Analogies between the black hole interior and the type II Weyl semimetals

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7th International Conference on New Frontiers in Physics

(ICNFP 2018, 4 July 2018 - 12 July, Kolymbari, Crete, Greece)

PLAN

1. The charged black hole in Gullstrand – Painleve reference frame

2. The Volovik's idea about the Fermi surface inside the black hole

3. The type II Weyl semimetal and the lattice regularized quantum field theory in the presence of the black hole

4. The particles that are able to escape from the black hole (without any tunneling) and the consequences for the quantum theory of black holes

Reissner — Nordstrom black hole in Painleve coordinates

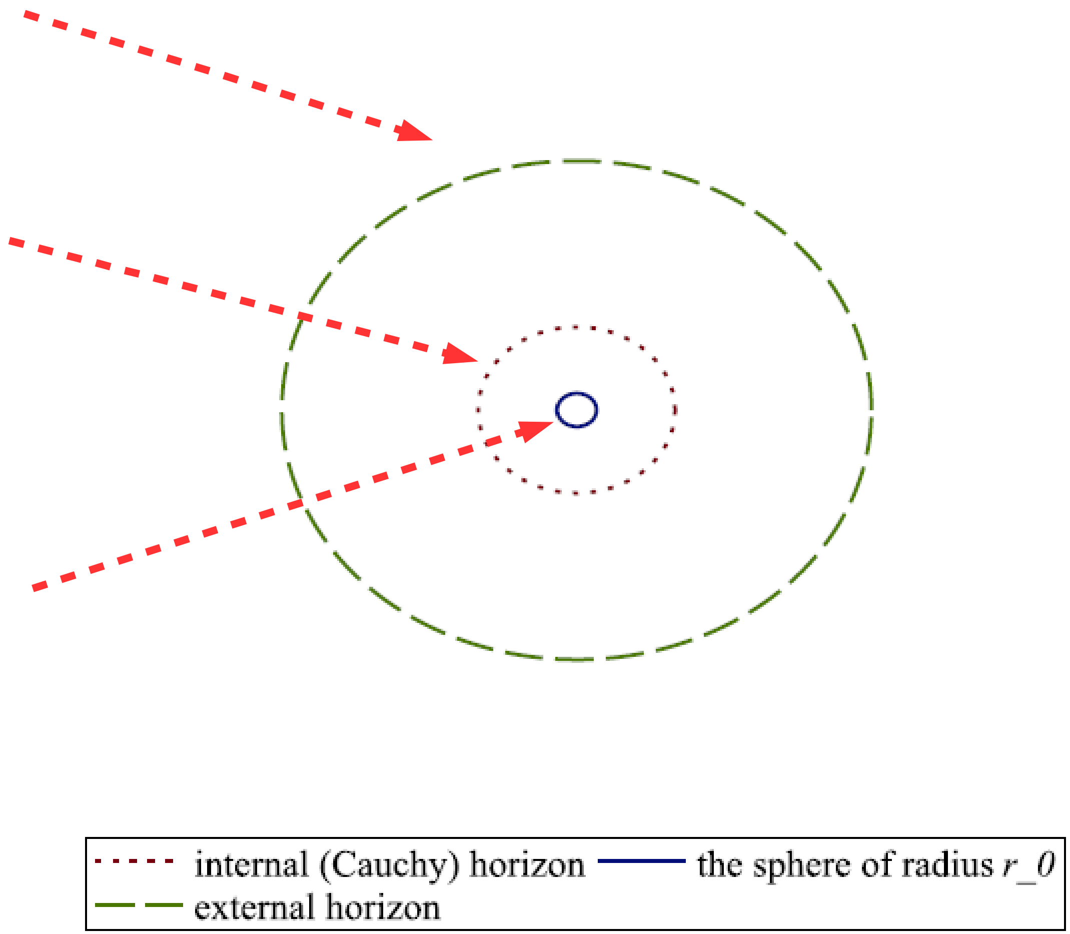
$$ds^2 = dt^2 - (d\mathbf{r} - \mathbf{v}(\mathbf{r})dt)^2$$

$$\mathbf{v} = -\frac{1}{m_P}\frac{\mathbf{r}}{r}\sqrt{\frac{2M}{r} - \frac{Q^2}{r^2}}$$

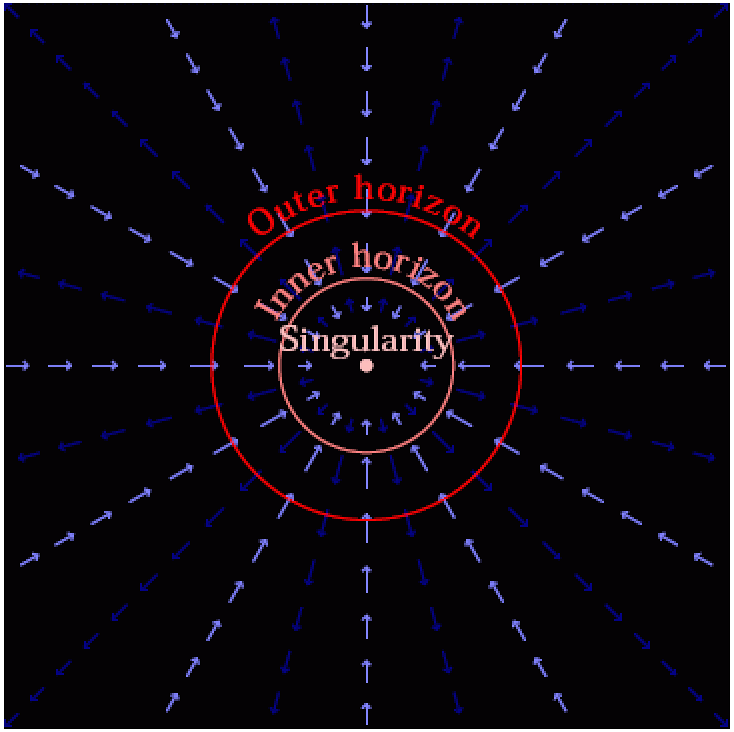
$$r_+ = \frac{M + \sqrt{M^2 - Q^2 m_P^2}}{m_P^2}$$

