In-medium magnetic moments of the octet, decuplet, low-lying charm and low-lying bottom baryons

Reimei Workshop "Hadrons in dense matter at J-PARC"

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K. Tsushima, eprint arXiv to be revised (submitted to PTEP)
K. Tsushima, Phys. Rev. D 99, 014026 (2019) (heavy baryon properties)
K. Saito, K. Tsushima and A. W. Thomas
Prog. Part. Nucl. Phys. 58, 1 (2007) (QMC model review)

1. Motivation, Focus
2. Introduction: QMC Model
3. Effective Hadron Masses and Potentials (Parametrizations)
4. Baryon Magnetic Moments in Medium
5. Summary, Perspective
6. (Backup: Low-lying Strange, Charm, Bottom baryons)
7. (Backup: Summary, Perspective)

Motivation, Focus

- In-medium magnetic moments of Octet, Decuplet, low-lying Charm and low-lying Bottom Baryons

- Estimates by in-medium/vacuum ratios (the QMC model)

- Experiments? influences on observables?

- Density dependent parametrizations:
Baryon and Meson $m^*_{B,M}$ and vector $V^{q,B,M}_{\omega,\rho}$ potentials

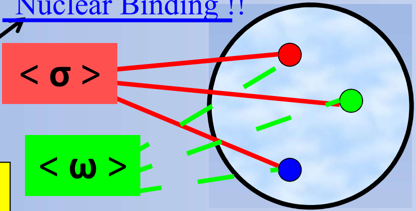
The QMC model

P. Guichon, PLB 200, 235 (1988)

(For a review, PPNP 58, 1 (2007))

Light (u,d) quarks interact **self-consistently** with mean **σ** and **ω** fields

Nuclear Binding !!



$m^*_q = m_q - g^q_\sigma \sigma = m_q - V^q_\sigma$

↓ nonlinear in **σ**

$M^*_N \approx M_N - g^N_\sigma \sigma + (d/2)\,(g^N_\sigma \sigma)^2$

$[\, i\gamma \cdot \partial - (m_q - V^q_\sigma) - \gamma_0 V^q_\omega \,]\, q = 0$

1. Start

$M^*_N = M_N - V^N_\sigma$

$V^N_\omega = 3 V^q_\omega$

$[\, i\gamma \cdot \partial - M^*_N - \gamma_0 V^N_\omega \,]\, N = 0$

Self-consistent !

(Applied quark model !)

Bound quark Dirac spinor ($1s_{1/2}$)

Quark Dirac spinor in **a bound hadron:**

$$q_{1s}(r) = \begin{pmatrix} U(r) \\ i\sigma\cdot\hat{r}\, L(r) \end{pmatrix} \chi$$

Lower component is **enhanced** !

$\Rightarrow$ $g_A^* < g_A$: $\sim |U|^{**}2 - (1/3)\ |L|^{**}2$,

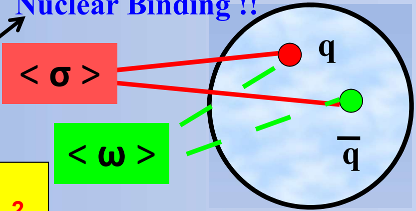
$\Rightarrow$ **Decrease** of scalar density $\Rightarrow$

Mesons in nuclear medium in **QMC**

(For a review, PPNP 58, 1 (2007))

Light (u,d) quarks interact self-consistently with mean σ and ω fields

Nuclear Binding !!



$m^*_q = m_q - g^q_\sigma \sigma = m_q - V^q_\sigma$

↓ **nonlinear** in σ

$M^*_M \approx M_M - g^M_\sigma \sigma + (d^M/2)\,(g^M_\sigma \sigma)^2$

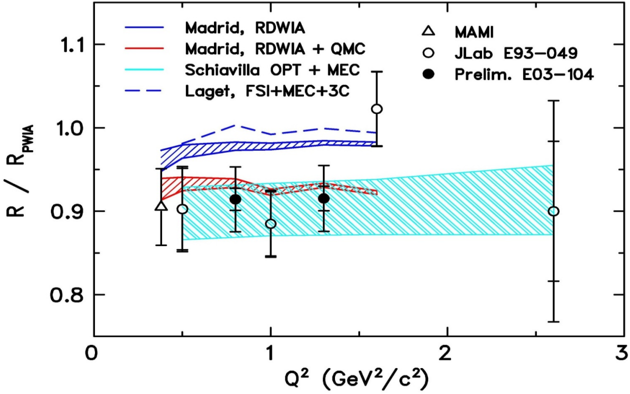
$$[\, i\gamma\cdot\partial - (m_q - V^q_\sigma) - \gamma_0 V^q_\omega \,]\; q = 0$$

σ,ω fields: **no couplings** with **s,c,b** quarks!!

