Gauge/Gravity Games

Ringberg2013

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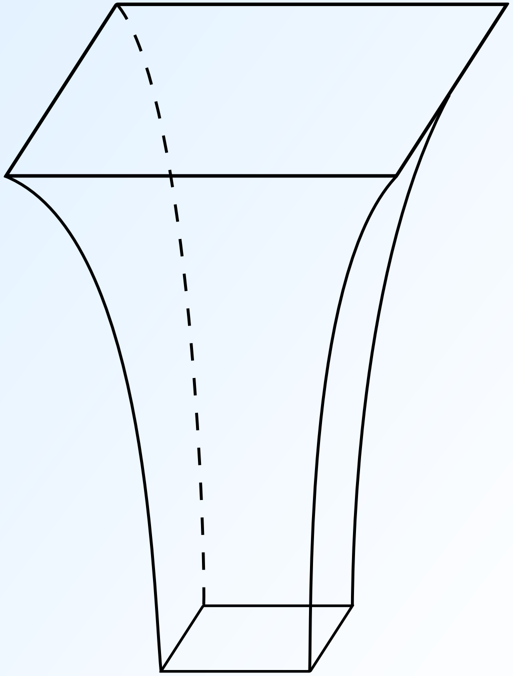
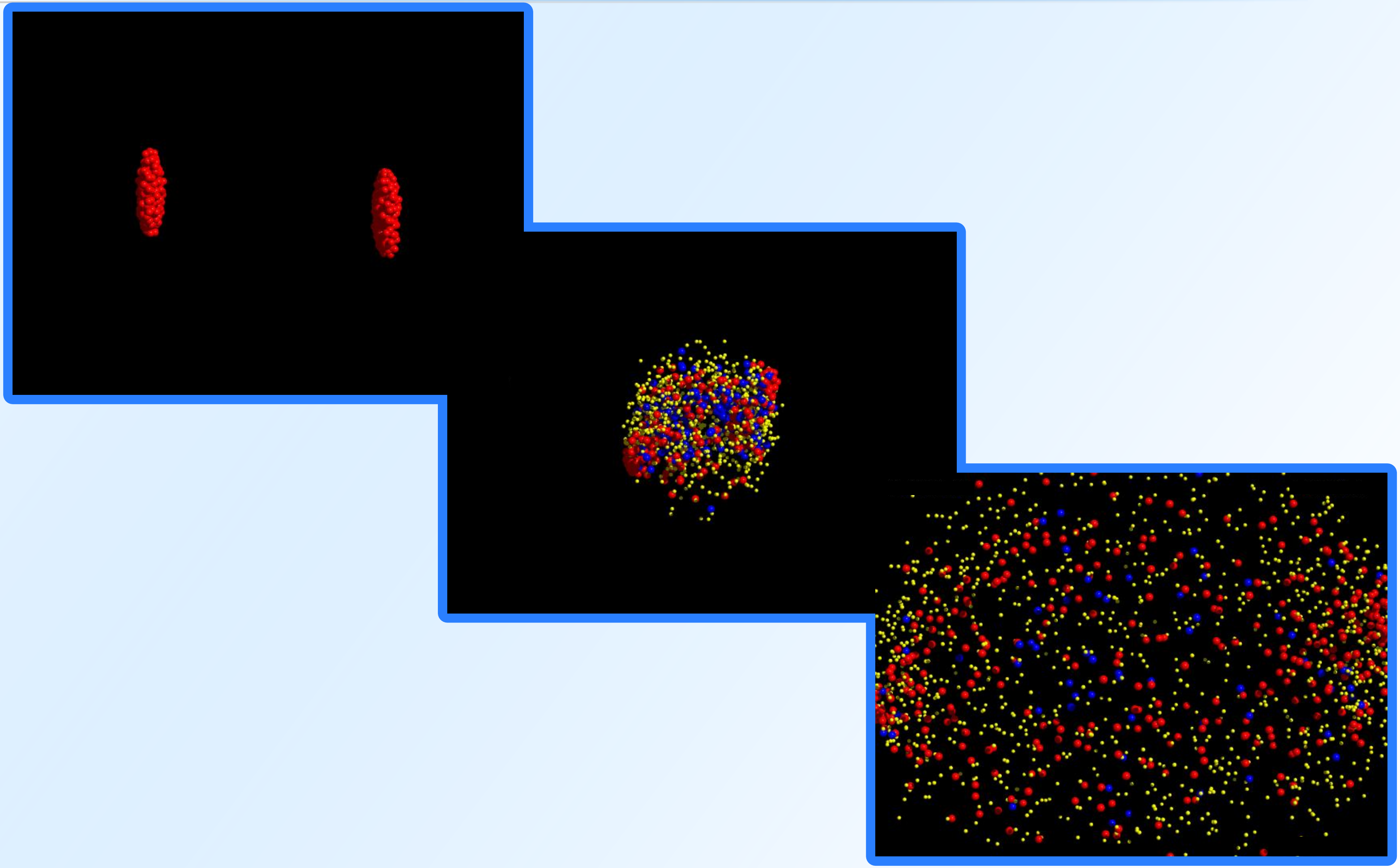
Applications

