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Holographic Nucleus

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Can Superstring describe nuclear physics?

Nuclear physics : Problem

Find “effective” description of multi-baryon system

Cause

Nucleon : bound state of 3 quarks via strong coupling

Nuclear properties from strongly coupled QCD?

My Solution

QCD + Superstring mathematics

→ Proper limit

New effective description,
Nuclear radius

1. Nucleus = Matrix
2. M-theory for nuclear physics?
3. Solve heavy nucleus
    - 3-1. Formation of nucleus
    - 3-2. Nuclear radius $\propto A^{1/3}$
    - 3-3. Analytic formula for nuclear radius

Nucleus = Matrix

AdS/CFT correspondence

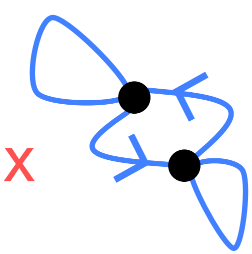
Large N_c QCD strong coupling $\simeq$ String theory in curved geometry

Nucleus is a matrix

Baryon : heavy at large N_c

= D-brane

Multiple D-branes described by matrix



M-theory for Nuclear Physics?

[Iizuka,Yi, KH 1003.4988]

$$S = c\int dt\ \mathrm{tr}\left[\frac{1}{2}(D_t X^I)^2 - \frac{g^2}{4}[X^I, X^J]^2\right] + \cdots$$

X^M $(M = 1,2,3,4)$: *A* x *A* Hermitian matrix

$X^{M=1,2,3}$ eigenvalues = *A* baryons' location

Only 2 parameters : $M_{\mathrm{KK}},\ \lambda \equiv N_c (g_{\mathrm{QCD}})^2$

Nuclear physics

$$S \sim \int dt \left[\sum_{i=1}^{A} \frac{1}{2} m_N |\partial_t \vec{x}^{(i)}|^2 + \sum_{i\neq j} V(x^{(i)} - x^{(j)}, \cdots) + \cdots\right]$$

Solve heavy nucleus

[Morita, KH 1103.5688]

Large *A* : Dimensionally reduced Yang-Mills

$$S = c \int dt \ \mathrm{tr} \left[\frac{1}{2} (D_t X^I)^2 - \frac{g^2}{4} [X^I, X^J]^2 \right]$$

Question :

Solve this quantum mechanics at large *A*.

Bound state?

Nuclear radius ? $\sqrt{r^2_{\mathrm{mean}}} \equiv \sqrt{\frac{1}{A} \mathrm{tr} \langle X^I X^I \rangle}$

Utilize: M-theory technologies

$$S = \frac{1}{g_s l_s} \int dt \ \mathrm{tr} \left[\frac{1}{2} (\partial_t X^M)^2 - \frac{1}{l_s^4} [X^M, X^N]^2 + \text{fermions} \right]$$

[Banks, Fischler, Shenker, Susskind (1996)]

Formation of Nucleus

$$S = c \int dt \, \mathrm{tr} \left[\frac{1}{2} (D_t X^I)^2 - \frac{g^2}{4} [X^I, X^J]^2 \right]$$

Classical : diagonal $X^I = \begin{pmatrix} x^I_{(1)} & & \\ & x^I_{(2)} & \\ & & \cdots \end{pmatrix}$

Quantum mechanical : not diagonal, because…

For large diagonal value *x* and take $X = \begin{pmatrix} x & \delta x \\ \delta x & -x \end{pmatrix}$

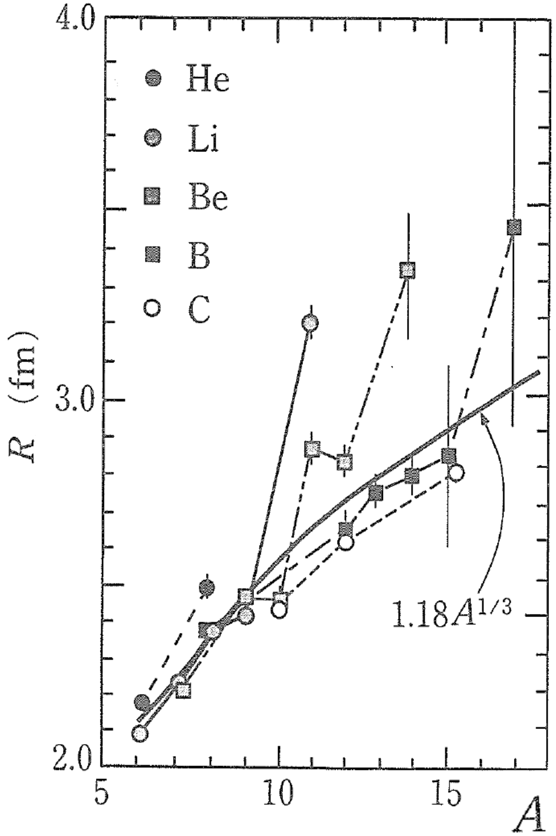
the potential is too narrow : $V \sim g^2 x^2 (\delta x)^2$

[Luscher, 1983]

Quantum Vacuum : Eigenvalues accumulate

= Nucleus inevitably forms

Nuclear radius $\propto \mathbf{A^{1/3}}$



[『大学院原子核物理』(講談社)]

$$\sqrt{r^2_{\mathrm{mean}}} \simeq 1.0 A^{1/3} \ \ [\mathrm{fm}]$$

$$S = c \int dt \, \mathrm{tr} \left[\frac{1}{2} (D_t X^I)^2 - \frac{g^2}{4} [X^I, X^J]^2 \right]$$

'tHooft expansion: fixed $\lambda_A \equiv A g^2$

→ Dimensional analysis

$$\frac{1}{A^2} \mathrm{tr} \langle X^I X^I \rangle = c \lambda_A^{-1/3} + \cdots$$

→ Nuclear radius, saturation beahvior

$$\sqrt{r^2_{\mathrm{mean}}} \equiv \sqrt{\frac{1}{A} \mathrm{tr} \langle X^I X^I \rangle} \propto A^{1/3}$$

Analytic formula for Nuclear radius

[Morita, KH 1103.5688]

Use large *D*, large *A* expansion （ $g^2 A D$ fixed ）

$$\left.\sqrt{r^2_{\rm mean}}\right|_{T=0} = \frac{3^{5/2}\pi^{2/3}}{2^{5/6}5^{1/6}} \frac{A^{1/3}}{M_{\rm KK}(N_c\lambda^2)^{1/3}}$$

Input :
- Rho meson mass $M_{\rm KK} \sim 0.95[{\rm GeV}]$
- Yukawa $g_{\pi NN}$ $\lambda \sim 5.3$

⇒ $\sqrt{r^2_{\rm mean}} \sim 0.7 A^{1/3}\ [{\rm fm}]$

Experiments : $\sqrt{r^2_{\rm mean}} \simeq 1.0 A^{1/3}\ [{\rm fm}]$

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