[Sakai,Sugimoto,KH (0806.3122)]

	Superstring	Experiment	Lattice
$\langle r^2 \rangle_{E,\mathrm{p}}$	$(0.74\ \mathrm{fm})^2$	$(0.875\ \mathrm{fm})^2$	
$\langle r^2 \rangle_{E,\mathrm{n}}$	0	$-0.116\ \mathrm{fm}^2$	
$\langle r^2 \rangle_A^{1/2}$	0.54 fm	0.674 fm	
μ_p	2.2	2.79	
μ_n	– 1.3	–1.91	
g_A	0.73	1.27	
$g_{\pi NN}$	7.5	13.2	
$g_{\rho NN}$	5.8	4.2 – 6.5	
$\mu_{\Delta^{++}}$	4.4	3.7 – 7.5	4.99
$\mu_{\Delta^{+}}$	2.3	–	2.49
$\mu_{\Delta^{0}}$	0.20	–	0.06
$\mu_{\Delta^{-}}$	–1.9	–	–2.45

RIKEN/RBRC workshop "Future directions in high energy QCD"
@ RIKEN, 22 Oct 2011

A Holographic Thermalization

Koji Hashimoto (RIKEN)

w/ N.Iizuka (CERN), T.Oka (Tokyo)

arXiv:1012.4463 (PRD84,066005(2011))

What can the dictionary deal with?

General : Chiral condensate, Quark antiquark forces,
Wilson / Polyakov loop, Phase diagram, Gluon scattering, …

Mesons : Spectra, interactions, Skyrme term,
Vector meson dominance, Hidden local symmetry,
Chiral perturbations, Quark mass effects, …

Baryons : Spectra, interactions, nuclear forces,
3-body nuclear forces, Giant resonances, …

Exotics : Glueball spectra, Glueball decays, …

Hot QCD : Deconfinement transition, Chiral restoration,
Quark gluon plasma, Viscosity, Jet quenching parameters,
Quark drag force, Meson melting, Thermalization, …

Dense QCD : Chiral restoration, Color superconductor,
Meson mass in nuclear matter, …

Superstrings useful for…

Superstring is …

Bad at :
- Precision evaluation (… Large Nc)
- Asymptotic freedom (… strong coupling)

Good at :
- Analytic calculation
- Finite density
- Time dependence

Superstring, better applied to :

Robust features of strongly coupled QCD,
time-dependent / independent

This talk : Thermalization at Heavy ion collisions

(1) Problem

Derivation of the Rapid thermalization at Heavy ion collision?

(2) Cause

QCD : strongly coupled, & confined → deconfined

Thermalization : non-equilibrium & time-dependent process

(3) Our solution

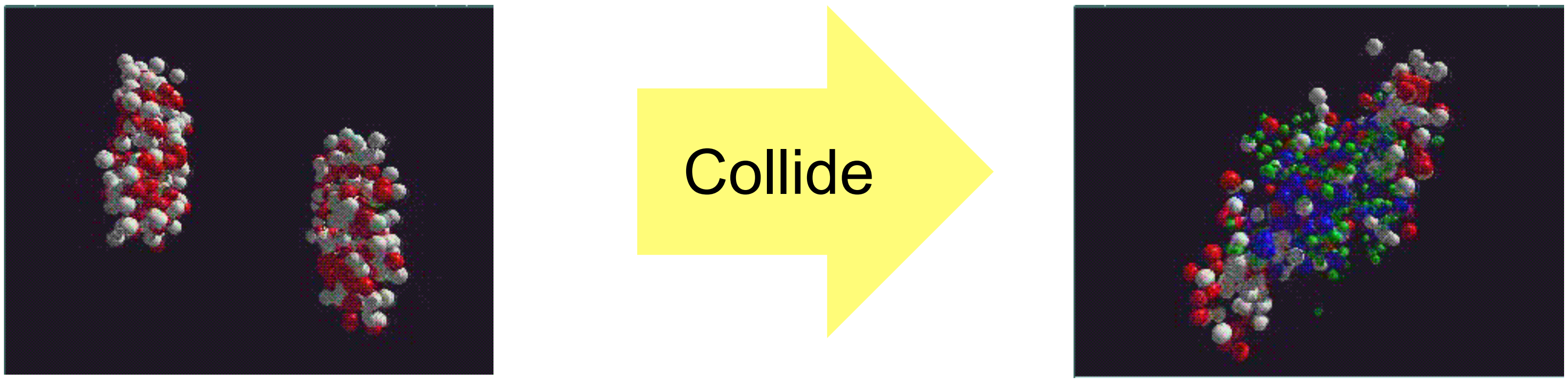
AdS/CFT can treat all the causes.