Gauge/Gravity Duality has many useful applications:

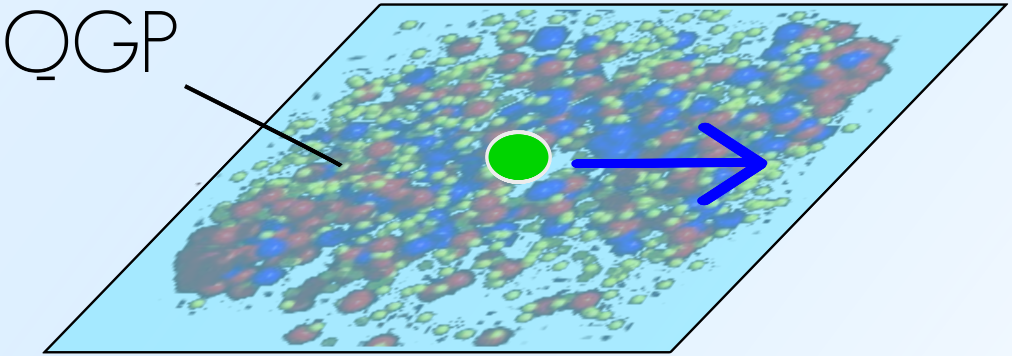
- Hydrodynamics
- Condensed Matter
- (Cosmology)
- Heavy Ion Collisions



Heavy Ion Collisions



Quark moving through QGP



$$\dot{p} = -\mu p + f$$

Friction coefficient

Driving force

How do we calculate this?

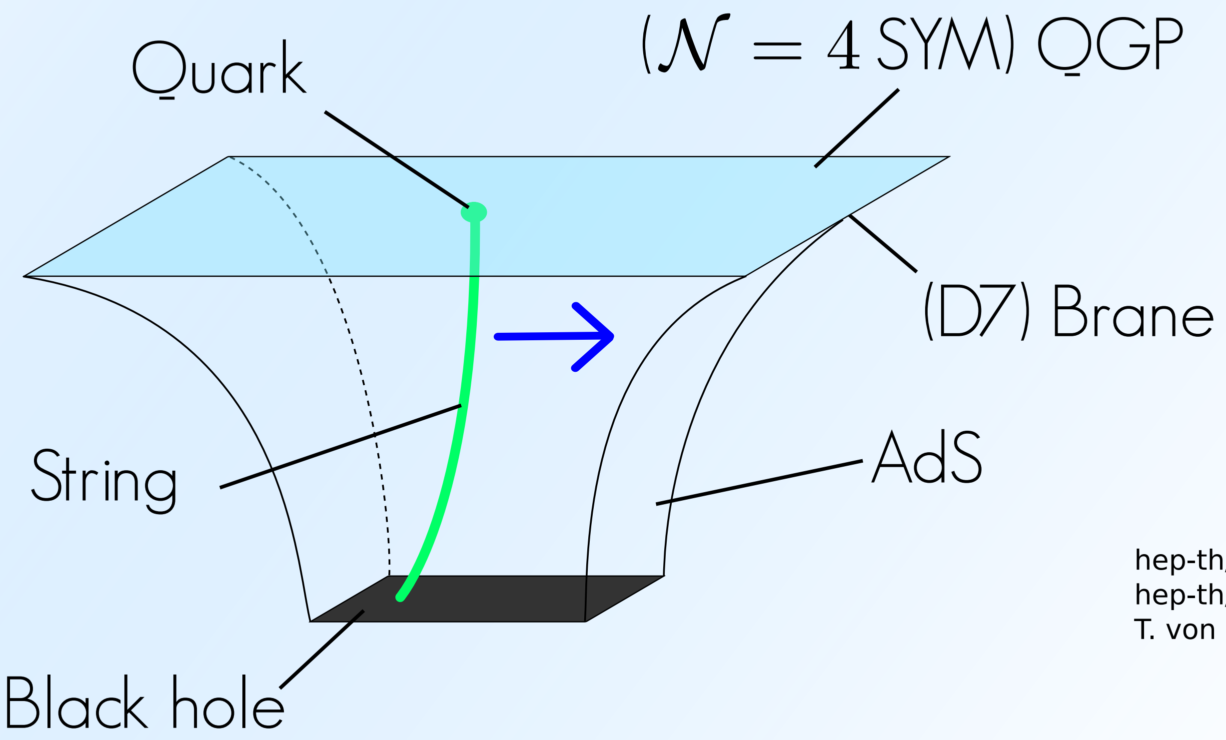
Problem:

