String theory:

Dualities between Gauge Theories and Gravity

Johanna Erdmenger

String Theory @ MPP

Dieter Lüst / Ralph Blumenhagen:

Non-associative closed string geometry in non-geometrical flux compactifications

Stephan Stieberger:

Superstring amplitudes and cross-relations with quantum field theory (jet cross-sections)

Thomas Grimm (Independent Research Group):

Constraints imposed by a consistent theory of quantum gravity (string theory or M theory) on effective lower-dimensional physics

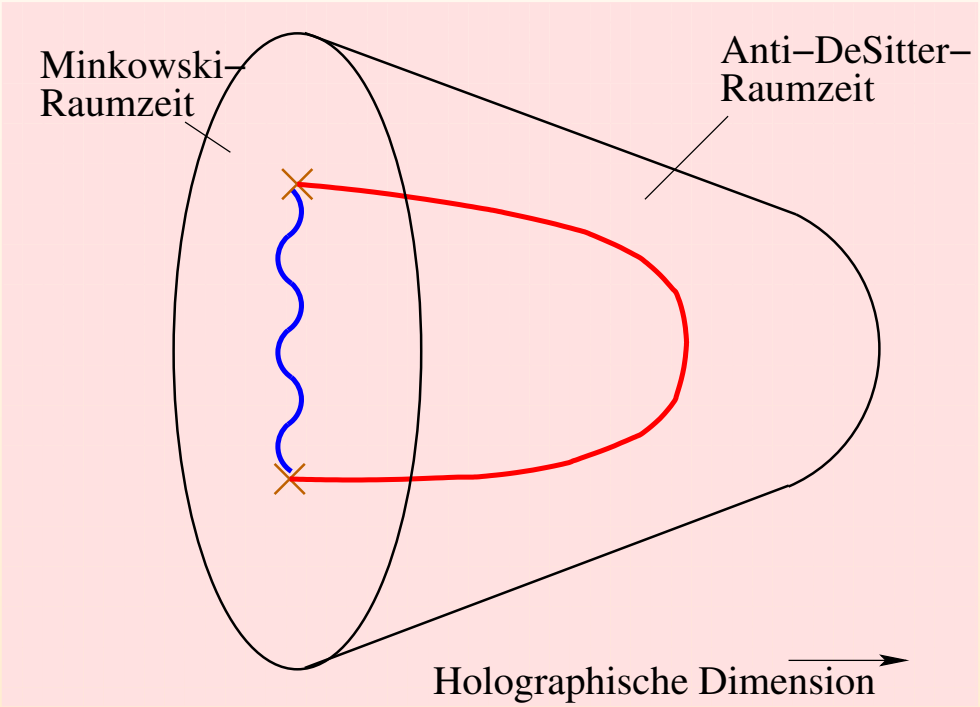
Johanna Erdmenger:

