Title: Unparticles and Fermi Arcs in the Cuprates

Date: Nov 07, 2013 10:45 AM

URL: http://pirsa.org/13100131

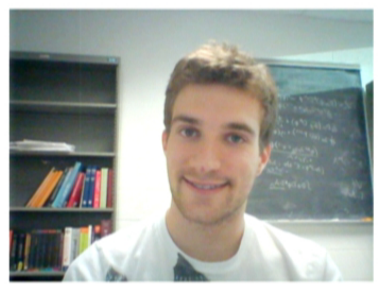
Abstract: One of the open problems in strong correlation physics is whether or not Luttinger's theorem works for doped Mott insulators, particularly in the pseudo gap regime where the pole-like excitations form only a Fermi arc. I will begin this talk by using this theorem to count particles and show that it fails in general for the Mott state. The failure stems from the divergent self energy that underlies Mottness. When such a divergence is present, charged degrees of freedom are present that have no particle interpretation. I will argue that such excitations are governed by a non-trivial IR fixed point and the propagator of which is of the unparticle form proposed by Georgi. I will show how a gravity dual can be used to determine the scaling dimension of the unparticle propagator. I will close by elucidating a possible superconducting instability of unparticles and demonstrate that unparticle stuff is likely to display fractional statistics in the dimensionalities of interest for strongly correlated electron matter. Time permitting, an underlying theory of the strongly coupled fixed point will be outlined.

Unparticles and Fermi Arcs

Thanks to: NSF, EFRC (DOE)

Kiaran dave

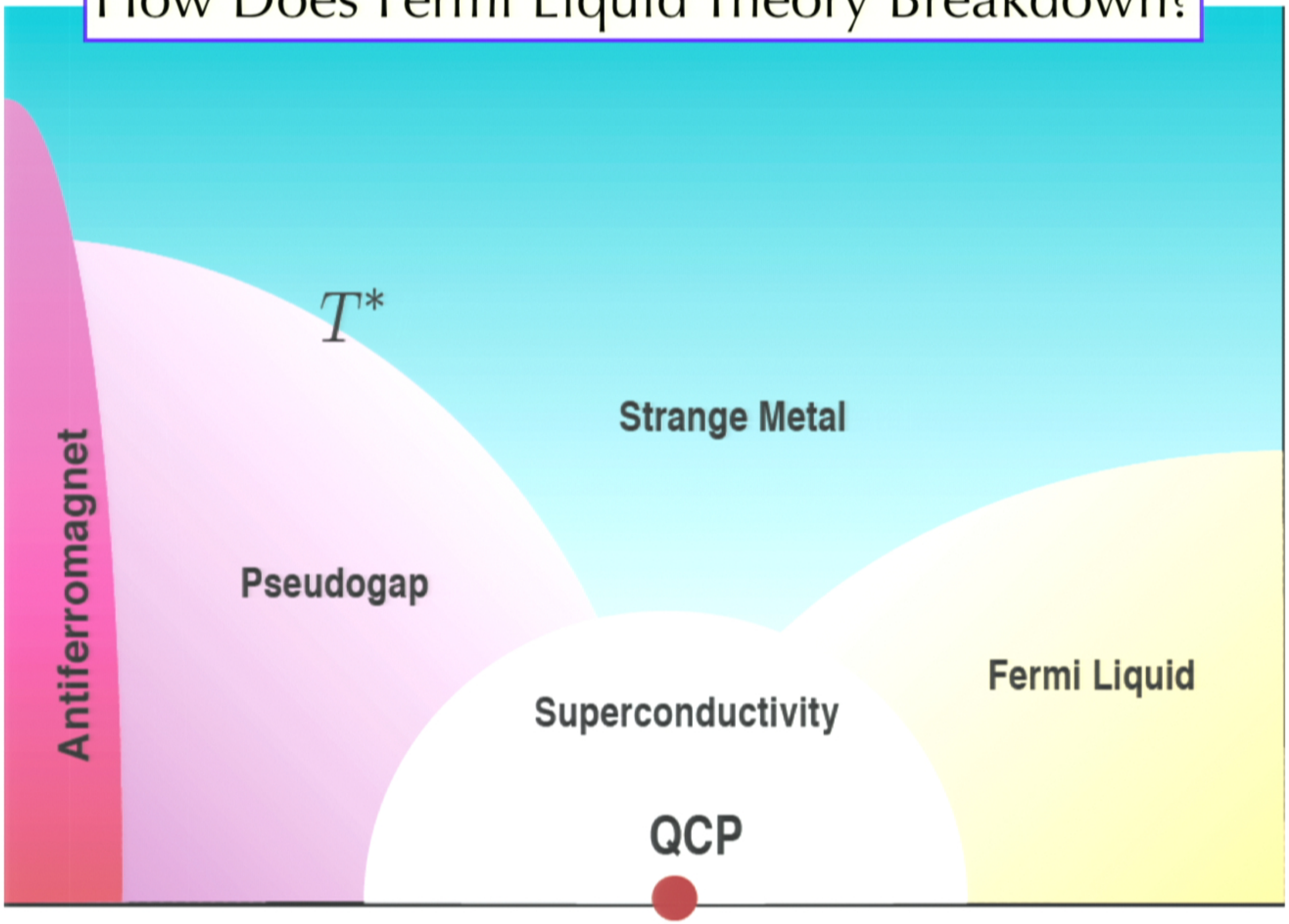
Charlie Kane



Brandon Langley

J. A. Hutasoit

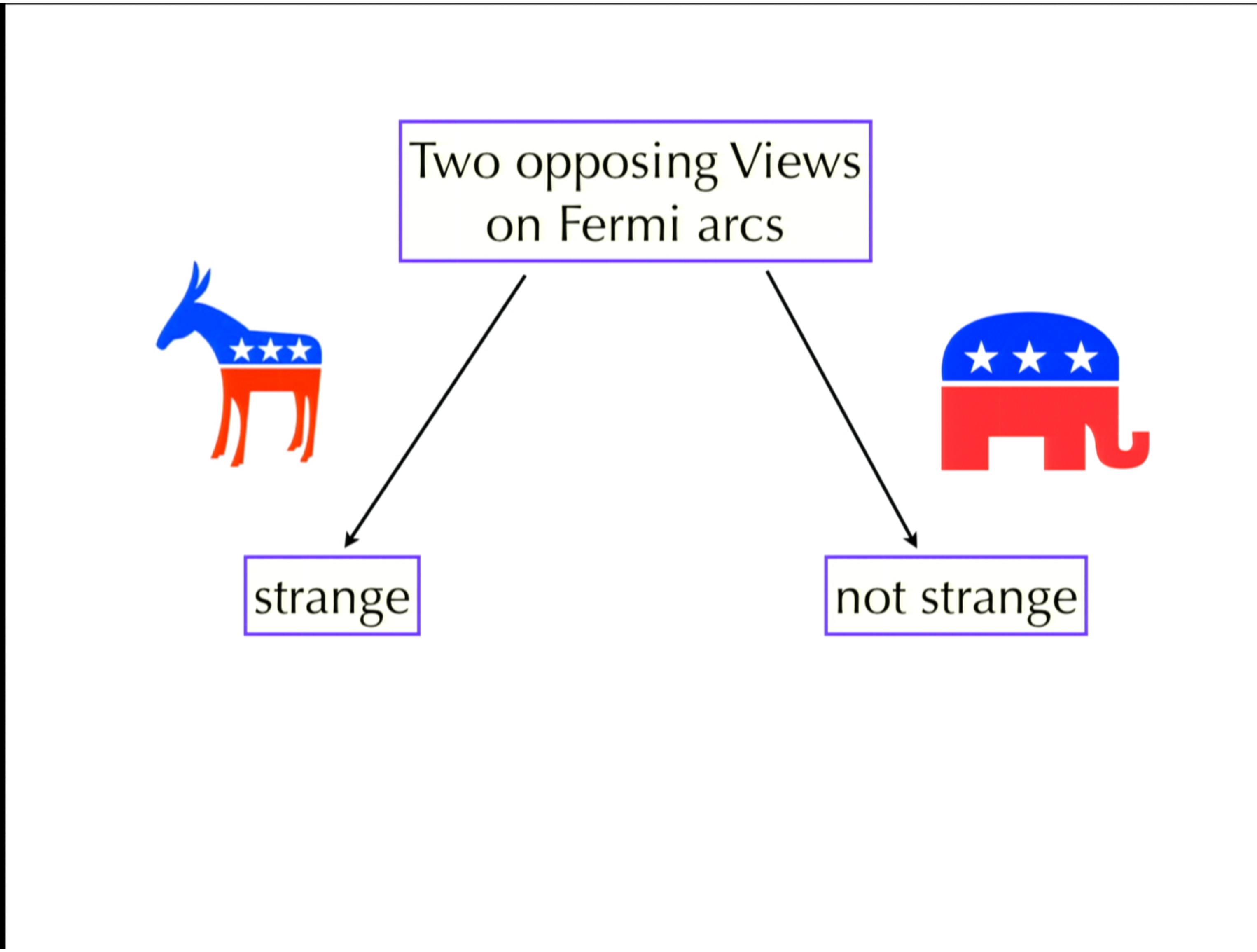
How Does Fermi Liquid Theory Breakdown?



