Hyperon Spectra

[Iizuka,Ishii,Kadoh,KH, 0910.1179]

Mass splitting of baryons with $\Delta Y = 1$ or $\Delta I = 1$

8	$\Delta m_{\Lambda-N}$	Δm_{Σ^0-N}	$\Delta m_{\Sigma^0-\Lambda}$	$\Delta m_{\Xi^0-\Lambda}$	$\Delta m_{\Xi^0-\Sigma^0}$
Superstring [MeV]	2.4×10^2	4.8×10^2	2.4×10^2	3.5×10^2	1.2×10^2
experiment [MeV]	1.8×10^2	2.5×10^2	77	2.0×10^2	1.2×10^2

10	$\Delta m_{\Sigma^{*0}-\Delta^0}$	$\Delta m_{\Xi^{*0}-\Sigma^{*0}}$	$\Delta m_{\Omega^- - \Xi^{*0}}$
Superstring [MeV]	1.8×10^2	1.8×10^2	1.8×10^2
experiment [MeV]	1.5×10^2	1.5×10^2	1.4×10^2

Mass splitting of baryons with $\Delta I_3 = 1$

8	Δm_{N-P}	$\Delta m_{\Sigma^- - \Sigma^0}$	$\Delta m_{\Sigma^0-\Sigma^+}$	$\Delta m_{\Xi^- - \Xi^0}$
Superstring [MeV]	2.1	5.1	5.1	8.2
experiment [MeV]	1.3	4.8 ± 0.1	3.3 ± 0.1	6.9 ± 0.3

10	$\Delta m_{\Delta\text{baryons}}$	$\Delta m_{\Sigma^{*-} - \Sigma^{*0}}$	$\Delta m_{\Sigma^{*0}-\Sigma^{*+}}$	$\Delta m_{\Xi^{*-} - \Xi^{*0}}$
Superstring [MeV]	3.1	3.1	3.1	3.1
experiment [MeV]	$(\lesssim 2)$	3.5 ± 1.5	0.9 ± 1.4	3.2 ± 0.9