- Quark-Gluon Plasma is strongly coupled: $\lambda \gg 1$

Solution:

- Gauge/Gravity Duality!

Holographic moving quark



hep-th/0605158
hep-th/0605182
T. von Glehn (2007)

AdS metric: $ds^2 = \frac{r^2}{L^2}\left(-hdt^2 + d\vec{x}^2\right) + \frac{L^2}{r^2}\frac{dr^2}{h} \quad \left(h(r) = 1 - \frac{r^4}{r_H^4}\right)$

String calculation

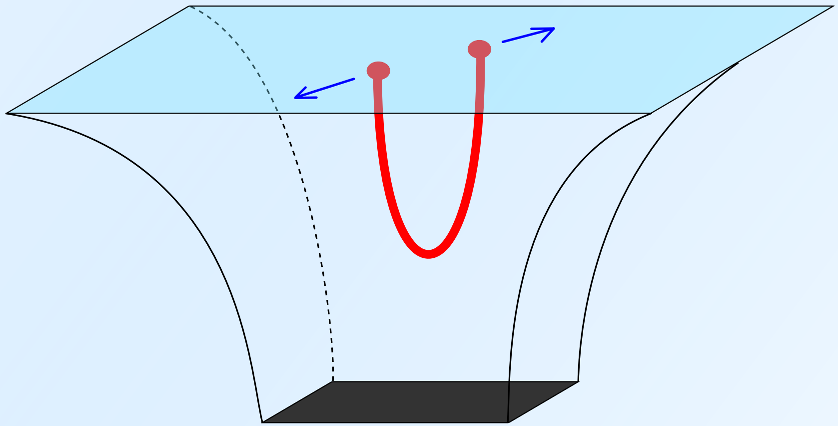
- Start with the string action:

$$S = -T_0 \int d\tau d\sigma \sqrt{-\mathrm{det} g_{ab}}$$
$$= -T_0 \int dt dr \sqrt{1 + \frac{hr^4}{L^4} x'^2 - \frac{1}{h} \dot{x}^2}$$

- Use the ansatz: $x(t, r) = vt + x(r)$

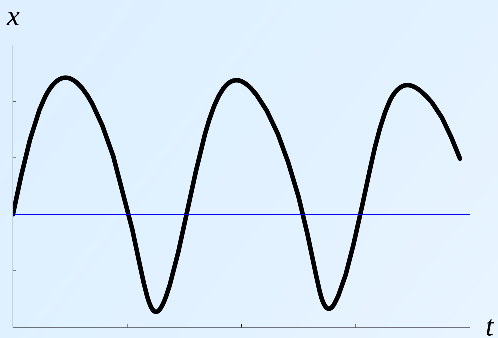
- Result: $\dot{p} = -\mu p$ $\qquad \mu = \frac{\pi}{2} \frac{\sqrt{\lambda} T^2}{M_{\mathrm{kin}}(T)}$

What about mesons?