$$r_- = \frac{M - \sqrt{M^2 - Q^2 m_P^2}}{m_P^2}$$

$$r_0 = \frac{Q^2}{2M}$$



Whaterfall representation

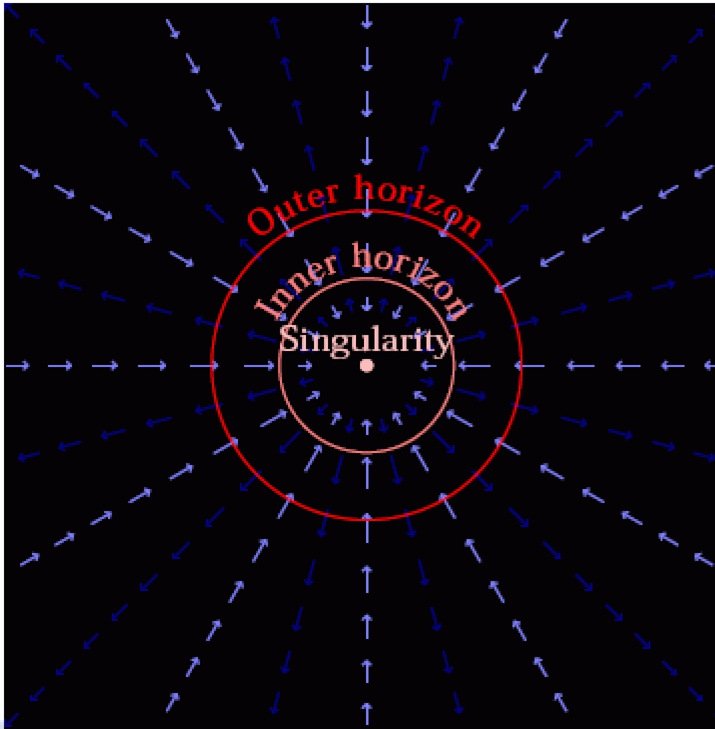


Space — time falls down to the black hole

Space — time falls down to the black hole

In the reference frame locally accompanying this falling

Space — time is flat



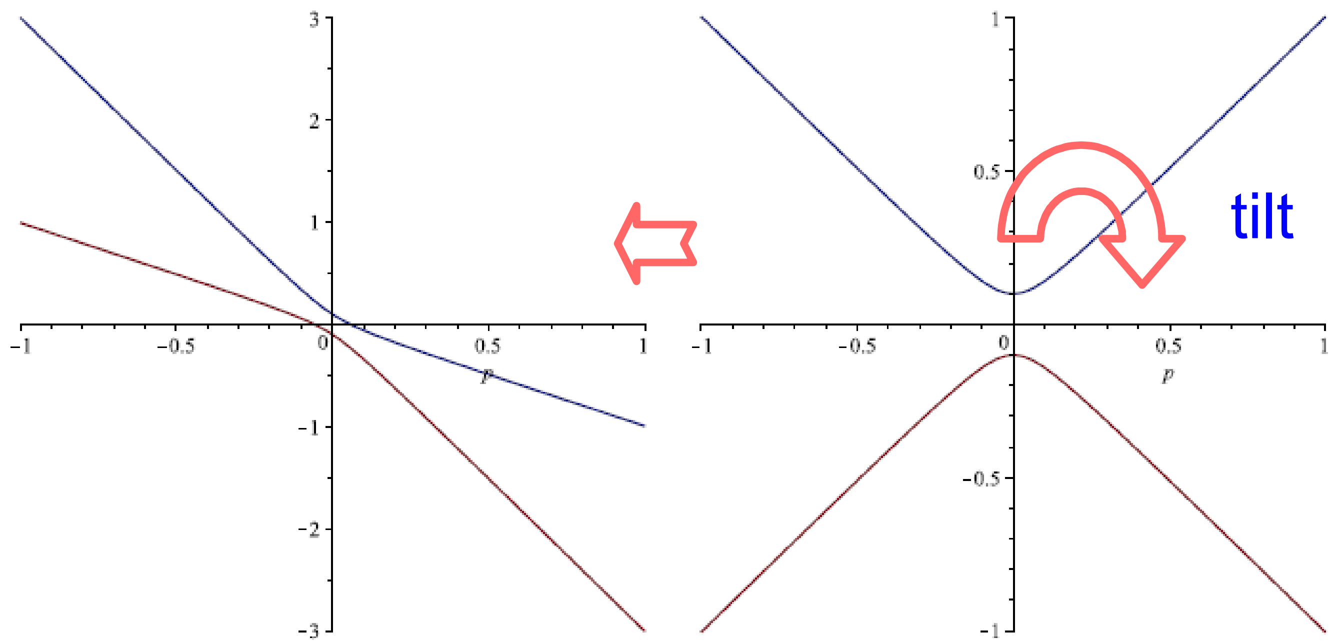
Weyl fermions in the accompanying reference frame in a small vicinity of a given point $H_0^{\pm}(\mathbf{p}) = \pm \mathbf{p}\sigma$

Dispersion of massive particles $E(p) = \pm\sqrt{p^2 + m^2}$

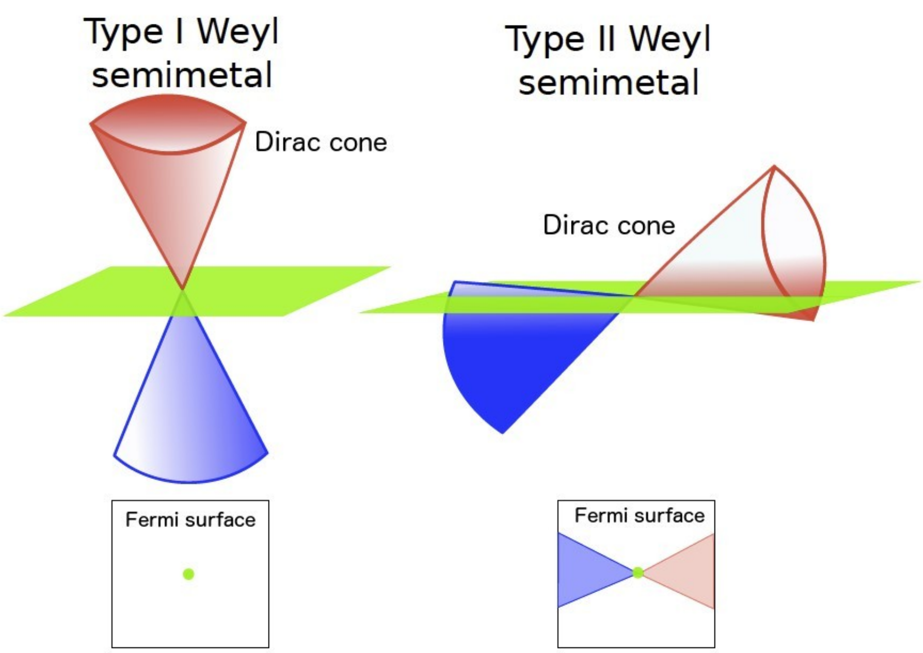
The Painleve Gullstrand reference frame moves with velocity v(r) with respect to the flat reference frame

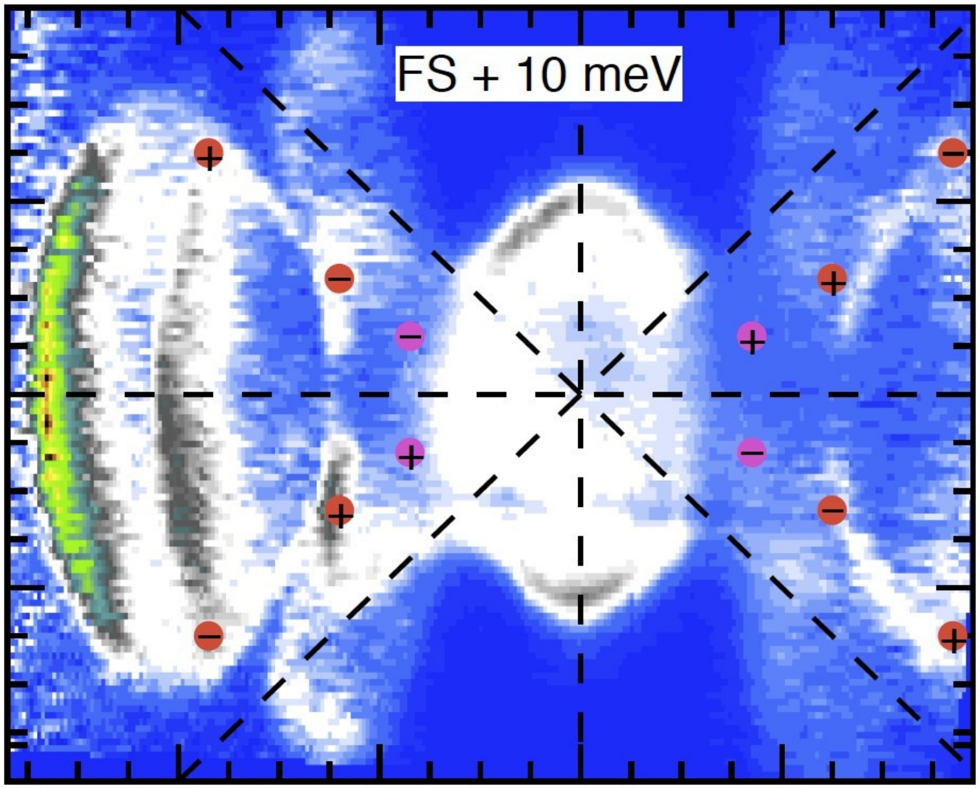
$$E(\mathbf{p}) = \pm\sqrt{p^2 + m^2} - \mathbf{v}\mathbf{p}$$