Two opposing Views
on Fermi arcs

strange

not strange


Two opposing Views
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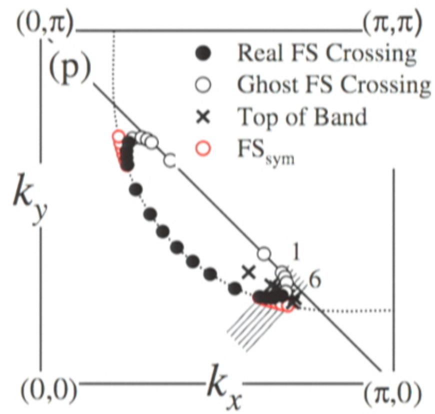
not strange

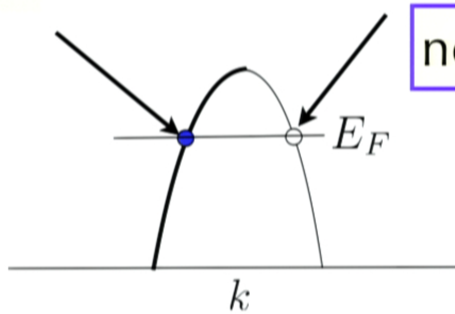
Fermi Arcs are Strange



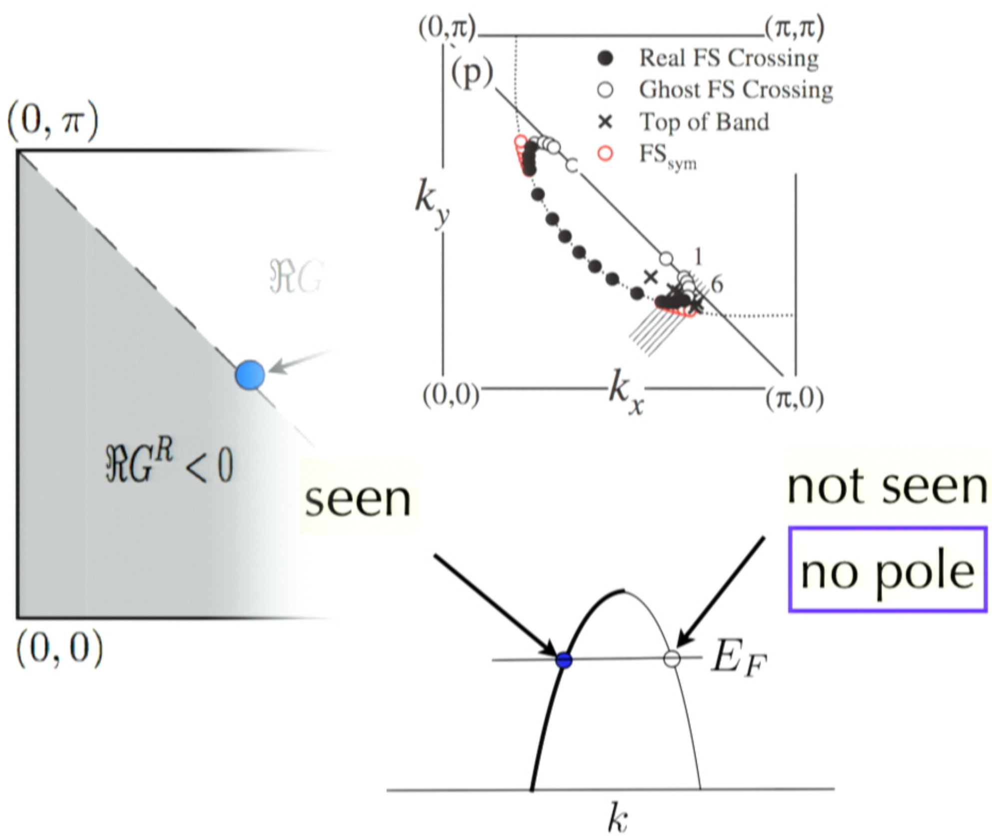
seen

not seen

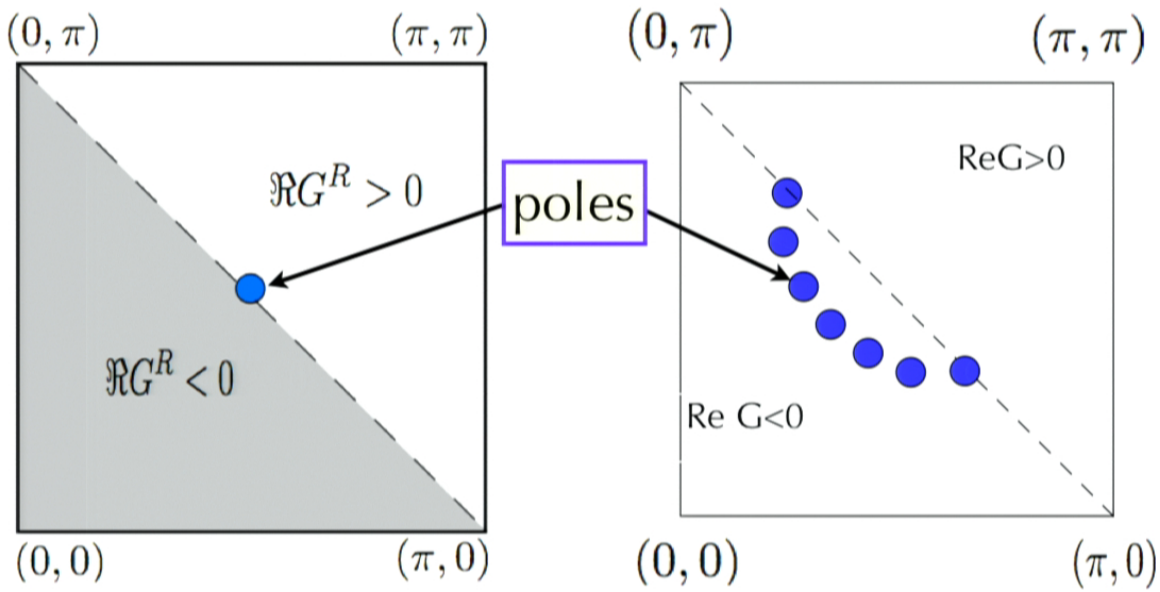
no pole



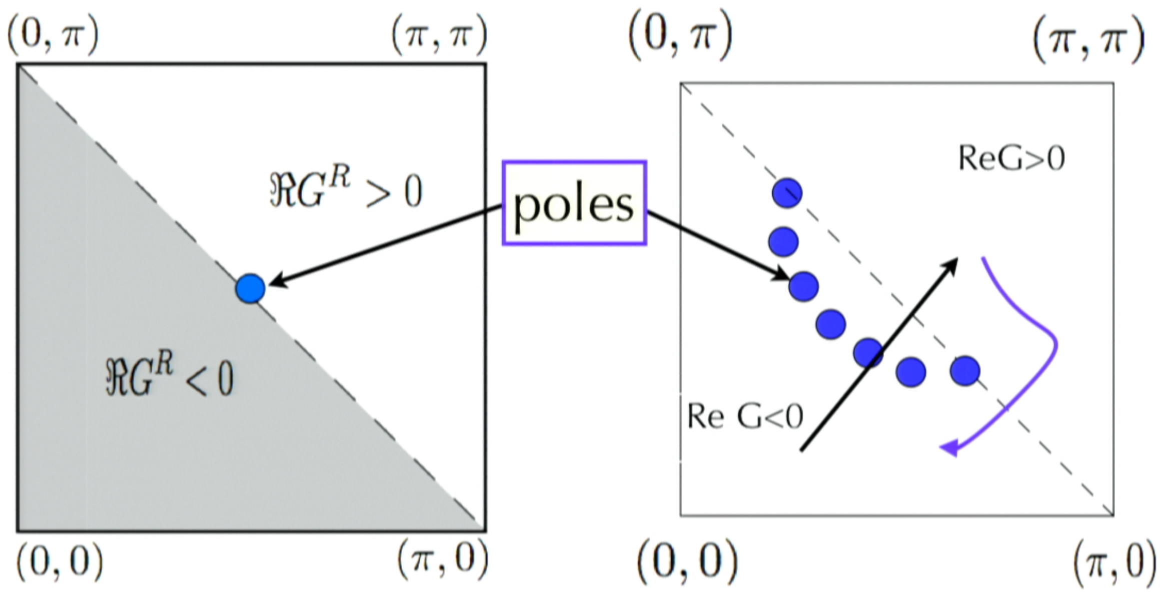
Fermi Arcs are Strange



Problem for left-wingers (me)

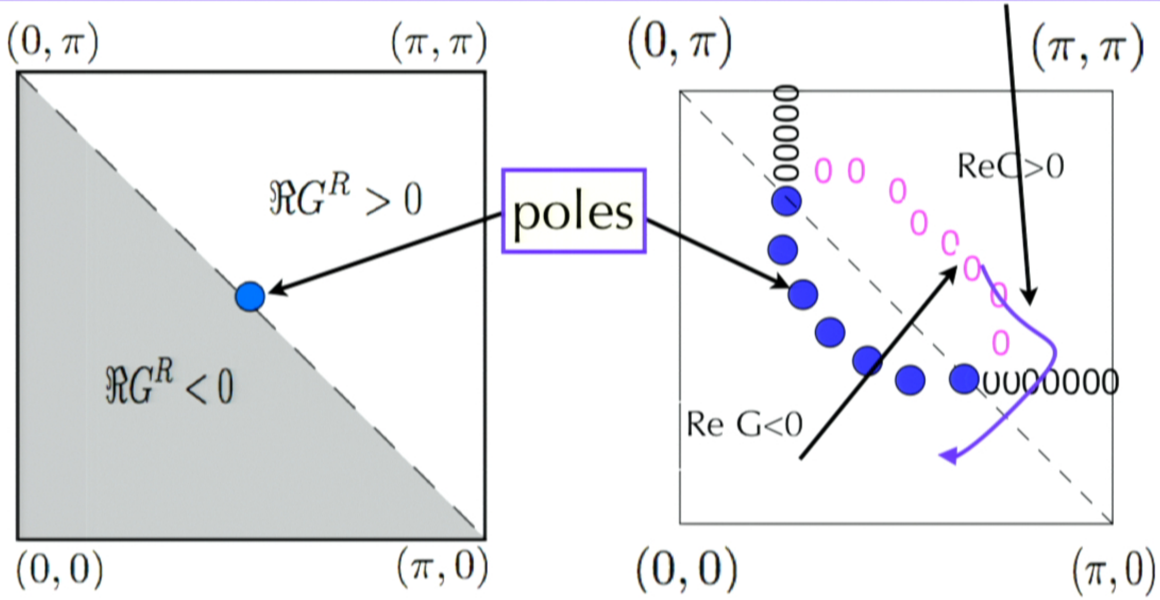


Problem for left-wingers (me)



Problem for left-wingers (me)

How to account for the sign change without poles?