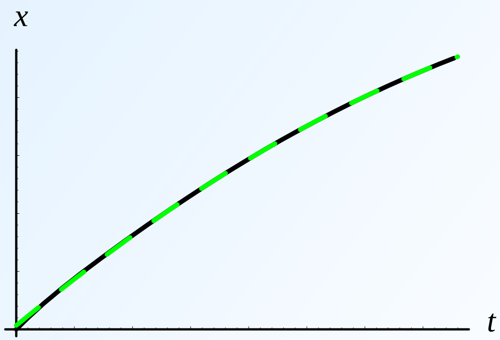


hep-th/0605158

$$E_{\text{init}} \ll 2M_{\text{rest}}$$

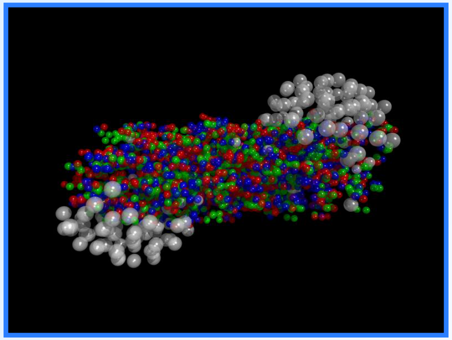


$$E_{\text{init}} \gg 2M_{\text{rest}}$$



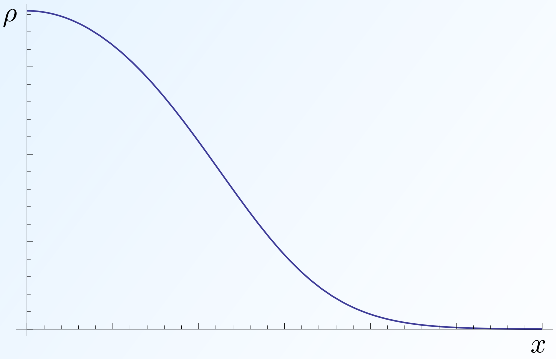
Collision!

- Gauge/Gravity Duality can also model colliding nuclei.

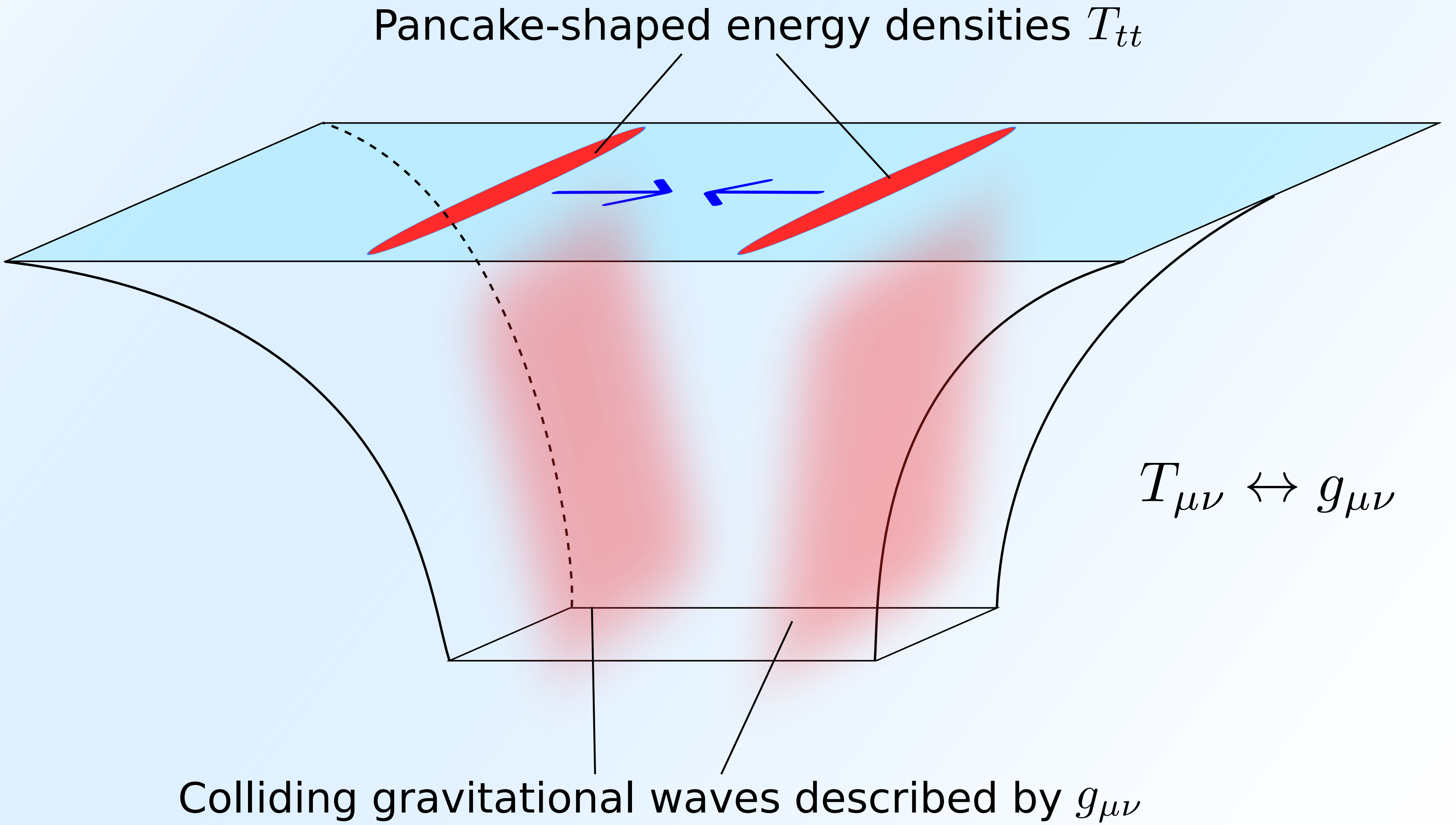


- Describe an ultra-relativistic nucleus travelling in the z direction with the energy density:

