Strong Force Fields and Stability of the Nucleon and a singly heavy baryon

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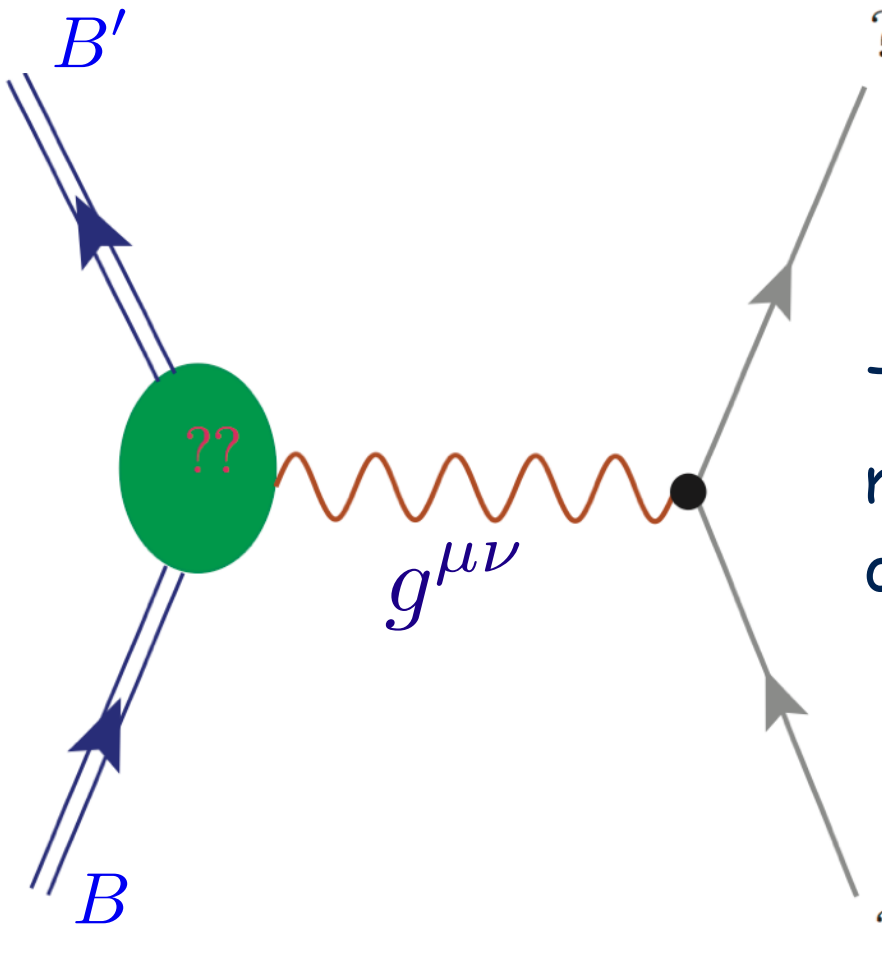
Gravitational form factors

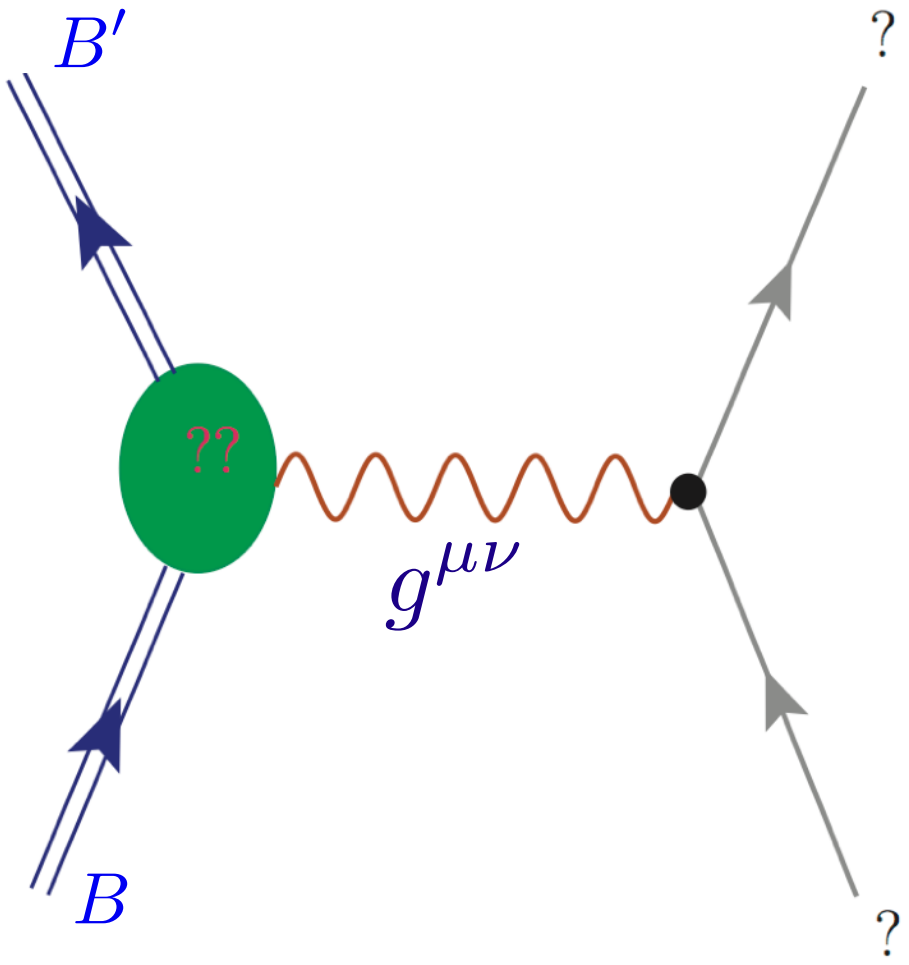
- Why Gravitational form factors?



