Drag Force in Quark-Gluon Plasma

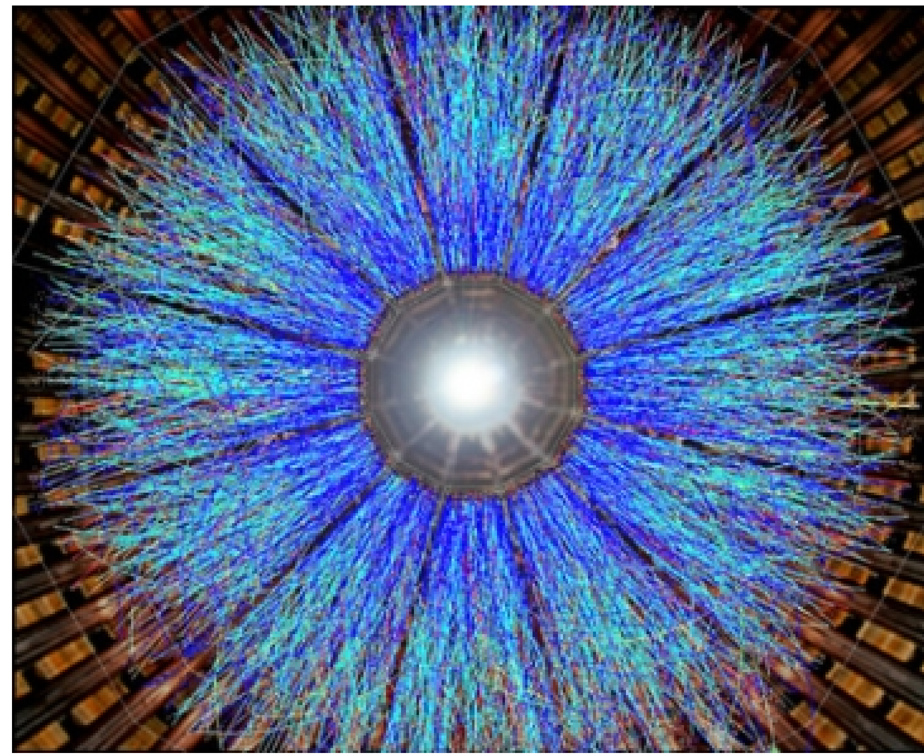
By
Suphakorn Chunlen

Durham University

21st February 2011

What is the quark-gluon plasma (QGP)?

- A plasma state of quarks and gluons.
- A high temperature phase of quantum chromodynamics (QCD).