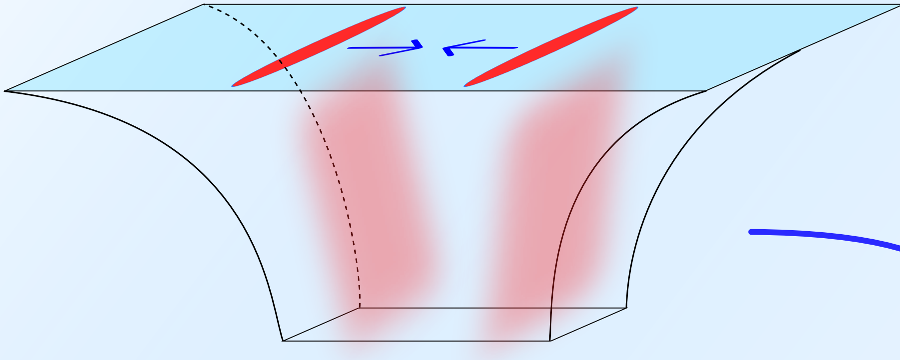
$$E = T_{tt} = \delta(t - z)\rho(x, y)$$



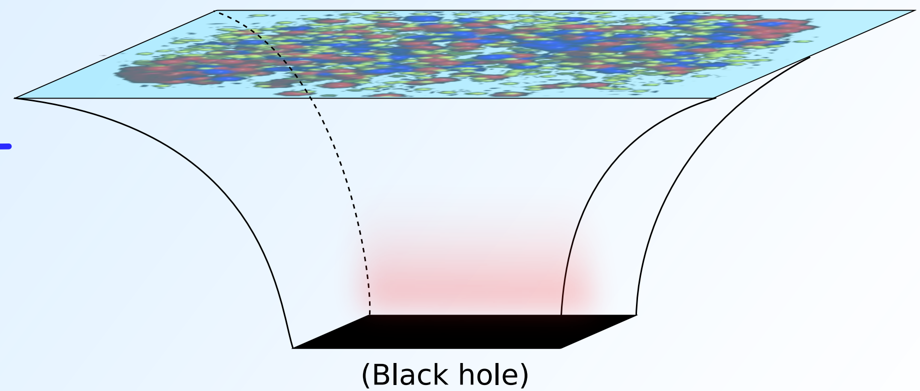
Colliding gravitational waves



After collision, thermalize



The colliding matter
undergoes
hydrodynamization

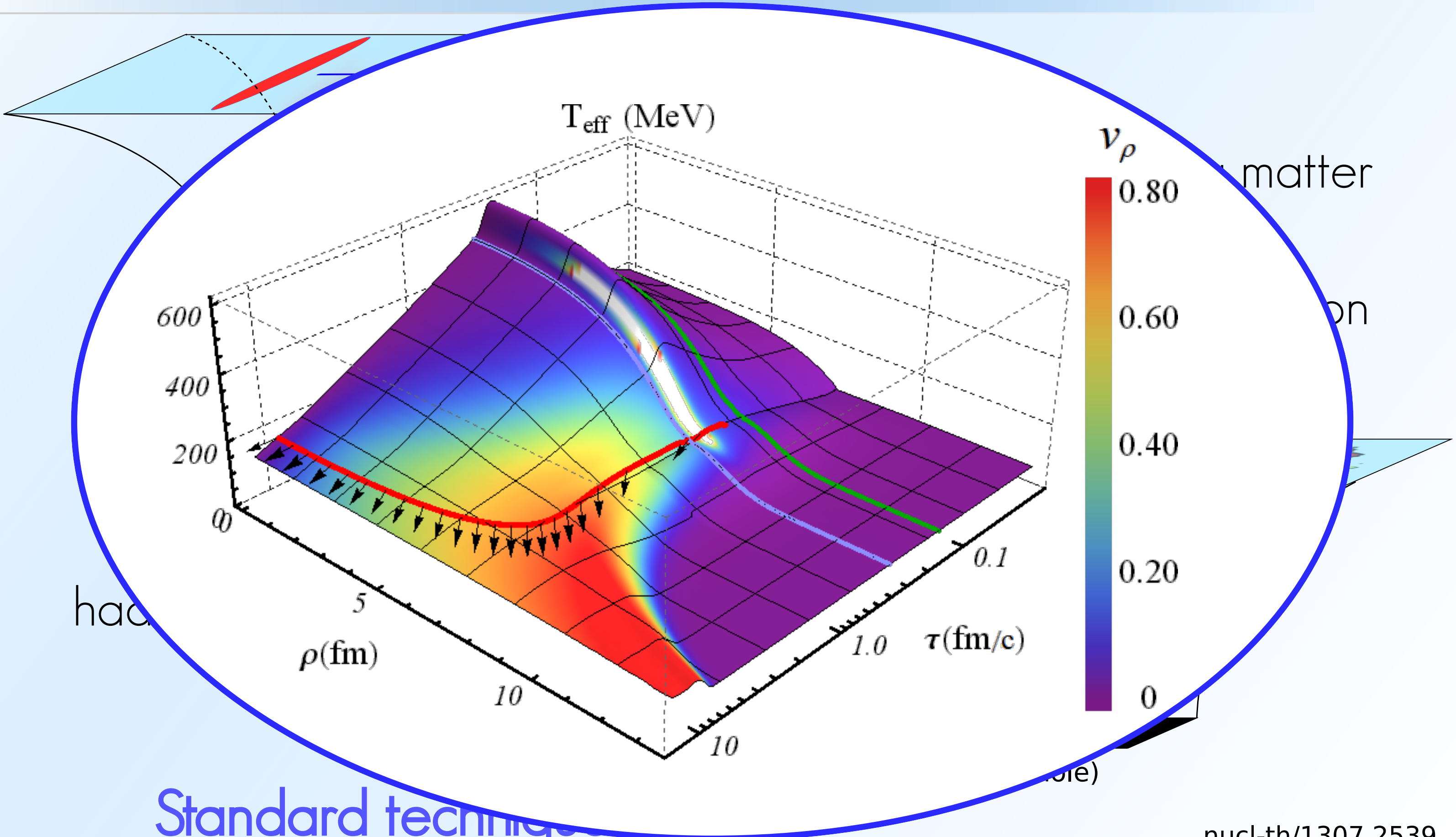


Then
hadronization

Standard techniques

nucl-th/1307.2539

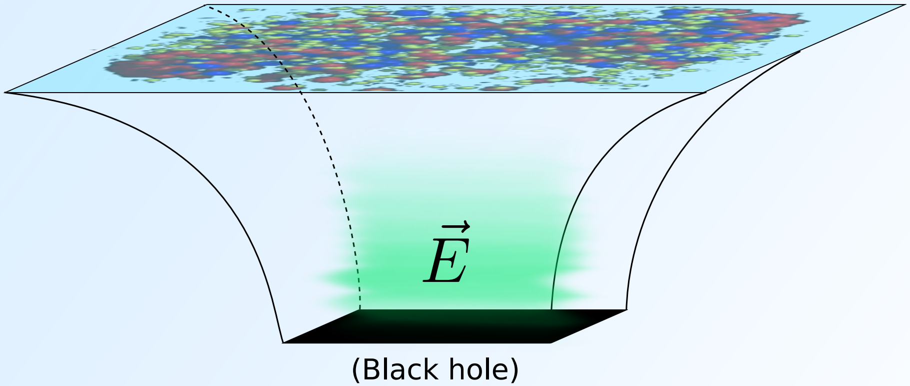
After collision, thermalize



nucl-th/1307.2539

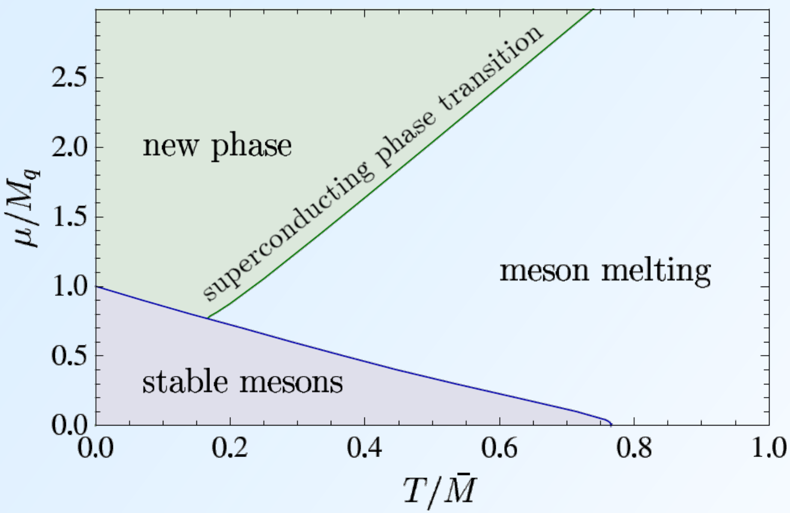
Properties of the QGP: Conductivity