They shed light on mechanical properties of hadrons.

Gravitational form factors

Probes are unknown for the **Gravitational form factors!**



Gravitational form factors

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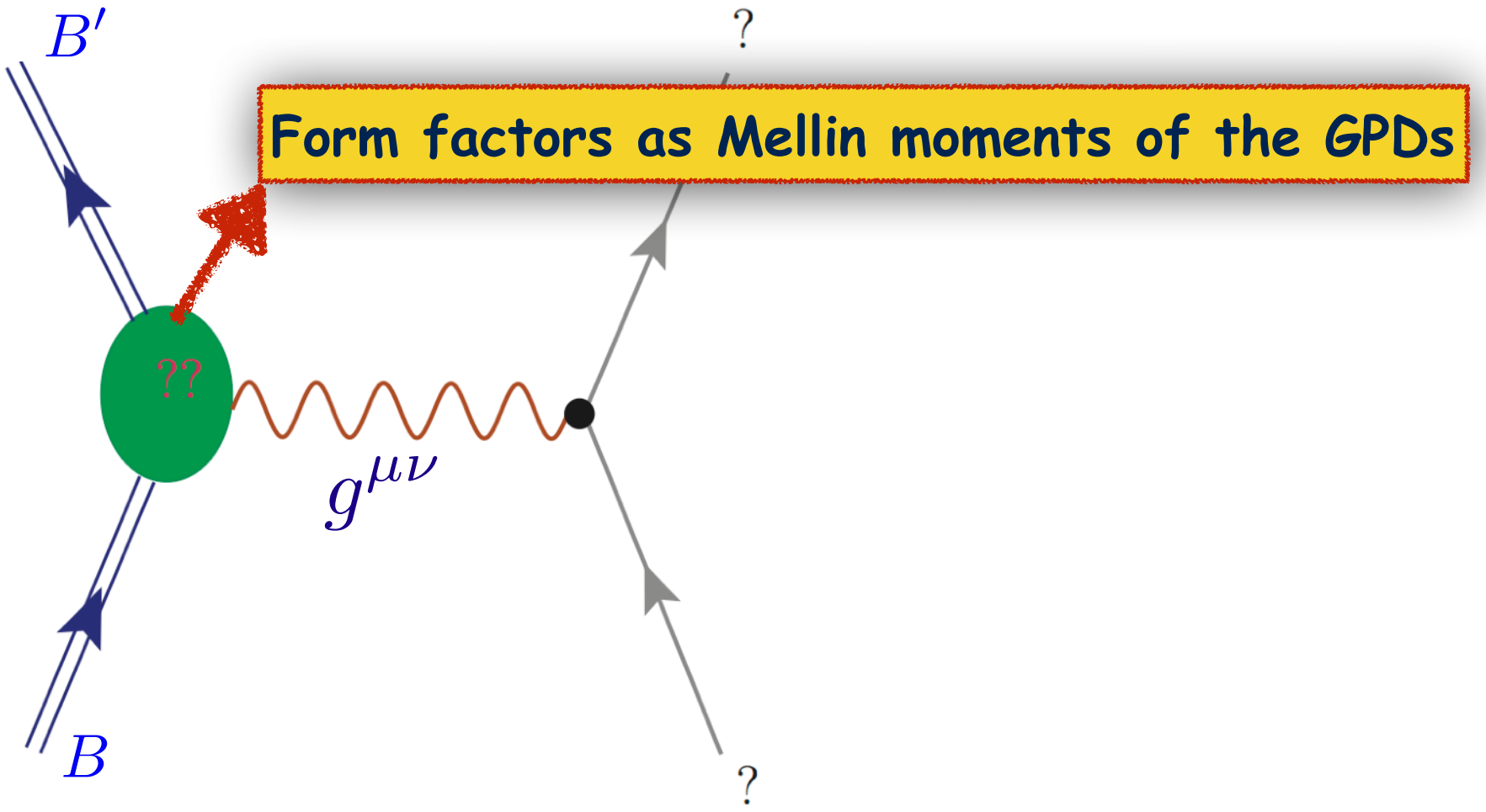


Gravitational form factors

- Unpolarized Generalized Parton Distributions

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \langle p', \sigma' | \overline{\psi}_q \left(-\frac{\lambda n}{2} \right) \not{n} \psi_q \left(\frac{\lambda n}{2} \right) | p, \sigma \rangle$$

$$= H^q(x,\xi,t) \overline{u}(p',\sigma') \not{n} u(p,\sigma) + E^q(x,\xi,t) \overline{u}(p',\sigma') \frac{i\sigma^{\mu\nu} n_\mu \Delta_\nu}{2M_B} u(p,\sigma)$$

$$n^2 = 1$$

$$\Delta = (p' - p)$$

$$n \cdot \Delta = -2\xi$$

The first moment: Electromagnetic form factors

- The second moment: Gravitational form factors

$$\int_{-1}^{1} dx \; x \sum_q H^q(x,\xi,t) = M_2^Q(t) + \frac{4}{5} d_1^Q(t) \xi^2,$$

$$\int_{-1}^{1} dx \; x \sum_q E^q(x,\xi,t) = 2J^Q(t) - M_2^Q(t) - \frac{4}{5} d_1^Q(t) \xi^2$$

Gravitational form factors

$$\langle p',\sigma'|\hat{T}^a_{\mu\nu}(0)|p,\sigma\rangle = \overline{u}(p',\sigma')\Big[M_2^a(t)\frac{P_\mu P_\nu}{M_B} + J^a(t)\frac{i(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M_B} + d_1^a(t)\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M_B} + \overline{c}^a(t)M_B g_{\mu\nu}\Big]u(p,\sigma)$$