AdS/CFT-Correspondence: Gauge/Gravity Duality

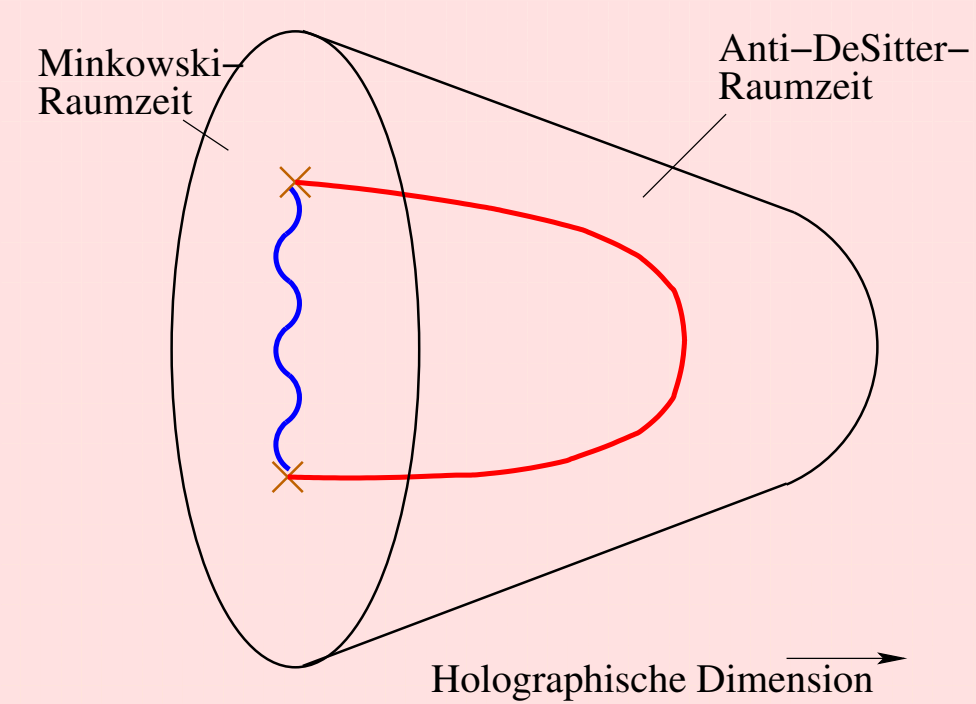
Dualities between gauge theories and gravity

Dualities between gauge theories and gravity

Map: Strongly Coupled Gauge Theory $\leftrightarrow$ Weakly Coupled Gravity Theory