Painleve v>1 (inside black hole) flat



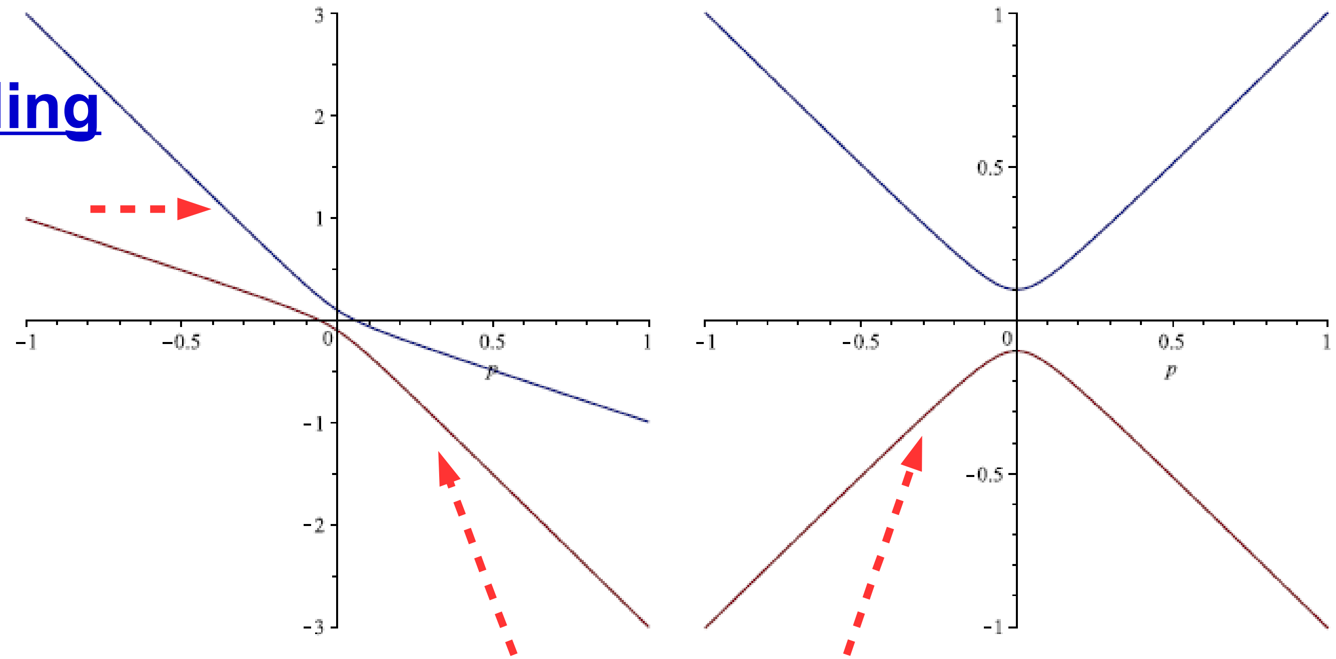
If the Dirac mass vanishes we would obtain the pattern of the type II Weyl semimetal





Hawking radiation

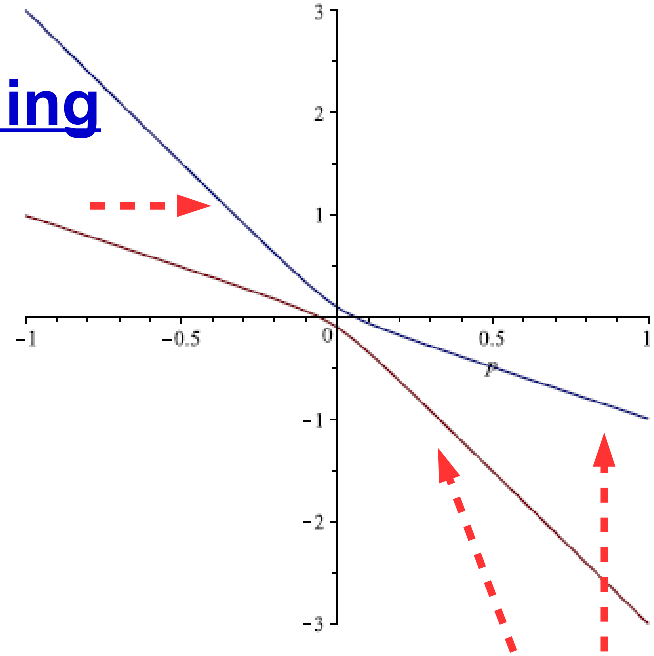
Tunneling

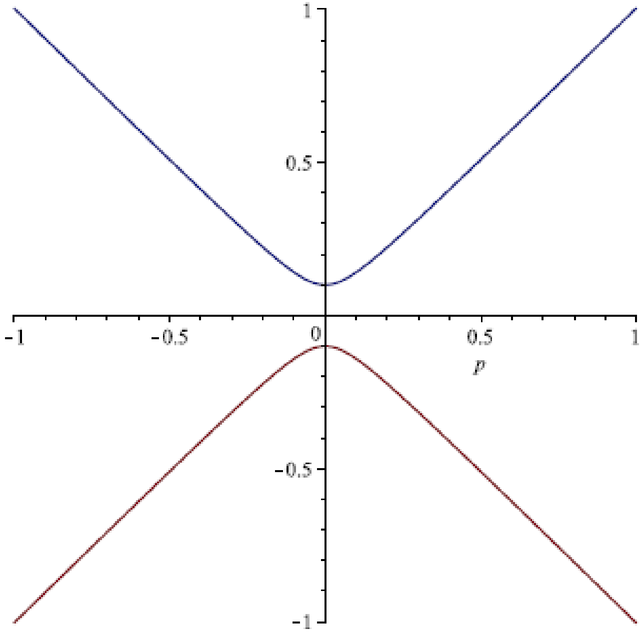


occupied branch of spectrum in the «falling» vacuum

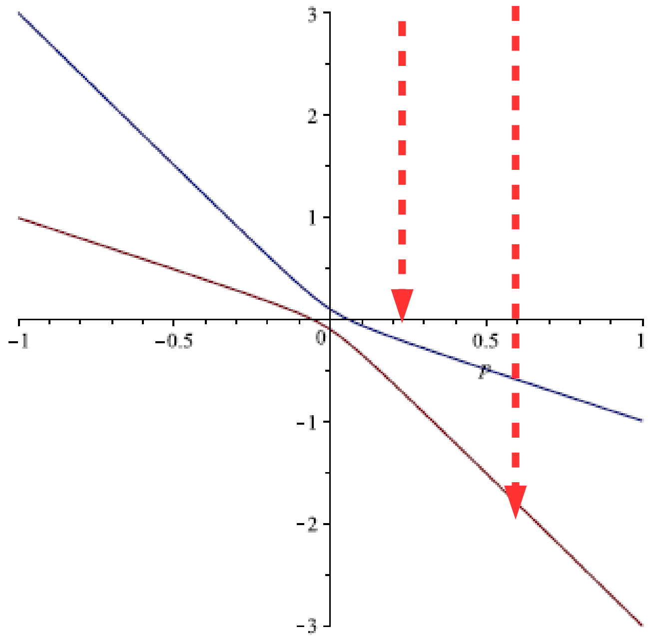
Tunneling and evolution to equilibrium leads to the reconstruction of vacuum

Tunneling

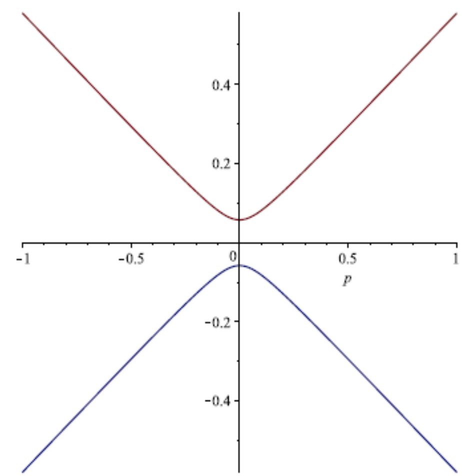




occupied branches of spectrum in the true vacuum of the Painleve reference frame are those which are placed below zero occupied branches of spectrum in the true vacuum of the Painleve reference frame are those which are placed below zero



Fermi surface inside the black hole



Prediction of the type II Weyl point

Emergent Weyl spinors in multi-fermion systems

M.Zubkov and G.Volovik in 2014

(Nuclear Physics B 881 (2014), 514 – 538)

Prediction of the real material with the type II Weyl points:

Type-II Weyl semimetals

Alexey A. Soluyanov[1], Dominik Gresch[1], Zhijun Wang[2], QuanSheng Wu[1], Matthias Troyer[1], Xi Dai[3] & B. Andrei Bernevig[2]