- Components of the Energy-momentum tensor

$$\int d^3r \sum_{a=Q,G} T^a_{00}(\boldsymbol{r},\sigma',\sigma) = M_B M_2(0) = M_B, \quad \text{: mass of a baryon}$$

$$\int dr^3 \sum_{a=Q,G} J^{a,i}_{\sigma'\sigma}(\boldsymbol{r}) = 2\hat{S}^i_{\sigma'\sigma}J(0) = \hat{S}^i_{\sigma'\sigma} \quad \text{: spin of a baryon}$$

Strong force field and Stability

- Conservation of the EMT

$$\partial^i T_{ij} = \frac{r_j}{r}\left[\frac{2}{3}\frac{\partial s(r)}{\partial r} + \frac{2s(r)}{r} + \frac{\partial p(r)}{\partial r}\right] = 0$$

$p(r)$: Pressure density

$s(r)$: Shear-force density

- Global Stability condition (von Laue condition)

$$\int_0^\infty dr\ r^2 p(r) = 0$$

Strong force field and Stability

- Strong force fields

$$dF^i_{(r,\theta,\phi)} = T^{ij} dS_{(r,\theta,\phi)} e^j_{(r,\theta,\phi)}$$

$$\frac{dF_r}{dS_r} = \frac{2}{3}s(r) + p(r), \qquad \frac{dF_\theta}{dS_\theta} = \frac{dF_\phi}{dS_\phi} = -\frac{1}{3}s(r) + p(r)$$

- Local stability condition

$$\frac{2}{3}s(r) + p(r) > 0$$

- 2D von Laue stability condition

$$\int_0^\infty dr\ r\left(-\frac{1}{3}s(r) + p(r)\right) = 0$$

Baryon in pion mean fields

* A baryon can be viewed as a state of Nc quarks bound by mesonic **mean fields** (E. Witten, NPB, 1979 & 1983).

  Its mass is proportional to *Nc*, while its width is of order *O(1)*.

  → Mesons are weakly interacting (Quantum fluctuations are suppressed by 1/Nc: *O(1/Nc)*.

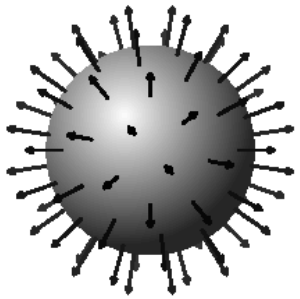
Meson mean-field approach (Chiral Quark-Soliton Model)

* Baryons as a state of Nc quarks bound by mesonic mean fields.

$$S_{\rm eff} = -N_c {\rm Tr} \ln \left(i\partial\!\!\!/ + iMU^{\gamma_5} + i\hat{m} \right)$$

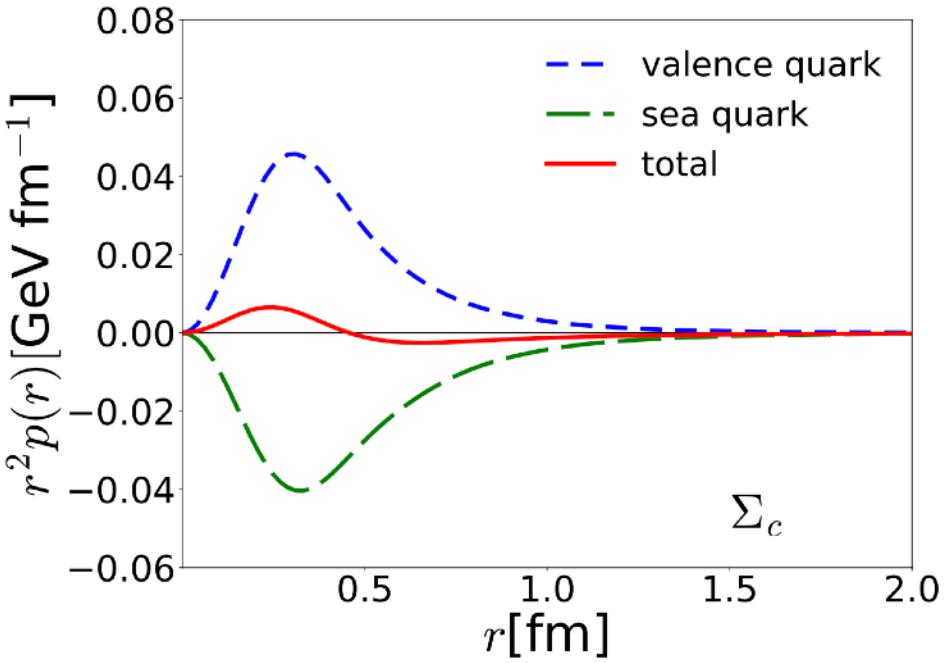
* Key point: Hedgehog Ansatz

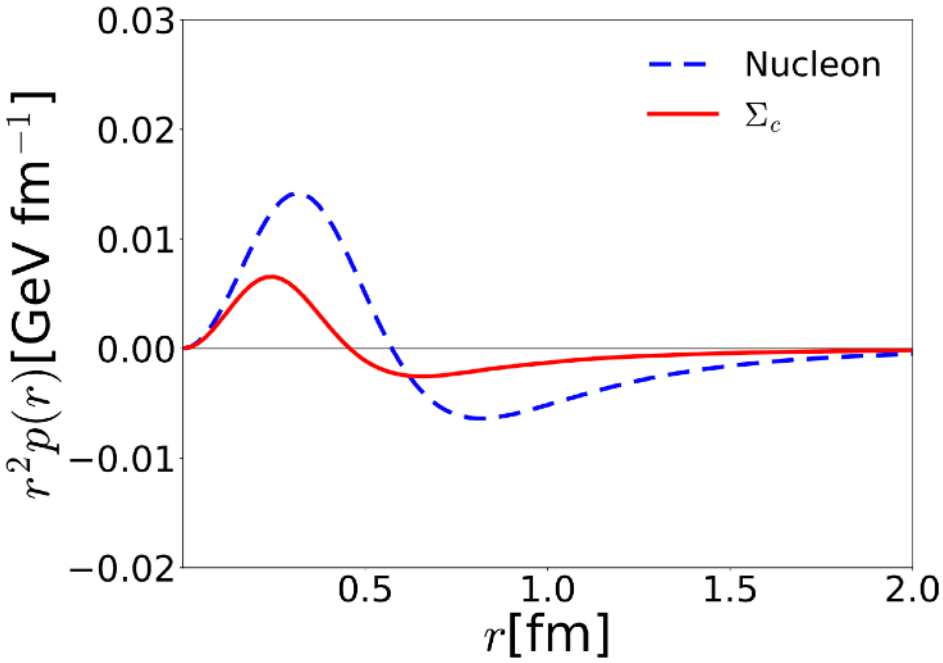
$$\pi^a(\boldsymbol{r}) = \begin{cases} n^a F(r),\ n^a = x^a/r, & a = 1,\ 2,\ 3 \\ 0, & a = 4,\ 5,\ 6,\ 7,\ 8. \end{cases}$$