Our inputs : $m_{\pi^\pm}, m_{K^\pm}, m_{K^0}, f_\pi$

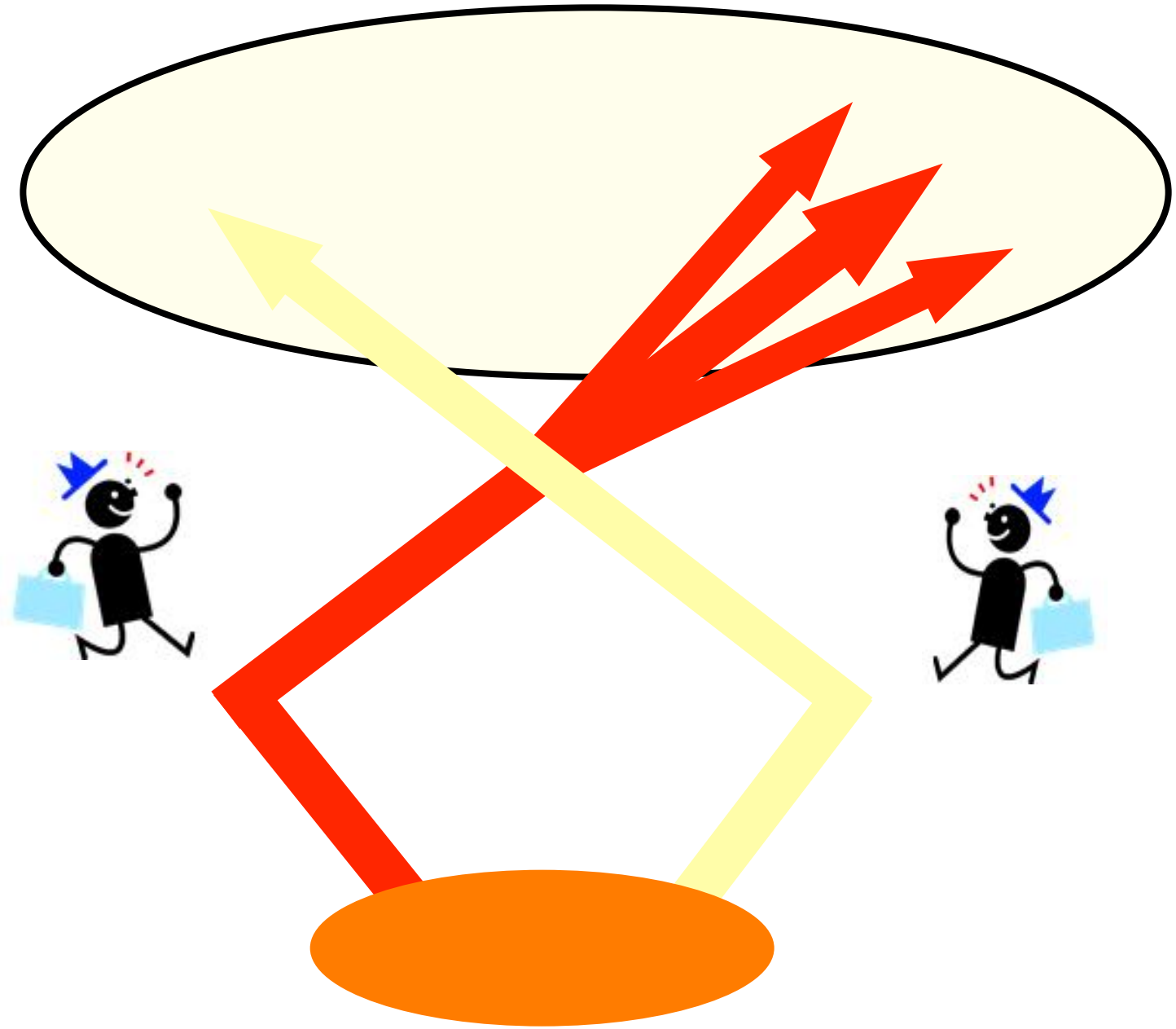
1st March 2011
"New hadron" workshop @ Nishina center

Holographic QCD and Hadron Physics

Koji Hashimoto (RIKEN Nishina Center)

w/ N.Iizuka (CERN), P.Yi (KIAS), T.Sakai (Nagoya)
S.Sugimoto (IPMU), T.Hirayama (Kyoto), T.Oka (Tokyo),
D.K.Hong (Pusan), H.U.Yee (Trieste), F.L.Lin (Taiwan),
T.Morita (Crete), T.Ishii, D.Kadoh, T.Nakatsukasa (RIKEN)

What is your goal of hadron physics?