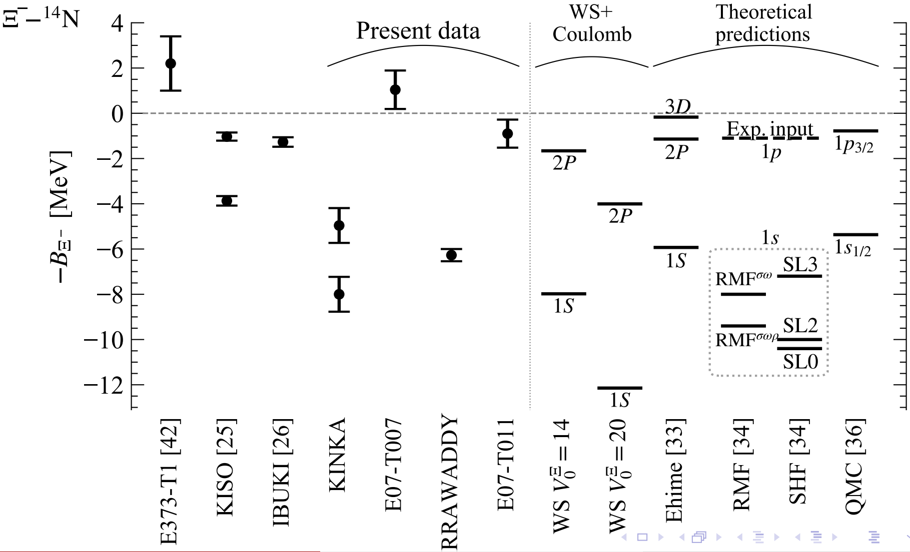
$$R=(p'_x/p'_z)=(G_E^p/G_M^p): {}^4He/{}^1H$$

S. Malace, M. Paolone and S. Strauch, arXiv:0807.2251 [nucl-ex]

S. Strauch *et al.*, *Phys. Rev. Lett.* ***91, 052301 (2003)***



Ξ^--^{14}N energy levels (Prog. Theor. Exp. Phys. 2021, 073D02)



QMC model 1: Hadron level

$$\begin{aligned}
\mathcal{L} &= \bar{\psi}[i\gamma \cdot \partial - m_N^*(\sigma) - g_\omega \omega^\mu \gamma_\mu]\psi + \mathcal{L}_{\rm meson}, \\
m_N^*(\sigma) &\equiv m_N - g_\sigma(\sigma)\sigma \simeq m_N - g_\sigma[1 - (a_N/2)(g_\sigma \sigma)]\sigma \\
g_\sigma &\equiv g_\sigma(\sigma = 0)
\end{aligned}$$

$$\begin{aligned}
\mathcal{L}_{\rm meson} &= \frac{1}{2}\partial_\mu \sigma \partial^\mu \sigma - m_\sigma^2 \sigma^2 - \frac{1}{2}\partial_\mu \omega_\nu (\partial^\mu \omega^\nu - \partial^\nu \omega^\mu) \\
&+ \frac{1}{2} m_\omega^2 \omega^\mu \omega_\mu \ ,
\end{aligned}$$

$$\begin{aligned}
\rho_B &= \frac{4}{(2\pi)^3}\int d^3k \ \theta(k_F - |\vec{k}|) = \frac{2k_F^3}{3\pi^2}, \\
\rho_s &= \frac{4}{(2\pi)^3}\int d^3k \ \theta(k_F - |\vec{k}|) \frac{m_N^*(\sigma)}{\sqrt{m_N^{*2}(\sigma) + \vec{k}^2}},
\end{aligned}$$

