Nucleon Dynamics in D4/D8 Holographic QCD

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with a string theoretical holographic QCD

of very few adjustable parameters,

to what extent can one do

a decent qualitative/quantitative particle physics ?

$$N_c \gg 1$$

1. holography keeps color-singlets (large N master fields) only:
   no trace of color indices remains in the 5D holographic description

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2. holography elevates a continuous global symmetry to a gauge symmetry:
   4D flavor symmetry → 5D flavor gauge symmetry

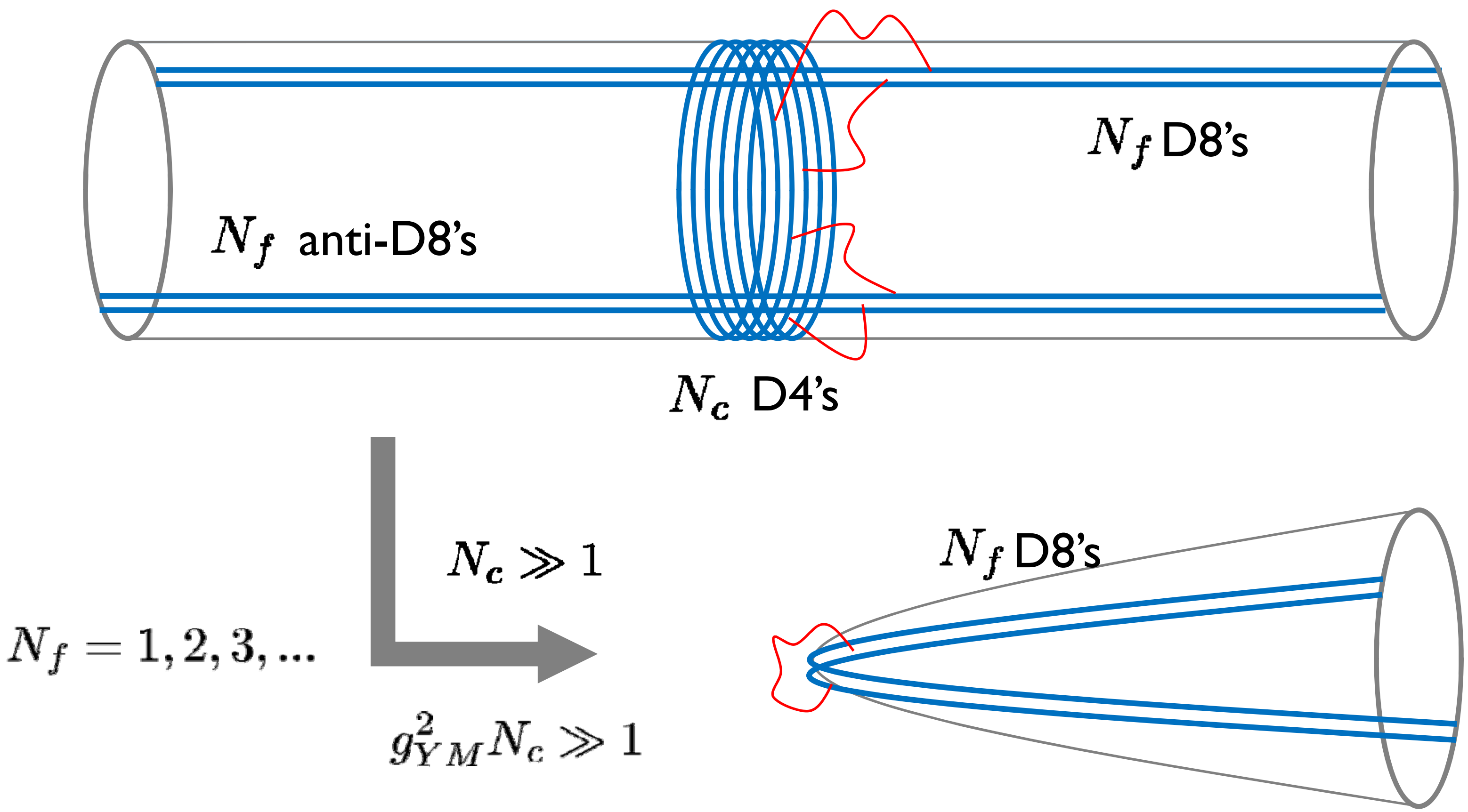
Sakai, Sugimoto., 2004

$$A_n,\ F_{mn}\ \in\ U(N_f)$$

$$\int dx^{3+1} \int dw\ \frac{1}{4e(w)^2}\,\mathrm{tr}\,F^{mn}F_{mn} + \frac{N_c}{24\pi^2}\int \omega_5(A)$$

$$\frac{1}{e(w)^2} = \frac{\lambda N_c}{108\pi^3} M_{KK}\frac{u(w)}{u(0)}$$

string theory origin: D4/D8-branes



warp factor

IR flavor coupling function:
it dictates all couplings and
mass distributions (with M_{KK})
in the flavor sector $\sim 4\Lambda_{QCD}$

$$\frac{1}{e(w)^2} = \frac{\lambda N_c}{108\pi^3} M_{KK} \boxed{\frac{u(w)}{u(0)}}$$

vs

an extra UV parameter
that appears because
the underlying color theory is
an open string theory and
becomes QCD only at low energy

$$\lambda \equiv g_{YM}^2 N_c$$

$$g_{YM}^2 = 2\pi g_s M_{KK} \sqrt{\alpha'}$$

$$N_c \gg 1$$

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$$\lambda \equiv g_{YM}^2 N_c \gg 1$$

3. holographic description becomes a controllable effective field theory,
   as stringy components become decoupled

Sakai+Sugimoto, 2004

5D flavor gauge theory → 4D chiral theory of mesons

$$\int dx^{3+1} \int dw \, \frac{1}{4e(w)^2} \, \mathrm{tr}\, F^{mn} F_{mn} + \frac{N_c}{24\pi^2} \int \omega_5(A)$$

$$= \int dx^{3+1} \left\{ \frac{f_\pi^2}{4} \mathrm{tr} \left(U^{-1} \partial U \right)^2 + \frac{1}{32 e_{Sk}^2} \mathrm{tr} \left[U^{-1} \partial U, U^{-1} \partial U \right]^2 \right\}$$

$$+ \int dx^{3+1} \left\{ \sum_n \frac{1}{4} (\partial_\mu a_\nu^{(n)} - \partial_\nu a_\mu^{(n)})^2 - \sum_n m_n^2 (a_\mu^{(n)} - \partial_\mu \phi^{(n)})^2 \right\}$$

$$+ \int dx^{3+1} \, \mathcal{L}_{interactions}$$

$$+ \int dx^{3+1} \, \mathcal{L}_{WZW}$$

$$f_\pi^2 = \frac{(g_{YM}^2 N_c) N_c}{54\pi^2} M_{KK}^2 \qquad \frac{1}{e_{Sk}^2} \simeq \frac{61 (g_{YM}^2 N_c) N_c}{54\pi^2}$$

extrapolation to real QCD

$$M_{KK} \sim 0.94GeV, \quad \lambda = g_{YM}^2 N_c \sim 17$$

$$f_\pi \sim 93MeV, \quad m_\rho \sim 770MeV$$

Sakai+Sugimoto, 2004

$$m_{\eta'}^2\Big|_{\text{D4-D8}} = \frac{1}{27\pi^2}\frac{N_f}{N_c}\lambda^2 M_{KK}^2$$

$$\sim (0.8GeV)^2 \quad \text{with } N_f = 2; N_c = 3$$

$$\sim (0.98GeV)^2 \quad \text{with } N_f = N_c = 3$$

$$m_{\eta'}\Big|_{exp} \sim 0.958GeV$$

also, consistent with E. Witten's large N_c prediction !

$$m_{\eta'}^2 \sim \frac{N_f}{N_c}$$

NPB156, 269-283 (1979)

