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Holographic QCD and Beyond

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Can Superstring describe nuclear physics?

Nuclear physics : Problem

Find “effective” description of multi-baryon system

Cause

Elementary particles : quarks and gluons in QCD

Nucleon : bound state of 3 quarks via strong coupling

Nuclear properties from strongly coupled QCD?

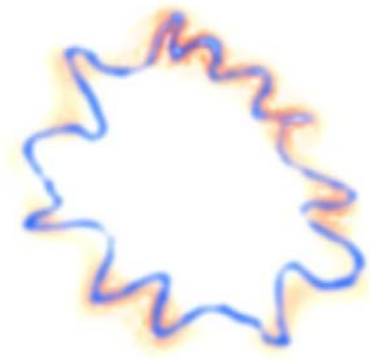
My Solution

QCD + Superstring mathematics

→ Proper limit

New effective description of Hadrons and Nuclei

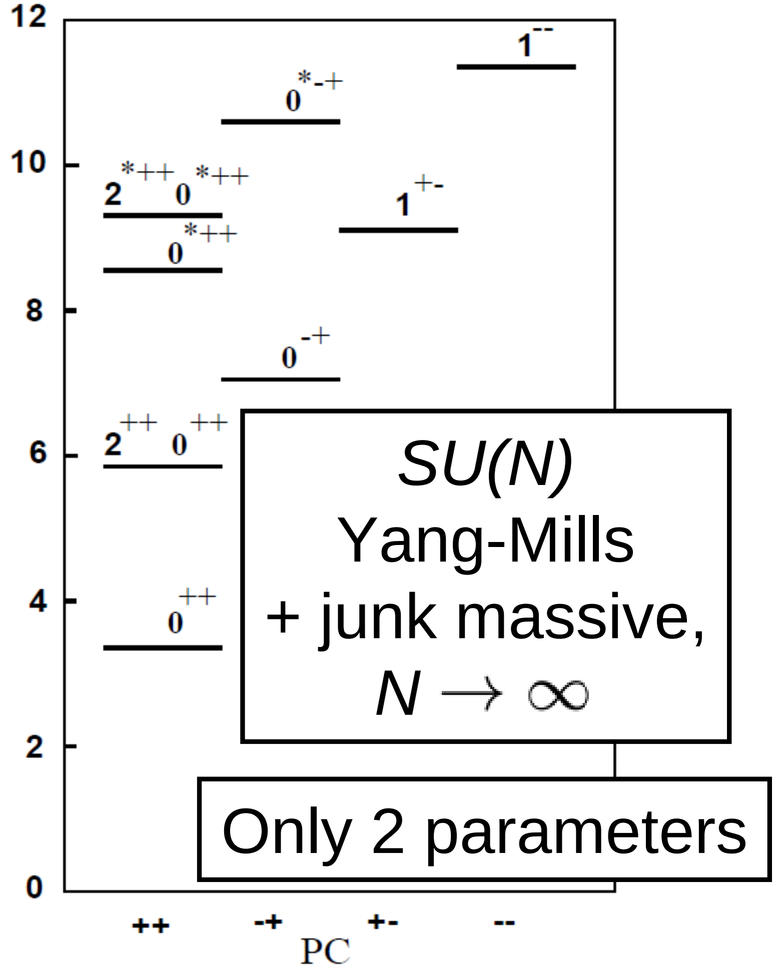
Superstring



Lattice

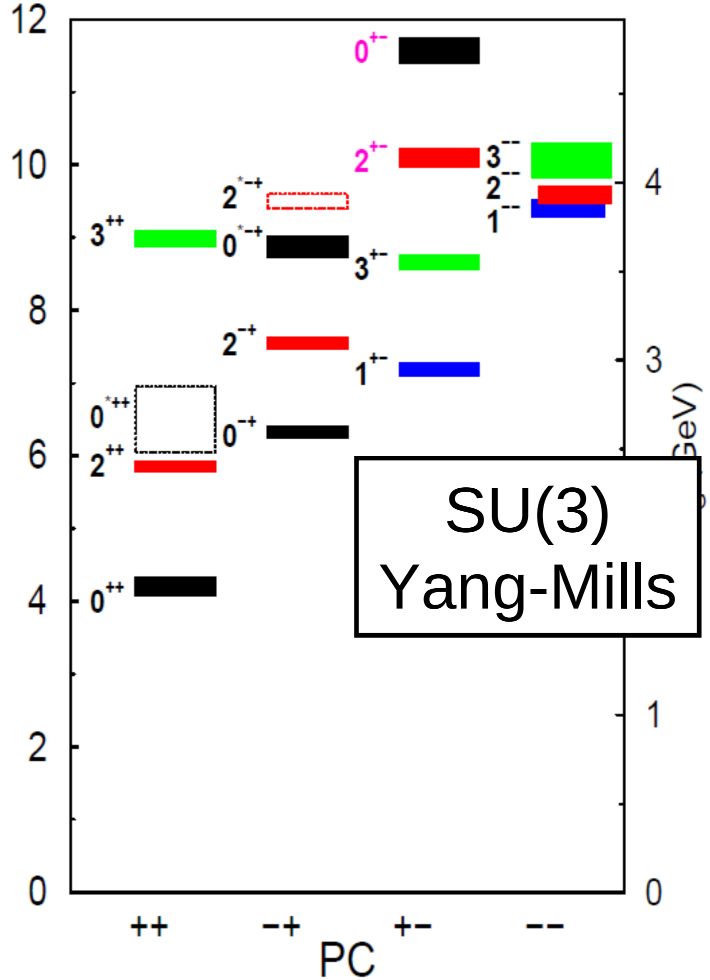
Glueball spectrum

Superstring



[Brower,Mathur,Tan (03)]

Lattice



[Morningstar,Peardon (99)]

Plan

Holographic Dictionary

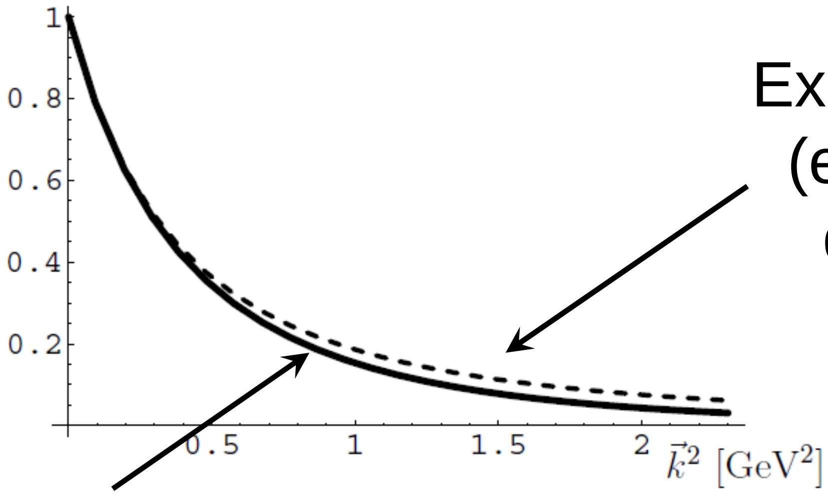
Beyond

Couplings, Radii of Nucleon

[Sakai,Sugimoto,KH (0806.3122)]

	Superstring	Experiment	
$\langle r^2 \rangle_{E,\mathrm{p}}$	(0.74 fm)^2	(0.875 fm)^2	
$\langle r^2 \rangle_{E,\mathrm{n}}$	0	– 0.116 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	Lattice