Unification

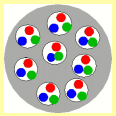
Quark / Gluon

Lattice
QCD

Hadron, Nucleon

AdS/CFT

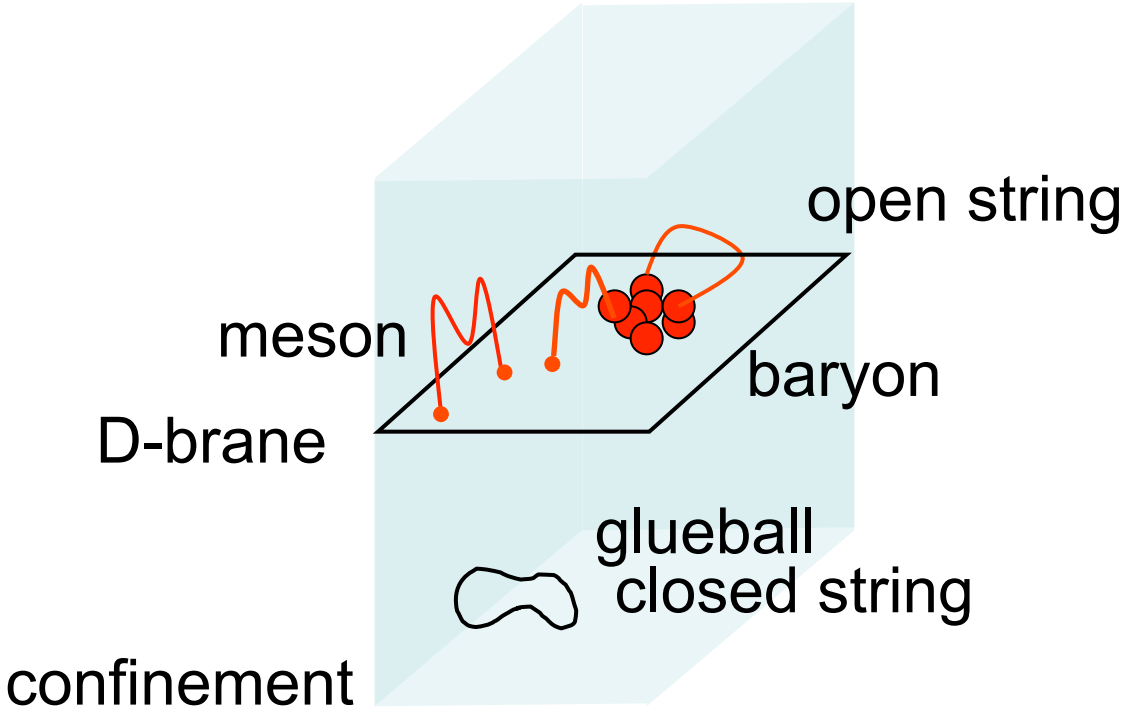
Nuclear
Physics



Nucleus

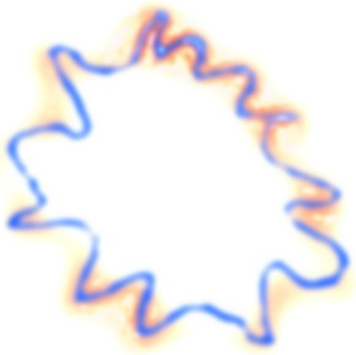
Unified picture of QCD