Sakai, Sugimoto., 2004

$A_n,\ F_{mn}\ \in\ U(2_f)$

$$\int dx^{3+1} \int dw\ \frac{1}{4e(w)^2}\,\mathrm{tr}\,F^{mn}F_{mn} + \frac{N_c}{24\pi^2}\int \omega_5(A)$$

$$A_n,\ F_{mn}\ \in\ U(2_f)$$

$$\int dx^{3+1} \int dw\, \frac{1}{4e(w)^2}\, \mathrm{tr}\, F^{mn} F_{mn} + \frac{N_c}{24\pi^2} \int \omega_5(A)$$

identify baryons as coherent state,

quantize them,

& derive the effective action thereof

Hong, Rho, Yee, P.Y., 2007

$$\mathcal{B}_\alpha \in [2_f] \otimes \mathrm{Dirac}$$

$$A_n,\ F_{mn} \in U(2_f)$$

$$\int dx^{3+1} \int dw\, \frac{1}{4e(w)^2}\,\mathrm{tr}\, F^{mn}F_{mn} + \frac{N_c}{24\pi^2}\int \omega_5(A)$$

$$- \int dx^{3+1} \int dw\, \left[i\bar{\mathcal{B}}\gamma^m(\partial_m - iA_m^{U(2_f)})\mathcal{B} + im_{\mathcal{B}}(w)\bar{\mathcal{B}}\mathcal{B} \right]$$

$$+ \int dx^{3+1} \int dw\, \left[\frac{g_5(w)\rho^2_{\mathrm{baryon}}}{e(w)^2}\bar{\mathcal{B}}\gamma^{mn}F_{mn}^{SU(2_f)}\mathcal{B} \right]$$

to be used at tree-level only, as demanded by the holography

2. holography elevates a continuous global symmetry to a gauge symmetry:
4D flavor symmetry → 5D flavor gauge theory

4D baryon number → 5D gauge U(1) charge

solitonic baryon

$$\int dx^{3+1} \int dw \frac{1}{4e(w)^2} \,\mathrm{tr}\, F^{mn} F_{mn} + \frac{N_c}{24\pi^2} \boxed{\int \omega_5(A)}$$

$$\sim \mathbf{3\,tr}\, \boldsymbol{A \wedge F \wedge F + \cdots}$$

$$\sim 3A^{U(1)} \wedge \mathbf{tr}\, F \wedge F + \cdots$$

unit baryon number
= quark number N
→ U(1) charge N

→ $$\int_{I\times R^3} tr(F \wedge F)/8\pi^2 = 1$$

$$A_m^{SU(2)a}\Big|_{\text{trial}} = \bar{\eta}^a_{mk} \partial_k \log\left(1 + \rho^2/(\vec{x}^2 + w^2)\right)$$

$$A_0^{U(1)}\Big|_{\text{trial}} = N_c \phi_{5D}^{(Coulomb)}(\vec{x}, w; \rho)$$

classical size

Hong, Rho, Yee, Yi, hep-th/0701276
Hata, Sakai, Sugimoto, Yamato, hep-th/0701280

$$\rho_{\text{baryon}} \simeq \frac{(2 \cdot 3^7 \cdot \pi^2/5)^{1/4}}{M_{KK}\sqrt{g_{YM}^2 N_c}} \simeq \frac{9.6}{M_{KK}\sqrt{\lambda}}$$

this soliton size has little to do with
either the charge radius or the NN repulsive core seen

the latter two are separately computable
and dictated by the couplings to spin 1 mesons and their masses

$$N_c \gg 1, \;\; \lambda \gg 1$$

Compton size << soliton size << meson Compton sizes

→ the shape of the classical soliton is trustworthy, yet,
it can still be treated point-like for interaction with mesons

→ the isospin ½ spin ½ baryon field $\mathcal{B}$

after a long song and dance…

Hong, Rho, Yee, P.Y., 2007

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$$A_n,\ F_{mn} \in U(2_f)$$

$$\int dx^{3+1} \int dw\, \frac{1}{4e(w)^2} \,\mathrm{tr}\, F^{mn} F_{mn} + \frac{N_c}{24\pi^2} \int \omega_5(A)$$

$$- \int dx^{3+1} \int dw \left[i\bar{\mathcal{B}}\gamma^m (\partial_m - iA_m^{U(2_f)})\mathcal{B} + i m_B(w) \bar{\mathcal{B}}\mathcal{B} \right]$$

$$+ \int dx^{3+1} \int dw \left[\frac{g_5(w)\rho^2_{\mathrm{baryon}}}{e(w)^2} \bar{\mathcal{B}}\gamma^{mn} F_{mn}^{SU(2_f)} \mathcal{B} \right]$$

$$\int dx^{3+1} \int dw \left[-i\bar{\mathcal{B}}\gamma^m(\partial_m - iA_m^{U(2_f)})\mathcal{B} - im_{\mathcal{B}}(w)\bar{\mathcal{B}}\mathcal{B} + \frac{g_5(w)\rho^2_{\mathrm{baryon}}}{e(w)^2}\bar{\mathcal{B}}\gamma^{mn}F_{mn}^{SU(2_f)}\mathcal{B} \right]$$

5D minimal coupling

5D tensor coupling

5D mass function

$$m_{\mathcal{B}}(w) = \frac{4\pi^2}{e(w)^2} = \frac{\lambda N_c}{27\pi} M_{KK} \frac{u(w)}{u(0)}$$

the holographic origin of

1. the leading axial coupling to pions,
2. nucleon anomalous magnetic moments,
3. minimal couplings to axial vectors,
4. tensor couplings to vectors,

etc

$$g_5(0) = \frac{2\pi^2}{3}$$

Hong, Rho, Yee, P.Y., 2007

$$\int dx^{3+1} \int dw \left[-i\bar{\mathcal{B}}\gamma^m(\partial_m - iA_m^{U(2_f)})\mathcal{B} - i m_B(w)\bar{\mathcal{B}}\mathcal{B} + \frac{g_5(w)\rho^2_{\rm baryon}}{e(w)^2}\bar{\mathcal{B}}\gamma^{mn}F_{mn}^{SU(2_f)}\mathcal{B}\right]$$