Only option: DetG=0! (zeros)

Fermi Arcs

↓

zeros + poles

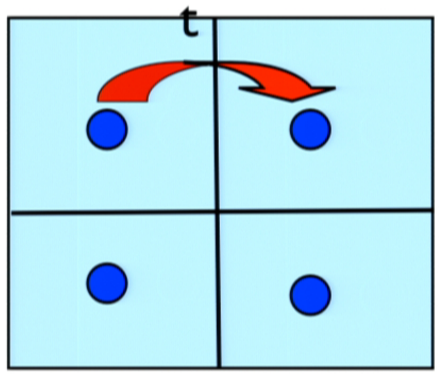
Luttinger, Dzyaloshinskii, Yang, Rice, Zhang,Tsvelik, Anderson (lots of smart people)...

n=zeros + poles

what are zeros?

are they (like poles) conserved?

Mott mechanism
(not Slater)



Sir Neville

singularities of $\ln G$

$$n = \frac{2i}{(2\pi)^{d+1}} \int d^d\mathbf{p} \int_{-\infty}^{0} d\xi \ln \frac{G^R(\xi,\mathbf{p})}{G_R^*(\xi,\mathbf{p})}$$

$$n = 2\sum_{\mathbf{k}} \Theta(\Re G(\mathbf{k}, \omega = \mathbf{0}))$$

poles+zeros
Luttinger's theorem

PHYSICAL REVIEW B **68**, 085113 (2003)

Some consequences of the Luttinger theorem: The Luttinger surfaces in non-Fermi liquids and Mott insulators

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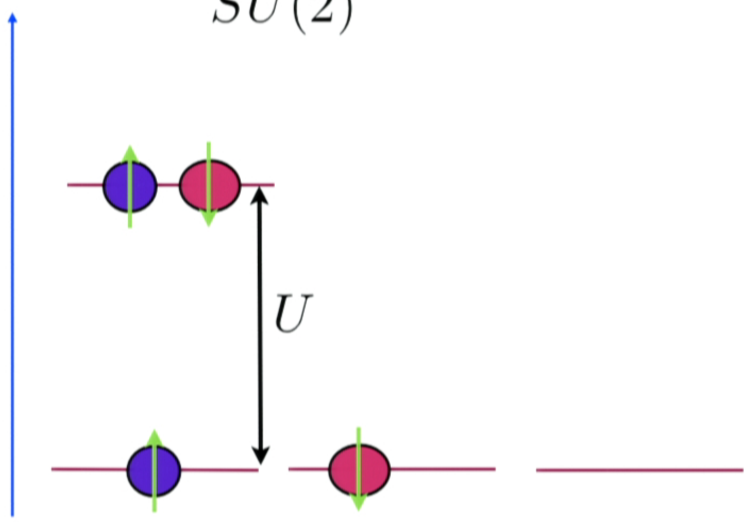
(Received 30 January 2003; published 27 August 2003)

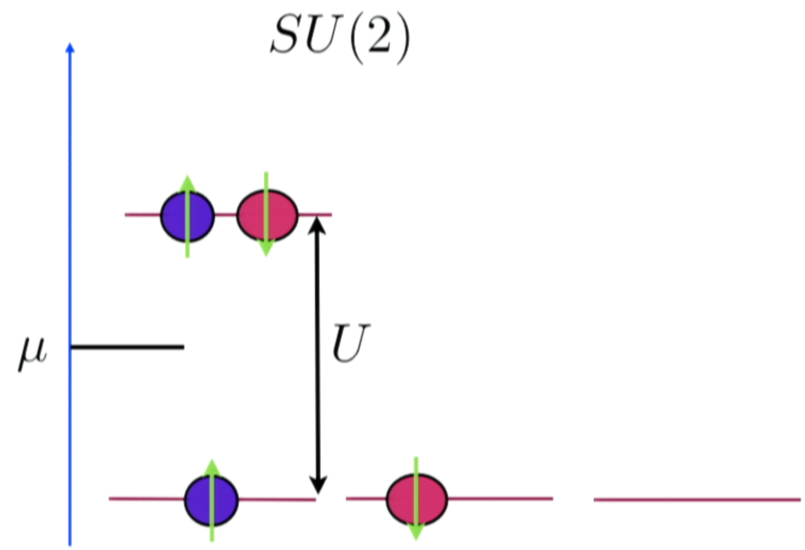
The proof just presented is good for any state of our system: FL, NFL, or MI [in other words, either of poles or zeros can be used to change the sign of G_r in Eq. (1)]. The only way to incapacitate the Luttinger theorem in form (1) is to assume that the limit $T \rightarrow 0$ is discontinuous. Actually, one has to require that the whole line $T=0$ is a line of phase transitions.

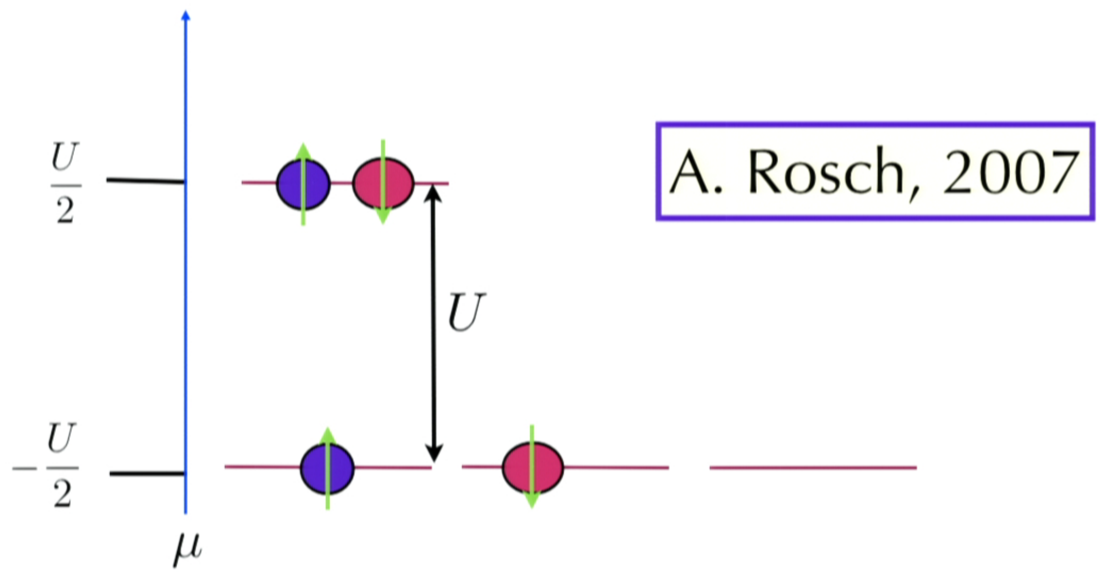
simple problem: n=1

$SU(2)$



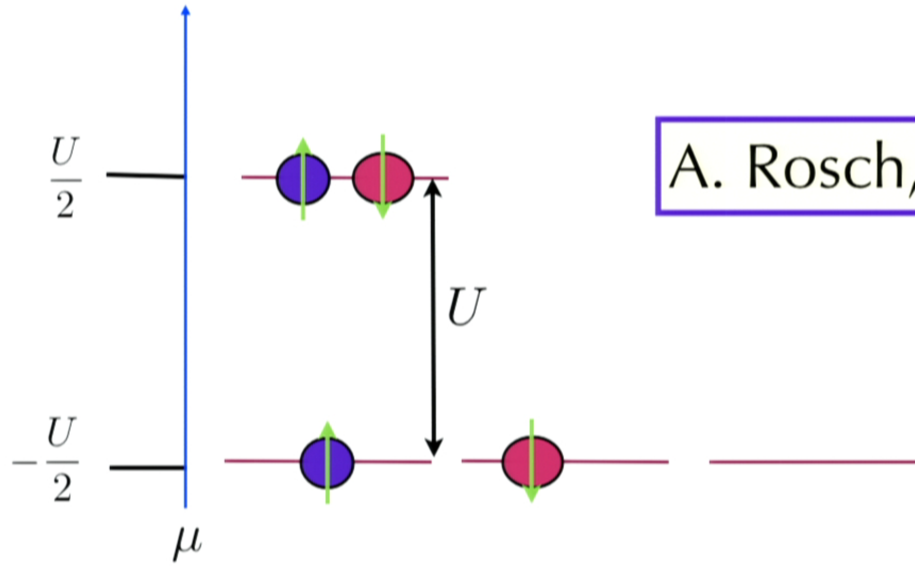
simple problem: n=1





$\frac{U}{2}$
U
$-\frac{U}{2}$
μ
A. Rosch, 2007

$$n = 2\theta\left(\frac{2\mu}{\mu^2 - \left(\frac{U}{2}\right)^2}\right) \quad \Longleftarrow \quad G(\omega = 0) = \frac{2\mu}{\mu^2 - \left(\frac{U}{2}\right)^2}$$