String theory + D-branes



10-dimensional curved spacetime

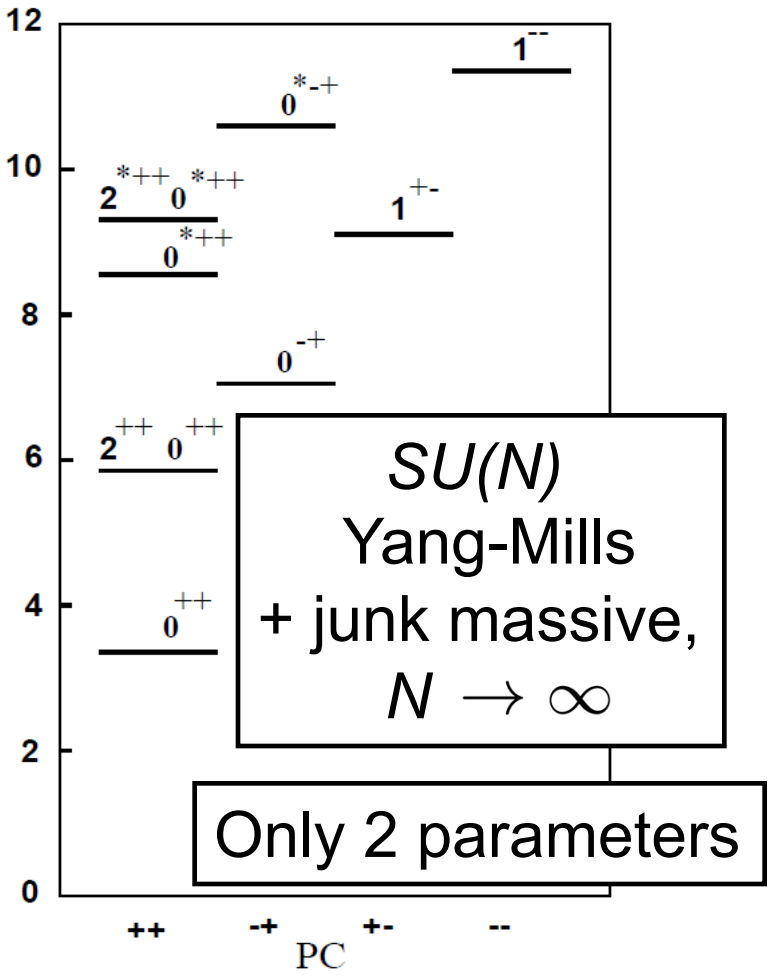
Superstring



Lattice

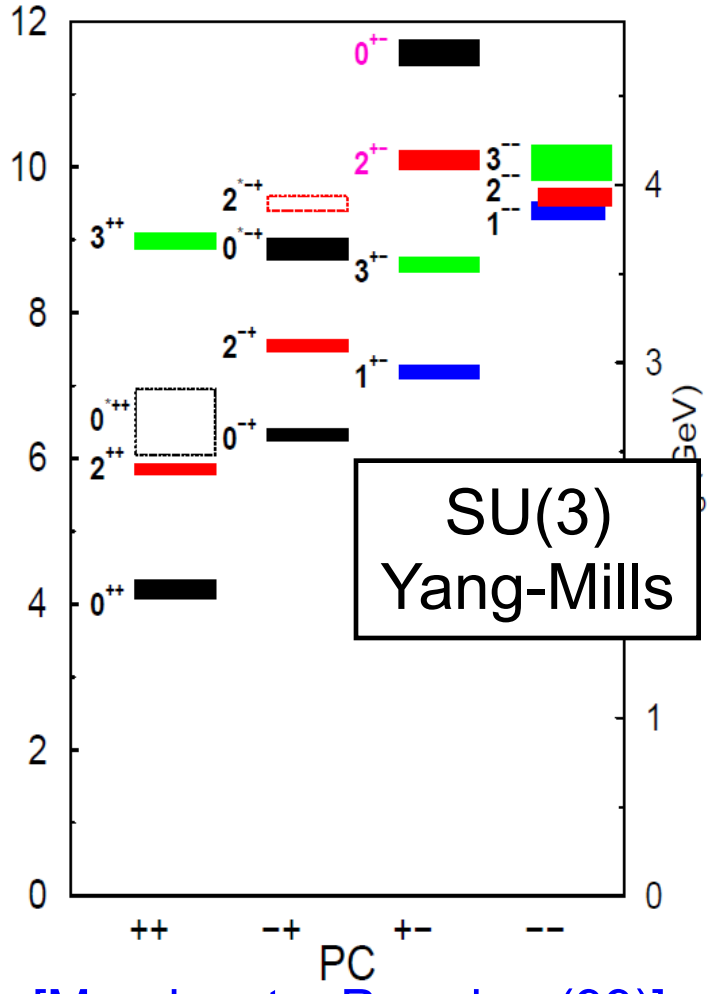
Glueball spectrum

Superstring



[Brower,Mathur,Tan (03)]

Lattice



[Morningstar,Peardon (99)]