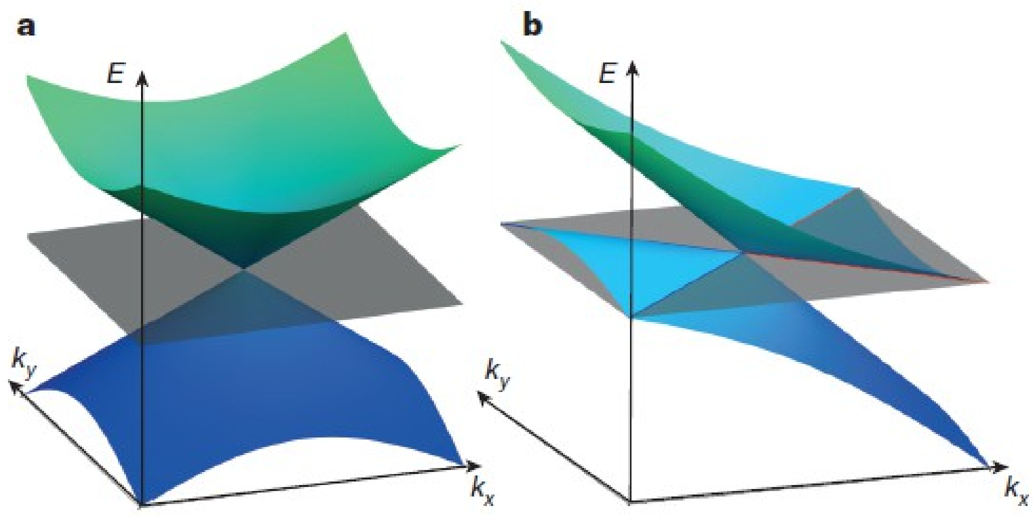
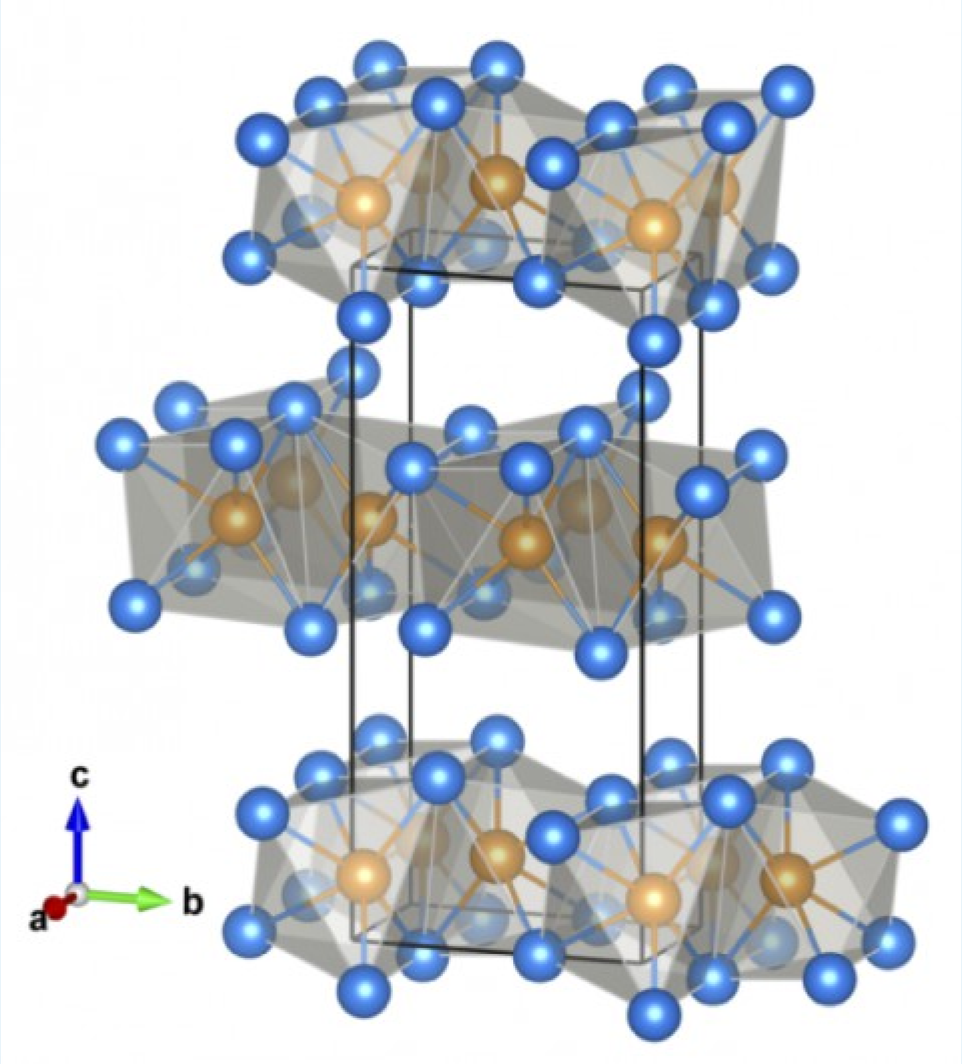


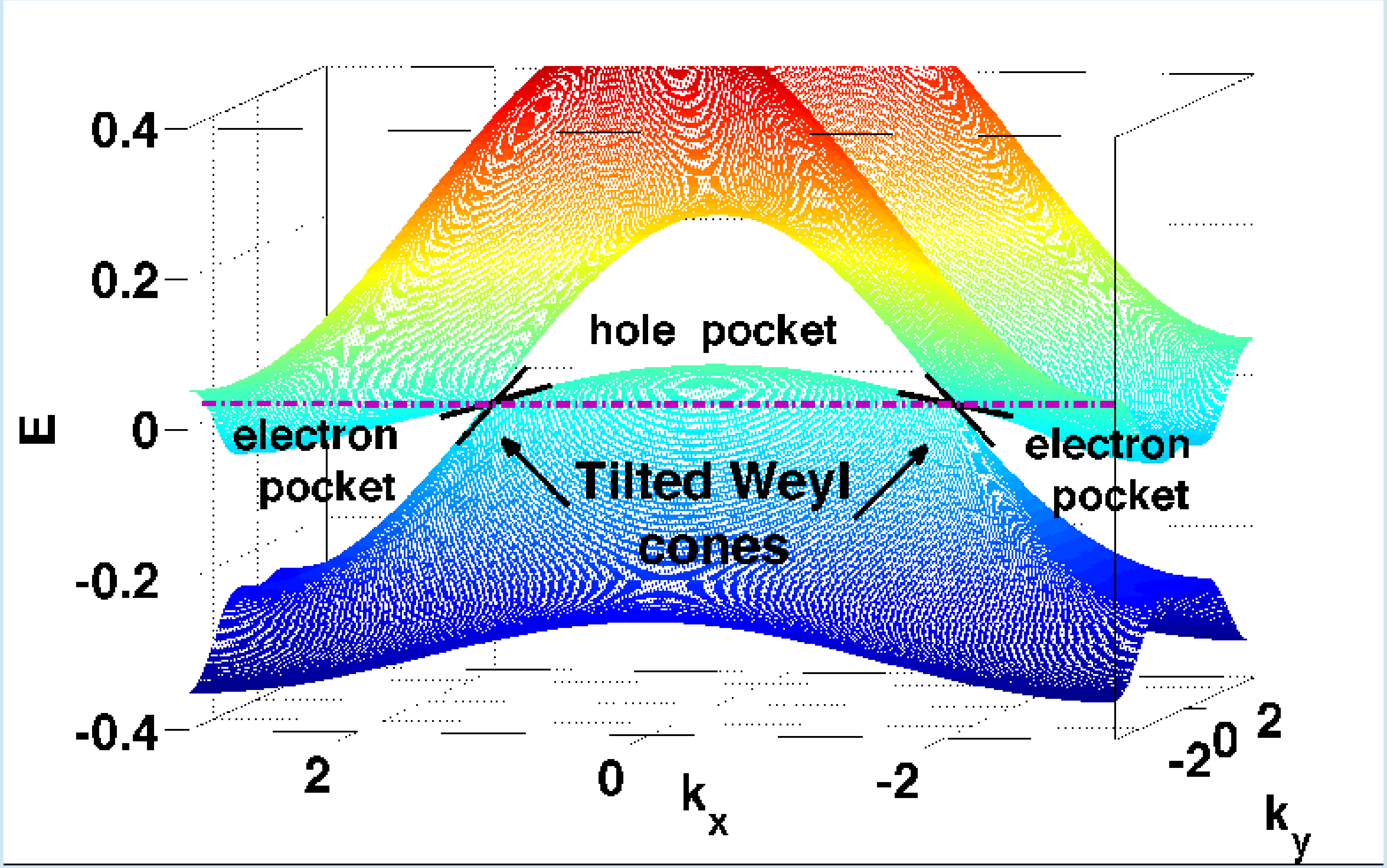
Figure 1 | Possible types of Weyl semimetals. a, Type-I WP with a point-like Fermi surface. **b,** A type-II WP appears as the contact point between electron and hole pockets. The grey plane corresponds to the position of the Fermi level, and the blue (red) lines mark the boundaries of the hole (electron) pockets.