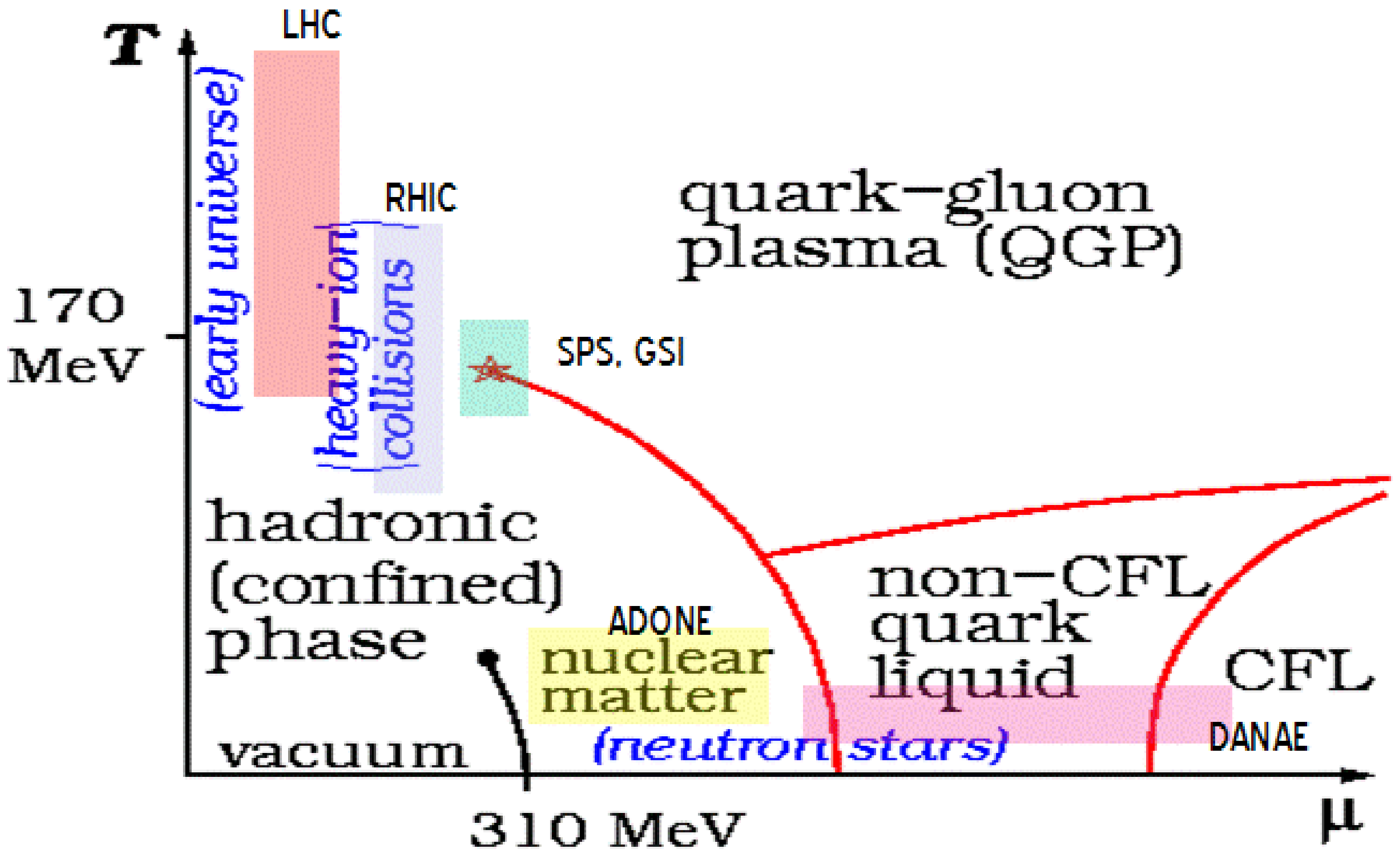


http://web.mit.edu/newsoffice/2010/exp-quark-gluon-0609.html

Why do we study QGP?

- It is a clue to understand the early universe after the inflation.
- Quarks and gluons are deconfined in this state.
- It could lead to know more features of the QCD.

The Phase Diagram of QCD



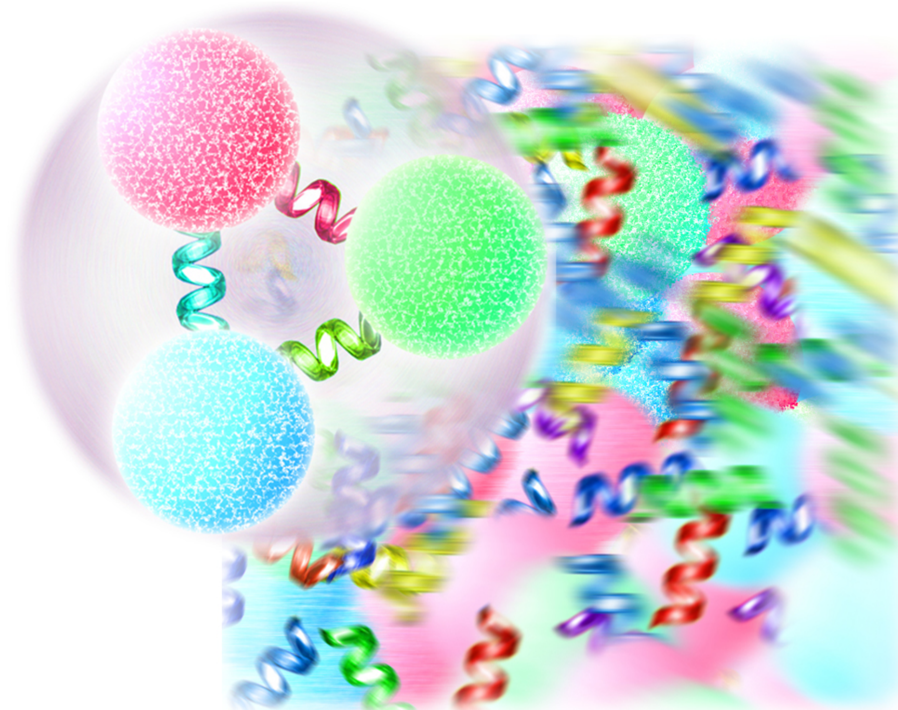
http://www.lnf.infn.it/esperimenti/alice/QGP/qgp.php