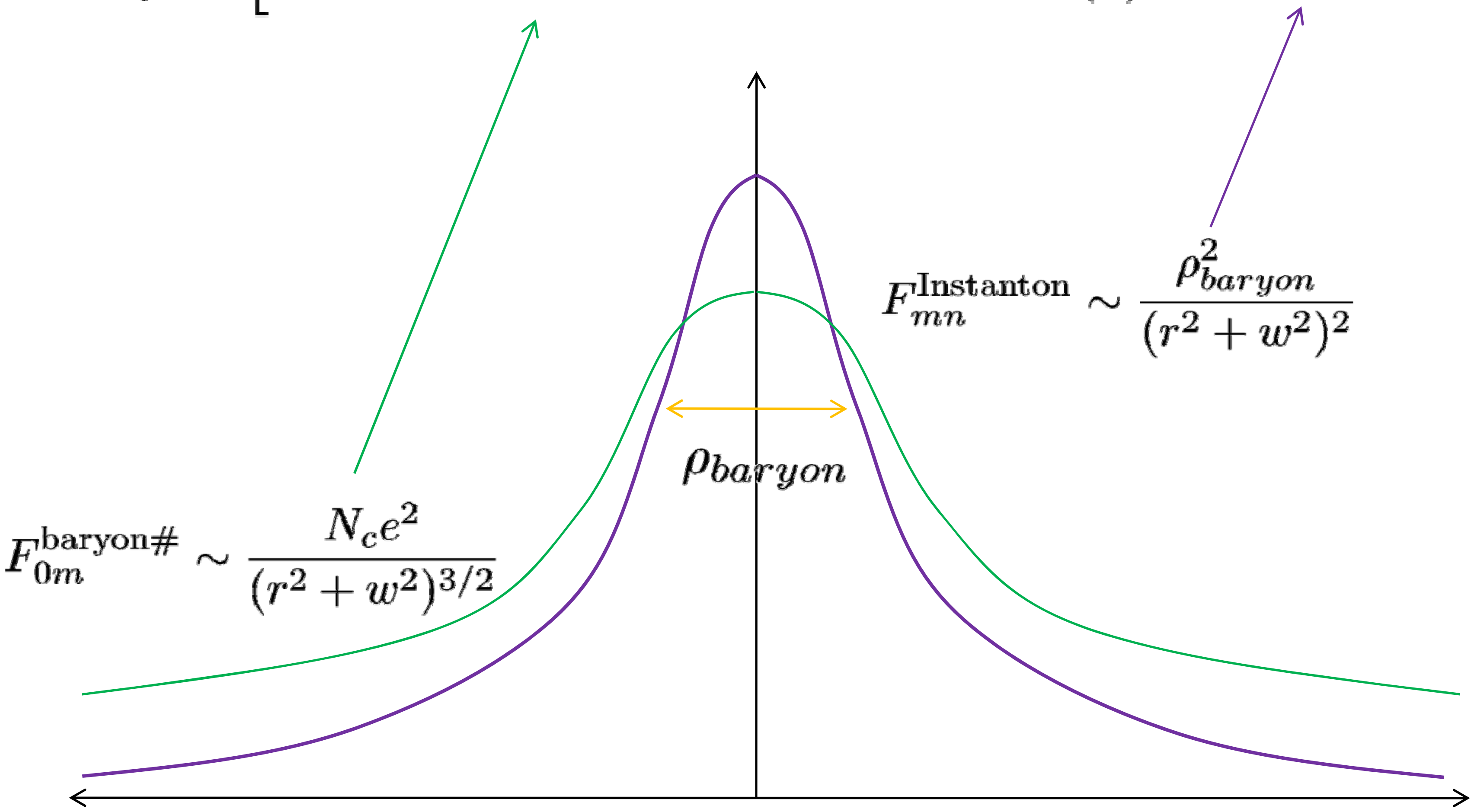
$U(1)$ part

leading in $1/\lambda$

leading in $1/N_c$

Hong, Rho, Yee, P.Y., 2007

$$\int dx^{3+1} \int dw \left[-i\bar{\mathcal{B}}\gamma^m(\partial_m - iA_m^{U(2_f)})\mathcal{B} - im_{\mathcal{B}}(w)\bar{\mathcal{B}}\mathcal{B} + \frac{g_5(w)\rho^2_{\rm baryon}}{e(w)^2}\bar{\mathcal{B}}\gamma^{mn}F_{mn}^{SU(2_f)}\mathcal{B}\right]$$



Hong, Rho, Yee, P.Y., 2007

an effective action for 4D nucleons/mesons

$$\int dx^{3+1} \int dw \left[-i\bar{\mathcal{B}}\gamma^m(\partial_m - iA_m^{U(2_f)})\mathcal{B} - im_{\mathcal{B}}(w)\bar{\mathcal{B}}\mathcal{B} + \frac{g_5(w)\rho^2_{\text{baryon}}}{e(w)^2}\bar{\mathcal{B}}\gamma^{mn}F_{mn}^{SU(2_f)}\mathcal{B}\right]$$

$$\mathcal{B}(x,w) = \begin{pmatrix} B_+(x)f_+(w) \\ B_-(x)f_-(w) \end{pmatrix}$$

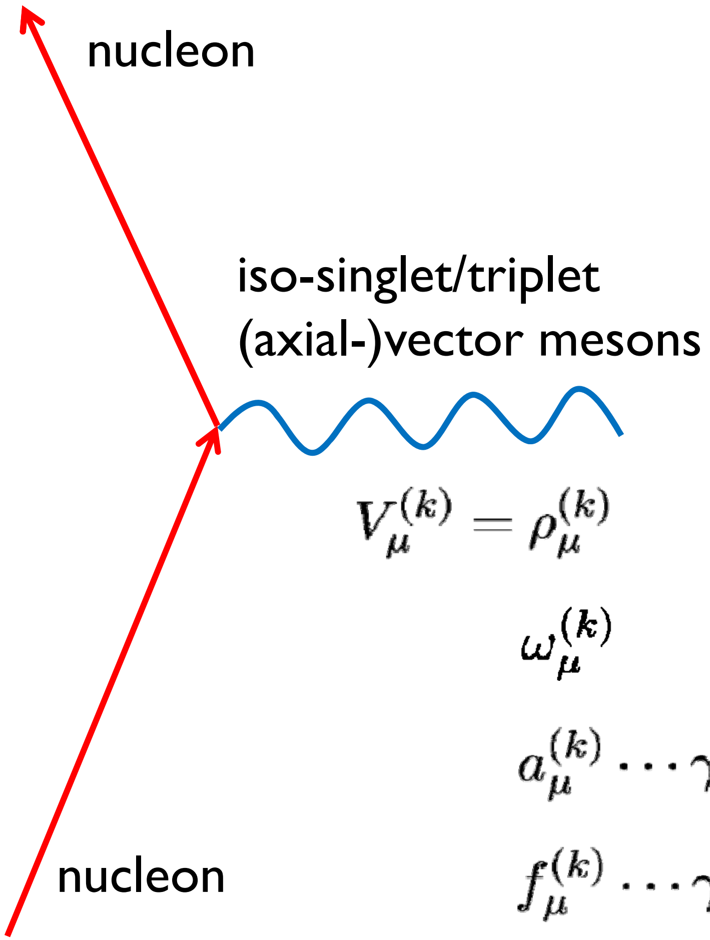
$$\mathcal{N}(x) \equiv \begin{pmatrix} B_+(x) \\ B_-(x) \end{pmatrix}$$

$$A_m(x^\mu; w) \;\rightarrow\; \text{mesons}$$

$$\int dx^{3+1}\; \left[-i\bar{\mathcal{N}}\gamma^\mu\partial_\mu\mathcal{N} - im_{\mathcal{N}}\bar{\mathcal{N}}\mathcal{N}\right] + \cdots$$

$$\pm\partial_w f_\pm(w) + m_{\mathcal{B}}(w)f_\pm(w) = m_{\mathcal{N}}f_\mp(w)$$

$$g_5(0) = \frac{2\pi^2}{3}$$



$$V_\mu^{(k)} = \rho_\mu^{(k)}$$

$$\omega_\mu^{(k)}$$

$$a_\mu^{(k)} \cdots \gamma^5$$

$$f_\mu^{(k)} \cdots \gamma^5$$

$$g_{V^{(k)}\mathcal{N}\mathcal{N}} \left[\bar{\mathcal{N}} V_\mu^{(k)} \gamma^\mu \mathcal{N}\right]$$

$$\tilde{g}_{V^{(k)}\mathcal{N}\mathcal{N}} \left[\frac{\bar{\mathcal{N}} \partial_\nu V_\mu^{(k)} \gamma^{\nu\mu} \mathcal{N}}{2m_\mathcal{N}}\right]$$

$VV\mathcal{N}\mathcal{N}$ quartic terms also present but not shown

numbers

Kim, Lee, P.Y. 2009

$$\tilde{g}_{\omega^{(k)}\mathcal{N}\mathcal{N}} = 0$$

$$\tilde{g}_{a^{(k)}\mathcal{N}\mathcal{N}} = 0$$

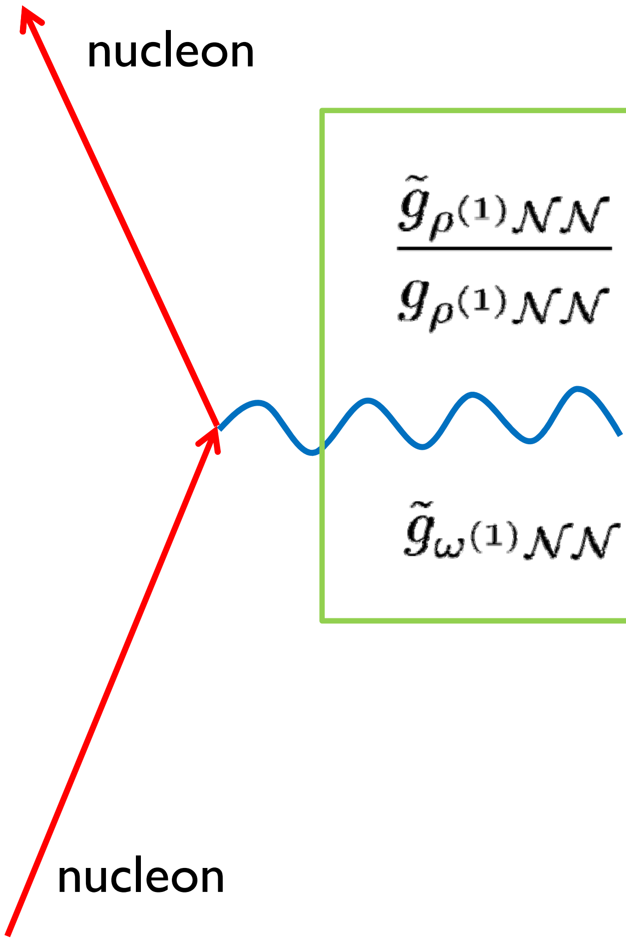
$$\tilde{g}_{f^{(k)}\mathcal{N}\mathcal{N}} = 0$$

all tensor couplings vanish identically,
except for those associated with
the tower of rho mesons (iso-triplet vectors)

