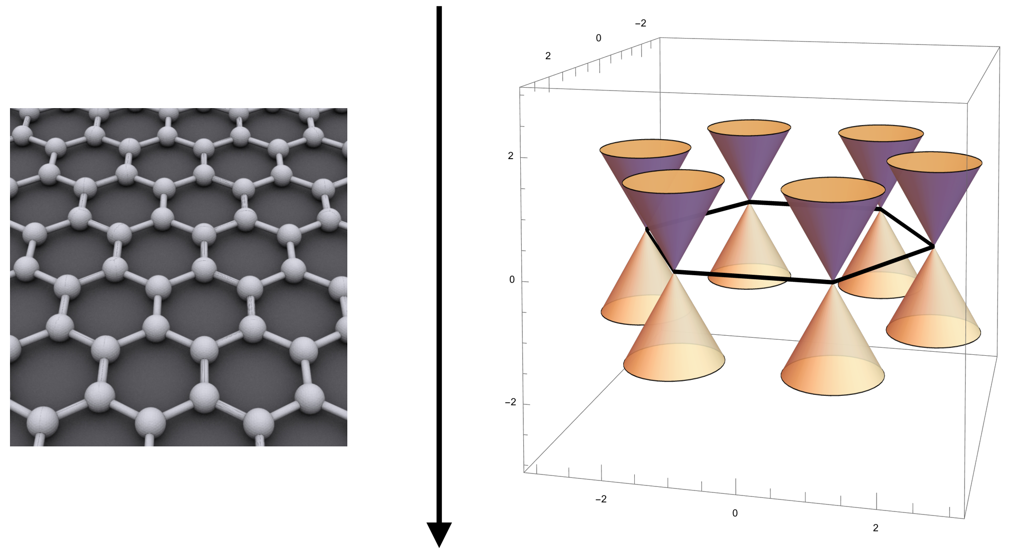
$$\begin{bmatrix} f_1(z,\bar z)\\ f_2(z,\bar z)\end{bmatrix} = \sum_\Delta \lambda_{\phi\phi\mathcal{O}_\Delta}\lambda_{\mathcal{O}_\Delta\bar\psi\psi}\begin{bmatrix} c & \frac{z+\bar z}{z\bar z} \\ 0 & 2\end{bmatrix}\begin{bmatrix} g^{(d)}_{\Delta,\ell}(z,\bar z)\\ g^{(d+2)}_{\Delta+1,\ell-1}(z,\bar z)\end{bmatrix}$$