+ Initial condition mimicking the collision

→ A Rapid Thermalization

(1) Problem

Derivation of the Rapid thermalization at Heavy ion collision?



Hydrodynamic simulation suggests a rapid thermalization :

$$t_{\rm th} \ < \ 2 \ \ [{\rm fm/c}]$$

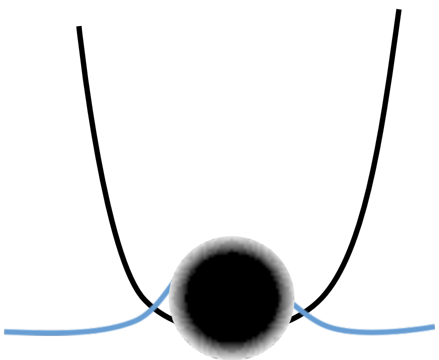
[Kolb, Huovinen, Heinz, Heiselberg (‘00)],
[Hirano (‘01)], [Huovinen (‘01)],
[Teaney, Lauret, Shuryak (‘01)], [Heinz, Kolb (‘02)], …

(2)

Cause

QCD : strongly coupled, & confined → deconfined

Thermalization : non-equilibrium & time-dependent process



AdS / CFT

Formation of Black Hole Horizon = Thermalization + deconfinement

(3)

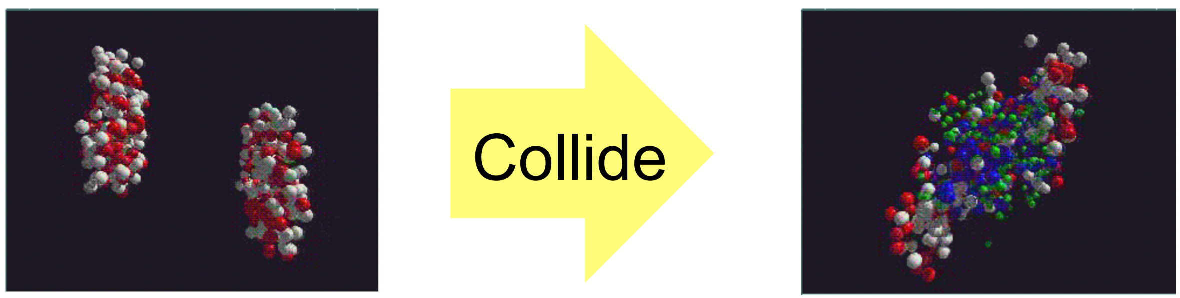
Our solution

AdS/CFT can treat all the causes.

+ Initial condition mimicking the collision

→ Rapid thermalization

Initial condition ?



- Bjorken expansion [Janik, Peschanski ('06)], [Chesler, Yaffe ('08)], [Bhattacharyya, Minwalla ('09)], … [Muller, et.al ('10)]

- Sudden change of Baryon number density [Ours]

Both should give the rapid thermalization

Plan of the remaining of this talk

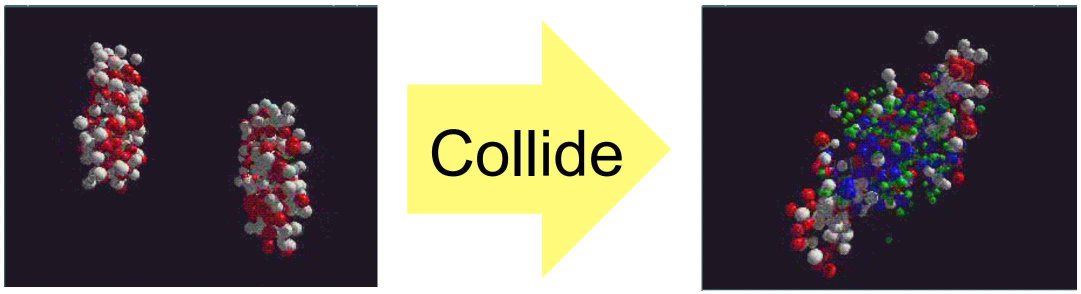
Our idea: Collision = a time dep. baryon density