$\mu_{\Delta^{++}}$	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

Nucleon Form factor



Experiment (empirically known dipole behavior)

[Sakai,Sugimoto,KH 0806.3122]

Superstring : $G_E^p(k^2) = 1 - 2.38k^2 + 4.02k^4 - 6.20k^6 + 9.35k^8 \cdots$

$949[\mathrm{MeV}] = 1$

Nucleon mass vs. Quark mass

$m_N = c_0 + c_1 m_\pi^2 +$ higher. [Hirayama,Hong,KH, 0906.0402]

Superstring : $c_1 = 4.1\ [\mathrm{GeV}^{-1}]$

Lattice : $c_1 = 3.6 - 4.4\ [\mathrm{GeV}^{-1}]$

What can superstring compute?

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 and decay width, …

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

Caveat : Large N_c, “QCD” with junk massive fields

Holographic QCD : two physics connected

Large N_c “QCD”	Superstring
Glueball sector	Supergravity in 10d curved spacetime
Meson sector	Flavor $U(N_f)$ Yang-Mills in higher dim.
Baryon	Soliton in $U(N_f)$ Yang-Mills
QCD string	Fundamental string in curved space
Deconfinement	Event horizon of Black hole
Finite temperature	Hawking temperature
Chiral symmetry breaking	Higgsing Flavor gauge symmetries
Dense matter	Electric field on Flavor $U(N_f)$