$\langle\, \phi\phi\bar\psi\psi \,\rangle =$



SUMMARY & OUTLOOK

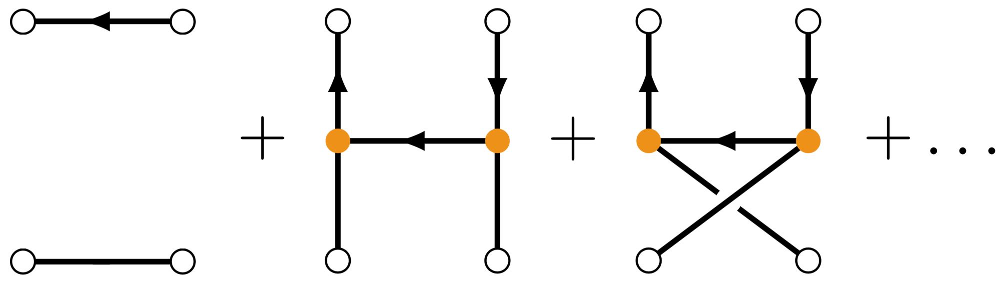
Phase transitions in graphene



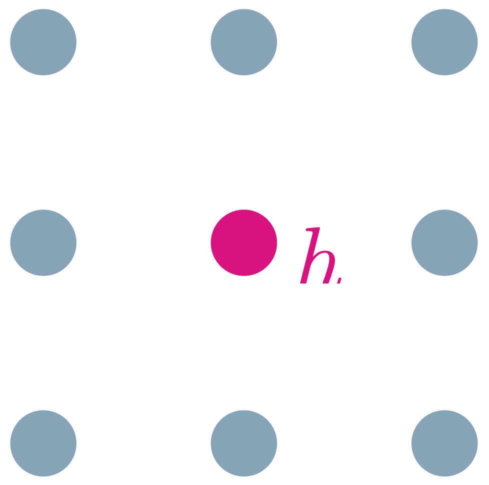
Yukawa CFT

$\langle\, \phi\phi\bar\psi\psi \,\rangle$

$$\begin{bmatrix} f_1(z,\bar z)\\ f_2(z,\bar z)\end{bmatrix} = \sum_\Delta \lambda_{\phi\phi\mathcal{O}_\Delta}\lambda_{\mathcal{O}_\Delta\bar\psi\psi}\begin{bmatrix} c & \frac{z+\bar z}{z\bar z}\\ 0 & 2\end{bmatrix}\begin{bmatrix} g^{(d)}_{\Delta,\ell}(z,\bar z)\\ g^{(d+2)}_{\Delta+1,\ell-1}(z,\bar z)\end{bmatrix}$$

$\langle\, \phi\phi\bar\psi\psi \,\rangle =$ 

Magnetic line



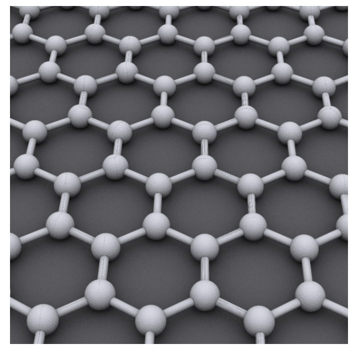
$$S \longrightarrow S + h\int d\tau\, \phi(\tau)$$

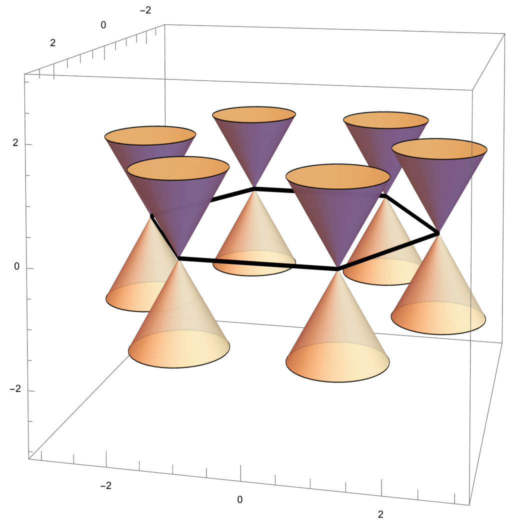
[Giombi, Helfenberger, Khanchandani, '23]

[JB, Liendo, van Vliet, '23]