Interesting Features of QGP

- Near Zero Viscosity
- Elliptic Flow
- Jet Quenching

Near Zero Viscosity

- The QGP from heavy-ion collisions has a perfect fluid behaviour with a very low viscosity (Zajc, 2008).
- The strong coupled plasma constituents is the cause of this perfect fluidity (Wang, 2010).



http://newscenter.lbl.gov/feature-stories/2010/01/14/jet/

S-Wave Interacting Fermionic Systems (Mekjian, 2010)	$$\frac{\eta}{s} \sim 10.14 \left(\frac{1}{4\pi}\right)$$
S-Wave Interacting Bosonic Systems (Mekjian, 2010)	$$\frac{\eta}{s} \sim 7.67 \left(\frac{1}{4\pi}\right)$$
Hard Sphere Gases (Mekjian, 2010)	$$\left.\frac{\eta}{s}\right\|_{min} \sim 2 \left(\frac{1}{4\pi}\right)$$
QGP measured at RHIC (Lacey et al., 2007)	$$\frac{\eta}{s} \sim 1.1 \left(\frac{1}{4\pi}\right)$$

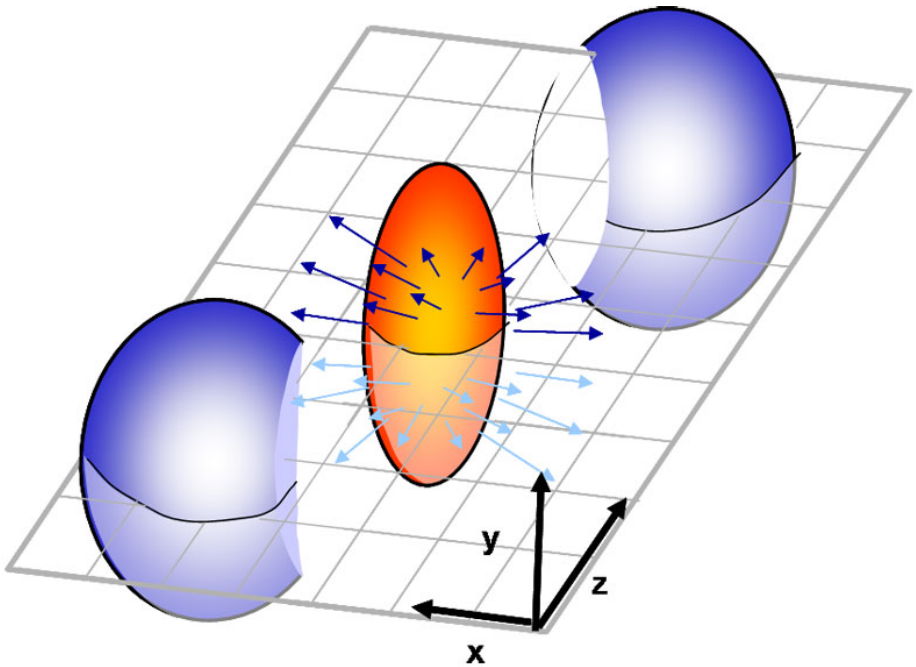
Fluid	P (Pa)	T (K)	η (Pa s)	η/n ($\hbar$)	η/s ($\hbar/k_B$)
H_2O	0.1×10^6	370	2.9×10^{-4}	85	8.2
^4He	0.1×10^6	2.0	1.2×10^{-6}	0.5	1.9
H_2O	22.6×10^6	650	6.0×10^{-5}	32	2.0
^4He	0.22×10^6	5.1	1.7×10^{-6}	1.7	0.7
^6Li ($a = \infty$)	12×10^{-9}	23×10^{-6}	$\leqslant 1.7 \times 10^{-15}$	$\leqslant 1$	$\leqslant 0.5$
QGP	88×10^{33}	2×10^{12}	$\leqslant 5 \times 10^{11}$		$\leqslant 0.4$