A. Rosch, 2007

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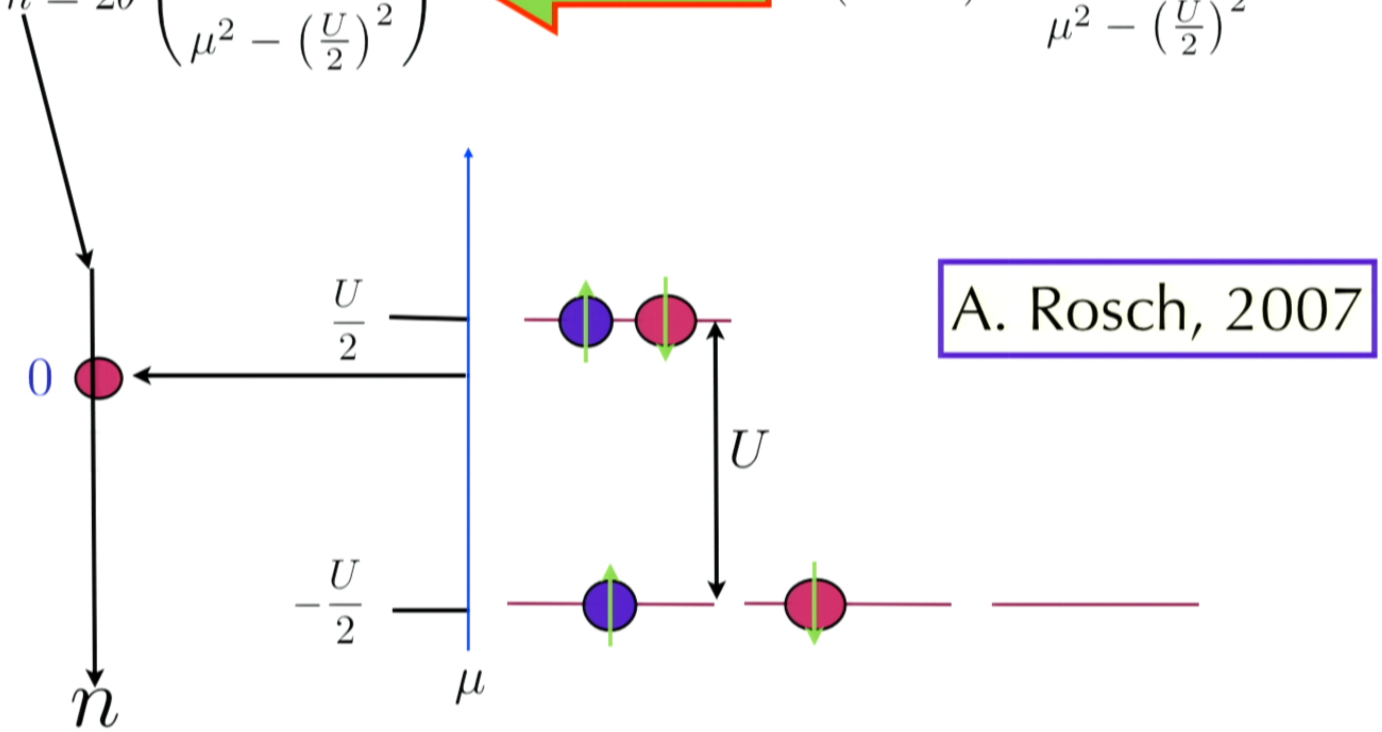
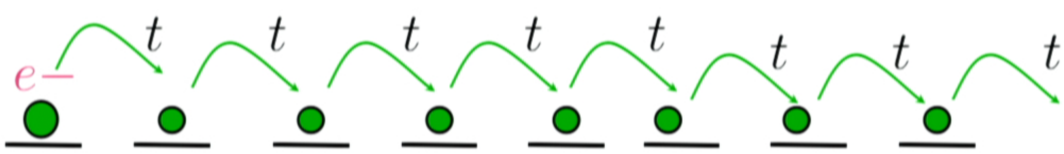


fix chemical potential

$$\lim_{T \to 0} \mu(T)$$

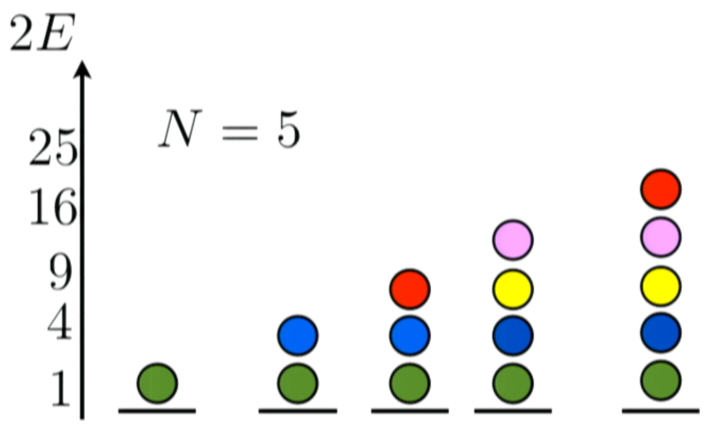
A model with zeros but Luttinger fails

A model with zeros but Luttinger fails

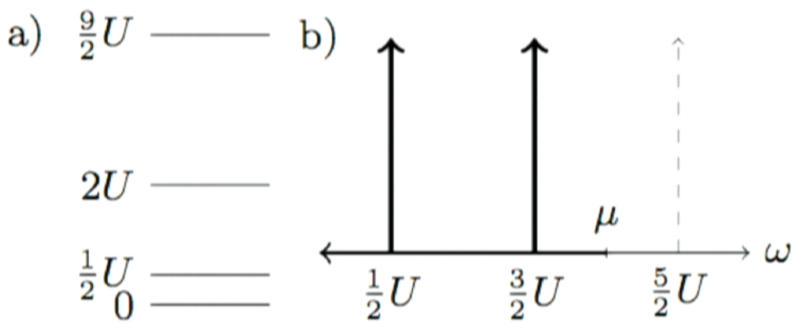


$SU(N)$

$$H = \frac{U}{2}(n_1 + \cdots n_N)^2$$



no particle-hole symmetry



$$G_{\alpha\beta}(\omega = 0) = \frac{\delta_{\alpha\beta}}{K(n+1) - K(n)} \left(\frac{2n - N}{N} \right)$$

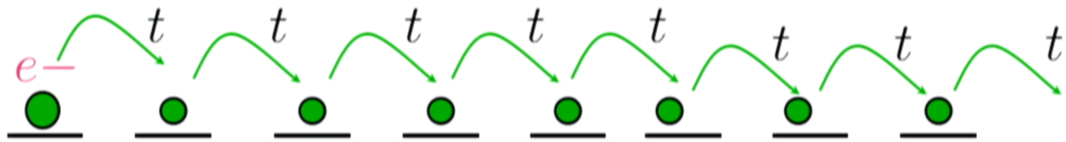
Luttinger's theorem

$$n = N\Theta(2n - N)$$

$\underbrace{\Theta(2n-N)}$: $0, 1, 1/2$

even

does the degeneracy matter?



$$t = 0^+$$

$$G_{ab}(\omega) = \mathrm{Tr}\left(\left[c_a^\dagger \frac{1}{\omega - H} c_b + c_b \frac{1}{\omega - H} c_a^\dagger\right] \rho(0^+)\right)$$

Problem

G=0

$$G = \frac{1}{E - \varepsilon_p - \Sigma}$$

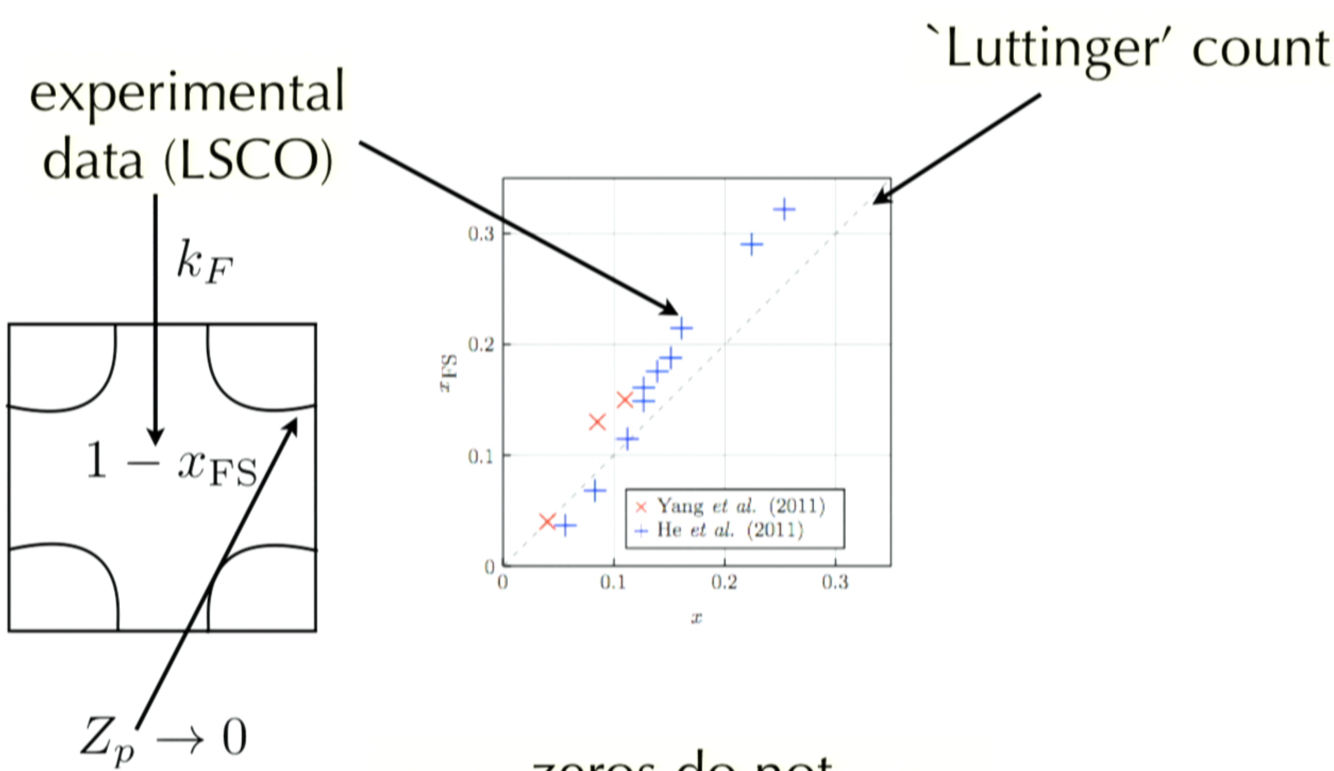
$\Sigma \rightarrow \infty$

what went wrong?