SUMMARY & OUTLOOK

Phase transitions in graphene

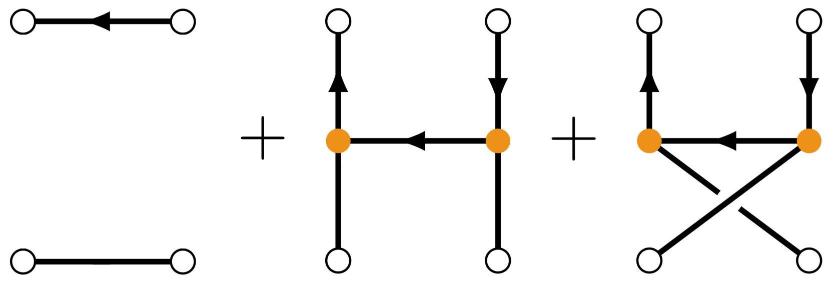




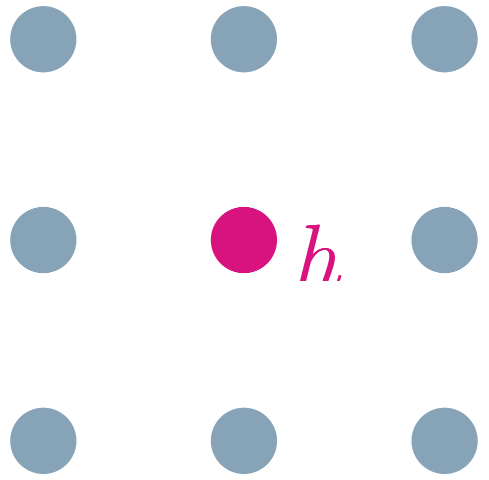
Yukawa CFT

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

$$\begin{bmatrix} f_1(z,\bar z) \\ f_2(z,\bar z) \end{bmatrix} = \sum_{\Delta} \lambda_{\phi\phi\mathcal{O}_\Delta} \lambda_{\mathcal{O}_\Delta \bar\psi\psi} \begin{bmatrix} c & \frac{z+\bar z}{z\bar z} \\ 0 & 2 \end{bmatrix} \begin{bmatrix} g^{(d)}_{\Delta,\ell}(z,\bar z) \\ g^{(d+2)}_{\Delta+1,\ell-1}(z,\bar z) \end{bmatrix}$$

$\langle\, \phi\phi\bar{\psi}\psi \,\rangle =$  $+ \dots$

Magnetic line



$$S \longrightarrow S + h \int d\tau\, \phi(\tau)$$

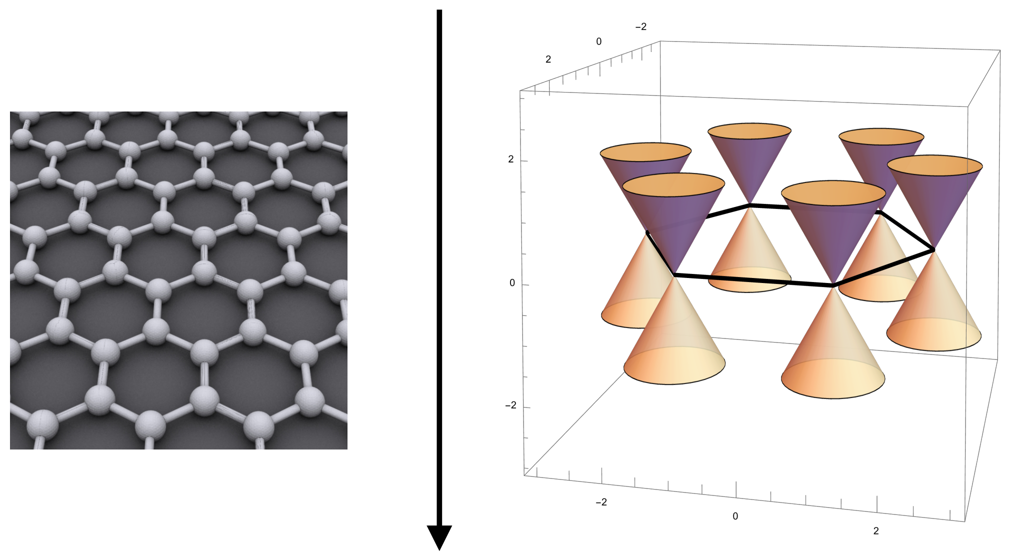
[Giombi, Helfenberger, Khanchandani, '23]

[JB, Liendo, van Vliet, '23]

SEE PHILINE'S TALK!