hedgehog

→ It breaks spontaneously $\mathrm{SU}(3)_{\rm flavor} \otimes \mathrm{O}(3)_{\rm space} \to \mathrm{SU}(2)_{\rm isospin+space}$

Pressure density

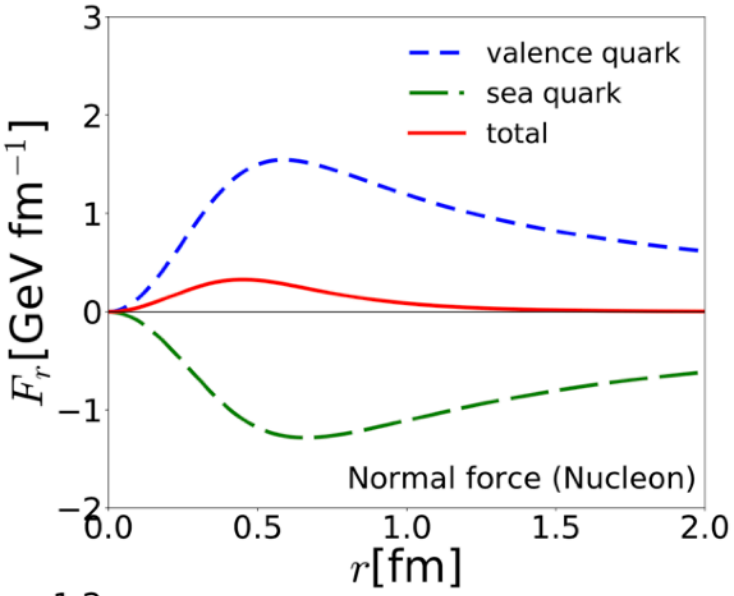


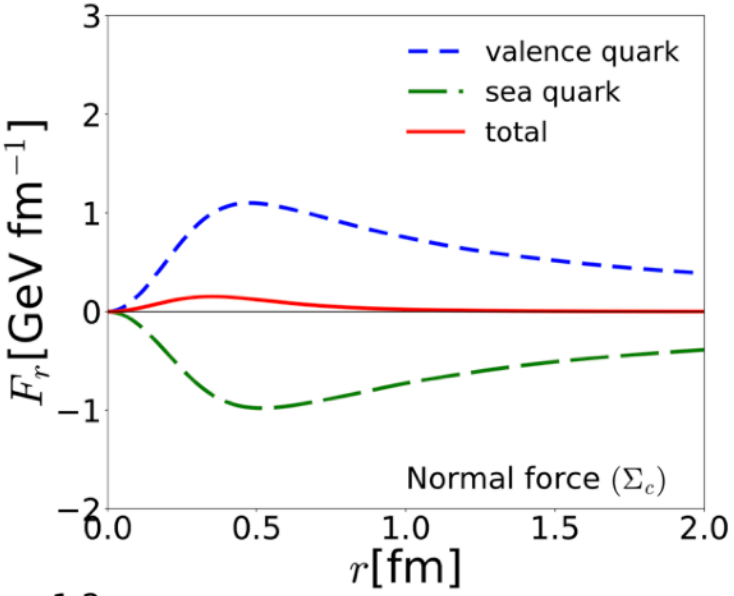


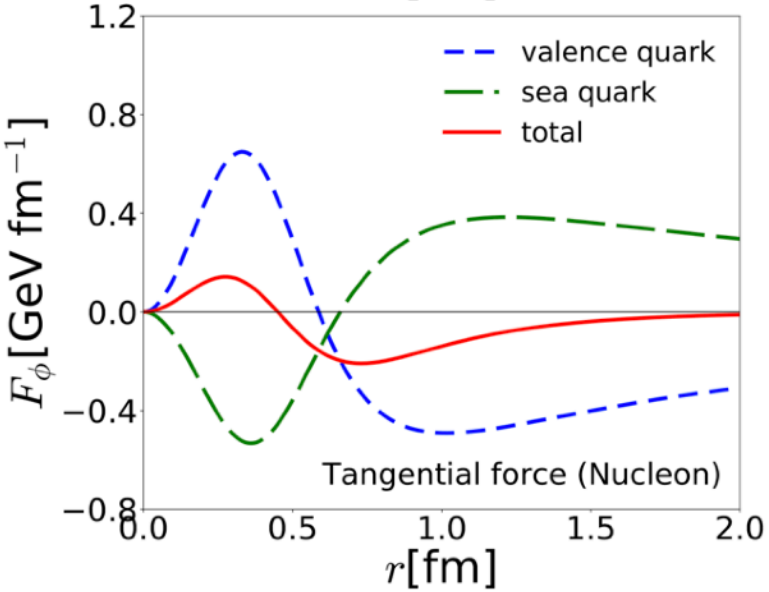
$$\int_0^\infty dr\ r^2 p(r) = 0$$

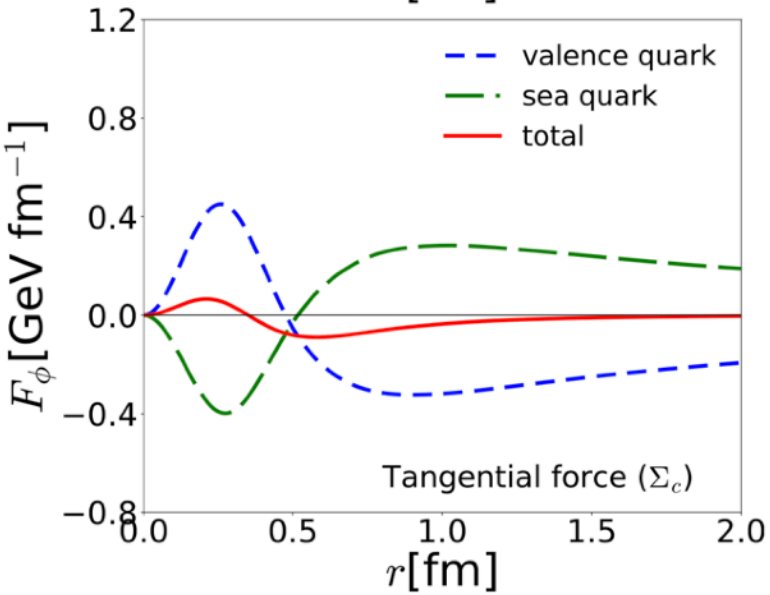
This condition is a nontrivial one.