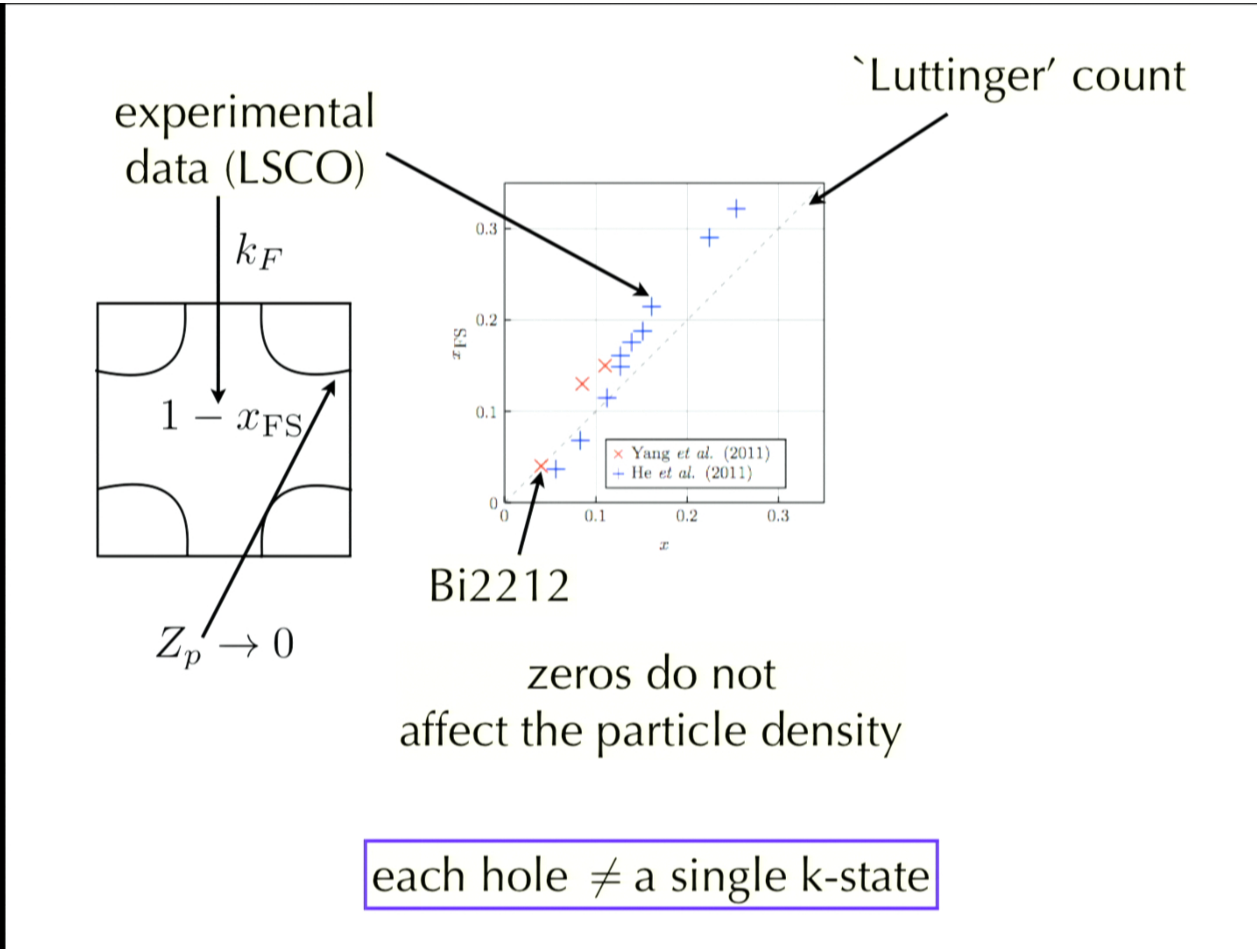
$$\delta I[G] = \int d\omega \Sigma \delta G$$

$\Downarrow$ if $\Sigma \to \infty$

experimental
confirmation
of violation?



zeros do not
affect the particle density


`Luttinger' count
experimental
data (LSCO)
k_F
$1 - x_{\rm FS}$
$Z_p \to 0$
0.3
0.2
0.1
0
$x_{\rm FS}$
0
0.1
0.2
0.3
x
× Yang et al. (2011)
+ He et al. (2011)
Bi2212
zeros do not
affect the particle density
each hole $\neq$ a single k-state

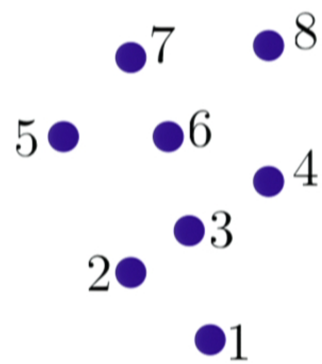
Two opposing Views on Fermi arcs

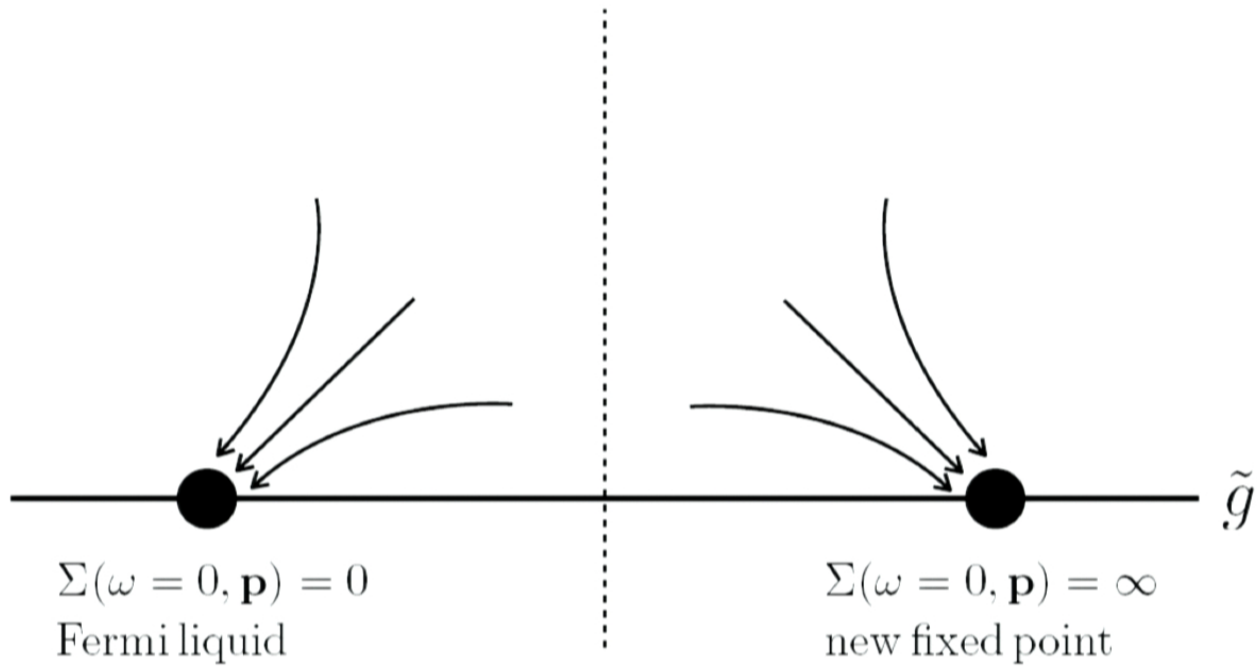
strange

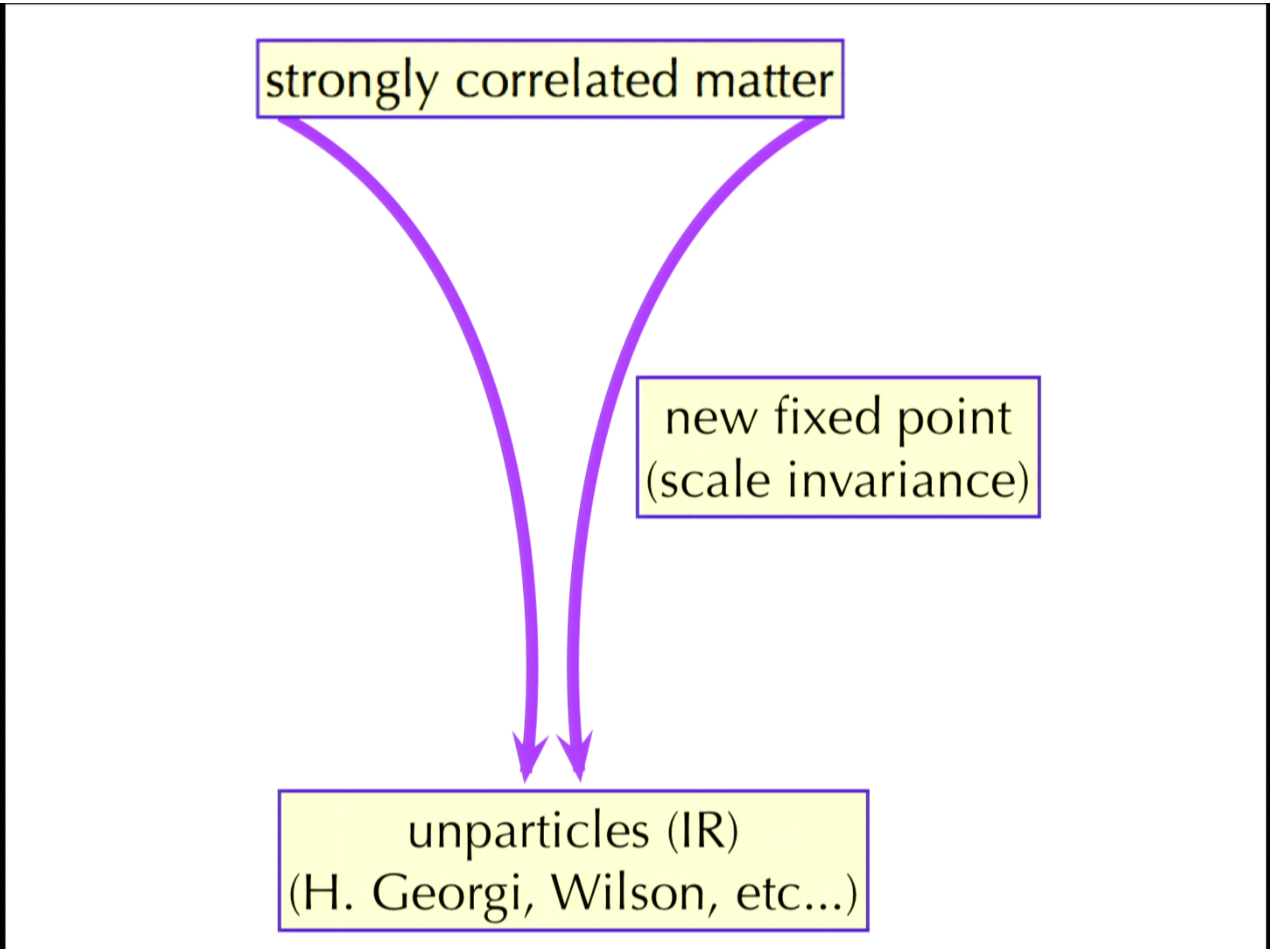
not strange

this dispute has an answer!

how to count particles?