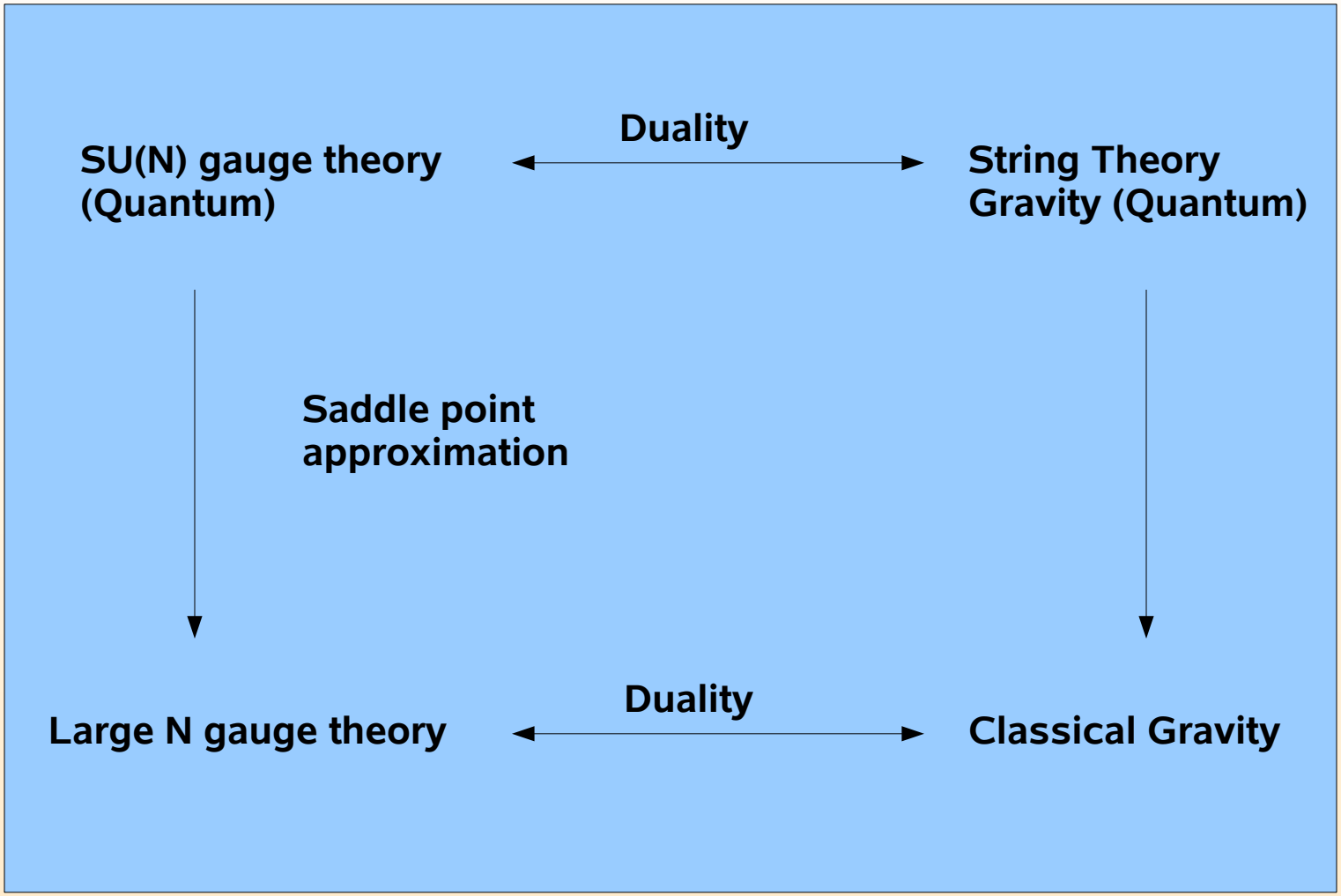


Map: Strongly Coupled Gauge Theory $\leftrightarrow$ Weakly Coupled Gravity Theory