Nature 527, 495 (2015)

the Type-II Weyl Semimetal WTe2

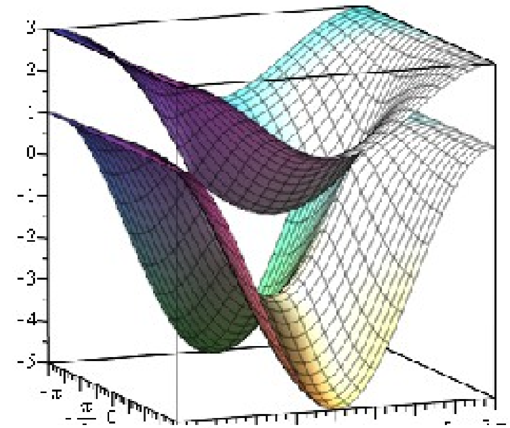


In the type II Weyl semimetals we always have two Weyl points with the Dirac cones tilted in different directions



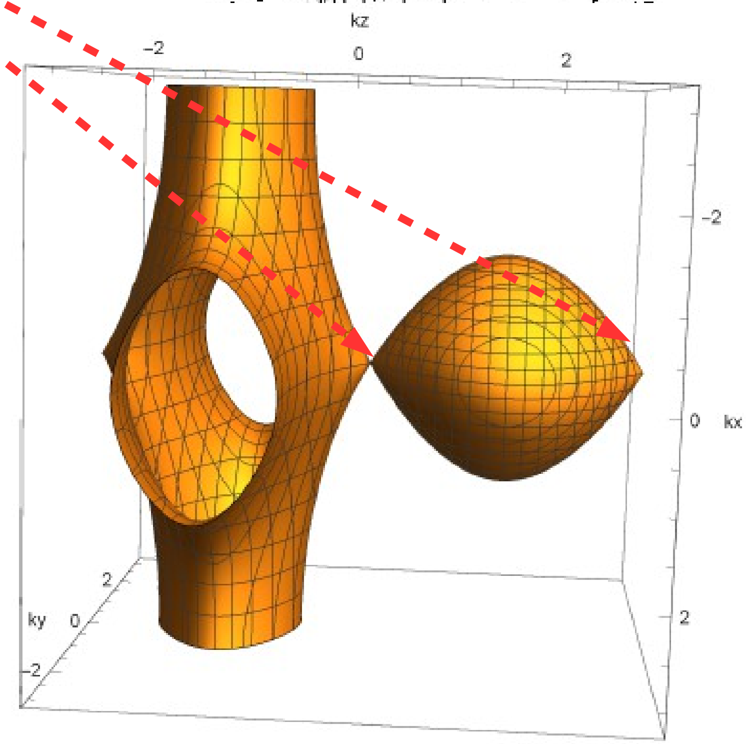
The dependence of energy on momentum in the typical type II Weyl semimetal

(from M.A. Zubkov, M. Lewkowicz, arXiv:1806.10558 [cond-mat.mes-hall])



Fermi points

Typical Fermi surface



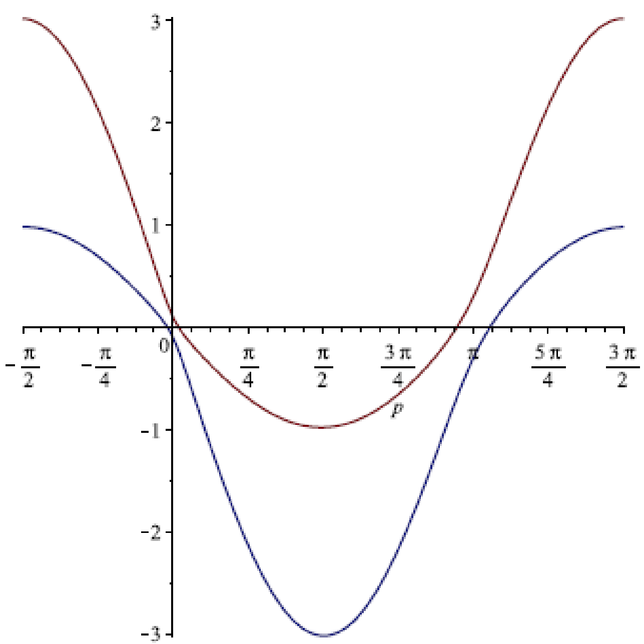
The lattice regularized QFT in the presence of the BH

toy model

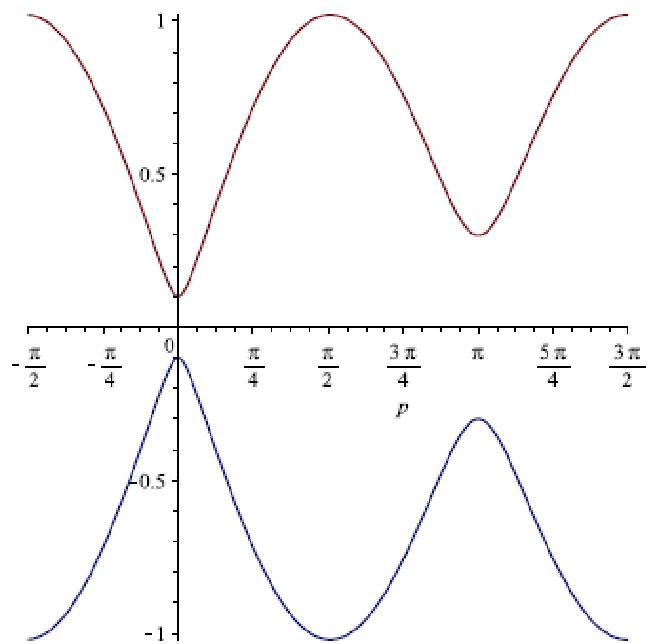
$$H = \sum_{k=1,2,3} \sin p_k \gamma^0 \gamma^k - (m + r \sum_{k=1,2,3} (1 - \cos p_k))\gamma^0$$
$$- v \sin p_3$$

Dispersion

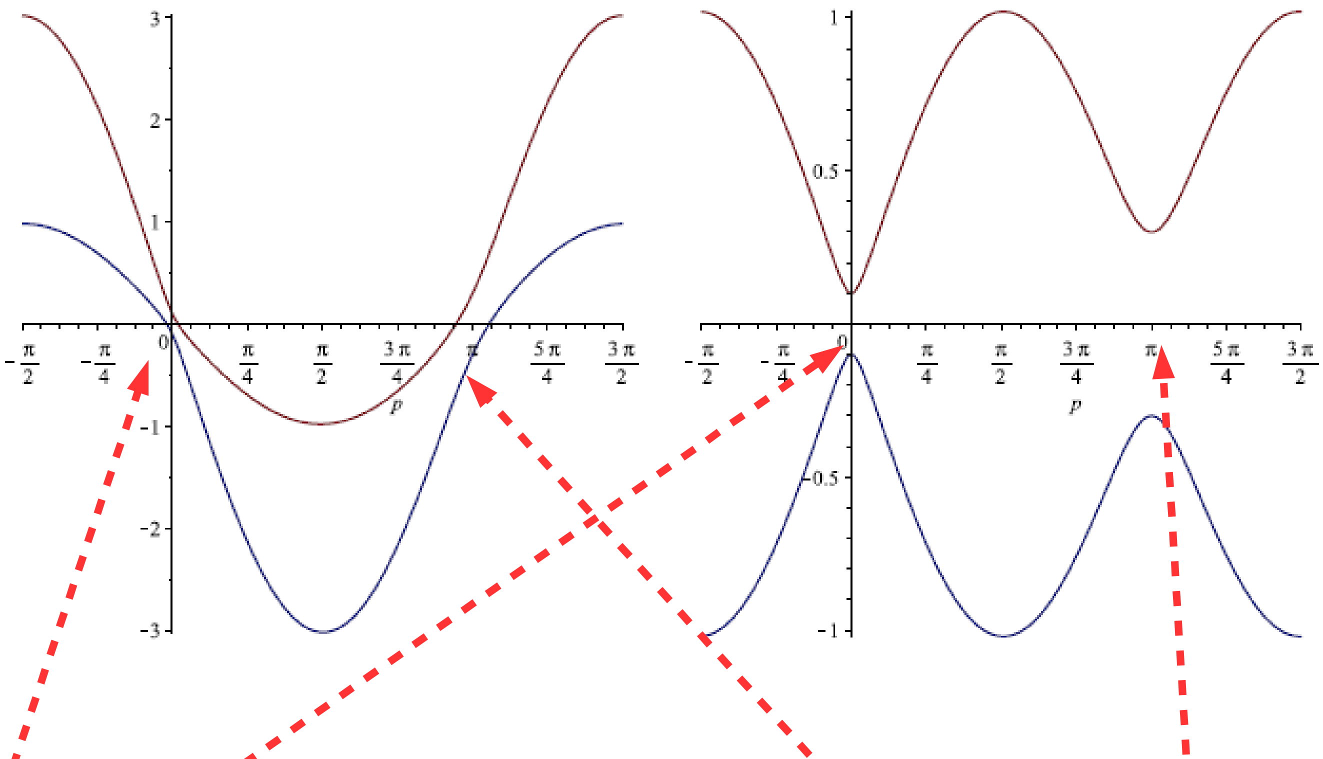
Inside the black hole



outside the black hole



Inside the black hole / *outside the black hole*



$$H \approx \begin{pmatrix} \mathbf{p}\sigma - \mathbf{p}\mathbf{v} & m \\ m & -\mathbf{p}\sigma - \mathbf{p}\mathbf{v} \end{pmatrix}$$