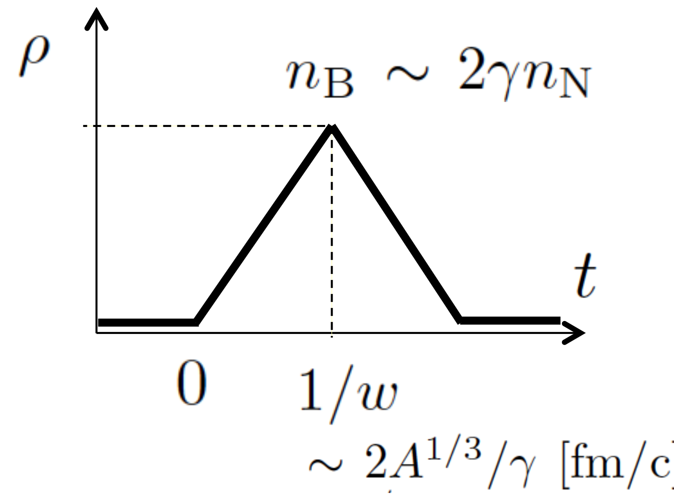
Time dependence, solved

Nonlinearlity → Effective horizon

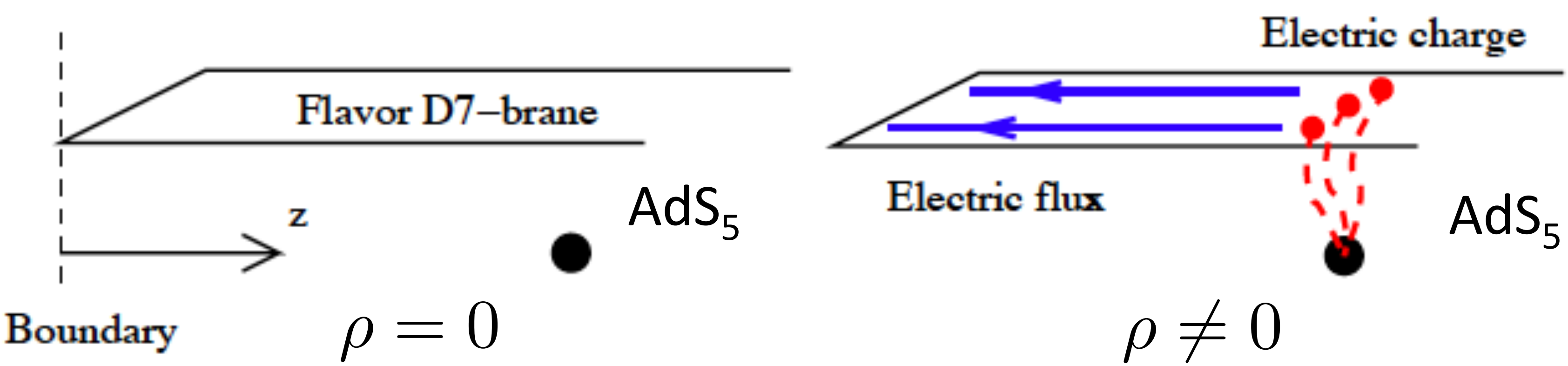
Thermalization timescale, a fun part

Our idea : Collision = a time-dep. baryon density



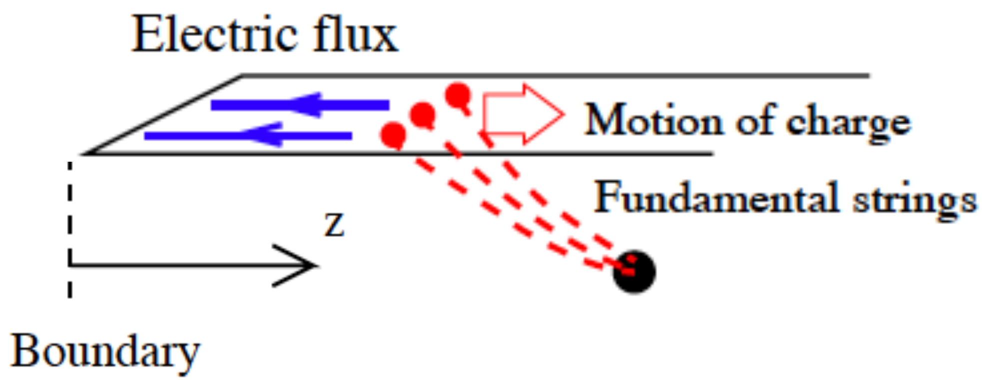


N=2 Supersymmetric QCD



[Apreda, Erdmenger, Evans, Fralnik ('05)], [Kim, Sin, Zahed ('06)], [Horigome, Tanii ('06)], [Parnachev, Sahakyan ('06)], [Kobayashi, Mateos, Matuura, Myers, Thomson ('06)], …

Time dependence, solved



On the Flavor D-brane in curved geometry,

solve nonlinear Maxwell with source motion