Table1: Some Properties of Fluids (Schäfer and Teaney, 2009)

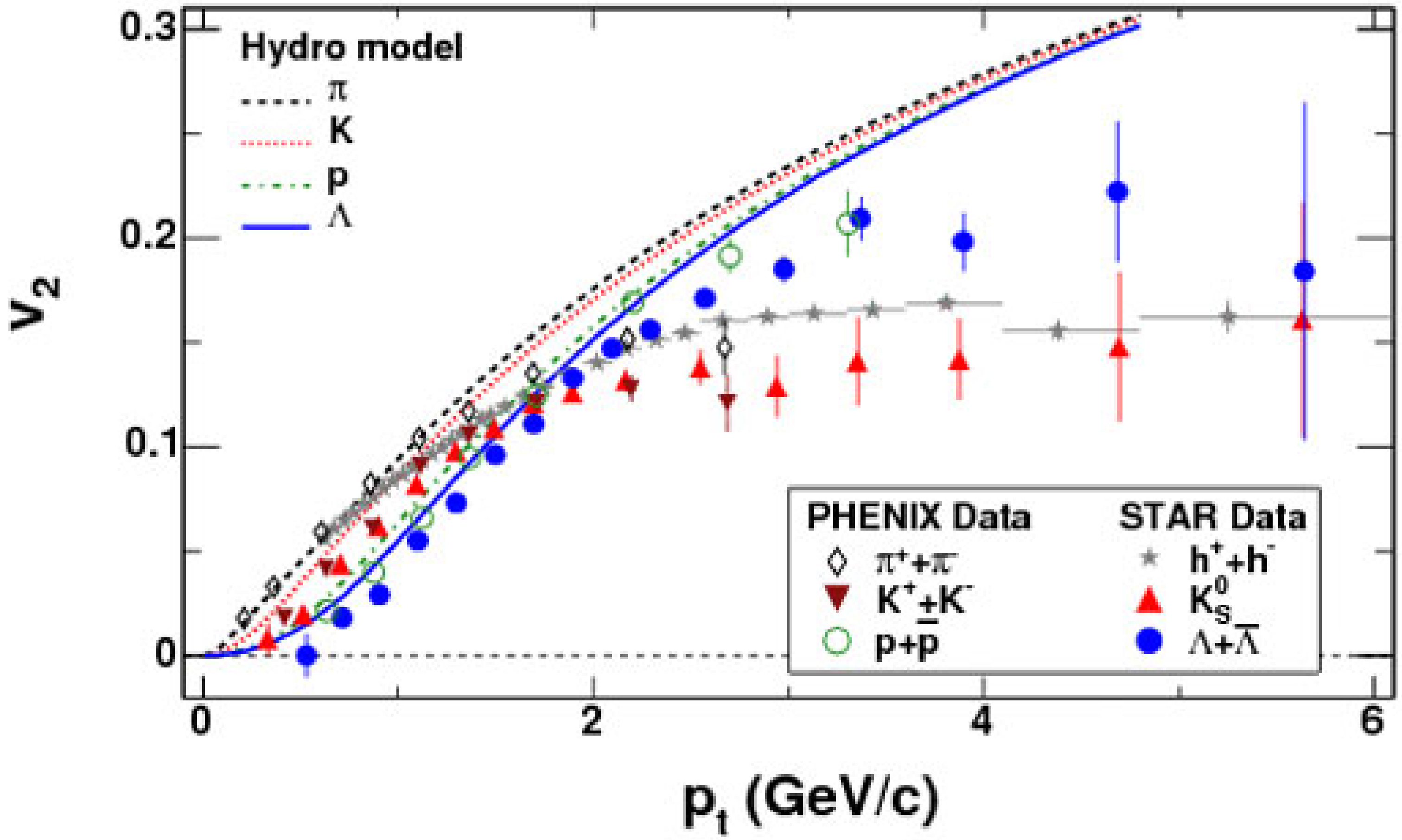
Elliptic Flow

- The QGP produced in the colliders has anisotropic momentum distribution (Adam et al., 2005).
- The elliptic flow parameter (v_2) is given by the fourier expansion of the azimuthal particle distribution:

$$\frac{dN}{d\varphi} \sim 1 + 2v_2 \cos 2\varphi + \cdots$$



http://www.interactions.org/sgtw/2006/1025/