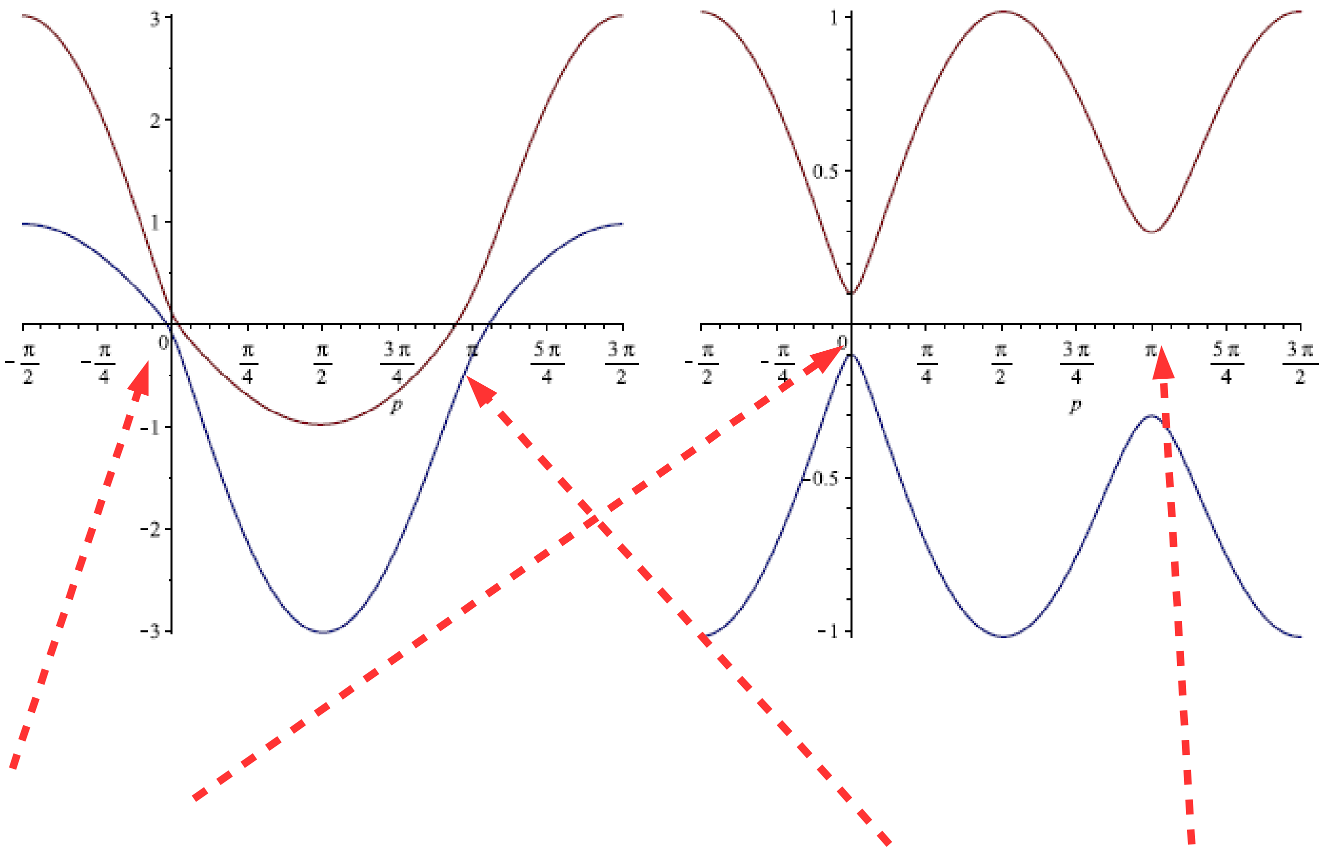
$$H \approx \begin{pmatrix} \delta\mathbf{p}\sigma' + \delta\mathbf{p}\mathbf{v} & (m+2r) \\ (m+2r) & -\delta\mathbf{p}\sigma' + \delta\mathbf{p}\mathbf{v} \end{pmatrix}$$

$$\delta\mathbf{p} = \mathbf{p} - (0, 0, \pi)$$

Standard Model particles

extra massive particles

Inside the black hole ***outside the black hole***



Standard Model particles

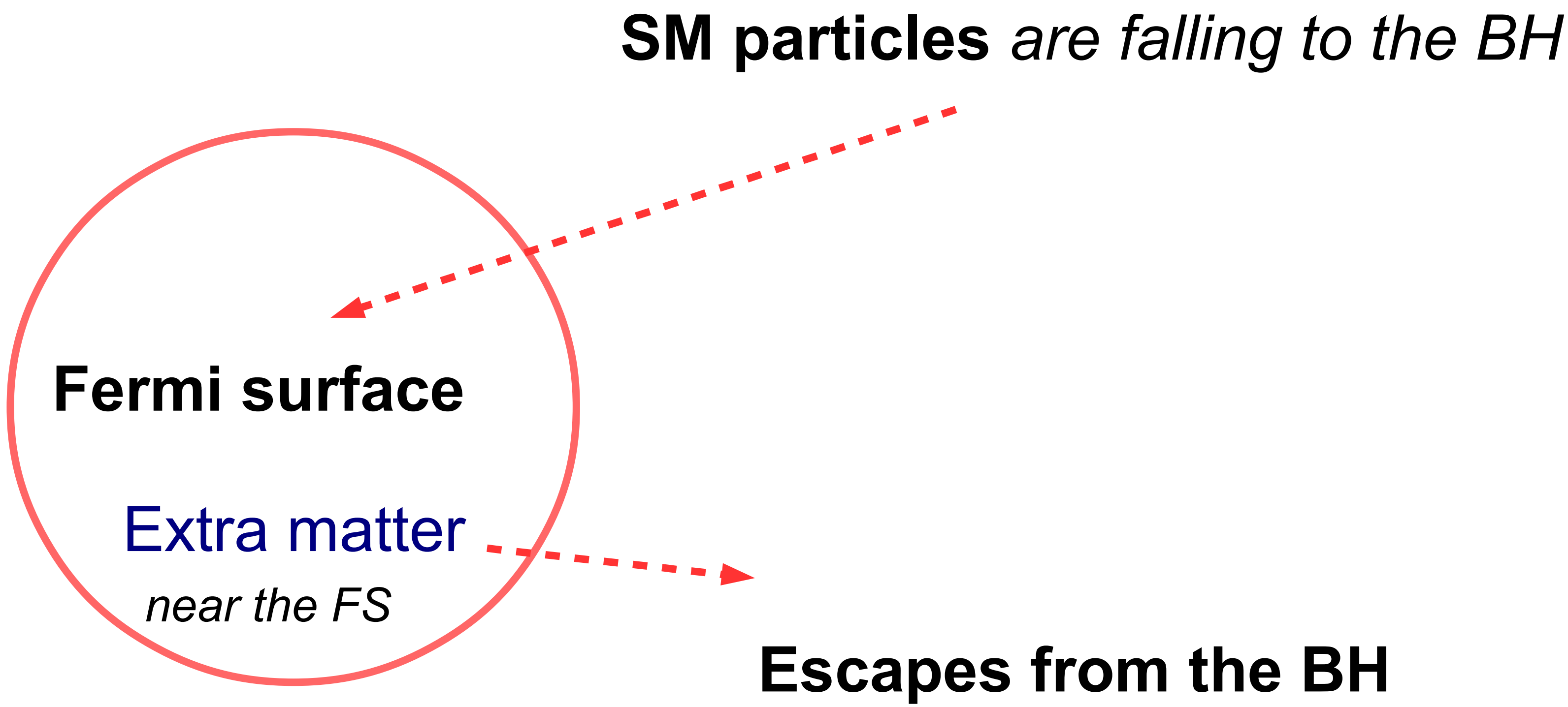
Move only towards the Interior of the BH

extra massive particles

move only towards exterior of the BH

Velocity = $\frac{\partial \mathcal{E}}{\partial p_3}$

Equilibrium black hole



And may reach the distance that is the solution of

$$\mathcal{E} = m' \sqrt{1 - \mathbf{v}^2(r')} \qquad \mathbf{v} = -\frac{1}{m_P} \frac{\mathbf{r}}{r} \sqrt{\frac{2M}{r} - \frac{Q^2}{r^2}}$$