Plan

Superstringy Hadron Physics

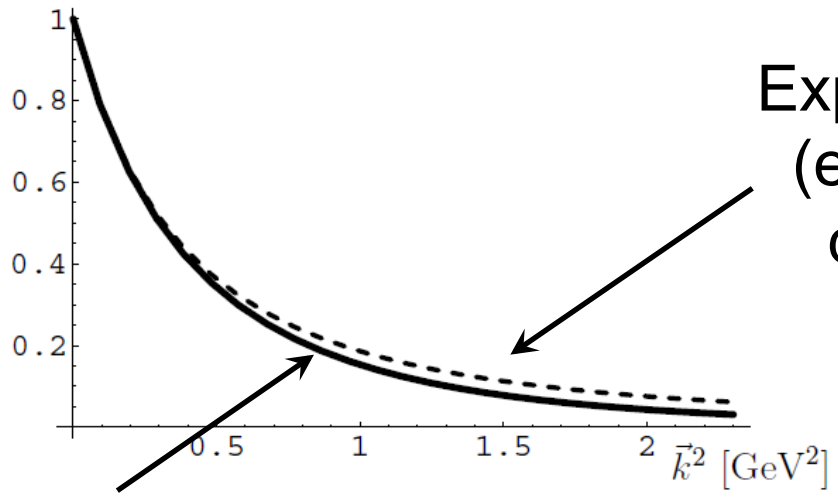
Superstringy Nuclear Physics

Couplings, Radii of Nucleon

[Sakai,Sugimoto,KH (0806.3122)]

	Superstring	Experiment	
$\langle r^2 \rangle_{E,\mathrm{p}}$	$(0.74\ \mathrm{fm})^2$	$(0.875\ \mathrm{fm})^2$	
$\langle r^2 \rangle_{E,\mathrm{n}}$	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	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 : $c_1 = 3.6 - 4.4\ [\mathrm{GeV}^{-1}]$

Hyperon Spectra

[Iizuka,Ishii,Kadoh,KH, 0910.1179]

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Mass splitting of baryons with $\Delta I_3 = 1$

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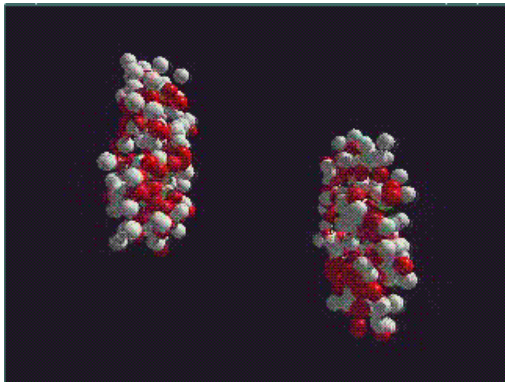
Our inputs : $m_{\pi^\pm}, m_{K^\pm}, m_{K^0}, f_\pi$

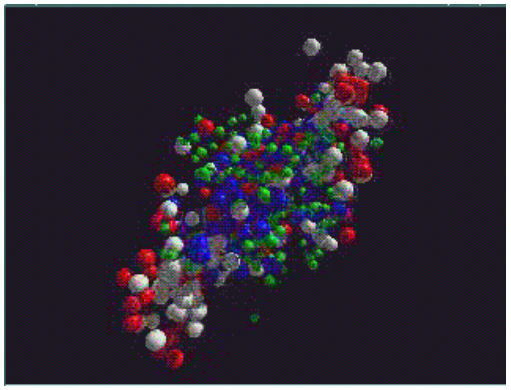
Thermalization

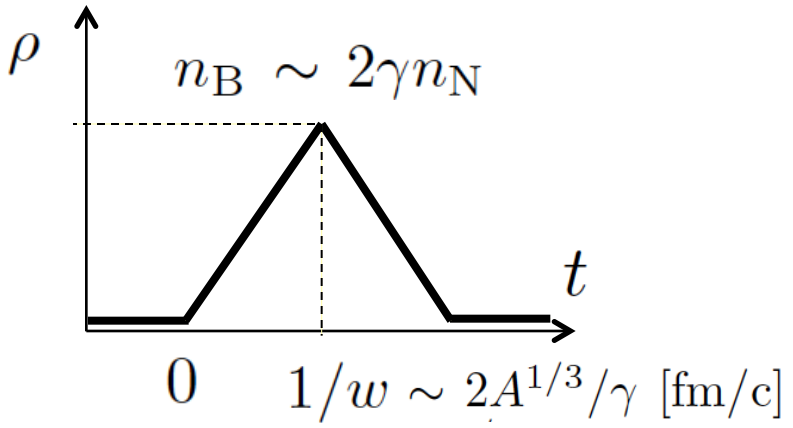
[Iizuka,Oka,KH, 1012.4463]

