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String theory for Nuclear physics

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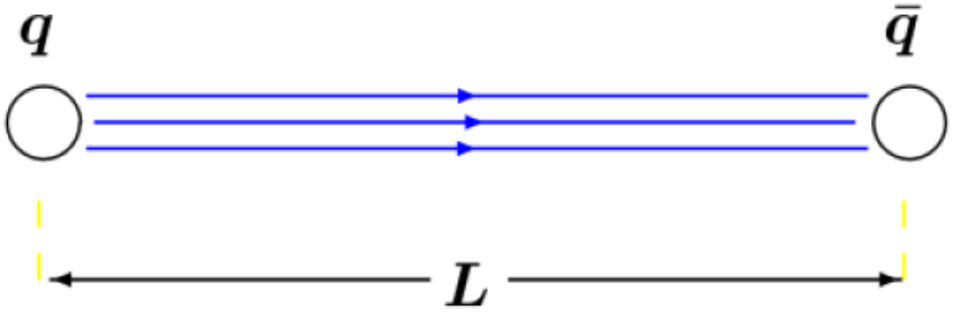
Why string theory?
I. Since there is a string in QCD

Confining theory: Linear potencial: $E \propto L$



- Confinement →
  Flux string or QCD string
- That is how string theory began 40 years ago.
- But not the reason today.

Why string theory? II

- Shear viscosity /entropy density in RHIC

  experiment: < 0.1

  pQCD: $\eta / s = \frac{1}{g^4 \ln g} >> 1$

  String Theory : ~ 1/4π =0.09

- The method used is AdS/CFT

- Q: Confinement and Hadron physics?

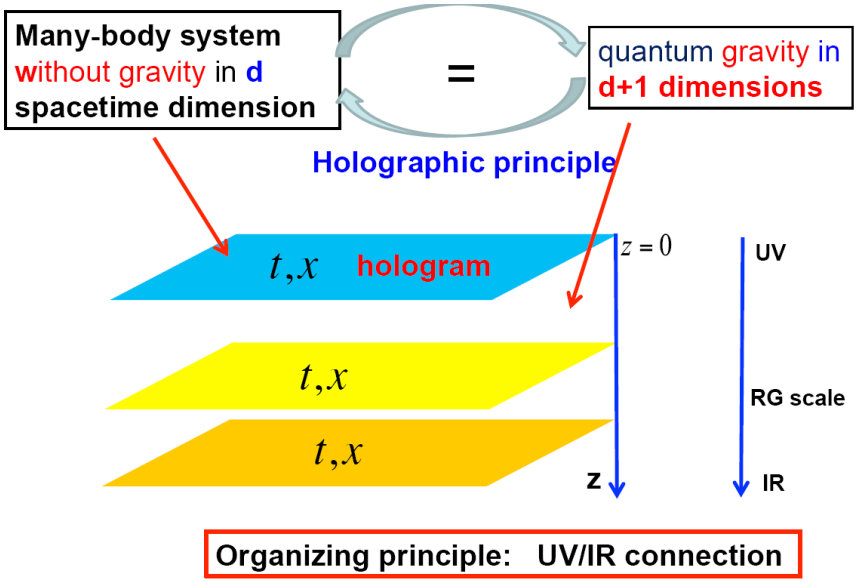
Gauge/gravity duality (ads/cft)

- Maldacena, GKP, Witten,
- D brane can be described in 2 ways.
  One is gauge theory
  The other is string theory
  in curved spacetime.
- So they must be equivalent.
- In certain limit,
  the latter is Einstein gravity theory

Character of AdS/CFT

- 1. Holographic:
  5d gravity theory for 4d QCD

origin of +1 dim? Scale

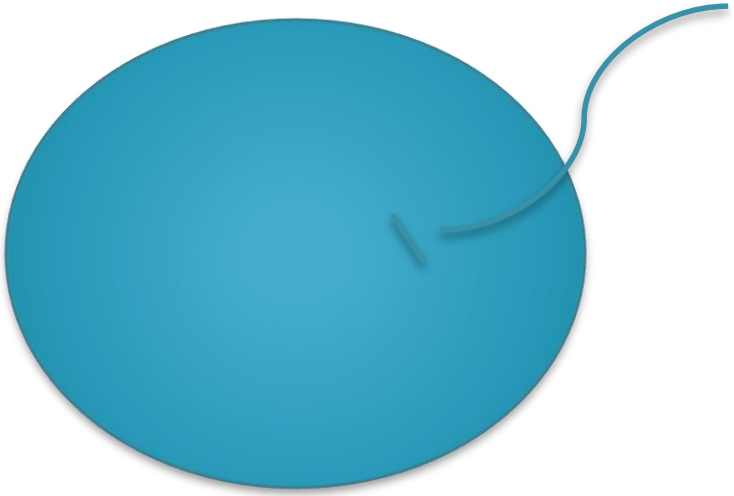


z direction is warped!
→ ads

Stolen from Hong Liu

Character of AdS/CFT II

- Within the validity,
  Do not need loop calculation.