- We can calculate further properties of our ($\mathcal{N}$=4 SYM) QGP, even ones that are hard to test in experiment (after all, we are theorists!)
- We can find how it responds to electric fields - its conductivity.
- To do this, take an electric field, poke it and measure the response: $\sim e^{-i\omega t}\vec{E}(\omega)$



Phase diagram

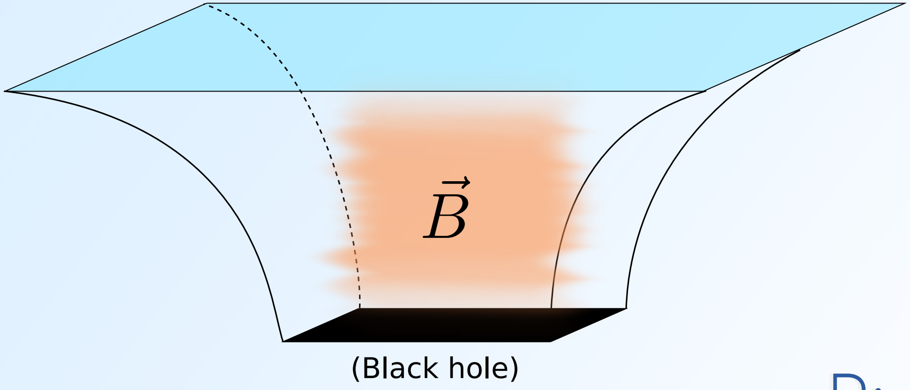
- Finding the conductivity was one of the things that helped in determining the phase diagram