Strong force field

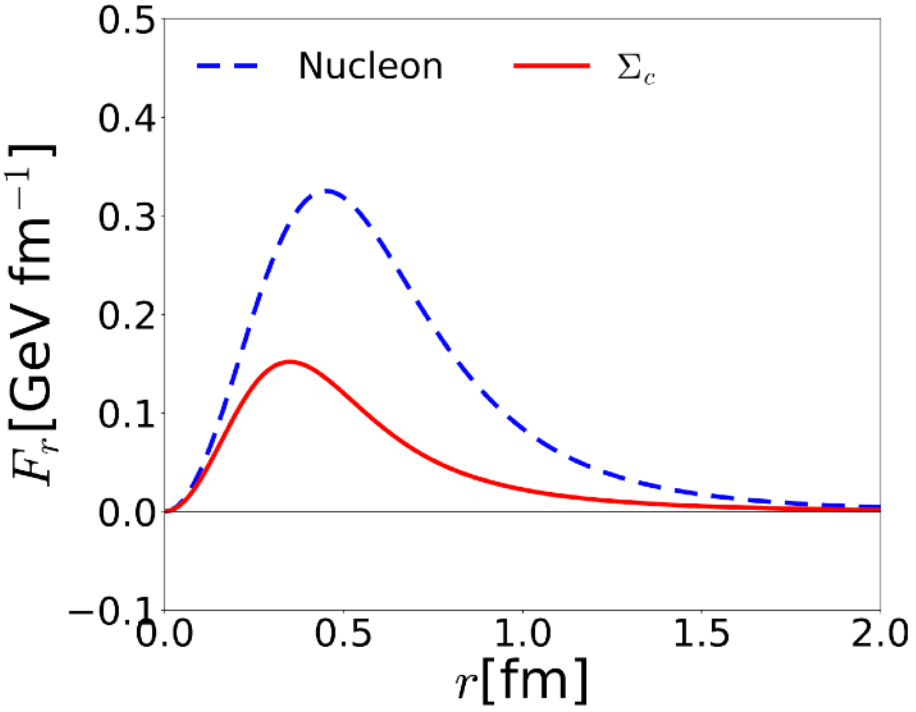


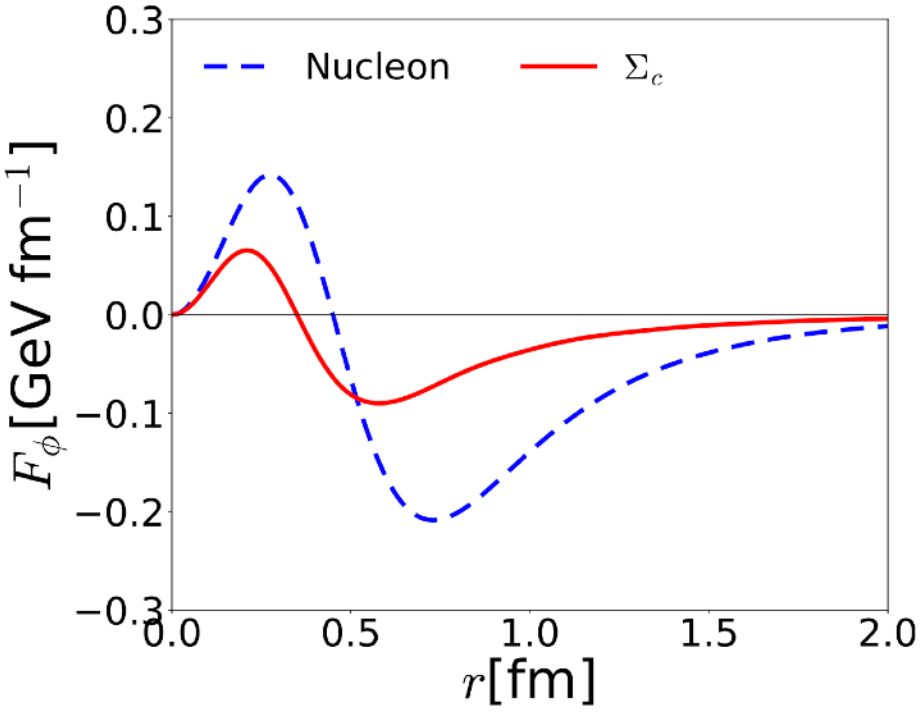






Strong force fields





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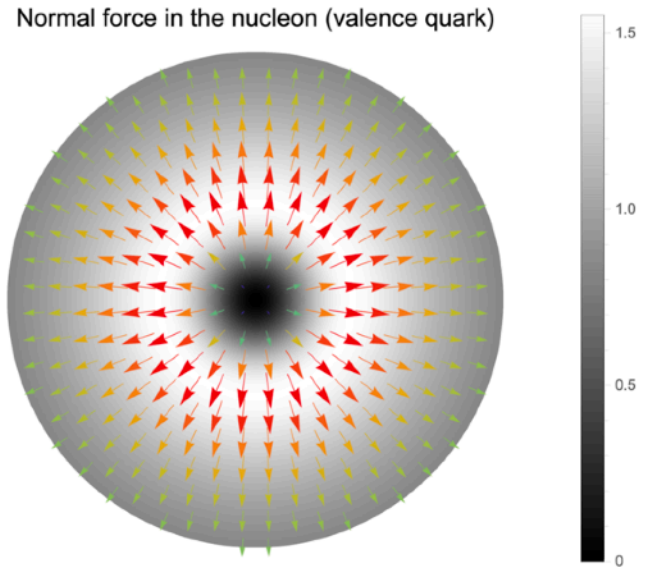