$\tilde{g}$
$\Sigma(\omega = 0, \mathbf{p}) = 0$
Fermi liquid
$\Sigma(\omega = 0, \mathbf{p}) = \infty$
new fixed point


strongly correlated matter
new fixed point
(scale invariance)
unparticles (IR)
(H. Georgi, Wilson, etc...)

massive free theory

mass

$$\mathcal{L} = \frac{1}{2}\partial^\mu\phi\partial_\mu\phi + m^2\phi^2$$

$$x \to x/\Lambda$$

$$\phi(x) \to \phi(x)$$

$$\Lambda^2\left(\frac{1}{2}\partial^\mu\phi\partial_\mu\phi\right) \qquad m^2\phi^2$$

no scale invariance

$$\mathcal{L} = \int_0^\infty \left(\partial^\mu \phi(x,m)\partial_\mu \phi(x,m) + m^2\phi^2(x,m)\right) dm^2$$

theory with all possible mass!

propagator

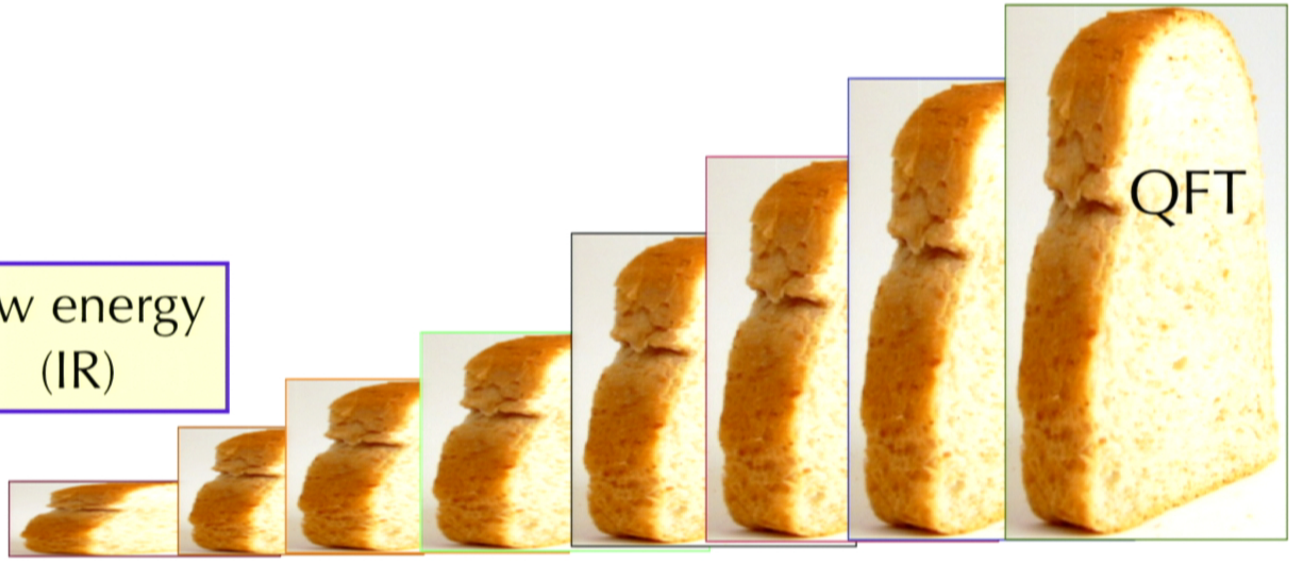
$$\left(\int_0^\infty dm^2 m^{2\gamma} \frac{i}{p^2 - m^2 + i\epsilon}\right)^{-1} \propto p^{2|\gamma|}$$

$|\gamma| \rightarrow d_U - 2$

S. Lee, S. Kachru,...

high energy
(UV)

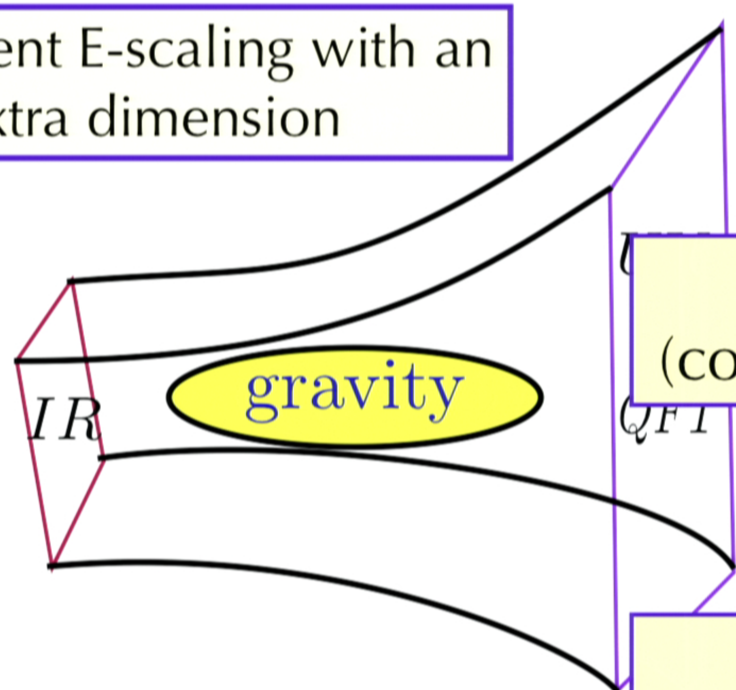
low energy
(IR)



related to sum
over mass

gauge-gravity duality
(Maldacena, 1997)

implement E-scaling with an extra dimension



no particles (conserved currents)

unparticles?

related to sum over mass

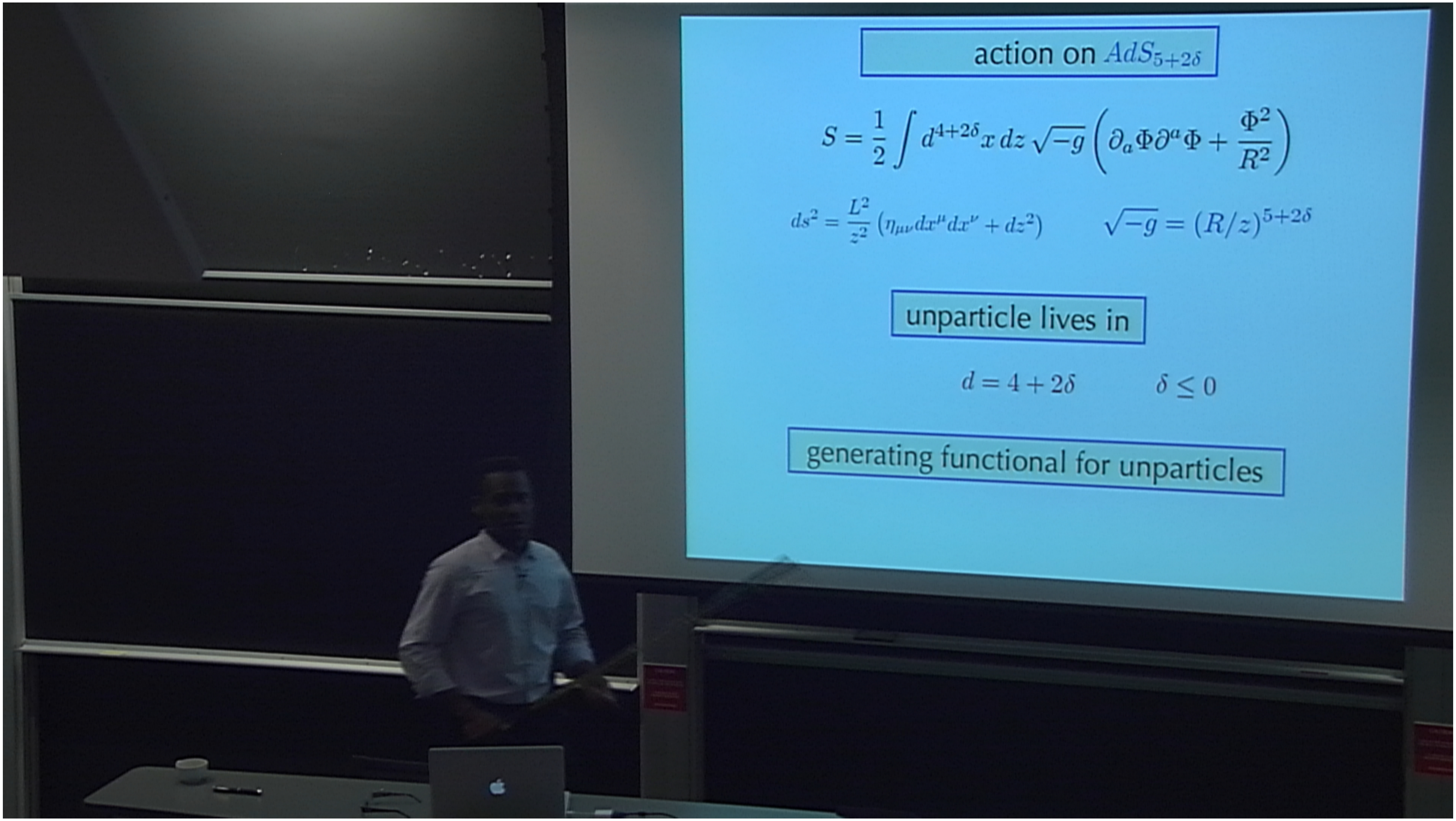
$$\frac{dg(E)}{dlnE} = \beta(g(E))$$

locality in energy

can something more exact be done?