The circle of life of the black hole

1) black hole formation (normal BH)

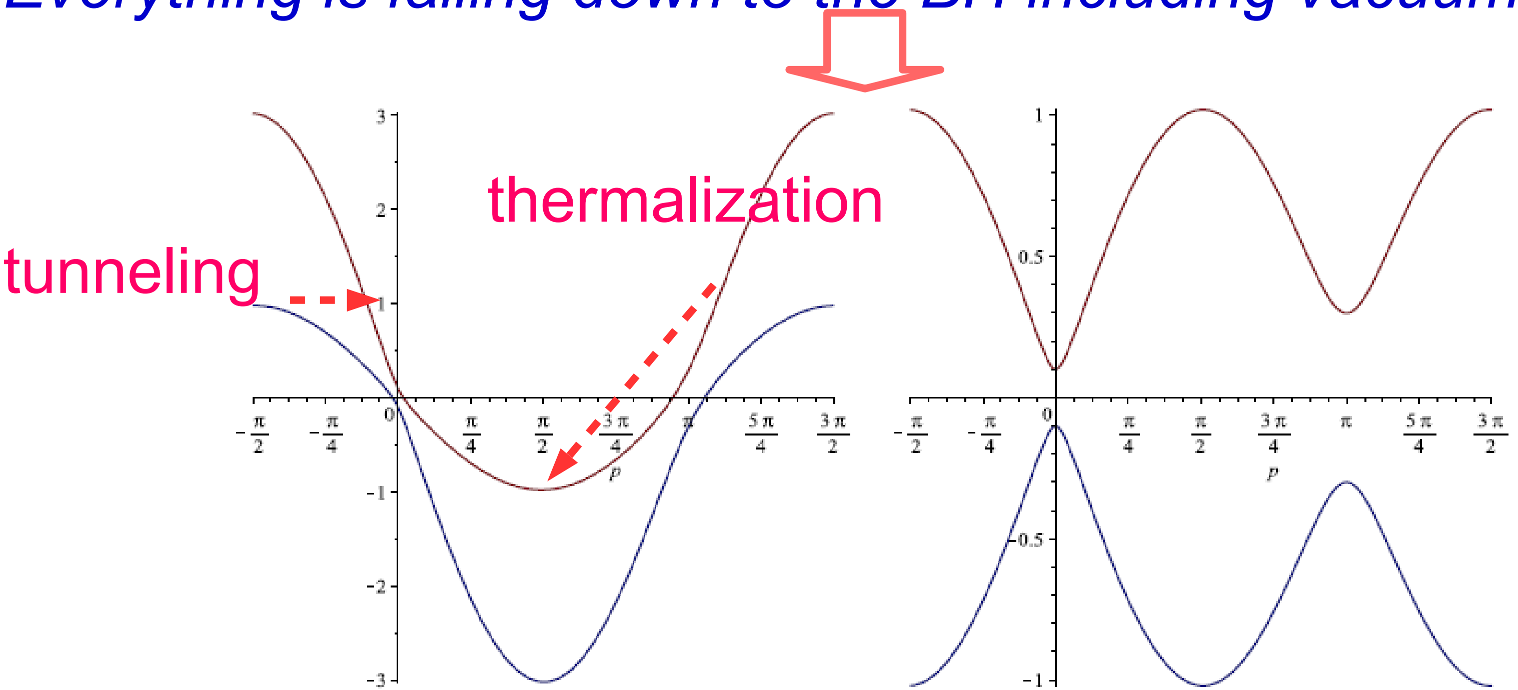
Everything is falling down to the BH including vacuum

vacuum is to be understood as the collection of the occupied energy levels in crystals or as the superfluid component of the fermionic fluid

The circle of life of the black hole

1) black hole formation (normal BH)

Everything is falling down to the BH including vacuum



inside *outside*

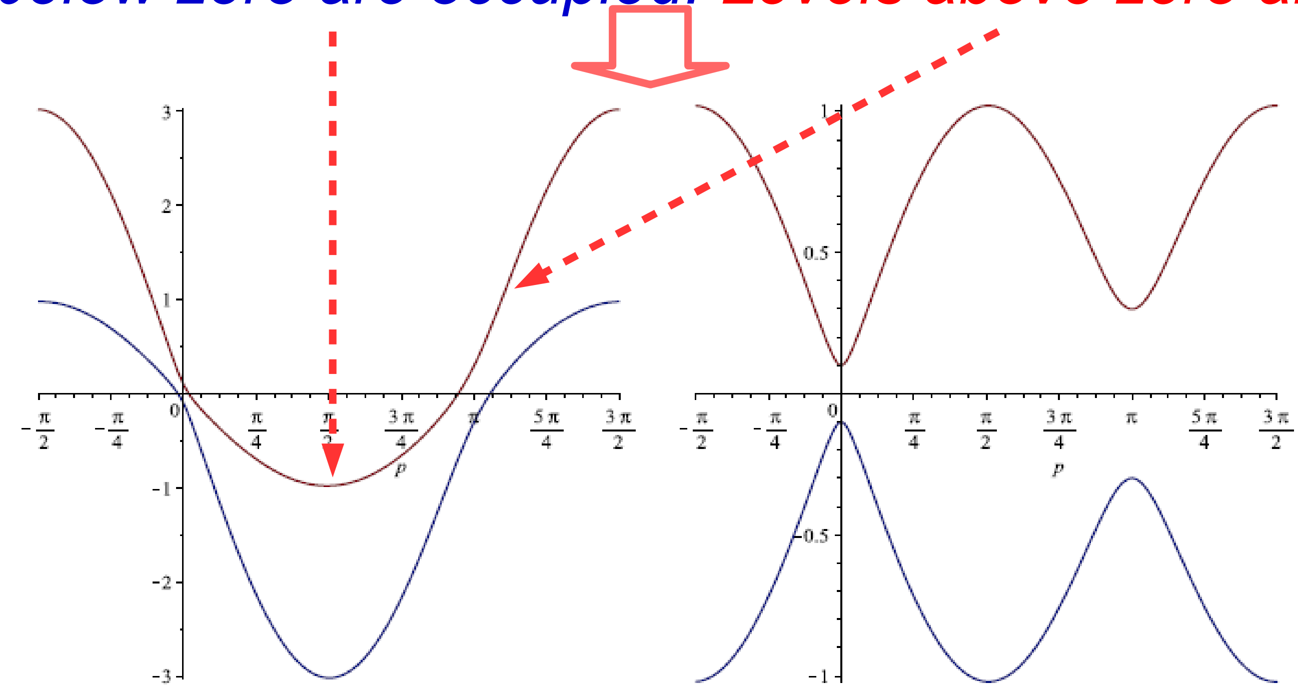
In the conventional «falling» vacuum the blue branch is occupied, the red branch is vacant