1. ls<<Rads
2. gs<<1

$$\lambda = g^2 N_c >> 1$$

Large N theory. Good and Bad

Character of AdS/CFT III

- Super-symmetry
  Original version is N=4 SUSY.
  SUSY can be broken by BC. T. d. etc

- Is it QCD?
  Hopefully some properties will be univer sal. Some results are too good to be irrel evant ……
  [eta/s, glueon mass, ads/qcd, SS]

Ads/cft Dictionary

- Let O(x) is an color singlet operator with dimension Δ and spin p
  A(x) is an source of it.

- Then AdS/CFT says:
  Extend it to d+1(=5) dim by

$$A(x,z) = A(x)z^{d-p-\Delta} - < O > z^{\Delta-p} + ...$$

- If we know action and BC, it can be calculated CLASSICALLY.
- So is all correlation functions and its corollaries.

Density and chemical potential

- In 4d, Source of baryon number op $J_0 = \bar{\psi}\gamma_0\psi$ is A_0
- Extend it to 5dim by

$$A_0 = \mu z^{3-\Delta} - Q z^{\Delta-1}$$

$$\Delta = \text{dimesion of Operator} = 3$$

$$Q = < \bar{\psi}\gamma_0\psi >$$

$$\mu = chemical\ potentia$$

Gluon condensation and dilaton

- Tr(F^2) is dual to scalar ϕ
- Extend it to 5dim by

$$\phi(x,z) = \phi_0 z^{4-\Delta} - c z^{\Delta}$$

$$\phi_0 = 0 \qquad c = < TrF^2 >$$

Chiral condensation and mass

- Mass op. $\bar{\psi}\psi$ is dual to a scalar σ
- Extend it to 5 dim by

$$\sigma(x,z) = m_q z - cz^3$$

$$c = <\bar{\psi}\psi>$$

Temperature

Finite temperature

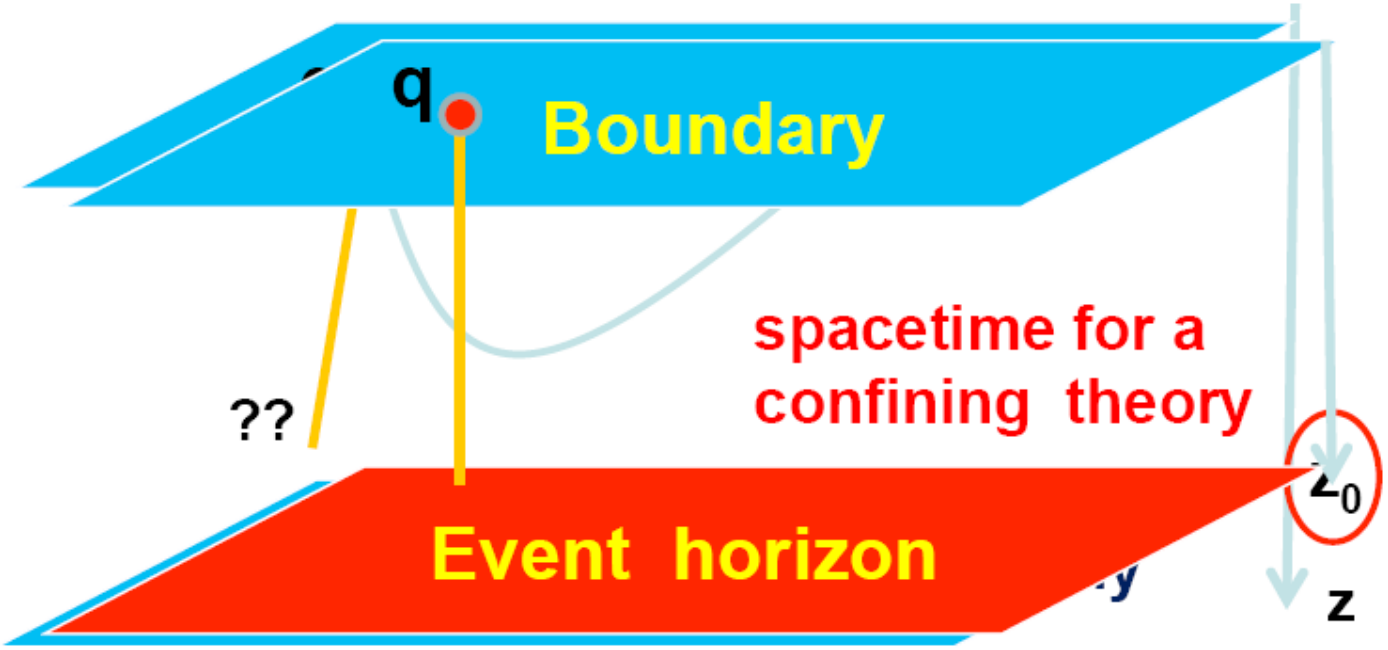
boundary system at a finite temperature

Black hole

Entropy, energy, Euclidean action of BH

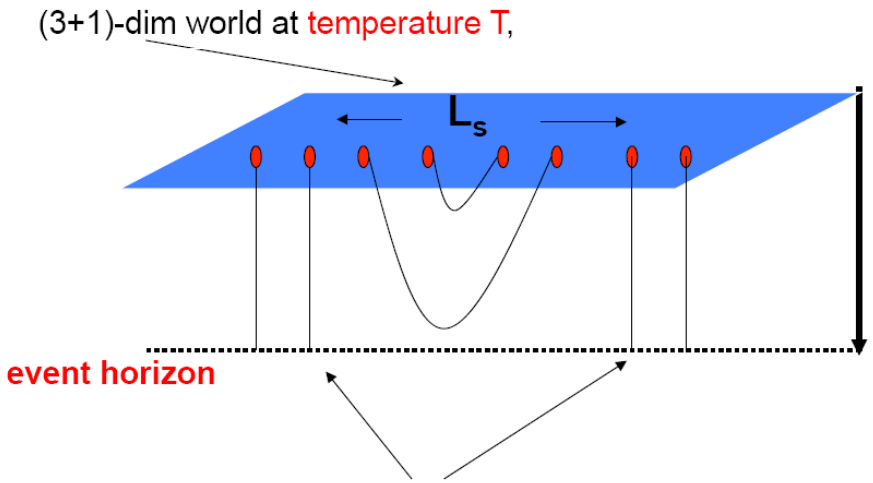
Entropy, energy, free energy of YM theory

Gluon dynamics→ Geometry.
Confinement or deConfinement depends on geometry.