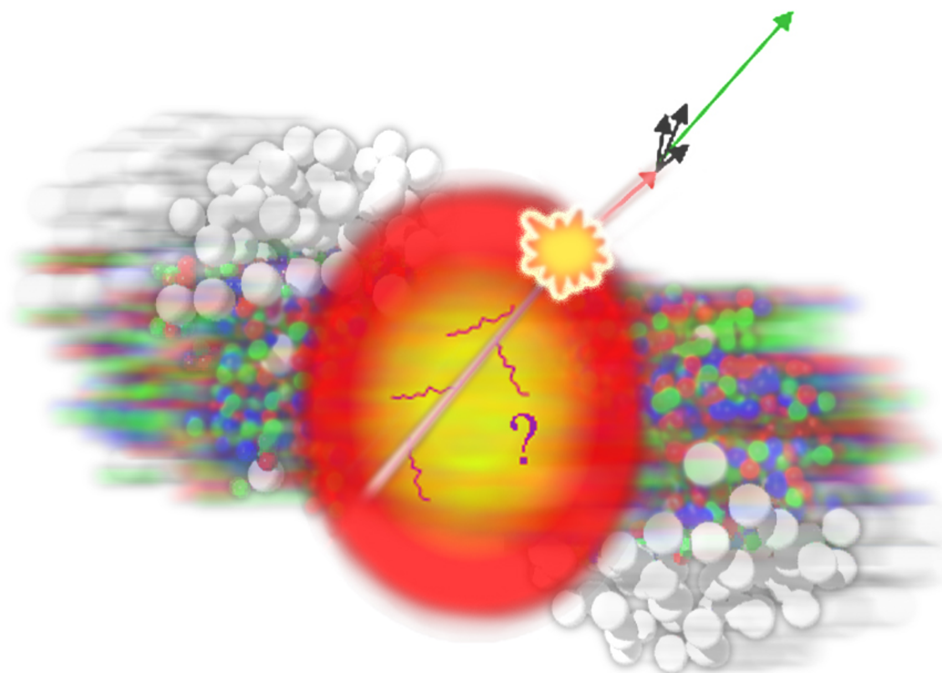
The elliptic flow parameter (v_2) versus the transverse momentum (p_t) from different particles measured at RHIC

http://www.interactions.org/sgtw/2006/1025/star_grid_more.html

Jet Quenching

The production of quark-antiquark pairs near the boundary of QGP does not lead to two back-to-back jets.

Rather, it gives rise to only one observed jet.