SUMMARY & OUTLOOK

Phase transitions in graphene

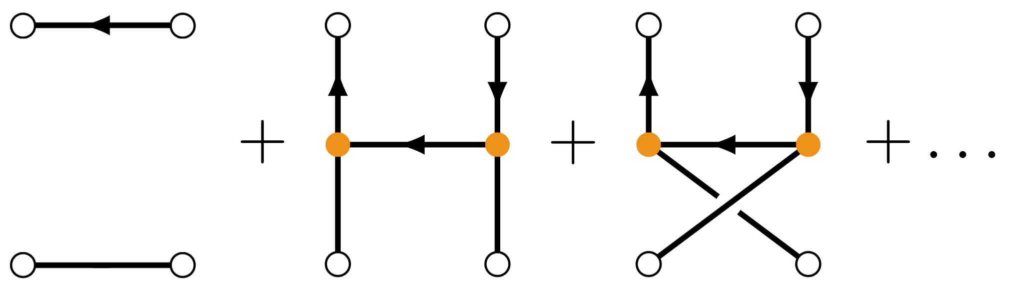


Yukawa CFT

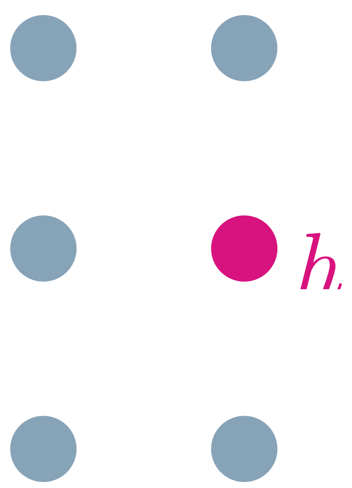
$\langle \phi\phi\bar{\psi}\psi \rangle$

$$\begin{bmatrix} f_1(z,\bar z) \\ f_2(z,\bar z) \end{bmatrix} = \sum_{\Delta} \lambda_{\phi\phi\mathcal{O}_\Delta}\lambda_{\mathcal{O}_\Delta\bar\psi\psi} \begin{bmatrix} c & \frac{z+\bar z}{z\bar z} \\ 0 & 2 \end{bmatrix} \begin{bmatrix} g^{(d)}_{\Delta,\ell}(z,\bar z) \\ g^{(d+2)}_{\Delta+1,\ell-1}(z,\bar z) \end{bmatrix}$$

$\langle \phi\phi\bar{\psi}\psi \rangle =$



Magnetic line



$$S \longrightarrow S + h\int d\tau\,\phi(\tau)$$

[Giombi, Helfenberger, Khanchandani, '23]

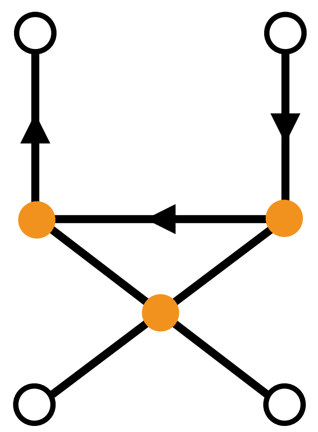
[JB, Liendo, van Vliet, '23]

SEE PHILINE'S TALK!

CFT data

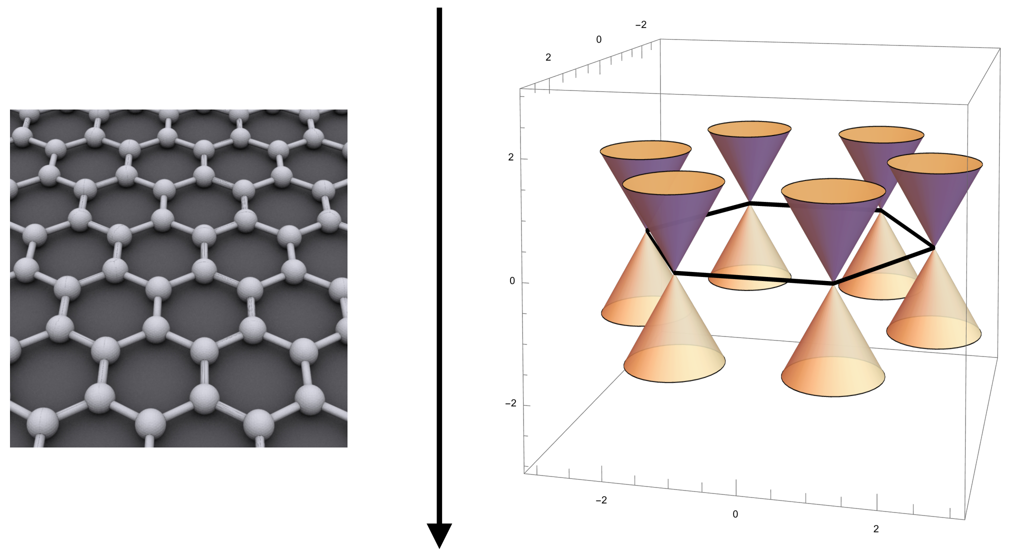
$\langle \phi\phi\bar{\psi}\psi \rangle$