Goemetry with

Screening of quarks in a QGP

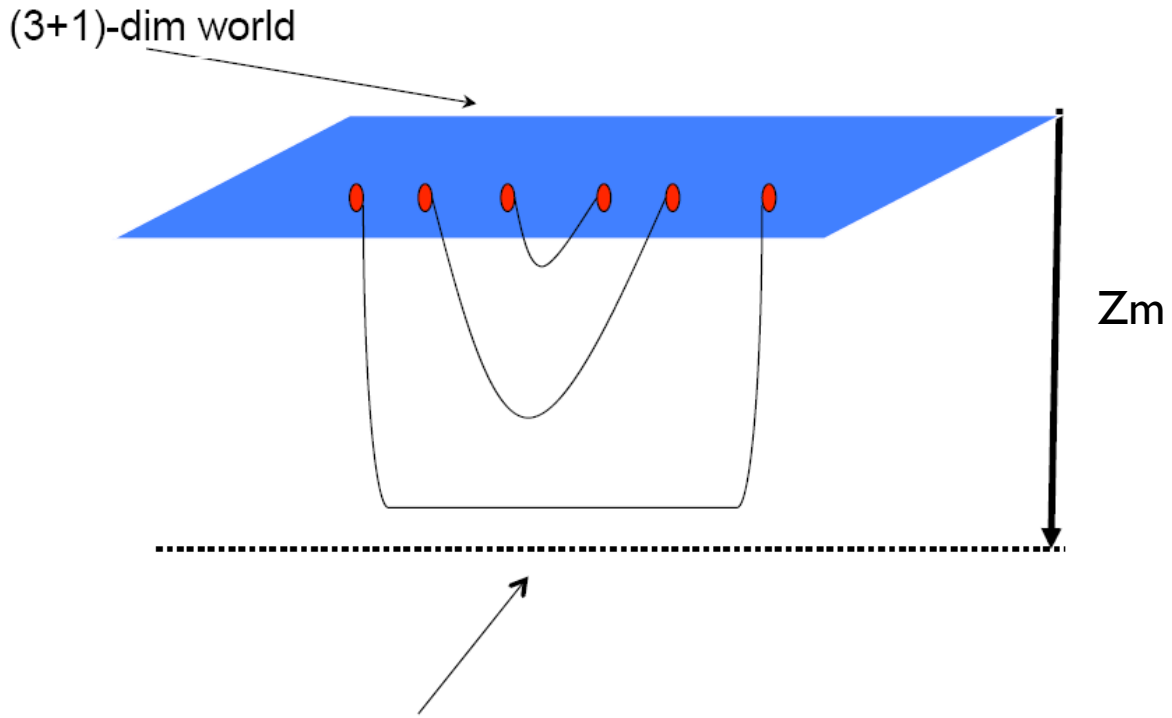


N=4 : $L_S = 0.277/T$, QCD (2 flavor): $L_S \sim 0.5/T$

(lattice)

Geometry with

Confinement



What can one do with it.

- Phase transition, equation of state.
- Two point function
  → Transports. Spectral fct
  Viscosity conductivity heat cd
- Elliptic flow(time dependence)
- Dissipation and energy loss. (dragging)
- Meson/Baryon spectrum
- Symmetry energy
- Lepto and Photo emission rate

……..……

Bottom up model

- Write down linear sigma model in ads5.
  with chiral symmetry SU(Nf)xSU(Nf)

$$S = \int d^5x \sqrt{g}\ \mathrm{Tr}\Big\{|DX|^2 + 3|X|^2 - \frac{1}{4g_5^2}(F_L^2 + F_R^2)\Big\}$$

$$X_0(z) = \frac{1}{2}Mz + \frac{1}{2}\Sigma z^3, \qquad \Sigma^{\alpha\beta} = \langle \bar{q}^\alpha q^\beta \rangle.$$

- Roughly, X=sU ,
  <sigma> by hand. No Potential
- No loop calcalculation: Point of the theory:
- Throw away Kaluza Klein

Observables

- Interaction: Overlapping integral

$$g_{\rho\pi\pi} = g_5 \int dz\, \psi_\rho(z) \left(\frac{\phi'(z)^2}{g_5^2\, z} + \frac{v(z)^2(\pi-\phi)^2}{z^3} \right).$$

- Decay constant:

$$F_\rho^2 = \frac{1}{g_5^2}[\psi_\rho{}'(\epsilon)/\epsilon]^2 = \frac{1}{g_5^2}[\psi_\rho{}''(0)]^2, \quad f_\pi^2 = -\frac{1}{g_5^2}\left.\frac{\partial_z A(0,z)}{z}\right|_{z=\epsilon};$$

- GOR relation

$$m_\pi^2 f_\pi^2 = (m_u + m_d)\langle \bar{q}q \rangle = 2m_q\sigma.$$

- Mass spectrum:

$$\psi_\rho(\epsilon) = 0, \;\; \partial_z \psi_\rho(z_m) = 0$$

Resuls:

TABLE II: Results of the model for QCD observables. Model A is a fit of the three model parameters to m_π, f_π and m_ρ (see asterisks). Model B is a fit to all seven observables.

Observable	Measured (MeV)	Model A (MeV)	Model B (MeV)
m_π	139.6±0.0004 [8]	139.6*	141
m_ρ	775.8±0.5 [8]	775.8*	832
m_{a_1}	1230±40 [8]	1363	1220
f_π	92.4±0.35 [8]	92.4*	84.0
$F_\rho^{1/2}$	345±8 [15]	329	353
$F_{a_1}^{1/2}$	433±13 [6, 16]	486	440
$g_{\rho\pi\pi}$	6.03±0.07 [8]	4.48	5.29

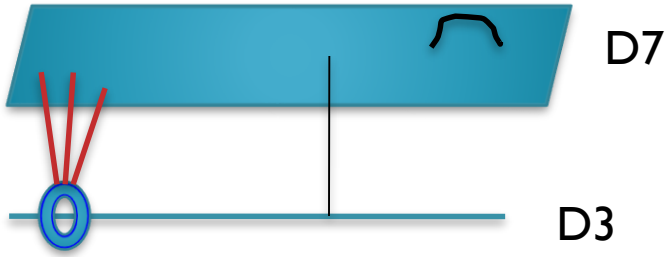
$z_m = 1/(323\ \text{MeV})$. $m_q = 2.29\ \text{MeV}$ and $\sigma = (327\ \text{MeV})^3$

The rms error, for Model A is 15%.

too good to be true?