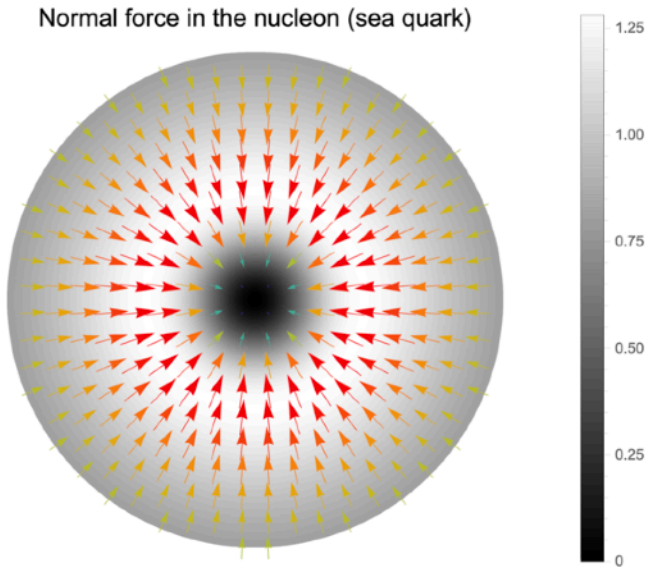

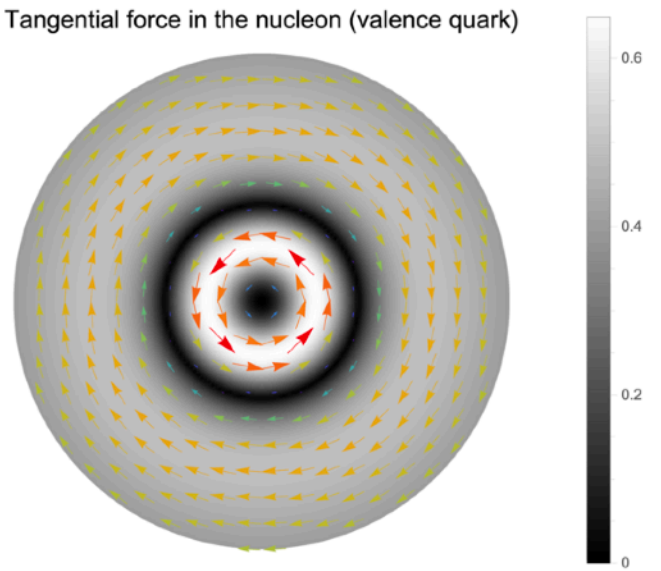

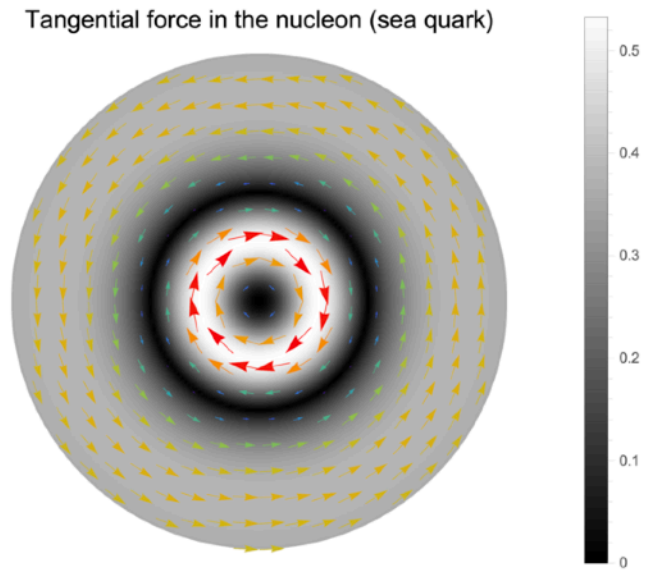

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