(meaning that coefficients of the respective leading 1/ N behavior vanish,
and, thus, is NOT a consequence of large N countings)

numbers

Kim, Lee, P.Y. 2009



$$\frac{\tilde{g}_{\rho^{(1)}NN}}{g_{\rho^{(1)}NN}} \simeq 6 \times \frac{m_N}{M_{KK}}$$

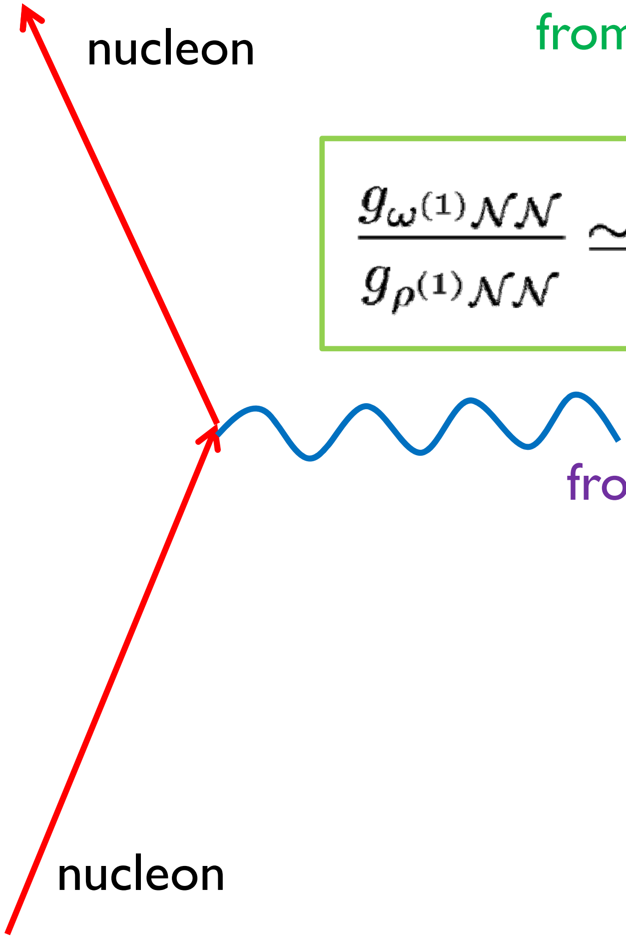
$$\tilde{g}_{\omega^{(1)}NN} = 0$$

$$\left(\frac{\tilde{g}_{\rho NN}}{g_{\rho NN}}\right)_{empirical} \simeq 6.1$$

$$\left(\frac{\tilde{g}_{\omega NN}}{g_{\omega NN}}\right)_{empirical} \simeq 0$$

R. Machaleidt,
in Advances in Nuclear Physics, Vol. 19
Edited by J. W. Negele and E. Vogt
(Plenum, New York, 1986),

numbers



from 5D minimal term

$$\frac{g_{\omega^{(1)}\mathcal{N}\mathcal{N}}}{g_{\rho^{(1)}\mathcal{N}\mathcal{N}}} \simeq N_c + \delta \sim 3.6$$

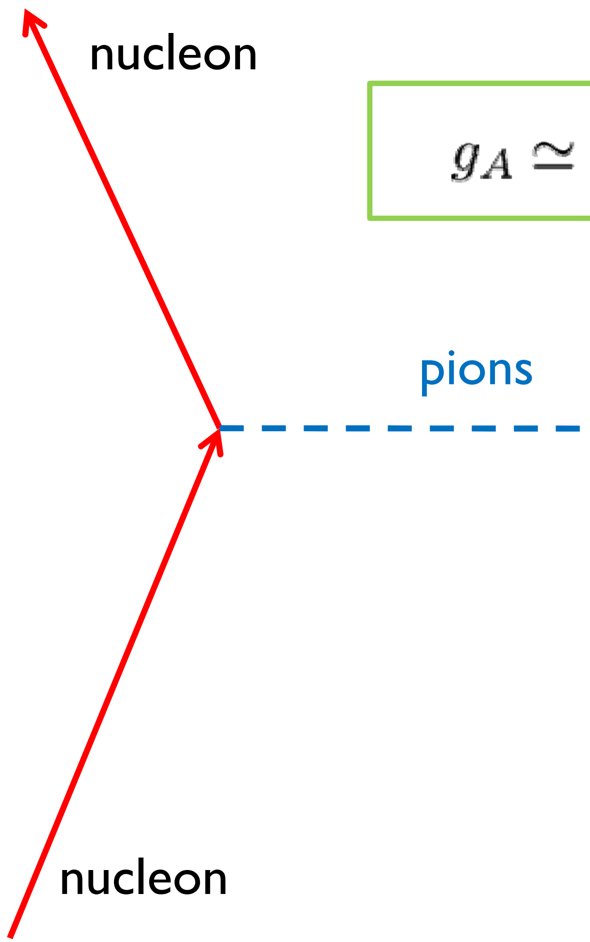
from 5D tensor term

$$\left(\frac{g_{\omega\mathcal{N}\mathcal{N}}}{g_{\rho\mathcal{N}\mathcal{N}}}\right)_{empirical} = 3.3 \sim 4.5?$$

Hoehler, Pietarinen, 1975
Stoks, Klomp, Terheggen, de Swart, 1994
Machleidt, 2001
Gross, Stadler, 2007

numbers

Hong, Rho, Yee, P.Y., 2007

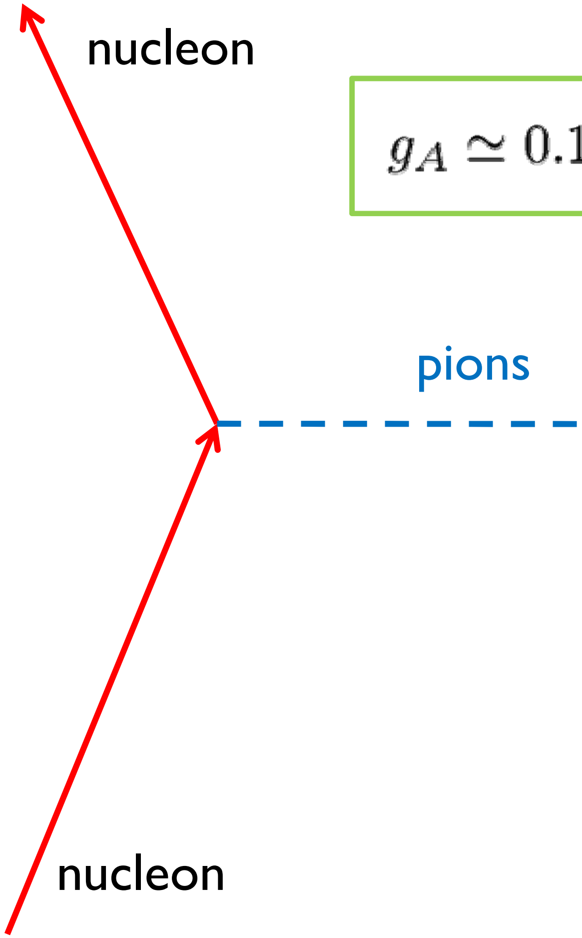


$$g_A \simeq 0.18 \times (4/\pi) \times N_c + O(N_c^{-1}) \simeq 0.69 + 0.14$$

$$(g_A)_{exp} \simeq 1.27$$

numbers

Hong, Rho, Yee, P.Y., 2007

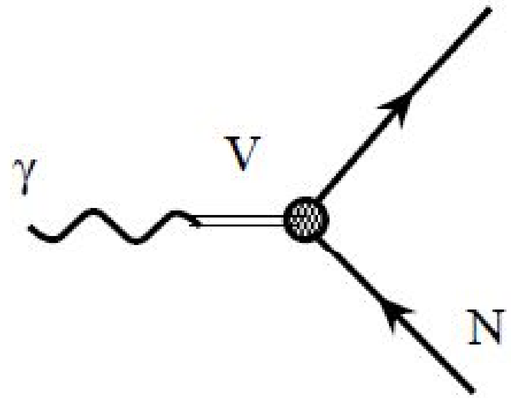


$$g_A \simeq 0.18 \times (4/\pi) \times (N_c + 2) + O(N_c^{-1}) \simeq 1.16 + 0.14$$