Top down

- Quark: Bifundamental,

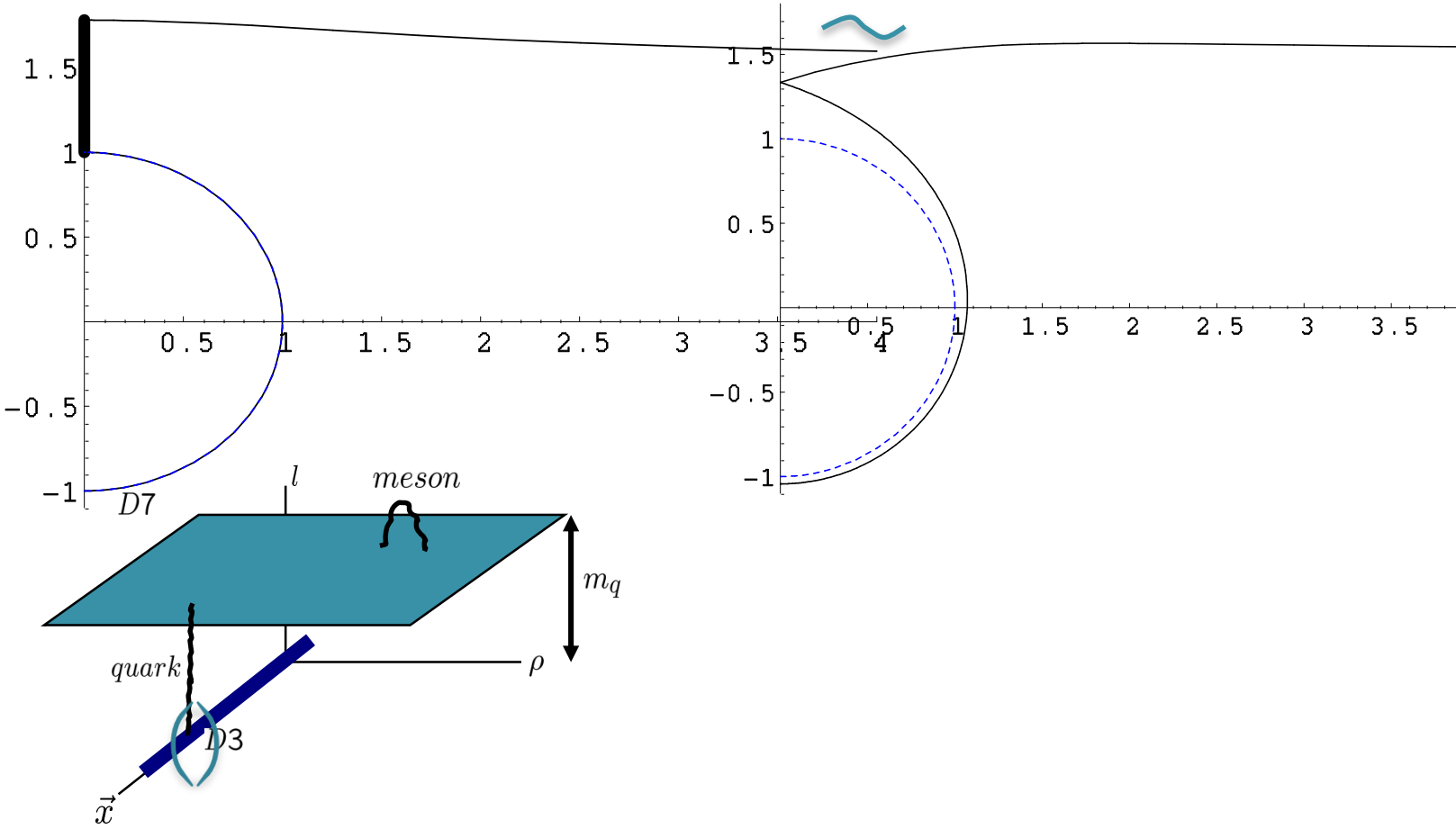


- Meson: adjoint
  Dynamics: Dirac-Born-Infeld action

$$S_{D4} = -\mu_4 \int e^{-\phi} \sqrt{\det(g + 2\pi\alpha' F)} + \mu_4 \int A_{(1)} \wedge G_{(4)}$$