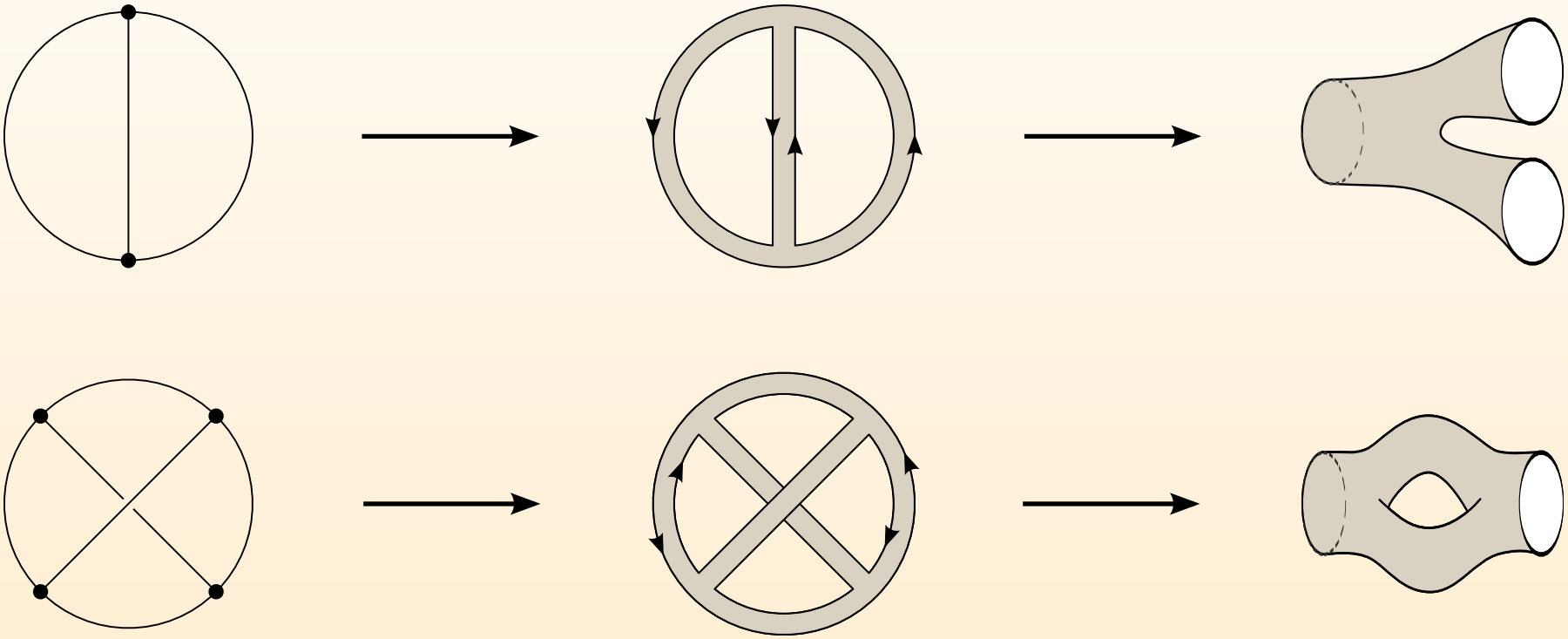


Prototype example for applications: QCD at low energies

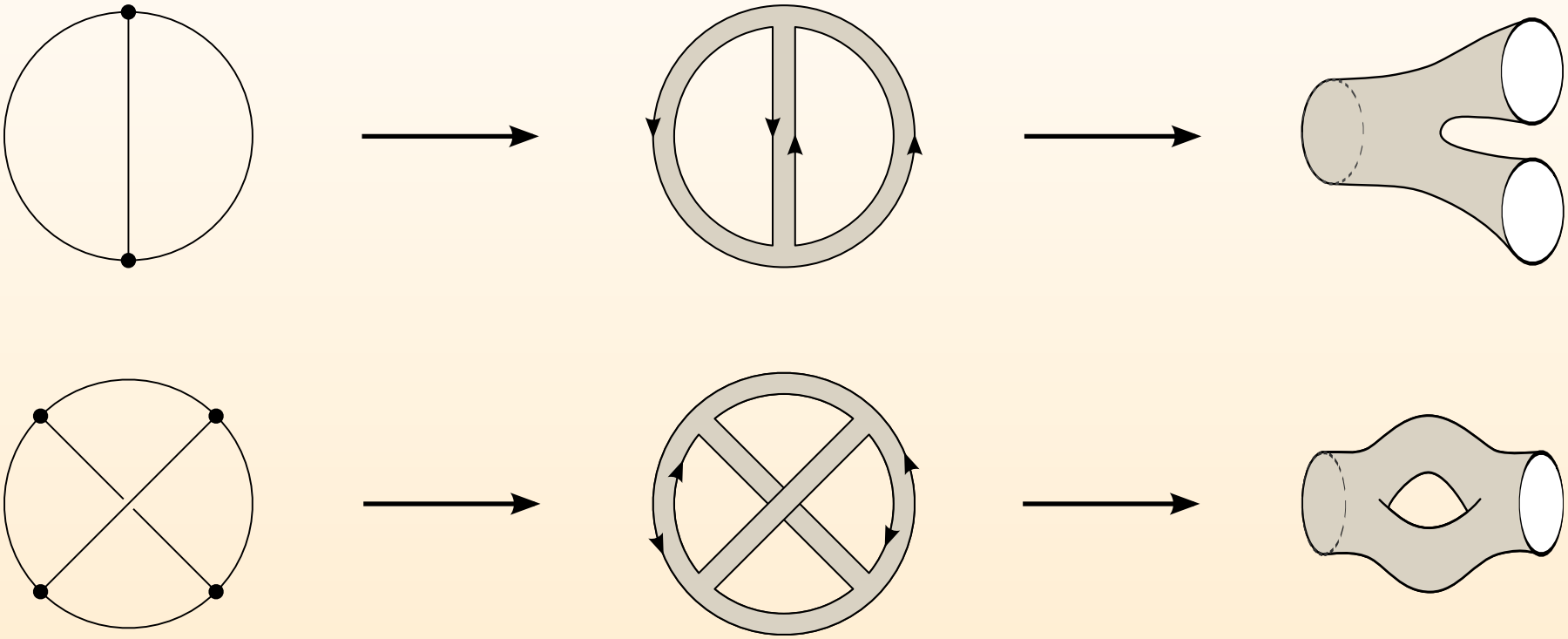
Dualities between gauge theories and gravity