$\langle \phi\phi\bar{\psi}\psi \rangle$



SUMMARY & OUTLOOK

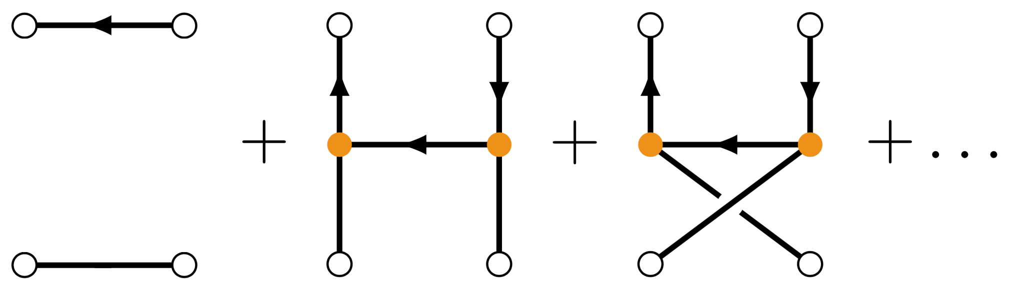
Phase transitions in graphene



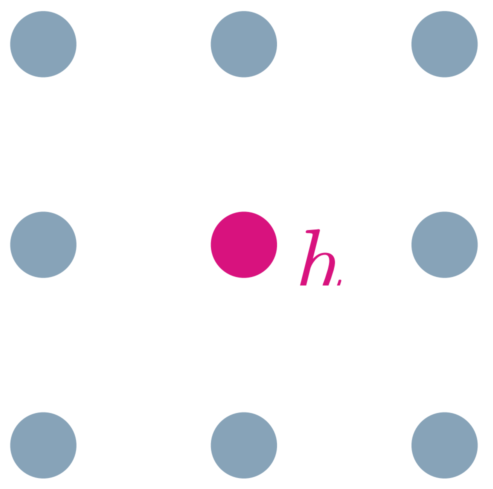
Yukawa CFT

$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$

$$\begin{bmatrix} f_1(z,\bar{z}) \\ f_2(z,\bar{z}) \end{bmatrix} = \sum_{\Delta} \lambda_{\phi\phi\mathcal{O}_\Delta} \lambda_{\mathcal{O}_\Delta \bar{\psi}\psi} \begin{bmatrix} c & \frac{z+\bar{z}}{z\bar{z}} \\ 0 & 2 \end{bmatrix} \begin{bmatrix} g^{(d)}_{\Delta,\ell}(z,\bar{z}) \\ g^{(d+2)}_{\Delta+1,\ell-1}(z,\bar{z}) \end{bmatrix}$$

$\langle\, \phi\phi\bar{\psi}\psi \,\rangle =$ 

Magnetic line



$$S \longrightarrow S + h \int d\tau\, \phi(\tau)$$

[Giombi, Helfenberger, Khanchandani, '23]

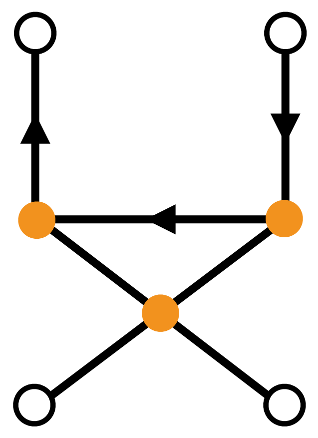
[JB, Liendo, van Vliet, '23]

SEE PHILINE'S TALK!

CFT data

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$

$$\langle\, \phi\phi\bar{\psi}\psi \,\rangle$$



THANK YOU