- Baryon: compact D5

Baryon density and meson at probe D7



BR-scaling

- In 1991, G.Brown and M.Rho

$$m_M^*(n)/m_M \approx m_B^*(n)/m_B \equiv \Phi(n)$$

$$\Phi(n) = 1 - Cn/n_0 \text{ with } C = 0.1 \sim 0.3$$

$$\Phi(n)_{BR} \approx f_\pi^*(n)/f_\pi.$$

$$\sim \langle\bar{q}q\rangle^*(n)/\langle\bar{q}q\rangle \quad \text{as} \quad n \to n_c. \quad \text{(HLS) model}$$

- Q: Is it true?

D4/D6 model

- Confining geometry.

$$
\begin{aligned}
ds^2 &= \left(\frac{U}{R}\right)^{3/2}\left(\eta_{\mu\nu}dx^\mu dx^\nu + f(U)dx_4^2\right) + \left(\frac{R}{U}\right)^{3/2}\left(\frac{dU^2}{f(U)} + U^2 d\Omega_4^2\right) \\
e^\phi &= g_s\left(\frac{U}{R}\right)^{3/4}, \quad F_4 = \frac{2\pi N_c}{\Omega_4}\epsilon_4, \quad f(U) = 1 - \left(\frac{U_{KK}}{U}\right)^3, \quad R^3 = \pi g_s N_c l_s^3.
\end{aligned}
$$

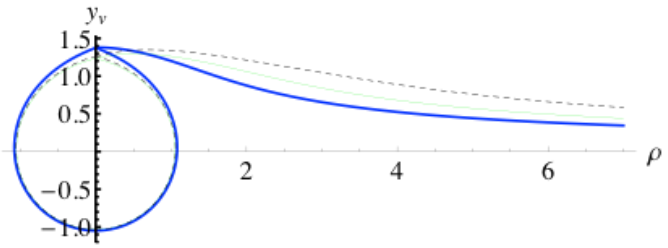
$$
g_s = \frac{\lambda}{2\pi l_s N_c M_{KK}}, \quad U_{KK} = \frac{2}{9}\lambda M_{KK} l_s^2, \quad R^3 = \frac{\lambda l_s^2}{2M_{KK}}, \quad \lambda = g_{YM}^2 N_c.
$$

	Boundary				S^1	r(S^4)	S^4			
coordinate	x^0	x^1	x^2	x^3	x^4	U ($\sim \xi$)	θ	ψ_1	ψ_2	ψ_3
Backgr D4	•	•	•	•	•					
Baryonic D4	•						•	•	•	•

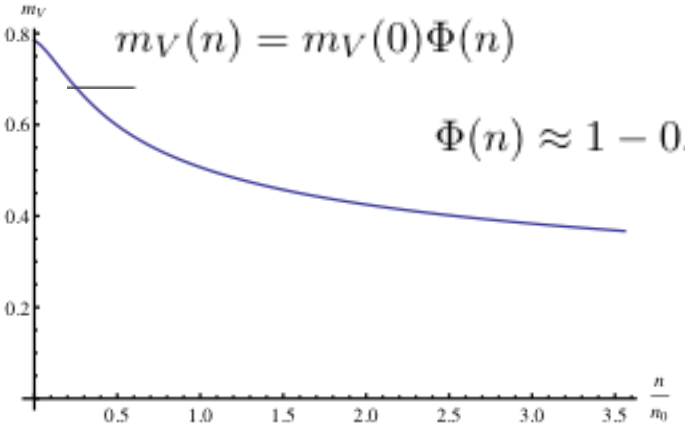
	Boundary				S^1	R^3			R^2	
coordinate	x^0	x^1	x^2	x^3	x^4	ρ	θ_1	θ_2	y	ϕ
Flavor D6	•	•	•	•		•	•	•		

Result: Yes in a model.