VACUUM RECONSTRUCTION PROCESS

The circle of life of the black hole

2) The equilibrium state

Levels below zero are occupied. *Levels above zero are vacant*



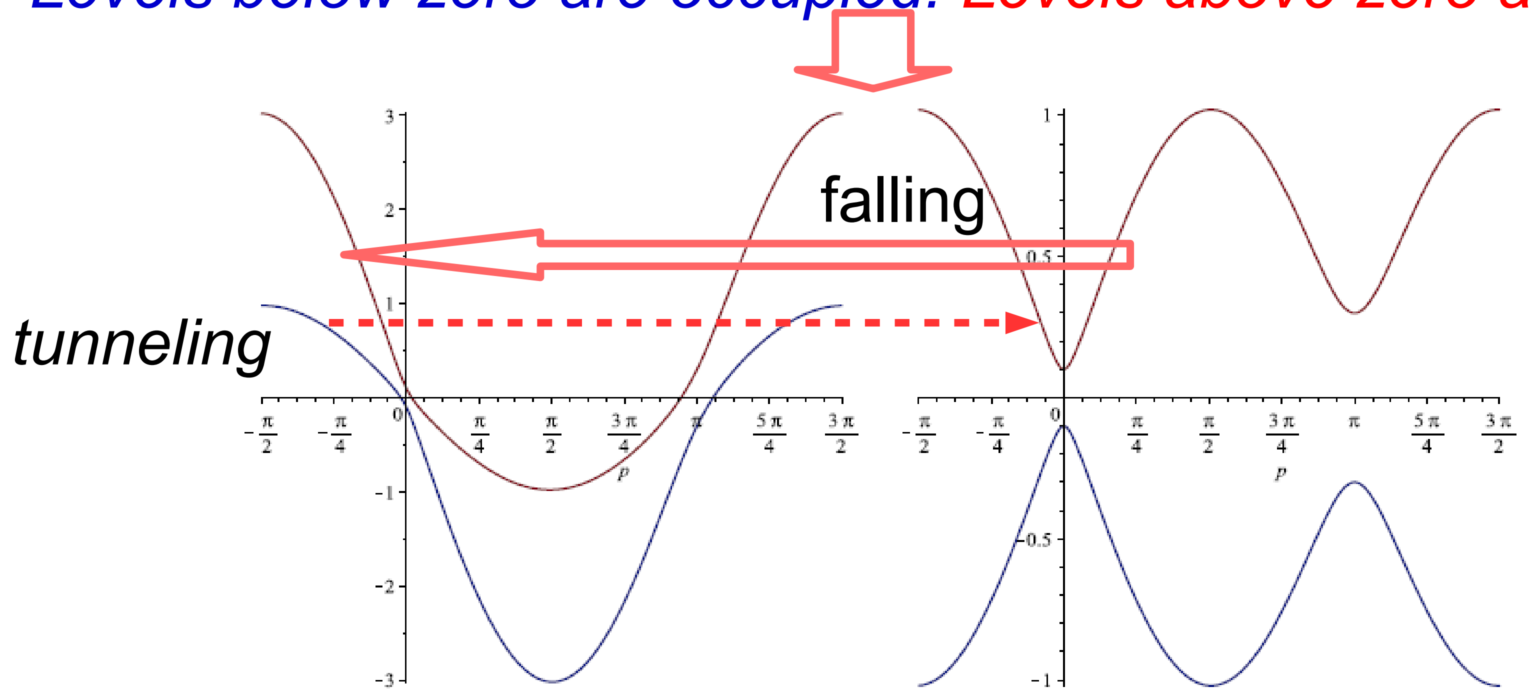
Inside *outside*

EQUILIBRIUM

The circle of life of the black hole

2) The equilibrium state

Levels below zero are occupied. Levels above zero are vacant



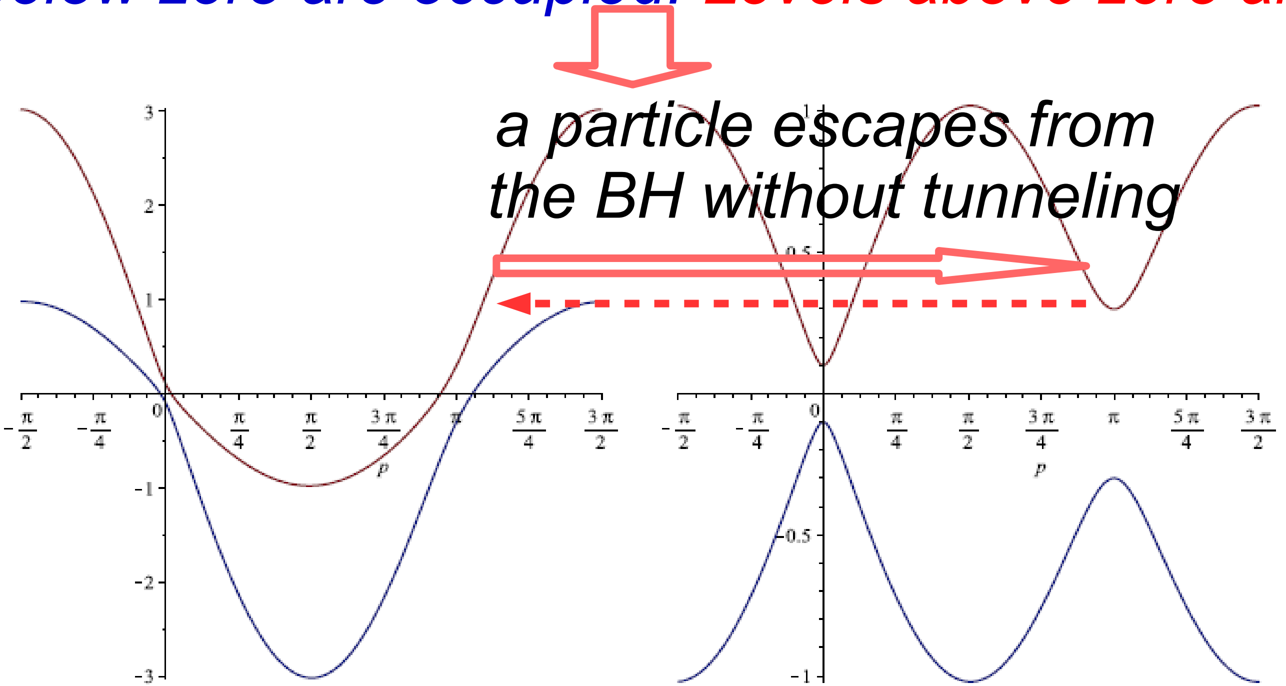
inside *outside*

EQUILIBRIUM

The circle of life of the black hole

2) The equilibrium state

Levels below zero are occupied. Levels above zero are vacant



inside *outside*

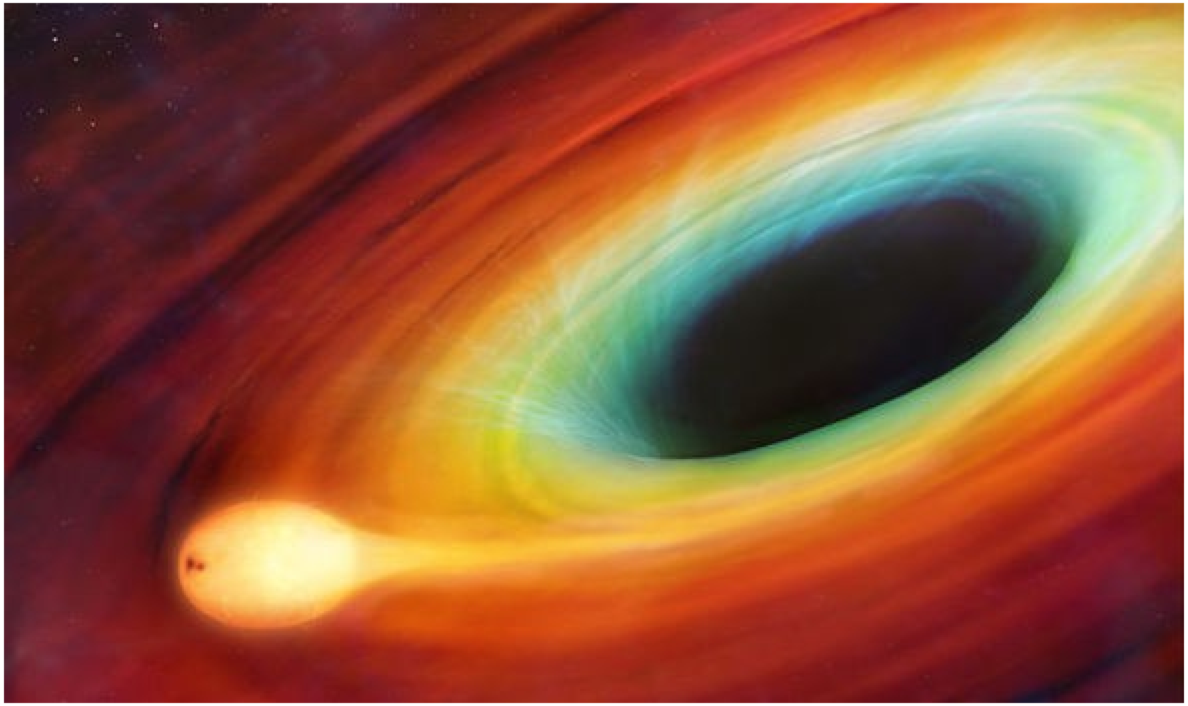
EQUILIBRIUM

The circle of life of the black hole

2) the equilibrium state

Normal matter is falling down to the BH

*Extra matter is falling **from** the BH towards its exterior*



The modifications of the gravitational field are not yet discussed ==> the question about the possibility of the **evaporation** of **the equilibrium BH** is open

Conclusions

1) *the black hole may undergo the transition to equilibrium state, in which in its interior the Fermi surface appears* **(Volovik)**

2) In the lattice regularized theory the Fermi surface is finite and closed as for the type II Weyl semimetals.

3) Only the states near P=0 are described by the SM, the states far from this point are extra massive outside of the BH

3) At low energy all states near the Fermi surface are relevant including those which would be extra massive outside.

4) Those states represent matter that may escape from the BH without tunneling

There may be the dramatic consequences for the black hole thermodynamics: it does not describe the BH if it is in the equilibrium state