$$(g_A)_{exp} \simeq 1.27$$

E&M charge form factor: complete vector dominance again

$$
\begin{aligned}
F_1^{proton} &= F_{1,min} + \frac{1}{2} F_{1,mag} \,, \\
F_1^{neutron} &= -\frac{1}{2} F_{1,mag} \,.
\end{aligned}
$$



$$F_{1,min}(q^2) = 1 - \sum_k \frac{g^{(k)}_{V,min}\zeta_k q^2}{q^2 + m^2_{2k+1}} = \sum_k \frac{g^{(k)}_{V,min}\zeta_k m^2_{2k+1}}{q^2 + m^2_{2k+1}} = \sum_k \frac{g_{v^{(k)}} g^{(k)}_{V,min}}{q^2 + m^2_{2k+1}}$$

$$F_{1,mag}(q^2) = -\sum_k \frac{g^{(k)}_{V,mag}\zeta_k q^2}{q^2 + m^2_{2k+1}} = \sum_k \frac{g^{(k)}_{V,mag}\zeta_k m^2_{2k+1}}{q^2 + m^2_{2k+1}} = \sum_k \frac{g_{v^{(k)}} g^{(k)}_{V,mag}}{q^2 + m^2_{2k+1}} .$$

k	m^2_{2k+1}	ζ_k	$g^{(k)}_{V,min}$	$g^{(k)}_{V,mag}$	$g^{(k)}_{V,min}\zeta_k$	$g^{(k)}_{V,mag}\zeta_k$	$g^{(k)}_2\zeta_k$
0	0.67	0.272	5.933	-0.816	1.615	-0.222	3.323
1	2.87	-0.274	3.224	-1.988	-0.882	0.544	-1.918
2	6.59	0.272	1.261	-1.932	0.343	-0.526	0.828
3	11.8	-0.271	0.311	-0.969	-0.084	0.262	-0.243
sum	-	-	-	-	0.992	0.058	1.989($g_2 = 2.028$)

nonrelativistic effective nucleon dynamics with contact terms

$$\mathcal{N} = \begin{pmatrix} N + \frac{\nabla^2}{8m_{\mathcal{N}}^2} N \\ \\ \frac{\sigma\cdot\nabla}{2m_{\mathcal{N}}} N \end{pmatrix} + \cdots$$

$$\mathcal{L}_{\mathrm{nucleon}} = \mathcal{L}(N,\pi) + \mathcal{L}^{(6)}_{\mathrm{contact}} + \mathcal{L}^{(8)}_{\mathrm{contact}} + \cdots$$

nonrelativistic effective nucleon dynamics with contact terms

$$\mathcal{L}^{(6)}_{\text{contact}} = -\frac{1}{2}C_S^{(I=0)}(N^\dagger N)(N^\dagger N) - \frac{1}{2}C_T^{(I=0)}(N^\dagger \sigma^a N)(N^\dagger \sigma^a N)$$

$$-\frac{1}{2}C_S^{(I=1)}(N^\dagger \tau_a N)(N^\dagger \tau_a N) - \frac{1}{2}C_T(N^\dagger \sigma^a \tau_b N)(N^\dagger \sigma^a \tau_b N)$$

$$\mathcal{L}^{(8)}_{\text{contact}} = -\frac{1}{2}\sum_{i=1}^{7}(C')_i^{(I=0)}O_i^{(8)(I=0)} - \frac{1}{2}\sum_{i=1}^{7}(C')_i^{(I=1)}O_i^{(8)(I=1)}$$

$*$ higher order correction to the operators needed

nonrelativistic effective dynamics with contact terms

$$C_S^{(I=0)} \simeq 1.44 \times 10^{-4}\mathrm{MeV}^{-2}$$

$$C_S^{(I=1)} \simeq 0.112 \times 10^{-4}\mathrm{MeV}^{-2}$$

$$C_T^{(I=0)} \simeq -0.0272 \times 10^{-4}\mathrm{MeV}^{-2}$$

$$C_T^{(I=1)} \simeq 0.078 \times 10^{-4}\mathrm{MeV}^{-2}$$

Kim, Yi, P.Y., in progress

nonrelativistic effective dynamics with contact terms

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Kim, Yi, P.Y., in progress

$$C_S^{(I=0)} \simeq 1.12 \times 10^{-4} \mathrm{MeV}^{-2}$$

$$C_S^{(I=1)} \simeq 0.135 \times 10^{-4} \mathrm{MeV}^{-2}$$

$$C_T^{(I=0)} \simeq -0.266 \times 10^{-4} \mathrm{MeV}^{-2}$$

$$C_T^{(I=1)} \simeq -0.689 \times 10^{-4} \mathrm{MeV}^{-2}$$

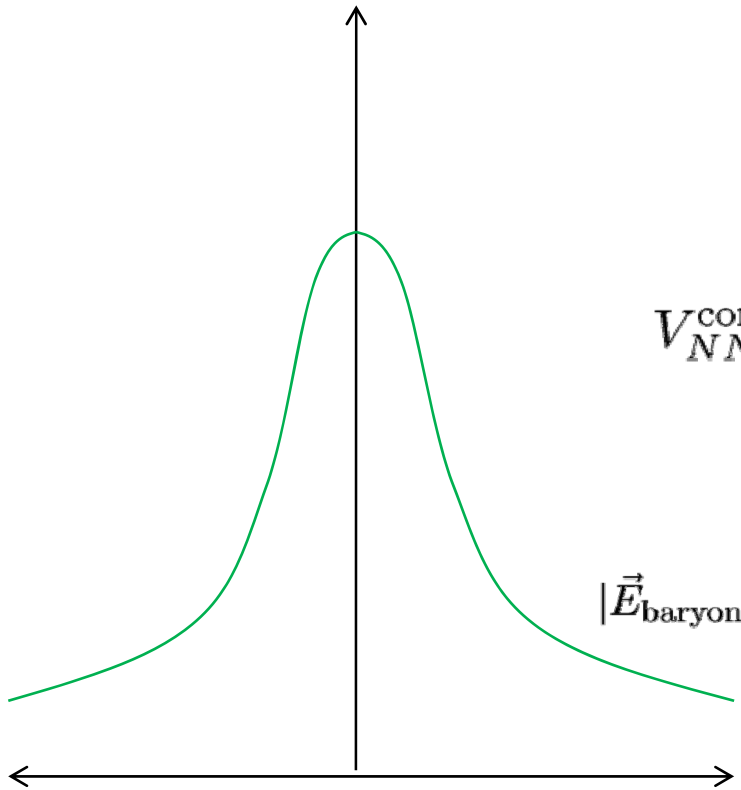
Ordonez, Ray, van Kolck 1996

nonrelativistic effective nucleon dynamics with contact terms

eventually, we wish to compute amplitudes
and compare directly against raw data

or alternatively, NN potential

a universal repulsive core between baryons from 5D Coulomb repulsion due to the baryon number as a gauge U(1) charge