below of a ($\mathcal{N}$ = 2 SYM) QGP at finite density and temperature.



Erdmenger, Kaminski, Kerner, Rust: arXiv:0807.2663

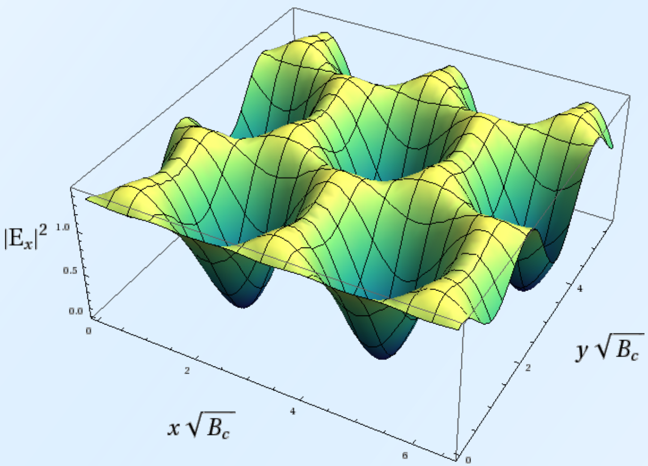
More exotic games

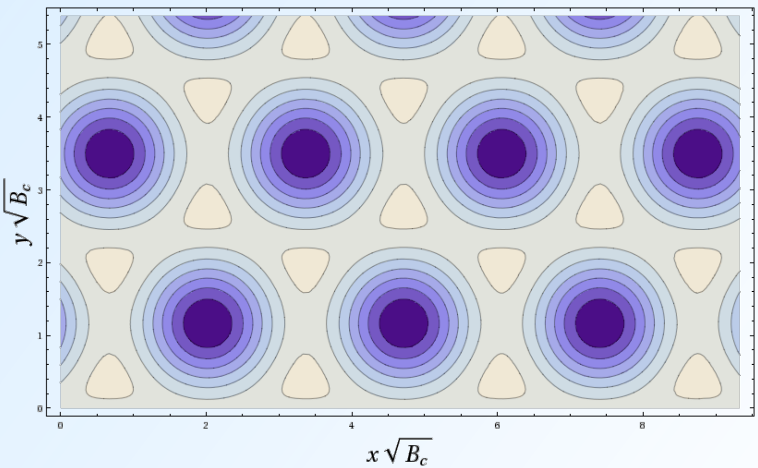
- We saw that a strong chemical potential can turn our system into a superconductor. What does a strong magnetic field do?
- It turns out that a magnetic field can do strange things to the vacuum of the theory. When strong enough, it causes ρ-mesons to emerge!