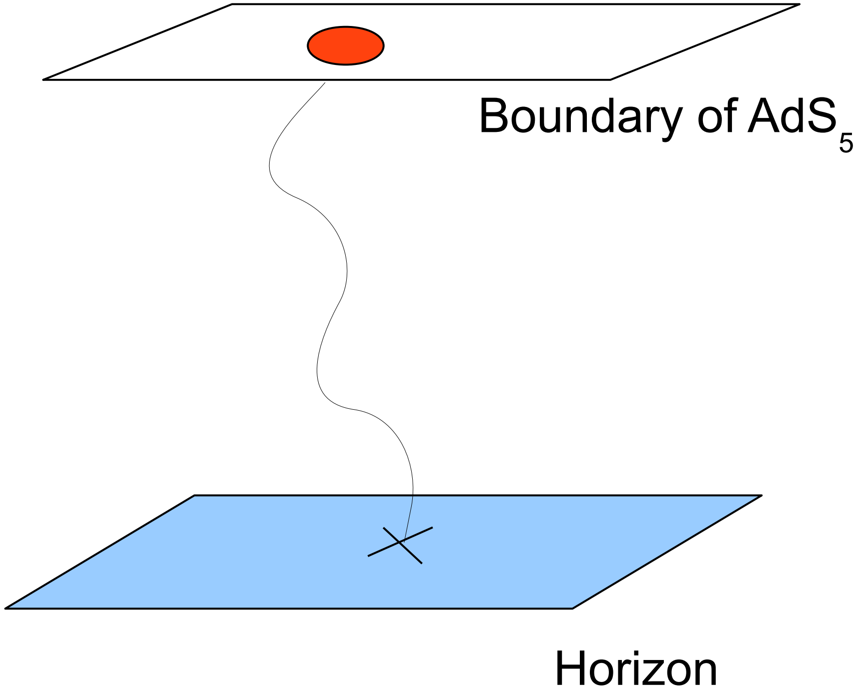


http://newscenter.lbl.gov/feature-stories/2008/02/15/catching-the-jets-2/

Drag Force in the Jet Quenching

- In AdS/CFT correspondence
  - A classical picture of a string can describe the dynamics of strong coupling gauges (Gubser, 2006).
  - The ultra relativistic quark was modelled with an open string ending on the boundary of AdS space, hanging deep in the interior of an AdS black hole (Gubser, 2006; Yaffe et al., 2006).

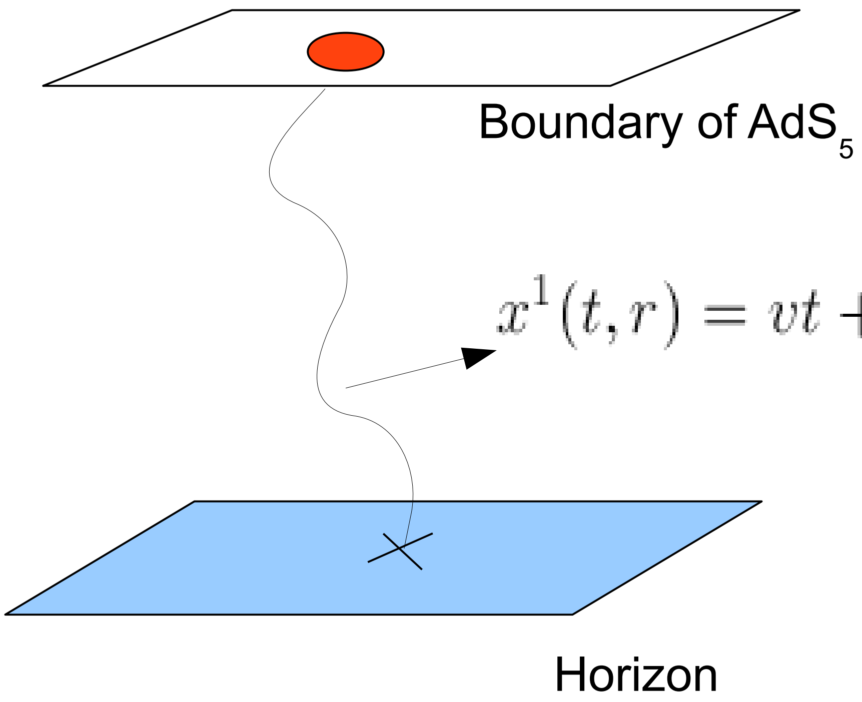
The Drag Force (Continued)



- For infinite size (Gubser, 2006)
  - They use Poincaré patch of AdS_5-Schwarzschild.
  - The quark moves with a constant velocity along a timelike path.
  - The string gives a drag force to the quark.