$$V_{NN}^{\rm core} \sim \frac{1}{M_{KK} r^2} \times I(spin, isospin, \hat{r})$$

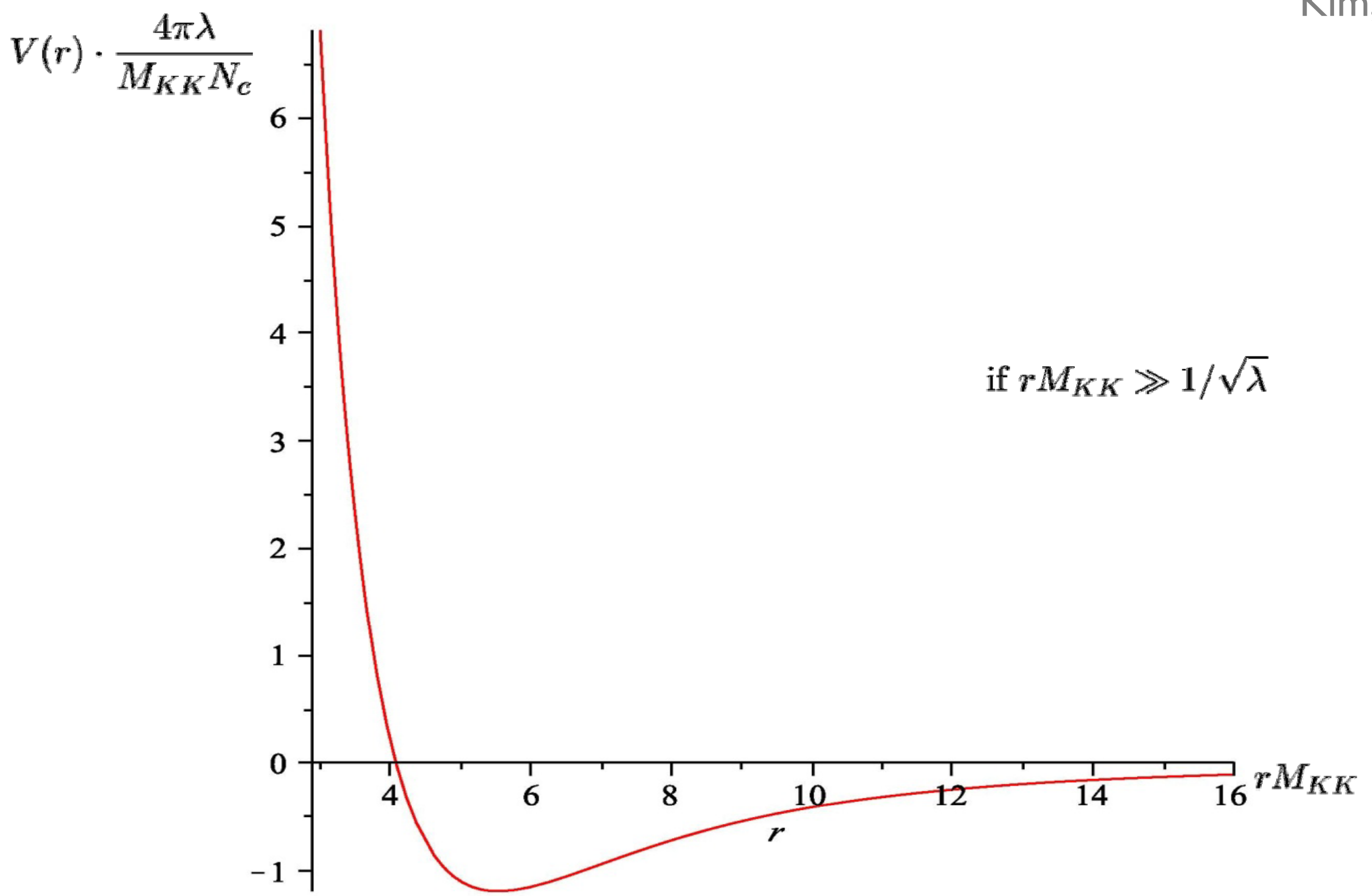
$$|\vec{E}_{\rm baryon}| \sim \frac{N_c e^2}{(r^2 + w^2)^{3/2}}$$

Kim, Zahed, 2009

Hashimoto, Sakai, Sugimoto, 2009

Lee, Kim, P.Y., 2009

Kim, Lee, P.Y. 2009



$$m_{\mathcal{N}} \sim \lambda N_c \quad \gg \quad E_{deformation} \sim N_c \quad \gg \quad E_{binding} \sim \frac{N_c}{\lambda}$$

issues

chiral limit → mass deformation by a technicolor sector ?

chiral condensate invisible → string theory tachyon ?

quenched → no practical answer here, yet

the small-sized/heavy baryon in stringy holographic QCD ? → matrix baryon !

the matter of size, again

$$1/m_{baryon} \ll \qquad \rho_{\rm baryon} \simeq \frac{(2\cdot 3^7\cdot \pi^2/5)^{1/4}}{M_{KK}\sqrt{g_{YM}^2 N_c}} \simeq \frac{9.6}{M_{KK}\sqrt{g_{YM}^2 N_c}} \qquad \ll 1/M_{KK}$$

the matter of size, again

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$$\simeq\ 4\sqrt{\alpha'}\ \times \text{warp factor at IR end}$$

$$\sim\ \text{comparable to local string size}$$

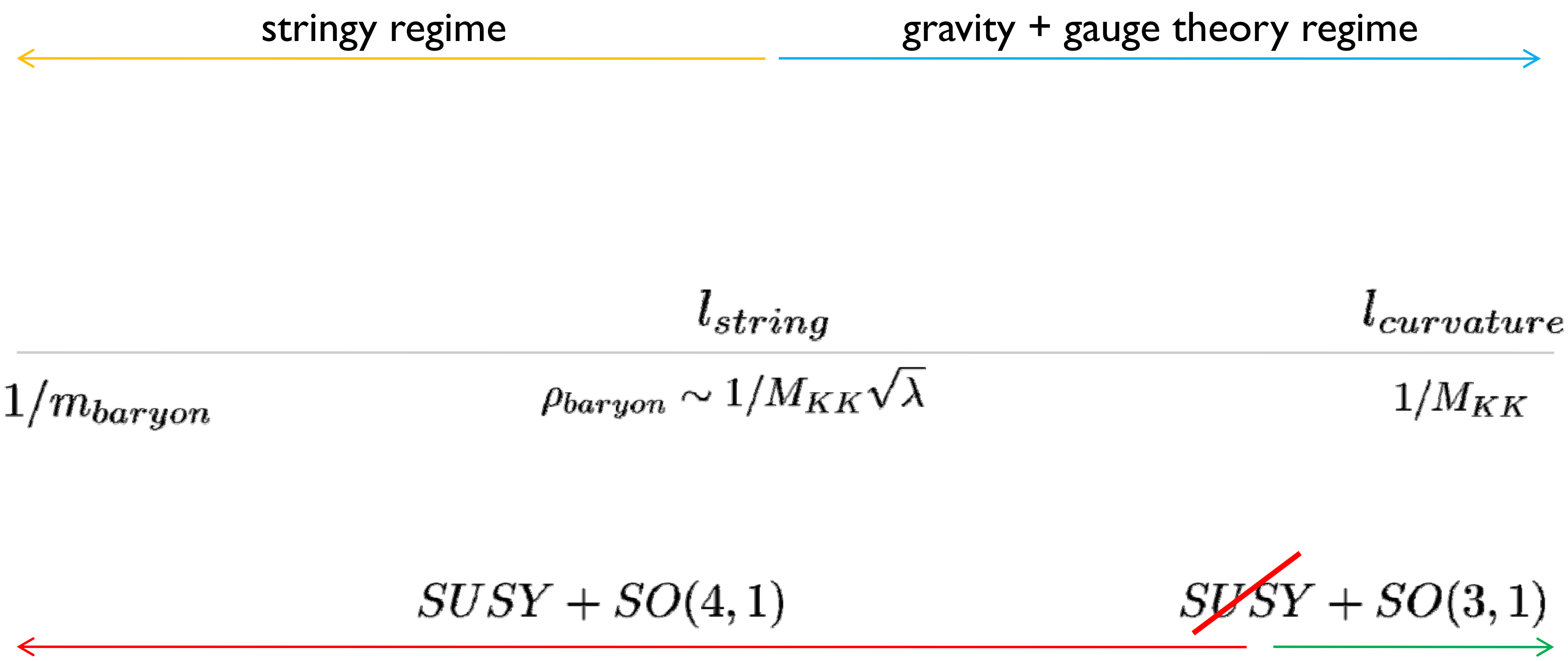
the matter of size, again

$$1/m_{baryon} \ll \qquad \rho_{\rm baryon} \simeq \frac{(2\cdot 3^7\cdot\pi^2/5)^{1/4}}{M_{KK}\sqrt{g_{YM}^2 N_c}} \simeq \frac{9.6}{M_{KK}\sqrt{g_{YM}^2 N_c}} \qquad \ll 1/M_{KK}$$