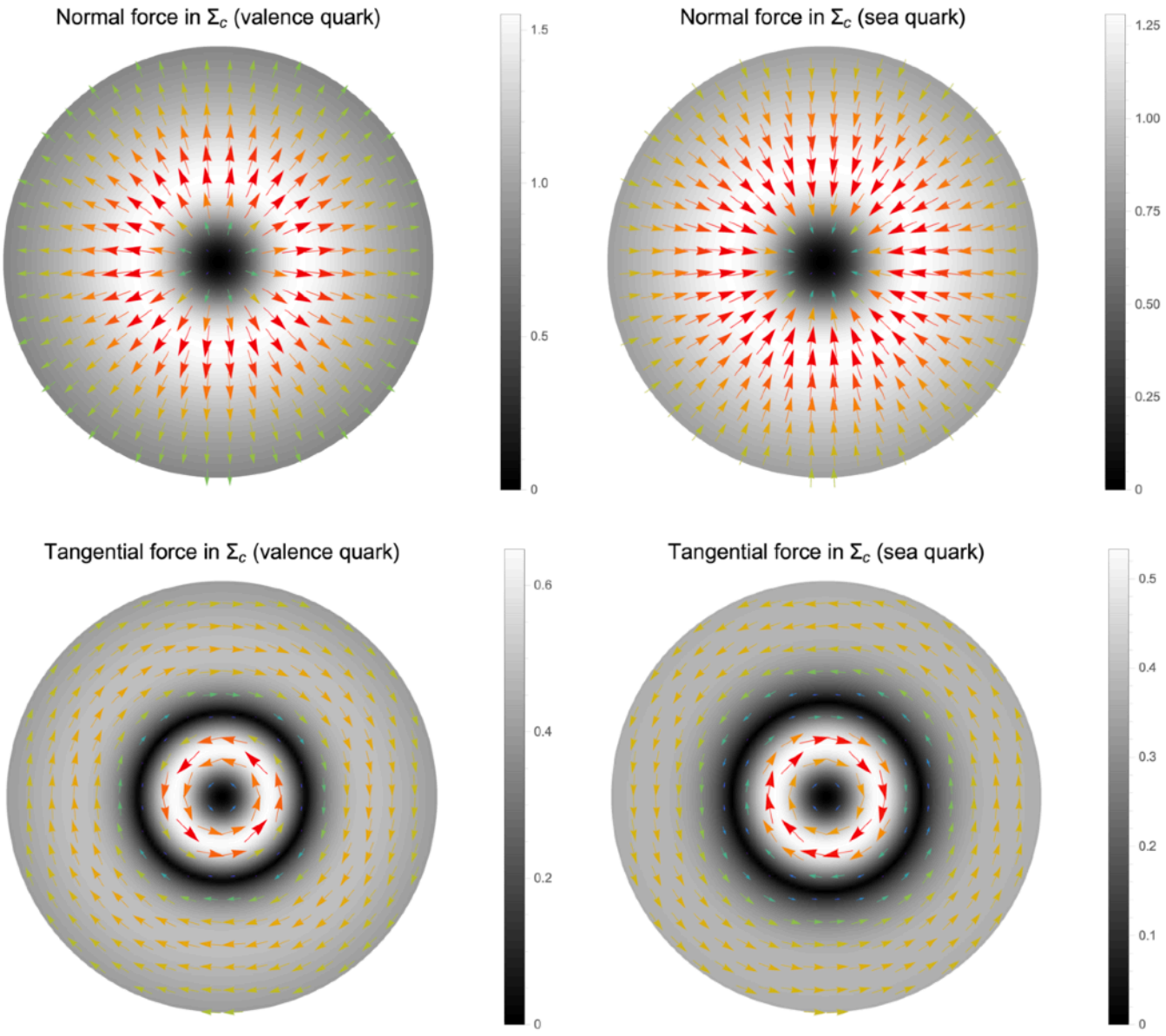

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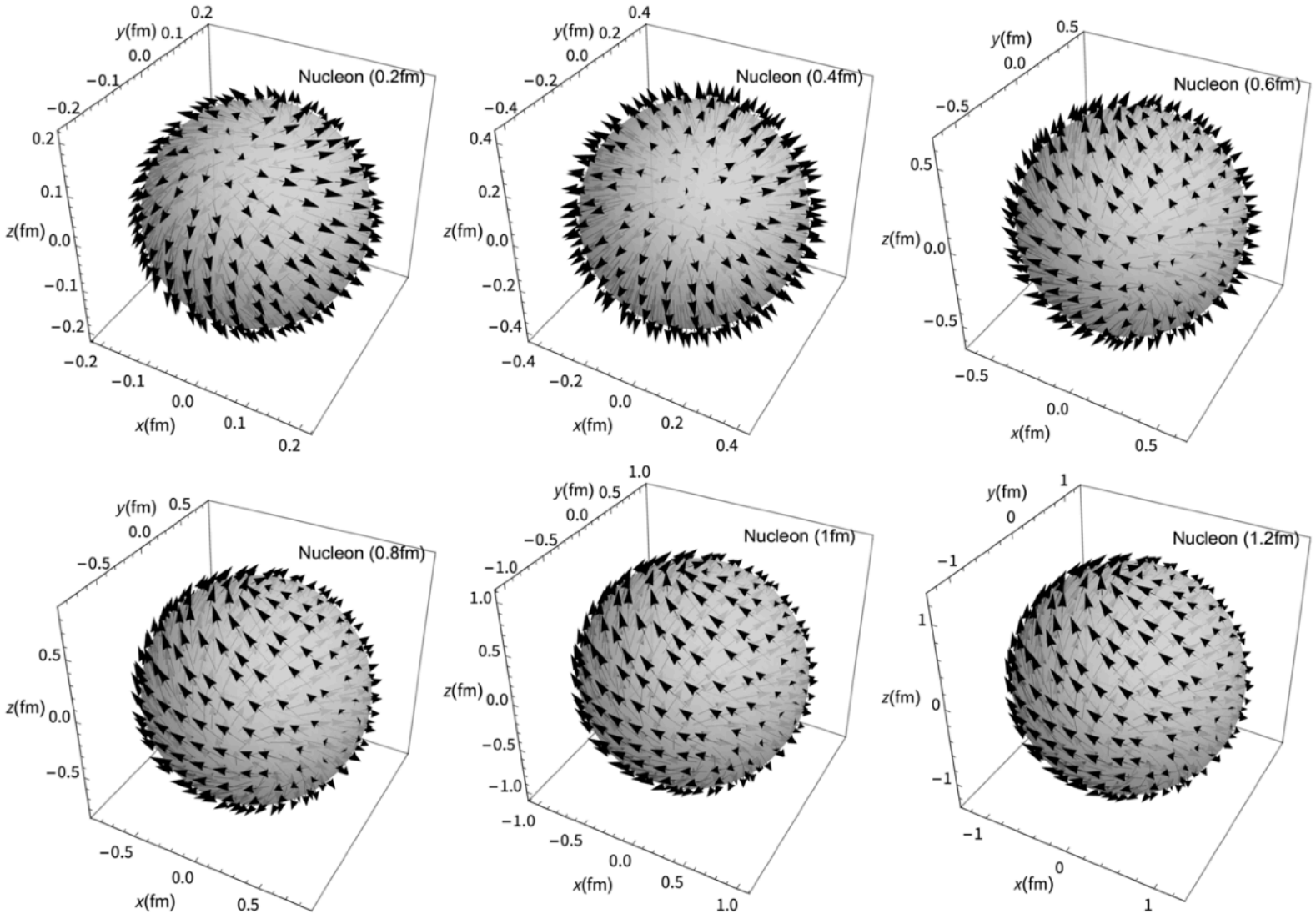