$$\mathcal{L} = \int_0^\infty \left(\partial^\mu \phi(x,m)\partial_\mu \phi(x,m) + m^2\phi^2(x,m)\right) m^{2\delta} dm^2$$

$$m = z^{-1}$$


action on $AdS_{5+2\delta}$
$S = \frac{1}{2}\int d^{4+2\delta}x\, dz\, \sqrt{-g}\left(\partial_a\Phi\partial^a\Phi + \frac{\Phi^2}{R^2}\right)$
$ds^2 = \frac{L^2}{z^2}\left(\eta_{\mu\nu}dx^\mu dx^\nu + dz^2\right)$
$\sqrt{-g} = (R/z)^{5+2\delta}$
unparticle lives in
$d = 4 + 2\delta$
$\delta \leq 0$
generating functional for unparticles

action on $AdS_{5+2\delta}$

$$S = \frac{1}{2}\int d^{4+2\delta}x\, dz\, \sqrt{-g}\left(\partial_a \Phi \partial^a \Phi + \frac{\Phi^2}{R^2}\right)$$

$$ds^2 = \frac{L^2}{z^2}\left(\eta_{\mu\nu}dx^\mu dx^\nu + dz^2\right) \qquad \sqrt{-g} = (R/z)^{5+2\delta}$$

unparticle lives in

$$d = 4 + 2\delta \qquad \delta \leq 0$$

generating functional for unparticles

Claim: $Z_{\rm QFT} = e^{-S^{\rm on-shell}_{\rm ADS}(\phi(\phi_{\partial \rm ADS = J_{\mathcal{O}}}))}$

$$S = \frac{1}{2}\int d^dx\, g^{zz}\sqrt{-g}\,\Phi(z,x)\partial_z\Phi(z,x)\Big|_{z=\epsilon}$$

$$\langle \Phi_U(x)\Phi_U(x')\rangle = \frac{1}{|x-x'|^{2d_U}}$$

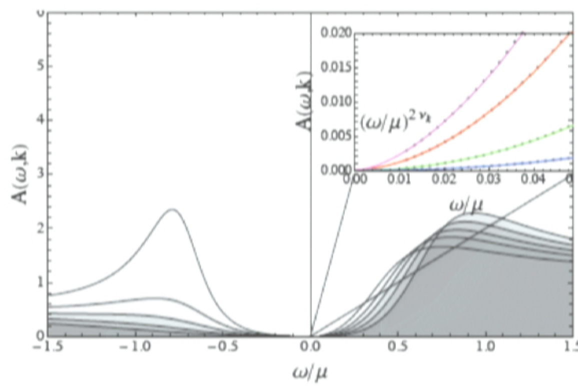
$$d_U = \frac{d}{2} + \frac{\sqrt{d^2+4}}{2} > \frac{d}{2}$$

Similar Problem

Universal fermionic spectral functions from string theory

Jerome P. Gauntlett,[1] Julian Sonner,[1,2] and Daniel Waldram[1]
[1] Theoretical Physics Group, Blackett Laboratory, Imperial College, London SW7 2AZ, U.K.
[2] D.A.M.T.P. University of Cambridge, Cambridge, CB3 0WA, U.K.

We carry out the first holographic calculation of a fermionic response function for a strongly coupled $d = 3$ system with an explicit $D = 10$ or $D = 11$ supergravity dual. By considering the supersymmetry current, we obtain a universal result applicable to all $d = 3$ $\mathcal{N} = 2$ SCFTs with such duals. Surprisingly, the spectral function does not exhibit a Fermi surface, despite the fact that the system is at finite charge density. We show that it has a phonino pole and at low frequencies there is a depletion of spectral weight with a power-law scaling which is governed by a locally quantum critical point.

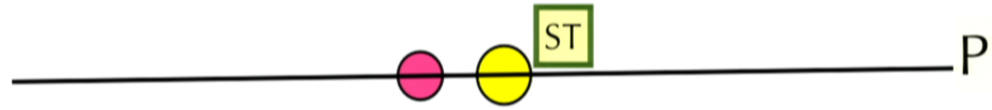


fixed by supersymmetry

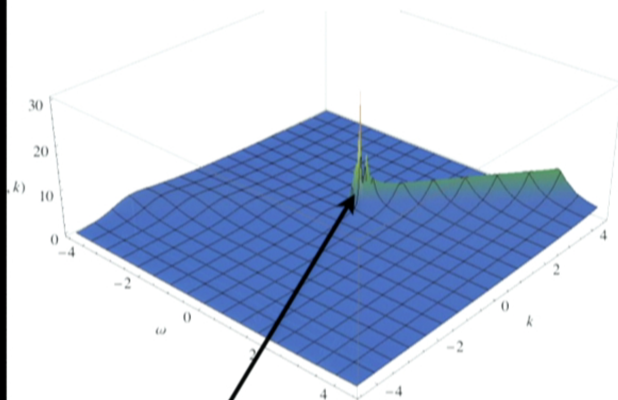
also Gubser, et al.

$$(\not{D} - m - \frac{i}{2}F^{\mu\nu}\Gamma_{\mu\nu})\psi_\rho + iF\mu\nu\Gamma_\mu\Gamma_\rho\psi_\nu = 0$$

How is the spectrum modified?



P=0



Fermi surface peak

$p = -0.53$

$\nu_{k_F} = 1/2$

MFL

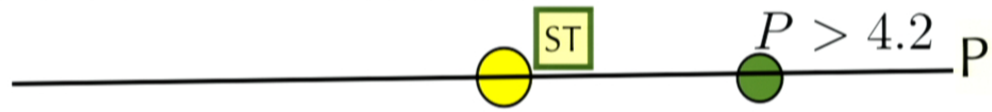
$-0.53 < p < 1/\sqrt{6}$

$1/2 > \nu_{k_F} > 0$

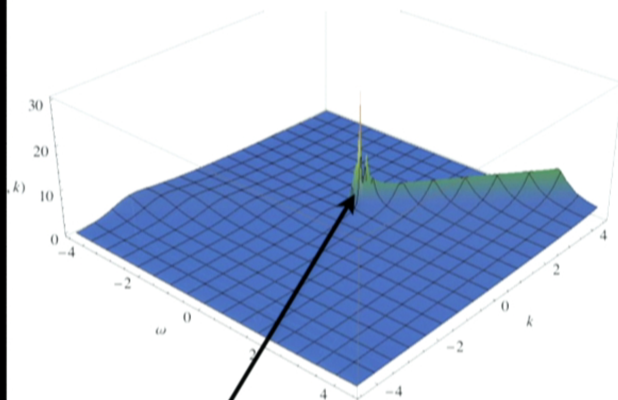
$\Re\omega = \Im\omega \propto (k - k_F)^{1/(2\nu_{k_F})}$

NFL

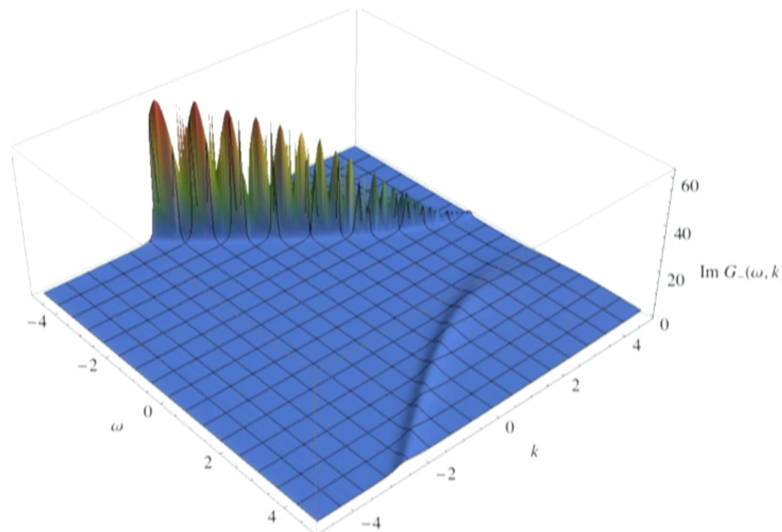
How is the spectrum modified?