The Drag Force (Continued)

$$ds^2 = \frac{r^2}{L^2}\left(-\left(1-\frac{r_H^4}{r^4}\right)dt^2 + d\vec{x}^2\right) + \frac{L^2}{r^2}\frac{dr^2}{1-\frac{r_H^4}{r^4}}$$



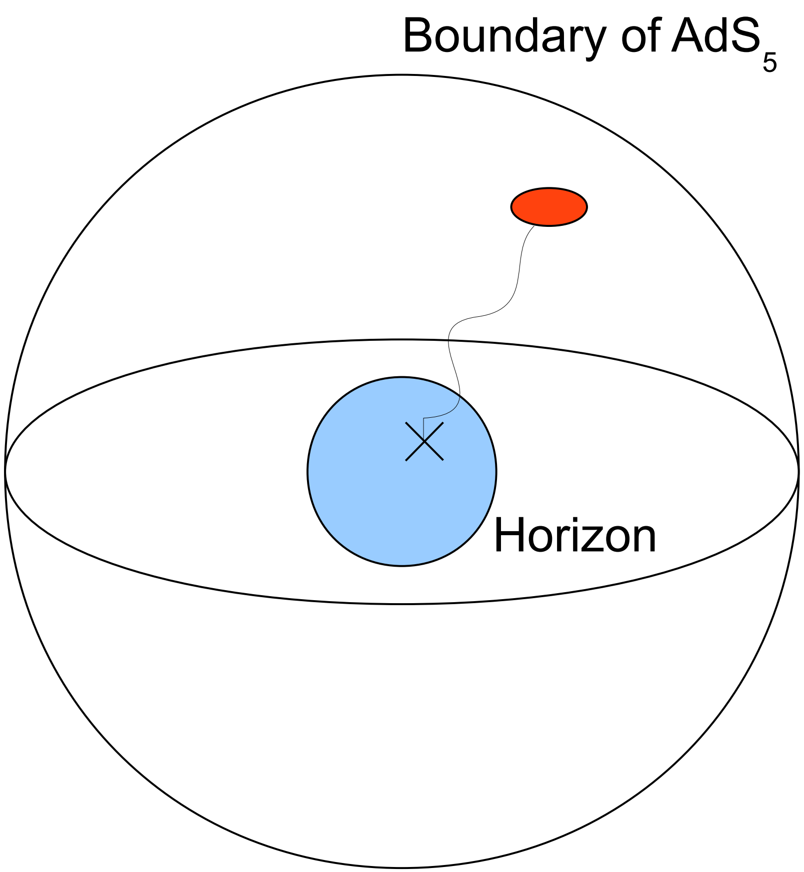
$$x^1(t,r) = vt + \xi(r)$$

$$\xi'(r) \propto \frac{\pi_\xi}{r^4 - r_H^4}\sqrt{\frac{1-\frac{r_H^4}{r^4}-v^2}{1-\frac{r_H^4}{r^4}-\frac{\pi_\xi^2 L^4}{r^4}}}$$

$$\pi_\xi = \frac{v}{\sqrt{1-v^2}}\frac{r_H^2}{L^2}$$

$$\frac{dp_1}{dt} = -\frac{1}{2\pi\alpha'}\pi_\xi$$

The Drag Force (Continued)