$$S = -\mu_7 \int d^8\xi \sqrt{-\det\left(G_{ab} + 2\pi\alpha' F_{ab}\right)}$$

$$\delta S = \mu_7 V_3 \mathrm{Vol}(S^3) \int dt dz \left(A_t j^t + A_z j^z\right)$$

$$j^t = j^z = g'(t-z) \qquad g(t) = (2/\pi)(2\pi\alpha')^4 \lambda\, n_{\mathrm{B}}(t)$$

"Holographic Quantum Quench" [Das, Nishioka, Takayanagi ('10)]

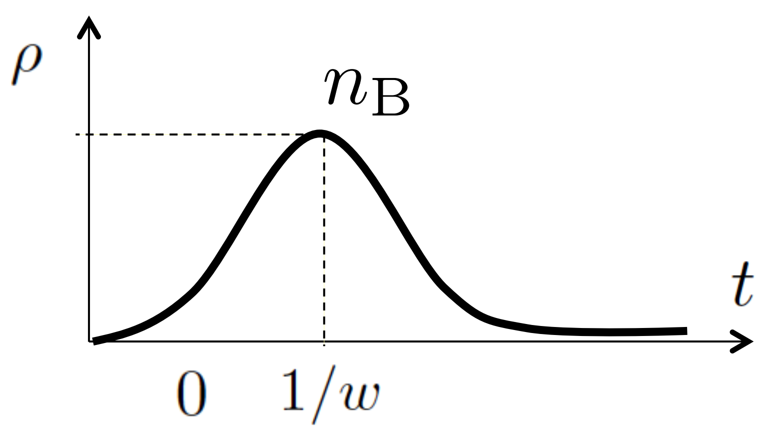
Nonlinearity → Effective Horizon

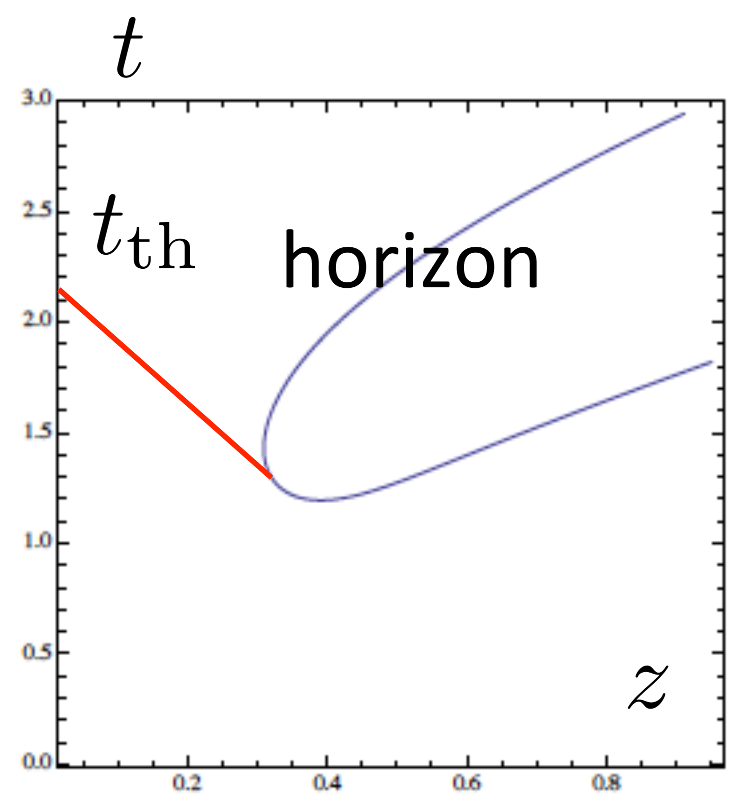
Small fluctuation on the flavor D-brane (meson modes) feels emergence of effective horizon → Thermalization

$$(\partial_z - \partial_t)\left[z^2(1 - z^4 R^{-4}(2\pi\alpha'^2)F_{tz}^2)\right] = 0$$