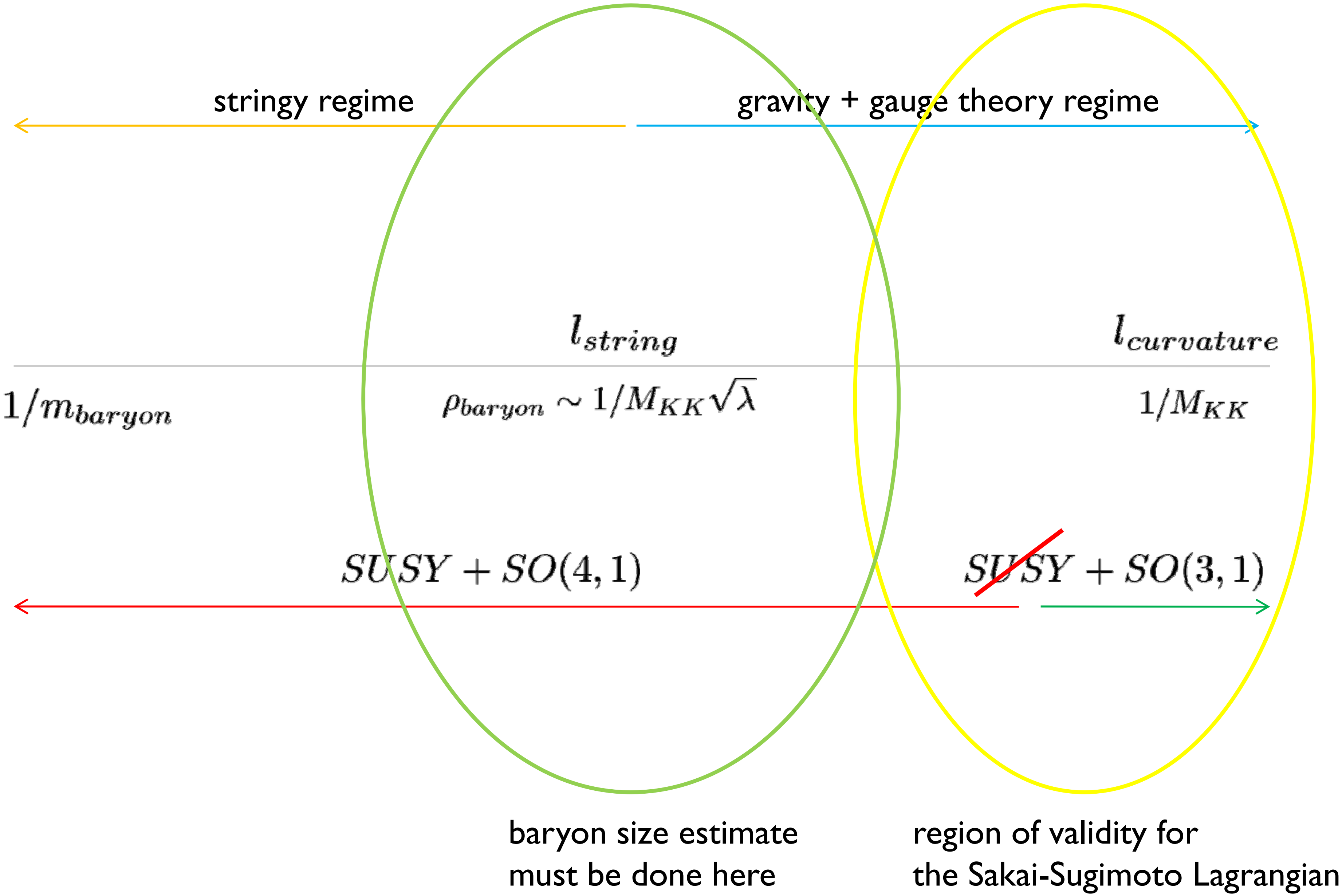
$$\simeq\ 4\sqrt{\alpha'}\ \times \text{warp factor at IR end}$$

$$\sim\ \text{comparable to local string size}$$

is the soliton size estimate reliable at all ?



stringy regime
gravity + gauge theory regime
l_{string}
$l_{curvature}$
$1/m_{baryon}$
$\rho_{baryon} \sim 1/M_{KK}\sqrt{\lambda}$
$1/M_{KK}$
$SUSY + SO(4,1)$
$SUSY + SO(3,1)$



stringy regime
gravity + gauge theory regime
l_{string}
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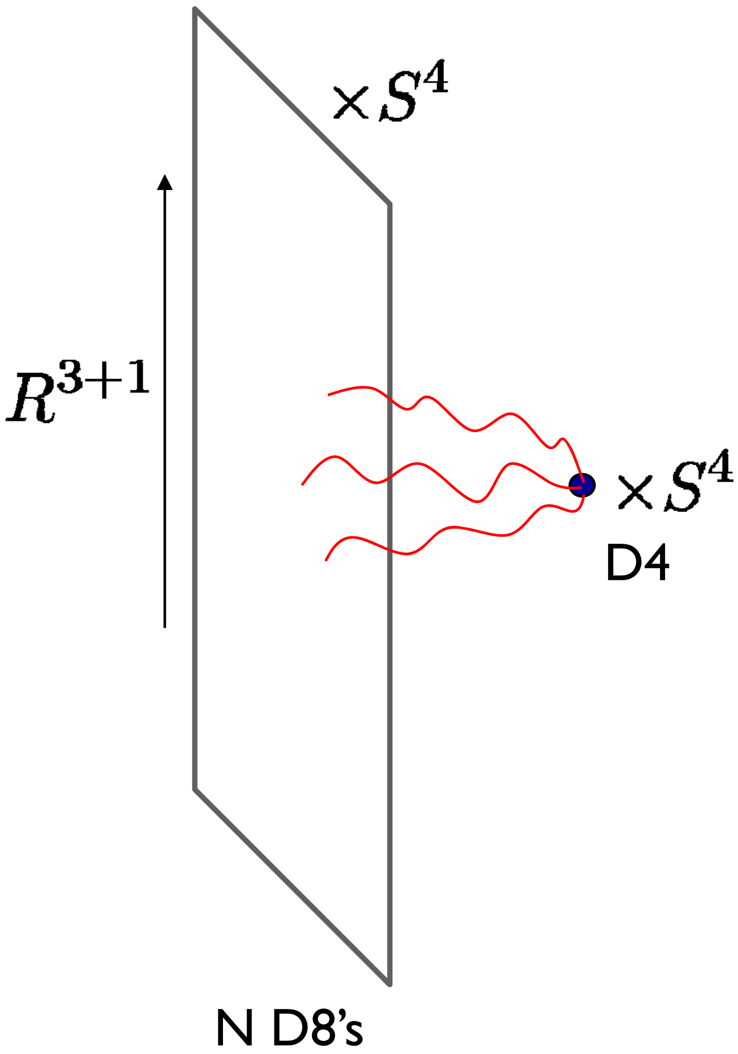
$1/m_{baryon}$
$\rho_{baryon} \sim 1/M_{KK}\sqrt{\lambda}$
$1/M_{KK}$
$SUSY + SO(4,1)$
$SUSY + SO(3,1)$
baryon size estimate must be done here
region of validity for the Sakai-Sugimoto Lagrangian