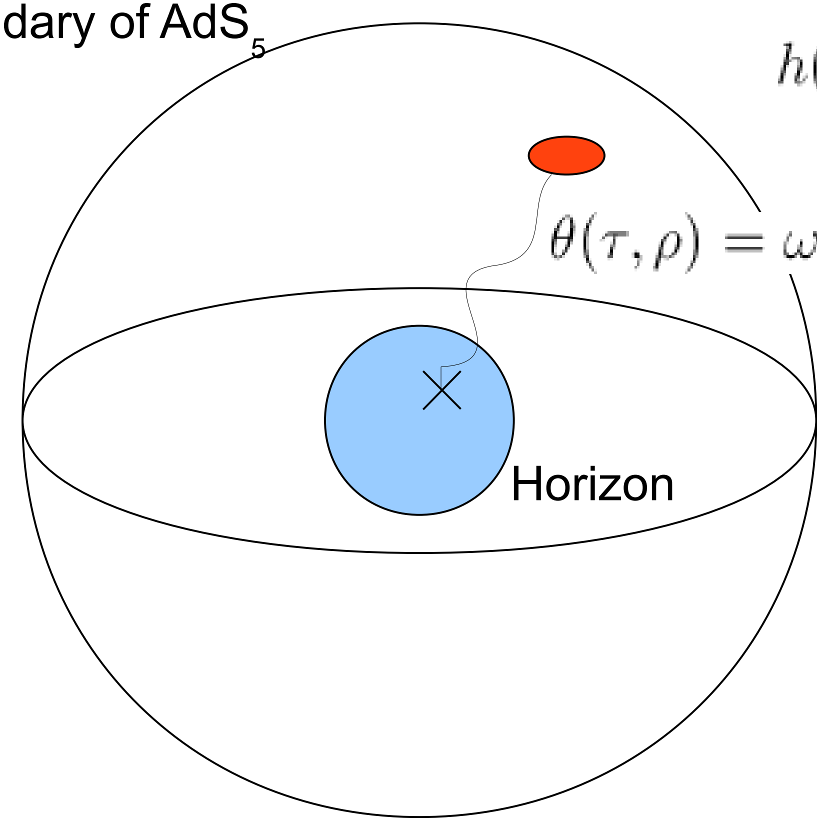


- For finite size (in the work with Kasper and Marija)
  - We use AdS_5-Schwarzschild in global coordinates.
  - The quark moves with a constant velocity along a timelike path.
  - The string gives a drag force to the quark.

The Drag Force (Continued)

$$ds^2 = -h(\rho)d\tau^2 + \frac{d\rho^2}{h(\rho)} + \rho^2\left(d\theta^2 + \cos^2\theta\left(d\phi^2 + \cos^2\phi\, d\chi^2\right)\right)$$

$$h(\rho) = 1 - \frac{\rho_0^2}{\rho^2} + \frac{\rho^2}{L^2} \qquad \rho_0^2 = \frac{8GM}{3\pi}$$



$$\theta(\tau,\rho) = \omega\tau + f(\rho)$$

$$f'(\rho) = \frac{\pi_f}{\rho h(\rho)}\sqrt{\frac{\rho^2\omega^2 - h}{\pi_f^2 - \rho^2 h}}$$

$$\pi_f = \omega L^2 \frac{\sqrt{1 + 4\frac{\rho_0^2}{L^2}(1-\omega^2L^2)} - 1}{2(1-\omega^2L^2)}$$

$$\frac{dp_\theta}{d\tau} = -\frac{1}{2\pi\alpha'}\pi_f$$

The Drag Force (Continued)

To compare each other,

$$x^1 \leftrightarrow L\theta \qquad v \leftrightarrow \omega L \qquad \pi_\xi \leftrightarrow \frac{\pi_f}{L}$$

In the limit of large black hole

$$\rho_H \gg L$$

Therefore,

$$\frac{1}{L}\frac{dp_\theta}{d\tau} = \frac{dp_1}{dt}\left[1 - \frac{1+\sqrt{1-v^2}}{2\pi^2\sqrt{1-v^2}}\left(\frac{1}{TL}\right)^2 + \frac{1}{8\pi^4}\frac{3v^2-2}{(1-v^2)}\left(\frac{1}{TL}\right)^4 + O\left(\left(\frac{1}{TL}\right)^8\right)\right]$$

Conclusion

- Three features of QGP mentioned in this presentation have some dynamics to be explained.
- There is an unusual finite-size effect for the jet quenching; the drag force decreases due to the finite size.
- It is interesting to check whether this effect occurs in other dual plasma systems.