- Embedding:



- Vector Mass



$$m_V(n) = m_V(0)\Phi(n)$$

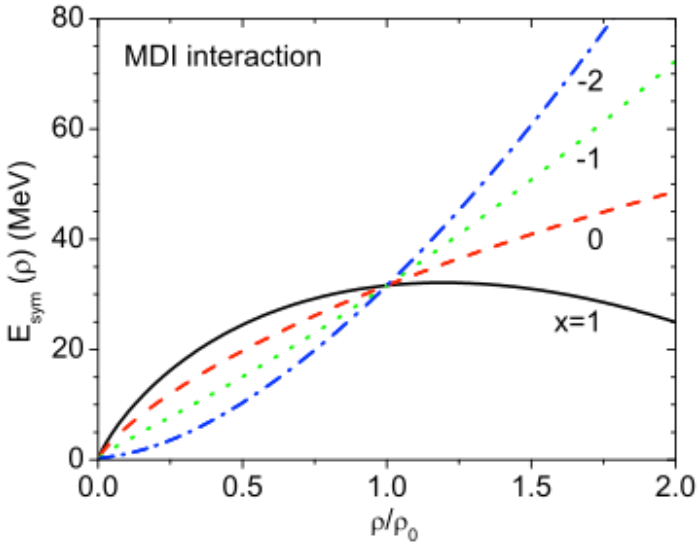
$$\Phi(n) \approx 1 - 0.18 \cdot \frac{6}{\lambda}\frac{n}{n_0}.$$

- GOR relation is true in Medium.

Symmetry energy I

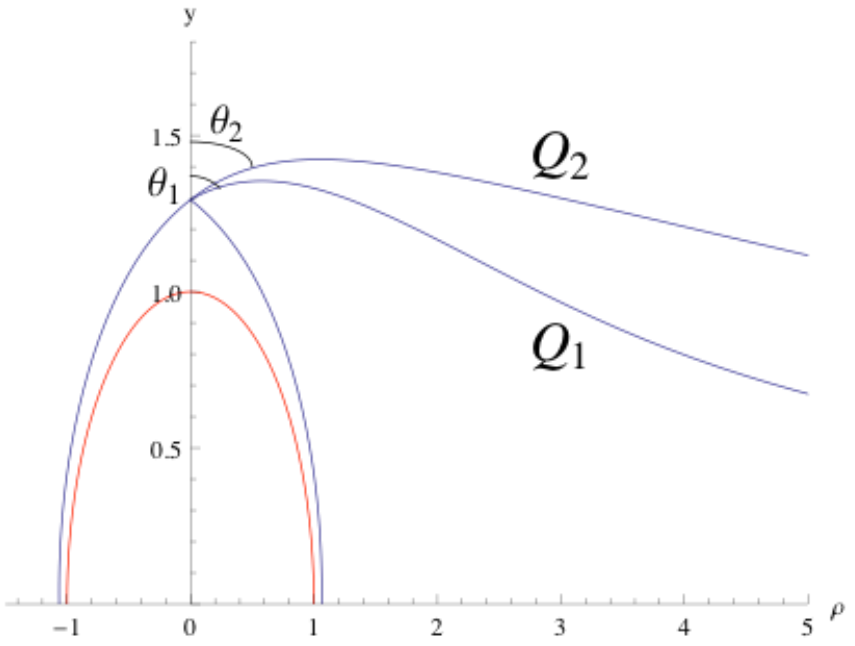
- Def: $$E_{\rm B} = a_{\rm v}A - a_a(N-Z)^2/A - a_c Z^2/A^{1/3} - a_s A^{2/3} \pm a_\delta/A^{3/4}\,.$$

- Present status:



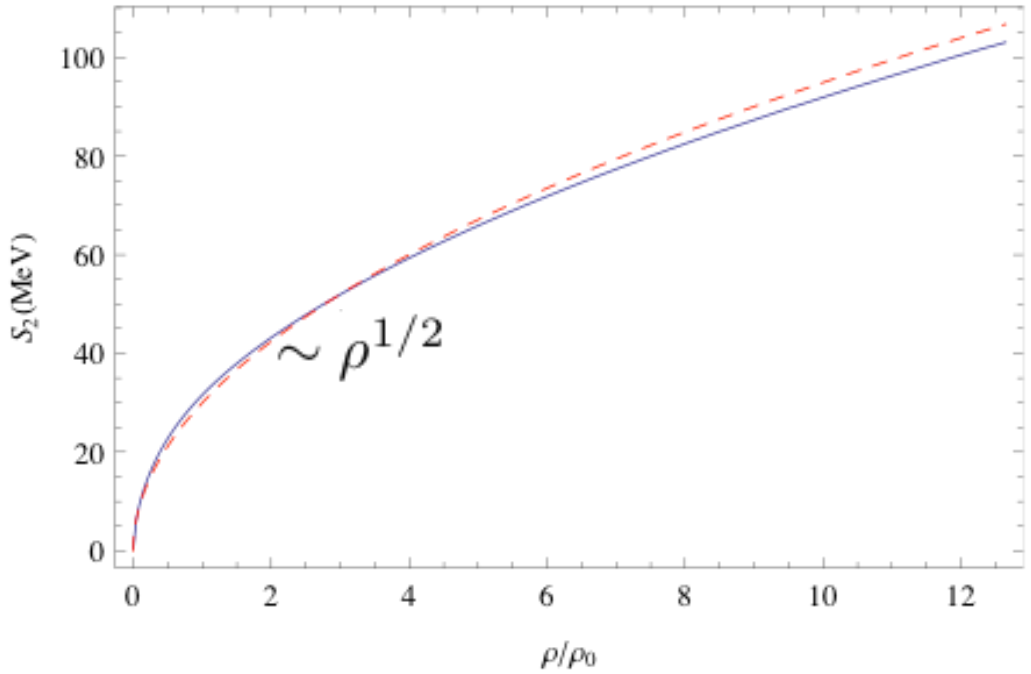
Symmetry energy II

- Main idea: different isospin ~ different number of strings attached to tw o probe brane



Symmetry energy : result

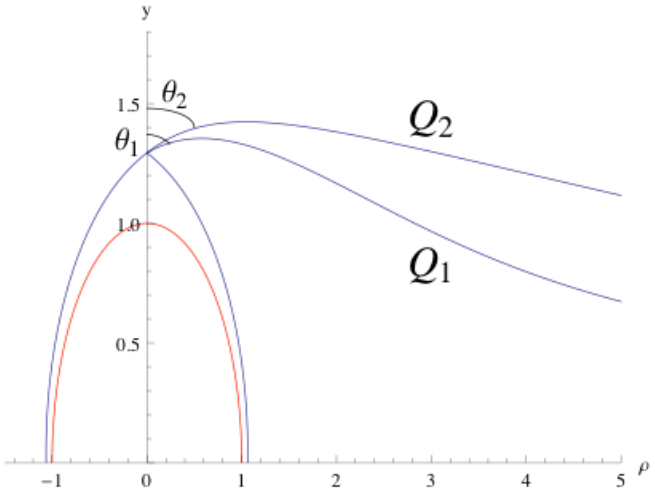
- Stiff → neutron star crest is Thin.



Pauli principle in hQCD.

- two puzzles
  in 4d: Driving force of Z=N is Pauli principle. Ads/cft is count ing QM by classical dynamics. So how to count Pauli force.

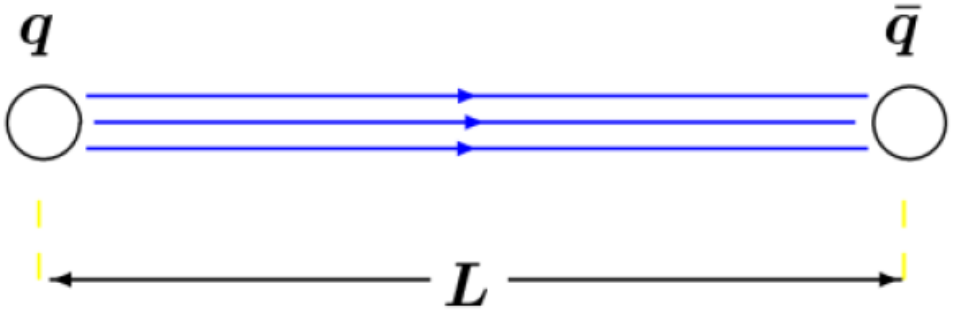
  In 5d: coulomb force by charge. But charge is dual to baryon number, which is global charge. So what is dual of the coulo mb force?



$$\mathcal{H}_{D6} = \tau_6 \int d\rho \sqrt{1+\dot{y}^2} \sqrt{\omega_+^{4/3}\left(\tilde{Q}^2 + \rho^4 \omega_+^{8/3}\right)},$$

String theory began as a Hadron Th.

Confining theory: Linear potencial: $E \propto L$



- Confinement →
  Flux string or QCD string

Conclusion

- One can do many things
- Omitted:

  Elliptic flow.
  Photo/Lepto emission in LHC?
  Non-fermiliquid
  Color superconductivity

  what I have shown is just tip of iceberg.

- Not really QCD but may be relevant.

- Can we do something together?

. QCD string:
good for Reggestrajectory
bad for deep inelastic scattering data