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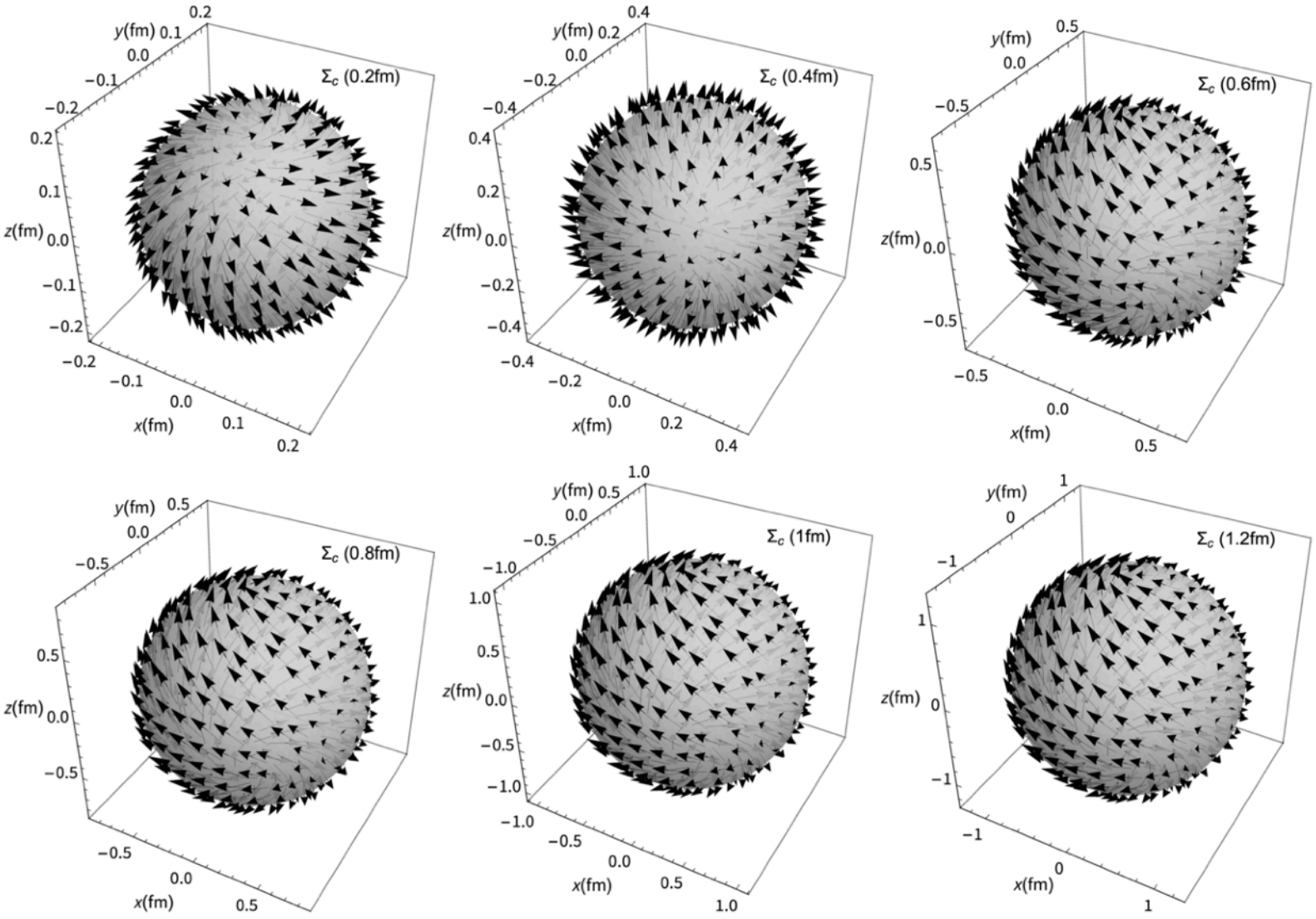

Summary & Outlook

Summary

- In the present talk, we aimed at showing how the nucleon and singly heavy baryons acquire their stabilities as particles.
- As shown in the results, the vacuum fluctuations are essential to secure the stabilities of baryons.
- This may give a clue on the mechanism of the quark confinement.
- The form factors were also computed (see the backup slide).

One can construct a theory of baryon seismology, based on the present work.

Though this be madness,
yet there is method in it.

Hamlet Act 2, Scene 2

by Shakespeare

Thank you very much for the attention!

Gravitational form factors