SU(N) gauge theory



SU(N) gauge theory



In the limit $N \to \infty$: Only planar diagrams remain

Applications

QCD in strong coupling regime

Applications

QCD in strong coupling regime

QCD at finite temperature and density

Applications

QCD in strong coupling regime

QCD at finite temperature and density

Predictions for

Heavy ion collisions and quark-gluon plasma

Applications

QCD in strong coupling regime

QCD at finite temperature and density

Predictions for

Heavy ion collisions and quark-gluon plasma

Applications to strongly coupled systems relevant for condensed matter physics

New tools for studying critical systems at RG fixed points

Recent results of our group

1. Gauge/gravity duality at finite temperature and density: Phase transitions

   Ammon, J.E., Lin, Müller, O'Bannon, Shock 1108.1798, JHEP 2011; J.E, Graß, Kerner, Ngo, 1103.4145, JHEP 2011; J.E., V. Filev 1012.0496, JHEP 2011.

2. ρ mesons: Spectral functions; Condensate at finite isospin density

   J.E., Kaminski, Kerner, Rust 0807.2663, JHEP 2008; J.E., Greubel, Kerner, Kaminski, Landsteiner, Peña-Benitez 0911.3544, JHEP 2010.

3. Superfluidity and superconductivity

   Ammon, J.E., Kaminski, Kerner 0810.2316, PLB 2009; 0903.1864, JHEP 2009; Ammon, J.E., Graß, Kerner, O'Bannon 0912.3515, PLB 2010; Ammon, J.E., Kaminski, O'Bannon 1003.1134, JHEP 2010.

4. Temperature-dependent corrections to shear viscosity/entropy ratio

   $$\frac{\eta}{s} = \frac{1}{4\pi}\frac{\hbar}{k_B}$$

   J.E., Kerner, Zeller
   1011.5912, PLB 2011; 1110.0007.

Recent results of our group

5. Non-equilibrium physics and thermalization

   J.E., Lin, Ngo 1101.5505, JHEP 2011; J.E., Hoyos, Lin 1112.1963.

6. Chiral vortex effect

   J.E., Haack, Kaminski, Yarom 0809.2488, JHEP 2008.

7. Strongly interacting matter in external magnetic fields

   Ammon, J.E., Kerner, Strydom 1106.4551, PLB 2011;
   V. Filev, D. Zoakos, 1106.1130, JHEP 2011.

8. Cosmology: Joint project with Stefan Antusch: Student Sebastian Halter

   Antusch, Dutta, J.E., Halter 1102.0093, JHEP 2011.

Chiral vortex effect

J.E., Haack, Kaminski, Yarom 0809.2488, JHEP 2008.

Action of $\mathcal{N} = 2$, $d = 5$ Supergravity:
From compactification of $d = 11$ supergravity on a Calabi-Yau manifold

$$S = -\frac{1}{16\pi G_5}\int\left[\sqrt{-g}\left(R + 12 - \frac{1}{4}F^2\right) - \frac{1}{2\sqrt{3}}A\wedge F\wedge F\right]d^5x$$

Chiral vortex effect

J.E., Haack, Kaminski, Yarom 0809.2488, JHEP 2008.

Action of $\mathcal{N} = 2$, $d = 5$ Supergravity:
From compactification of $d = 11$ supergravity on a Calabi-Yau manifold

$$S = -\frac{1}{16\pi G_5}\int\left[\sqrt{-g}\left(R + 12 - \frac{1}{4}F^2\right) - \frac{1}{2\sqrt{3}}A\wedge F\wedge F\right]d^5x$$

Chern-Simons term leads to axial anomaly for boundary field theory:

$$\partial^\mu J_\mu = \frac{1}{16\pi^2}\varepsilon_{\mu\nu\rho\sigma}F^{\mu\nu}F^{\rho\sigma}$$

Chiral vortex effect

J.E., Haack, Kaminski, Yarom 0809.2488, JHEP 2008.