Example: gaussian change

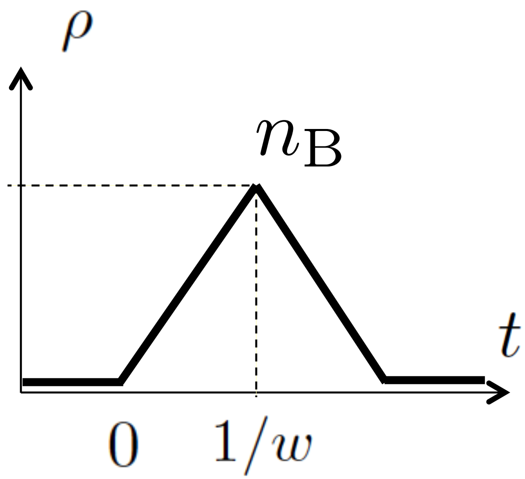
$$\rho(t) = n_{\rm B} \exp\left[-(2w)^2(t - 1/w)^2\right]$$

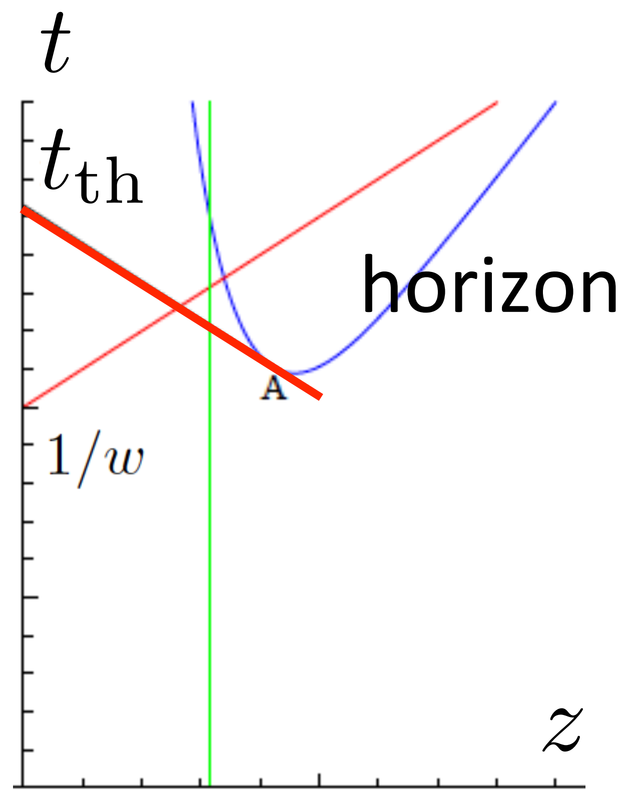




Thermalization timescale

Example: linear change





$$t_{\mathrm{th}} \sim \min_{\{k=0,1,2\}} \left\{ \left(\frac{\lambda}{n_{\mathrm{B}}^2 w^k} \right)^{1/(6+k)} \right\}$$

Fun : physical parameters

$$t_{\rm th} \sim \min_{\{k=0,1,2\}} \left\{ \left(\frac{\lambda}{n_{\rm B}^2 w^k} \right)^{1/(6+k)} \right\}$$

RHIC Au Collision:

$$n_{\rm B} \sim 2\gamma n_{\rm N}$$
$$1/w \sim 2A^{1/3}/\gamma \ [{\rm fm/c}]$$
$$\gamma = E/m_{Au} \sim 100$$

$\Rightarrow$ $t_{\rm th} < 1\,[{\rm fm/c}]$ Rapid thermalization, consistent with hydrodynamics

$t_{\rm th} \lesssim \mathcal{O}(0.1)\ [{\rm fm/c}]$ for LHC

Superstrings useful for…

Superstring is …

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Good at :
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- Chemical potential
- Time dependence

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