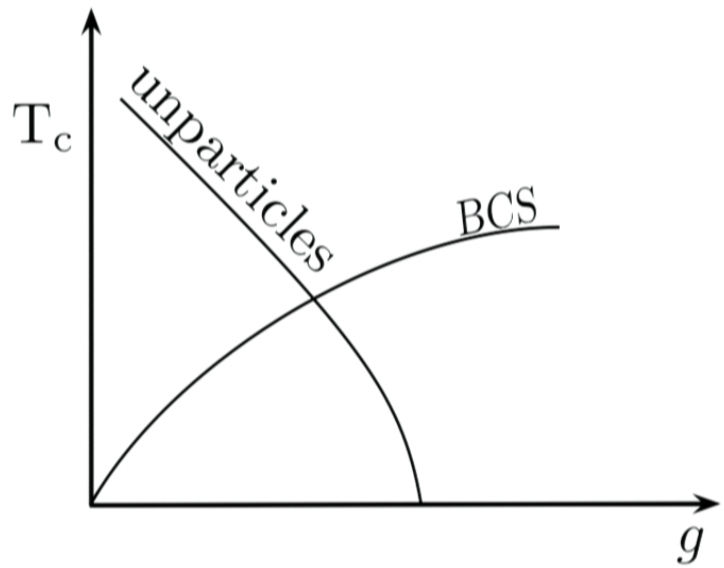
P=0



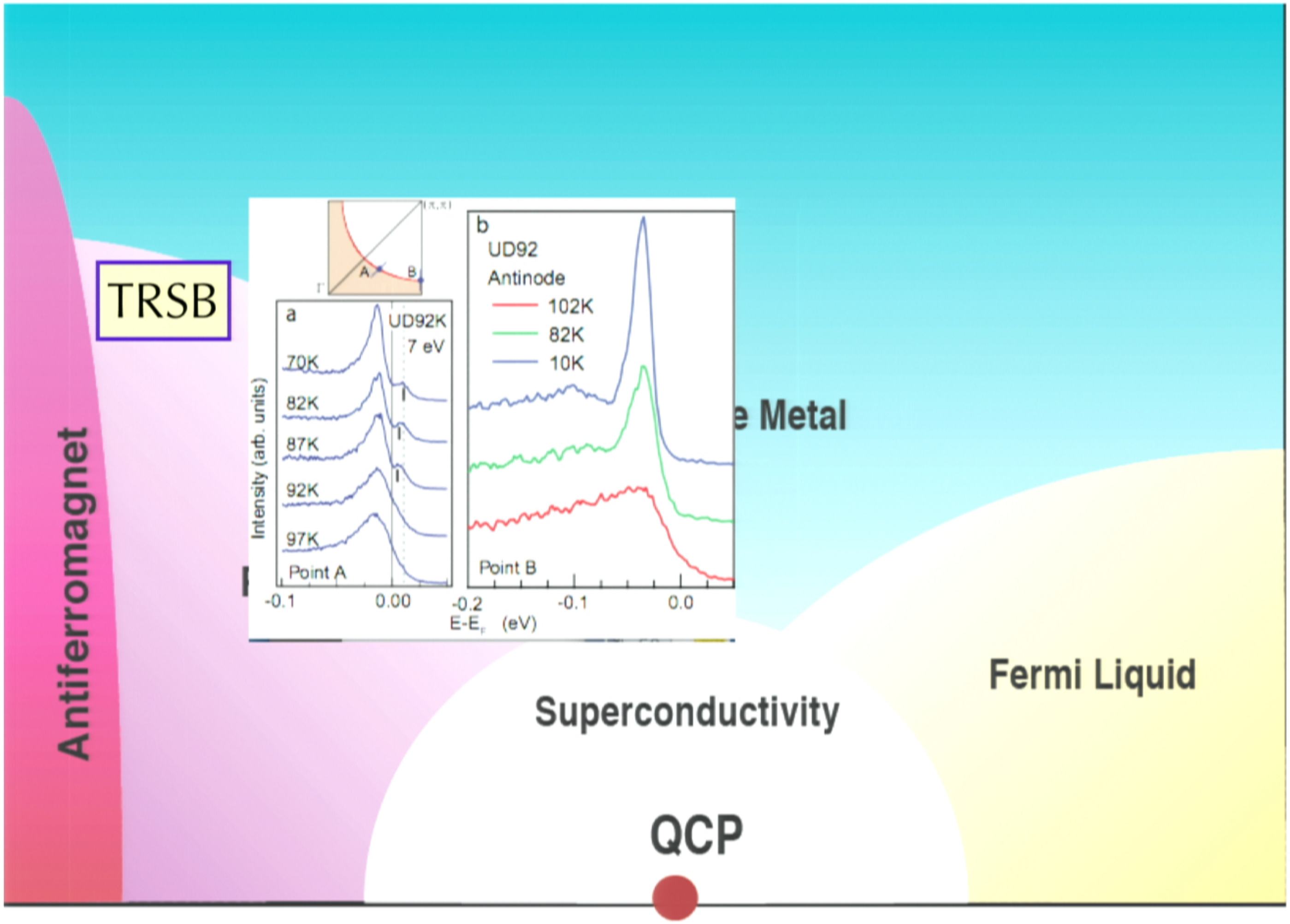
Fermi surface peak

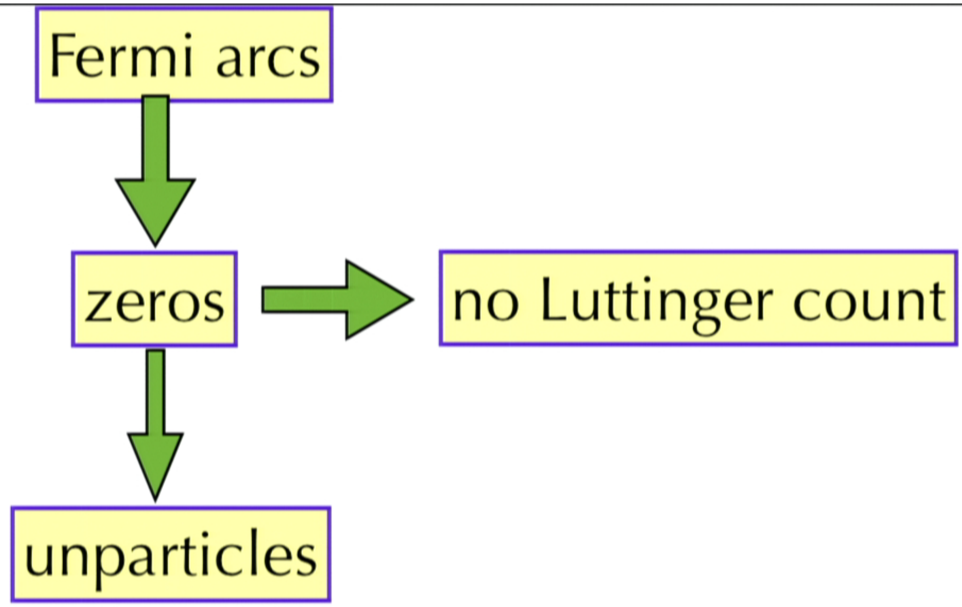


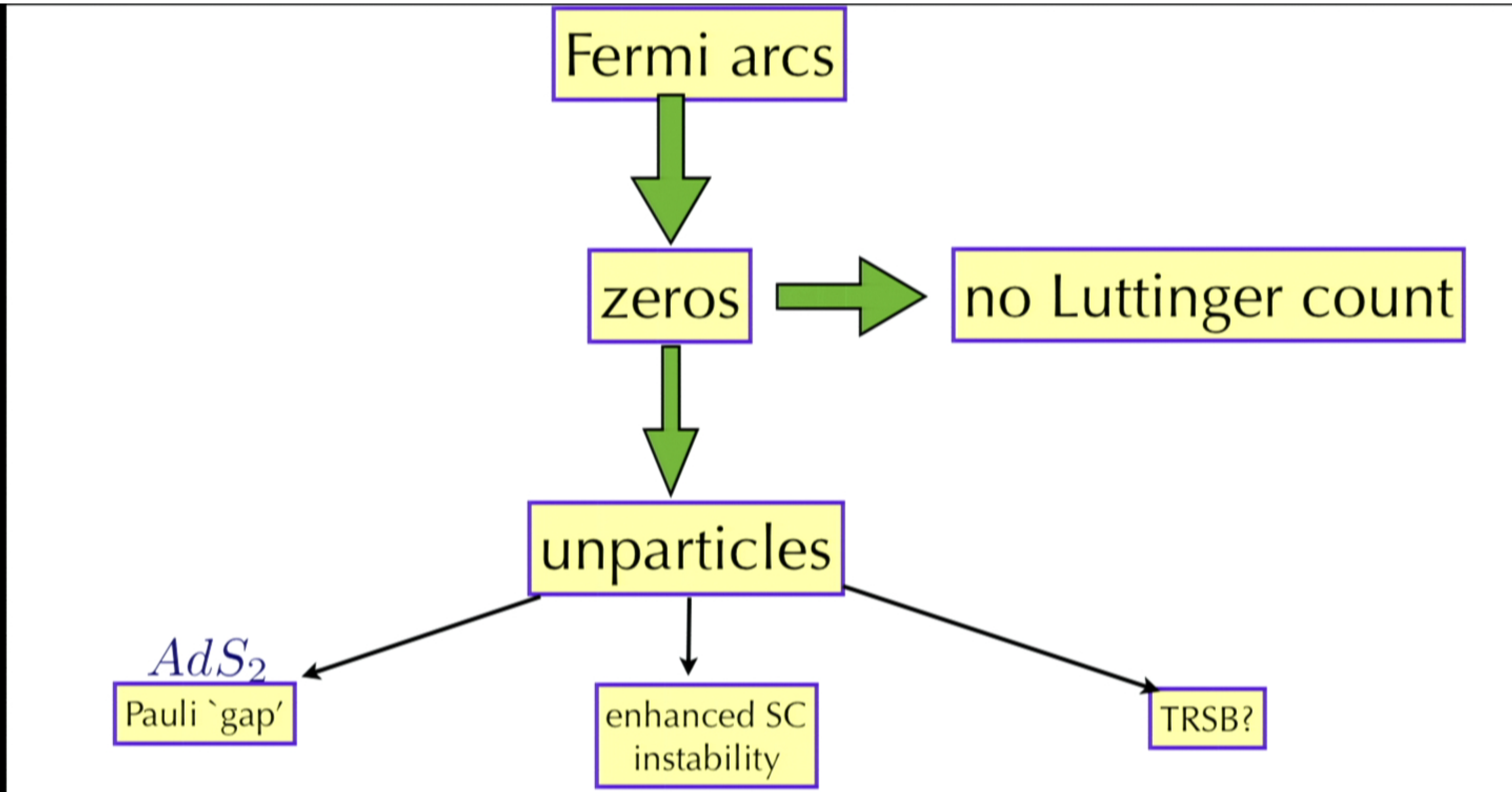
Edalati,Leigh, PP PRL, 106 (2011)



tendency towards pairing (any instability which establishes a gap)


TRSB
Antiferromagnet
e Metal
Fermi Liquid
Superconductivity
QCP
a
UD92K
7 eV
70K
82K
87K
92K
97K
Point A
Intensity (arb. units)
-0.1
0.00
b
UD92
Antinode
102K
82K
10K
Point B
-0.2
-0.1
0.0
E-E$_F$ (eV)


Fermi arcs
zeros
no Luttinger count
unparticles



Fermi arcs
zeros
no Luttinger count
unparticles
AdS_2
Pauli `gap'
enhanced SC instability
TRSB?