Action of $\mathcal{N}=2$, $d=5$ Supergravity:
From compactification of $d=11$ supergravity on a Calabi-Yau manifold

$$S=-\frac{1}{16\pi G_5}\int\left[\sqrt{-g}\left(R+12-\frac{1}{4}F^2\right)-\frac{1}{2\sqrt{3}}A\wedge F\wedge F\right]d^5x$$

Chern-Simons term leads to axial anomaly for boundary field theory:

$$\partial^\mu J_\mu=\frac{1}{16\pi^2}\varepsilon_{\mu\nu\rho\sigma}F^{\mu\nu}F^{\rho\sigma}$$

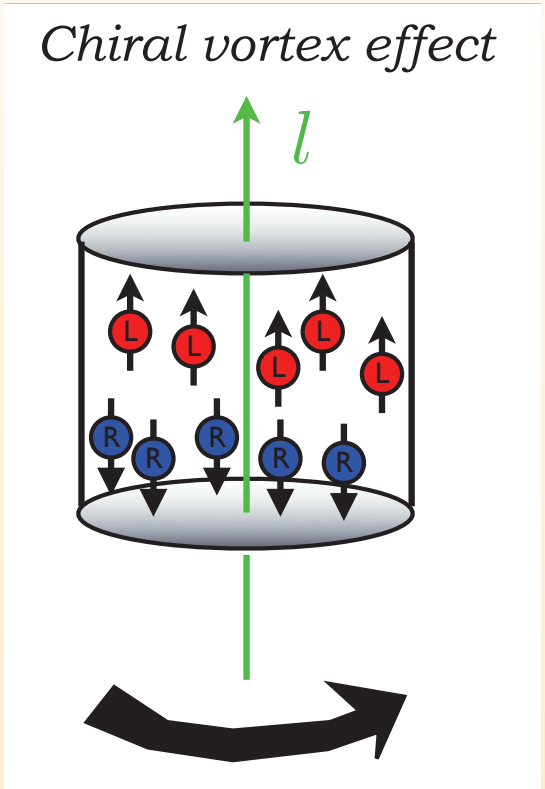
Contribution to relativistic hydrodynamics, proportional to angular momentum:

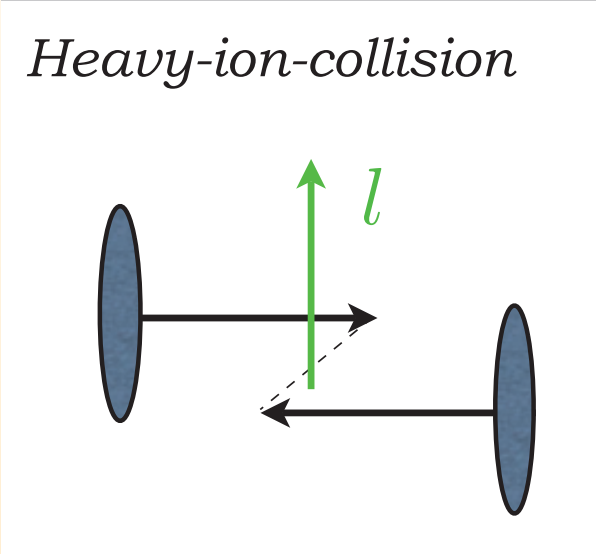
$J_\mu=\rho u_\mu+\xi\omega_\mu$, $\quad\omega_\mu=\frac{1}{2}\epsilon_{\mu\nu\sigma\rho}u^\nu\partial^\sigma u^\rho$, in fluid rest frame $\vec{J}=\frac{1}{2}\xi\nabla\times\vec{v}$