Heavy ion collision: Non-equilibrium thermodynamics



Collide





Superstring : thermalization time is

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

$< 1\,[\mathrm{fm/c}]$ for RHIC

consistent with hydrodynamics

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

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, Thermalization, …

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

Superstringy Hadron Physics

Superstringy Nuclear Physics

Superstring derives multi-nucleon system

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

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

"Nuclear Matrix Theory" : String 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 :

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

$\Rightarrow$ $I = J = 1/2$ $940^+, 1359^+, 1359^-, 1778^+, 1778^-, \ldots$

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

A=2 : Nuclear force, repulsive core

[Iizuka,Yi, KH 1003.4988]

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

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

Repulsive core reproduced.

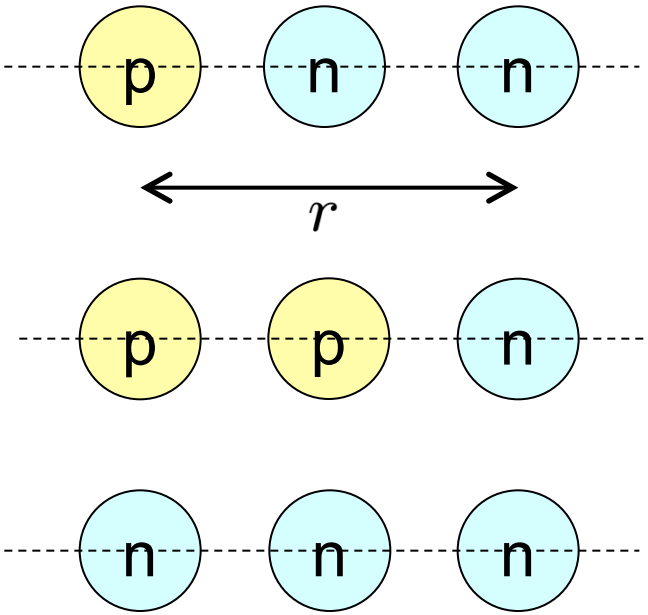
Interesting scaling : $1/r^2$

A=3 : 3-body nuclear force

3-body forces suppressed by $1/\lambda \sim \mathcal{O}(1/10)$

[Iizuka, Nakatsukasa, KH, 0911.1035]

Explicit evaluation [Iizuka, KH,1005.4412]



Triton

He-3 nucleus

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

Neutron star

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

spin : averaged

All positive, consistent with expectations from various data

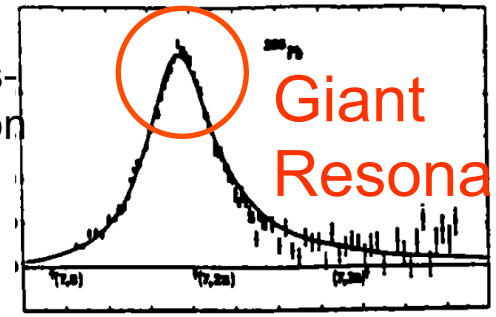
Large A : Formation of nucleus

Many baryons : bound to form a nucleus [Morita, KH, to appear]

To appear

Large A : Giant resonance

Pb nucleus



[KH (0809.3141,0910.2303)]

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

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

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

Reproducing *A* dependence

Unification

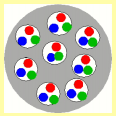
Quark / Gluon

Lattice
QCD

Hadron, Nucleon

AdS/CFT

Nuclear
Physics



Nucleus

What is your goal of hadron physics?