A surprising ground state

- And the ρ-mesons emerge in a surprising pattern. The ground state is a triangular Abrikosov lattice!



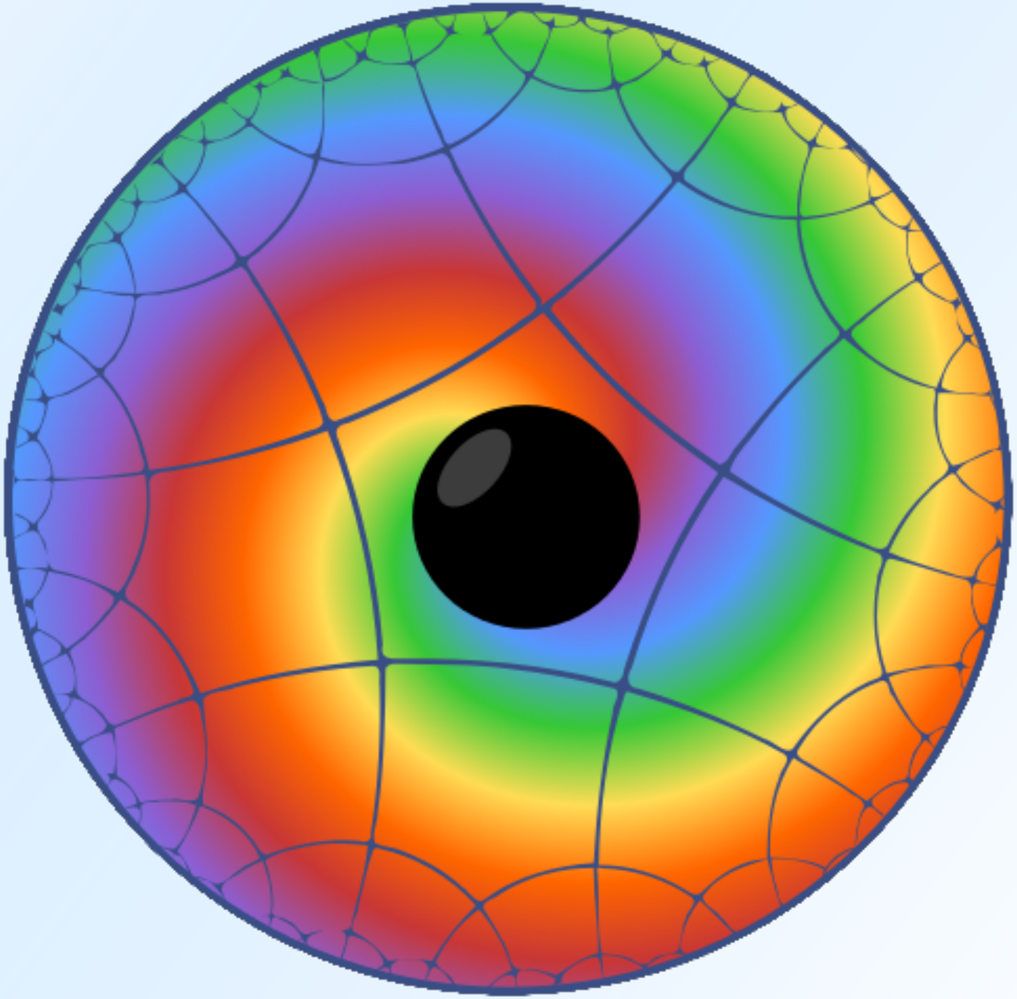


- If this applies to QCD as well, there is a small chance that we may see it at the LHC in highly off-center collisions where very strong magnetic fields are present.

Recap

With Gauge/Gravity Duality, we saw that we can...

- ...make a quark drag through the ($\mathcal{N}$= 4 SYM) QGP.
- ...examine the behaviour of a meson in the ($\mathcal{N}$= 4 SYM) QGP.
- ...make two nuclei collide using a model of colliding gravitational waves.
- ...calculate the conductivity and phase diagram.
- ...explore more exotic effects with magnetic fields.
- ...and much more!



Thank you!