Chiral vortex effect

Prediction for quark-gluon plasma:

Chiral separation: In a volume of rotating quark matter, quarks of opposite helicity move in opposite directions. (Son, Surowka 2009)



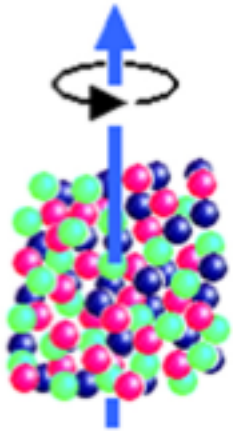


Proposal for experimental confirmation (Oz, Keren-Zur 2010):
Enhanced production of spin-excited hadrons along rotation axis

Chiral vortex effect

Chiral separation: Relativistic quantum effect

Chiral separation: Relativistic quantum effect



$\xi_\omega \neq 0$

$\xi_\omega = 0$

coffee with sugar
(chiral molecules)

External electromagnetic fields

A magnetic field leads to

- ρ meson condensation and superconductivity in the QCD vacuum

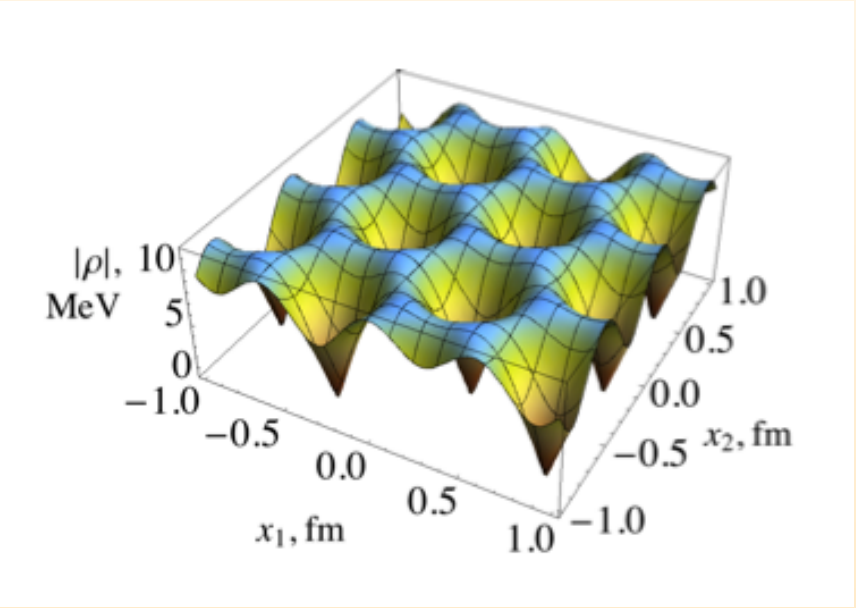
External electromagnetic fields

A magnetic field leads to

ρ meson condensation and superconductivity in the QCD vacuum

Effective field theory:

(Chernodub)