Plan

Holographic Dictionary

Beyond

Superstring derives multi-nucleon system

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

$$S = \frac{\lambda N_c}{54\pi} M_{\rm KK} \int dt \, {\rm tr} \left[(D_0 X^M)^2 - \frac{2}{3} M_{\rm KK}^2 (X^4)^2 + D_0 \bar{w}_i^{\dot\alpha} D_0 w_{\dot\alpha i} - \frac{1}{6} M_{\rm KK}^2 \bar{w}_i^{\dot\alpha} w_{\dot\alpha i} - \frac{3^6 \pi^2}{4\lambda^2 M_{\rm KK}^4} \left(\vec{D}\right)^2 + i\vec{D} \cdot \vec{\tau}^{\dot\alpha}{}_{\dot\beta} \bar{X}^{\dot\beta\alpha} X_{\alpha\dot\alpha} + i\vec{D} \cdot \vec{\tau}^{\dot\alpha}{}_{\dot\beta} \bar{w}_i^{\dot\beta} w_{\dot\alpha i} \right] + 4N_c \int dt \, {\rm tr} \, A_0$$

“Nuclear Matrix Theory” : New Description of Multi-Baryons

[Iizuka,Yi, KH 1003.4988]

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

Eigenvalues of $X^{M=1,2,3}$ → location of *A* baryons

Only two parameters : $M_{\rm KK}, \ \lambda = N_c g_{\rm QCD}^2 \sim \mathcal{O}(15)$

A=1 : Baryon spectrum

Hamiltonian spectrum :

$$M = M_0 + \frac{1}{\sqrt{6}}\left[\sqrt{(I/2+1)^2 + N_c^2} + 2n_\rho + 2n_{X^4} + 2\right]$$

⇒ $I = J = 1/2$ 940$^+$,1359$^+$,1359$^-$,1778$^+$,1778$^-$,…

M_N, M_Δ :inputs Exp. : 940$^+$,1440$^+$,1535$^-$,1710$^+$,1655$^-$,…

A=2 : Nuclear force, repulsive core

[Iizuka,Yi, KH 1003.4988]
[Iizuka, S.Aoki, KH, in progress]

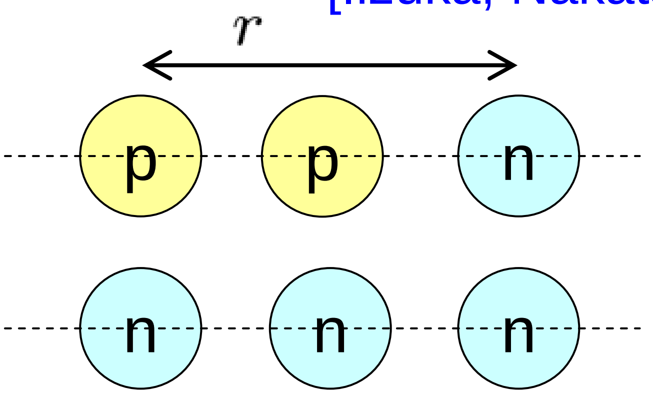
$$V_{\rm T}(\vec{r}) = 2\pi I_1^i I_2^i \frac{N_c}{\lambda M_{\rm KK}}\frac{1}{r^2}$$

$$V_{\rm C}(\vec{r}) = \pi\left(\frac{3^3}{2} - 8 I_1^i I_2^i J_1^j J_2^j\right)\frac{N_c}{\lambda M_{\rm KK}}\frac{1}{r^2},$$

Repulsive core, Universal (even for 3 flavors), Scaling : 1/r^2

A=3 : 3-body nuclear force

[Iizuka, Nakatsukasa, KH, 0911.1035][Iizuka, KH,1005.4412]



spin : averaged

He-3 nucleus

$$\langle V_{3-\text{body}} \rangle = \frac{2^{5/2} 3^{9/2} 5 \pi^2 N_c}{\lambda^2 M_{\text{KK}}^3 |r|^4}$$

Neutron star

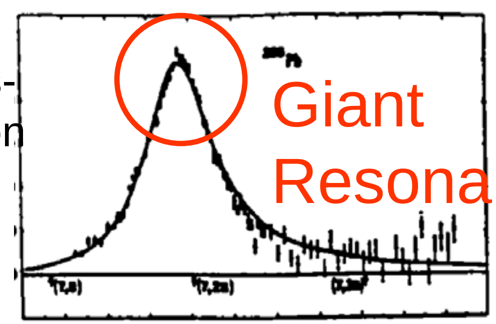
$$\langle V_{3-\text{body}} \rangle = \frac{2^{-1/2} 3^{15/2} \pi^2 N_c}{\lambda^2 M_{\text{KK}}^3 |r|^4}$$

All positive

Large A : Giant resonances

[KH (0809.3141,0910.2303)]

Pb nucleus



Excitation energy E

$$E = \sqrt{\frac{2^3\, c\, N_c}{3^5}} \sqrt{\rho_0 M_{\text{KK}}^3}\, A^{-1/3}$$

$$c = 2.23,\ 3.68,\ 4.75,\ \cdots$$

Exp.: $E(A) \sim 80 A^{-1/3}$ [MeV]

Reproducing *A* dependence

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