an alternate picture: a D4-brane wrapped on S^4



w_α^{af}

$a = 1, \ldots, k$

$k = \text{baryon\#}$

$f = 1, \ldots, N_f$

$\alpha = 1, 2$

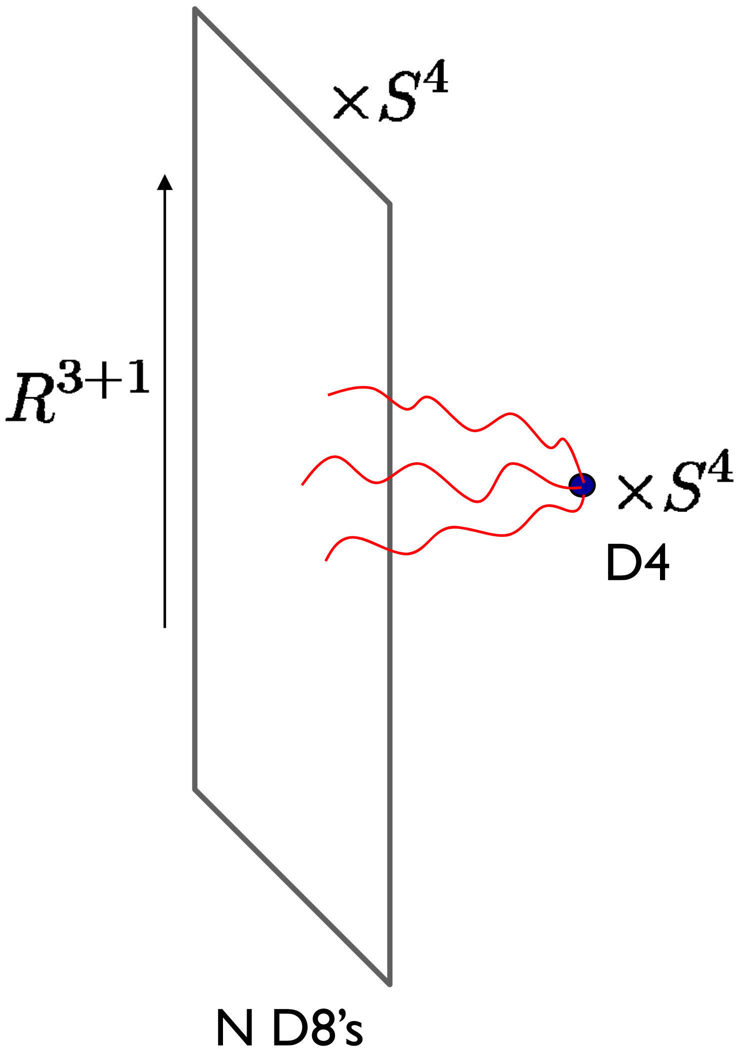
X_α^{ab}

$a, b = 1, \ldots, k$

$k = \text{baryon\#}$

$\alpha = 1, 2$

→ modified D4-D8 ADHM dynamics

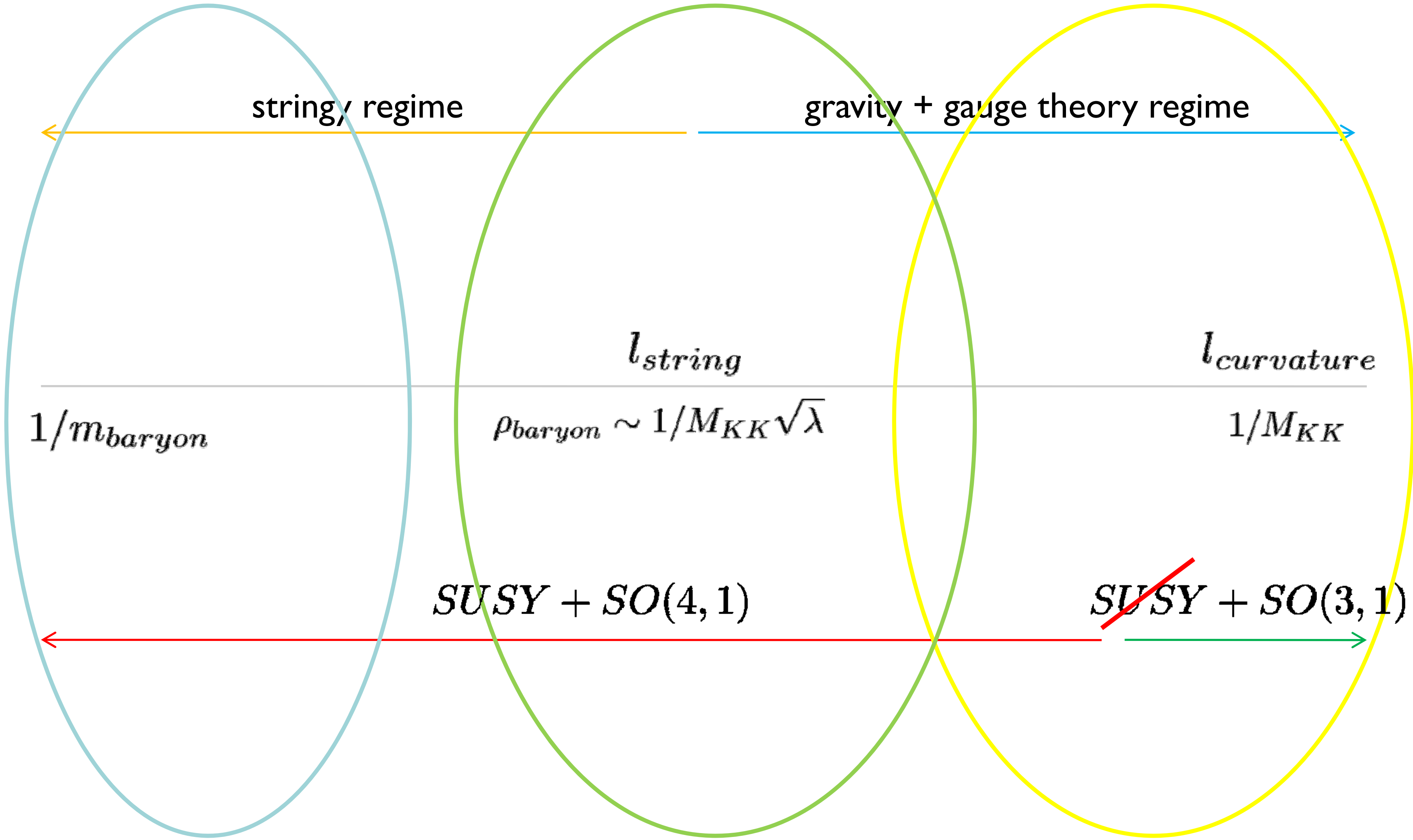


w_α^{af} X_α^{ab}

sizes of baryons   positions of baryons

$$\int dt\, \mathcal{L}_{\text{D4-D8}}$$
$$\sim \int |D_t w|^2 + |D_t X|^2 + |ww + XX|^2$$
$$+ \int M_{KK}^2 |w|^2 + \cdots$$
$$+ \int N_c A_0$$

Hashimoto, Iizuka, P.Y. 2010



region of validity for D4-D8 matrix model

baryon size estimate must be done here

region of validity for the soliton picture

Is the D4-D8 size estimate very different from the soliton one ?

$$\rho_{\text{baryon}}\Big|_{D4-D8} \simeq \frac{(3^7 \cdot \pi^2/2)^{1/4}}{M_{KK}\sqrt{g_{YM}^2 N_c}}$$

$$= \left(\frac{5}{4}\right)^{1/4} \rho_{\text{baryon}}\Big|_{soliton}$$

$$\rho_{\text{baryon}}\Big|_{soliton} \simeq \frac{(2 \cdot 3^7 \cdot \pi^2/5)^{1/4}}{M_{KK}\sqrt{g_{YM}^2 N_c}}$$

$$\rho^2_{\text{baryon}}\Big|_{D4-D8} \simeq \frac{1}{2}|w|^2\Big|_{k=1}^{vacuum}$$

Hashimoto, Iizuka, P.Y. 2010

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the correct answer must be
somewhere in-between

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$$\rho_{\text{baryon}}\Big|_{soliton} \simeq \frac{(2 \cdot 3^7 \cdot \pi^2/5)^{1/4}}{M_{KK}\sqrt{g_{YM}^2 N_c}}$$

therefore, these estimates must be reliable within 5% or so,
despite the completely wrong regions of validities

stringy regime

gravity + gauge theory regime

l_{string} $l_{curvature}$

$1/m_{baryon}$ $\rho_{baryon} \sim 1/M_{KK}\sqrt{\lambda}$ $1/M_{KK}$

$SUSY + SO(4,1)$

~~$SUSY$~~ $+ SO(3,1)$

(approximate) supersymmetry at high scale actually allows
a simple interpolation between high scale and low scale

bulk supersymmetry important even for nonsusy field theories like QCD

things to do

compute physical processes directly within this model
for meaningful comparisons with data

better handling of many nucleon system → matrix baryons ?

incorporation of gravity for neutron star → cut-off geometry

understand why such naïve extrapolation from holographic limit
sometimes work at all for some quantities