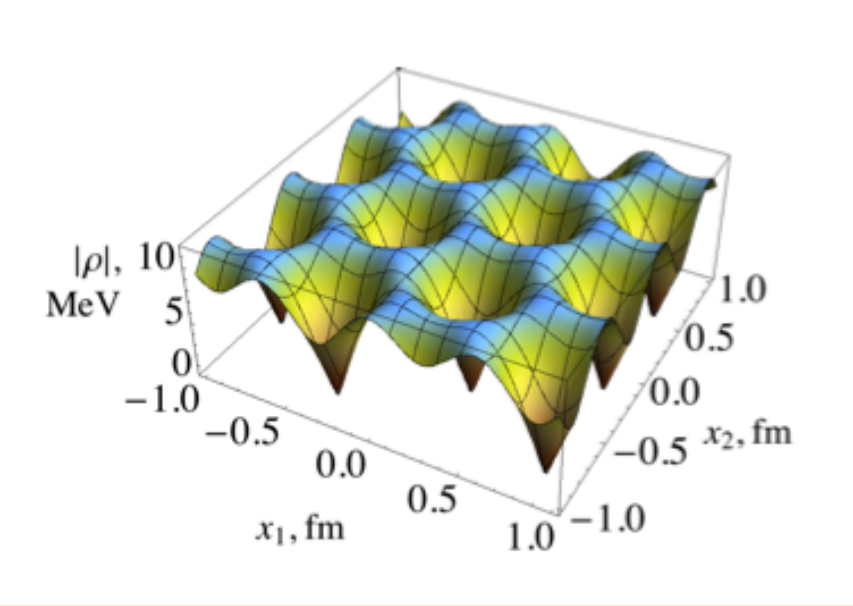


External electromagnetic fields

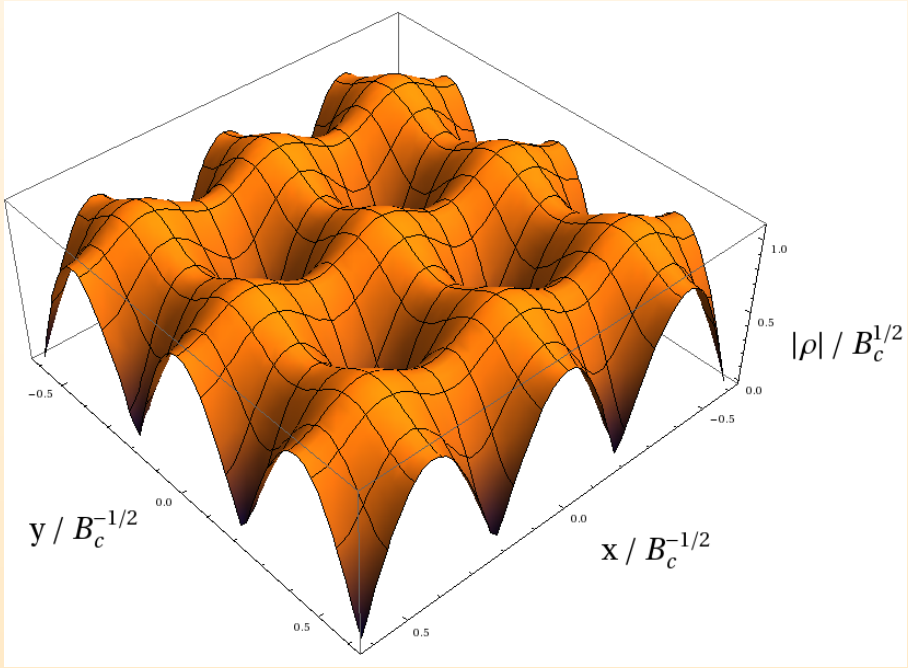
A magnetic field leads to

ρ meson condensation and superconductivity in the QCD vacuum

Effective field theory:
(Chernodub)



Gauge/gravity duality
magnetic field in black hole supergravity background
(J.E., Kerner, Strydom PLB 2011)



Conclusion

- New relations between string theory and strongly coupled gauge theories
- Useful tools for predicting new physical phenomena
- Comparison and combination with other approaches

Our group

J. Erdmenger

Postdocs:

J. Shock (Marie Curie fellow)
V. Filev (Marie Curie/IRCSET fellow)
S. Lin (A. v. Humboldt fellow)

PhD students:

P. Kerner
C. Greubel
S. Halter (Excellence Cluster)
S. Müller
H. Zeller
M. Strydom (Excellence Cluster)
S. Steinfurt

Guest:

F. Peña-Benitez (Spanish Gov.)

Recent Alumni:

A. O'Bannon (now Cambridge, UK)
M. Ammon (now UCLA)
M. Kaminski (now INT, Seattle)
R. Meyer (now Univ. of Crete)
V. Graß (now Patent Attorneys)
H. Ngo (now Patent Attorneys)
F. Rust (now Software Company)