QMC model 2: Quark level

$x = (t, \vec{r})$ ($|\vec{r}| \leq$ bag radius), $V^q_\sigma = g^q_\sigma \sigma$

$$\left[i\gamma \cdot \partial_x - (m_q - V^q_\sigma) \mp \gamma^0 \left(V^q_\omega + \frac{1}{2} V^q_\rho \right) \right] \begin{pmatrix} \psi_u(x) \\ \psi_{\bar{u}}(x) \end{pmatrix} = 0$$

$$\left[i\gamma \cdot \partial_x - (m_q - V^q_\sigma) \mp \gamma^0 \left(V^q_\omega - \frac{1}{2} V^q_\rho \right) \right] \begin{pmatrix} \psi_d(x) \\ \psi_{\bar{d}}(x) \end{pmatrix} = 0$$

$$[i\gamma \cdot \partial_x - m_Q]\, \psi_Q(x) \ (\text{or } \psi_{\overline{Q}}(x)) = 0$$

$$m^*_h = \sum_{j=q,\bar{q},Q\overline{Q}} \frac{n_j \Omega^*_j - z_h}{R^*_h} + \frac{4}{3}\pi R^{*3}_h B, \quad \left. \frac{dm^*_h}{dR_h} \right|_{R_h = R^*_h} = 0$$

$$\Omega^*_q = \Omega^*_{\bar{q}} = [x^2_q + (R^*_h m^*_q)^2]^{1/2}, \text{ with } m^*_q = m_q - g^q_\sigma \sigma$$

$$\Omega^*_Q = \Omega^*_{\overline{Q}} = [x^2_Q + (R^*_h m_Q)^2]^{1/2} \quad (Q = s, c, b)$$

QMC model 3: From quarks

$$\omega = \frac{g_\omega \rho_B}{m_\omega^2},$$

$$\sigma = \frac{g_\sigma}{m_\sigma^2} C_N(\sigma) \frac{4}{(2\pi)^3} \int d^3k \, \theta(k_F - |\vec{k}|) \frac{m_N^*(\sigma)}{\sqrt{m_N^{*2}(\sigma) + \vec{k}^2}}$$

$$= \frac{g_\sigma}{m_\sigma^2} C_N(\sigma) \rho_s \quad (g_\sigma \equiv g_\sigma(\sigma = 0)),$$

$$C_N(\sigma) = \frac{-1}{g_\sigma(\sigma = 0)} \left[\frac{\partial m_N^*(\sigma)}{\partial \sigma} \right],$$

$$E^{\mathrm{tot}}/A - m_N = \frac{4}{(2\pi)^3 \rho_B} \int d^3k \, \theta(k_F - |\vec{k}|) \sqrt{m_N^{*2}(\sigma) + \vec{k}^2}$$

$$+ \frac{m_\sigma^2 \sigma^2}{2\rho_B} + \frac{g_\omega^2 \rho_B}{2m_\omega^2} - m_N.$$

QMC model 4: Couplings etc.

m_q(MeV)	$g_\sigma^2/4\pi$	$g_\omega^2/4\pi$	m_N^*	K	Z_N	$B^{1/4}$(MeV)
5	5.39	5.30	754.6	279.3	3.295	170
220	6.40	7.57	698.6	320.9	4.327	148

$$\frac{\partial m_N^*(\sigma)}{\partial \sigma} = -3g_\sigma^q \int_{bag} d^3r \, \overline{\psi}_q(\vec{r})\psi_q(\vec{r}) \quad \text{the lowest bag w.f.}$$

$$\equiv -3g_\sigma^q S_N(\sigma) = -\frac{\partial}{\partial\sigma}\left[g_\sigma(\sigma)\sigma\right],$$

$$C_N(\sigma) = \frac{-1}{g_\sigma(\sigma=0)}\left[\frac{\partial m_N^*(\sigma)}{\partial\sigma}\right],$$

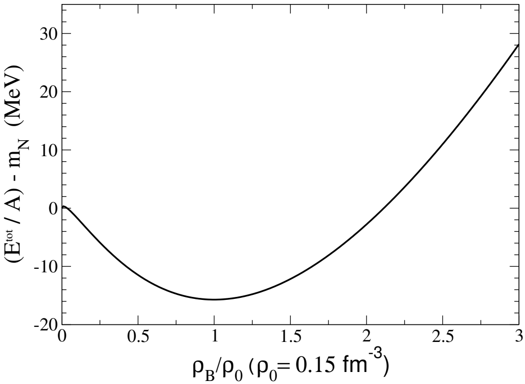
$$g_\sigma \equiv g_\sigma^N \equiv 3g_\sigma^q S_N(\sigma=0).$$

Parameters

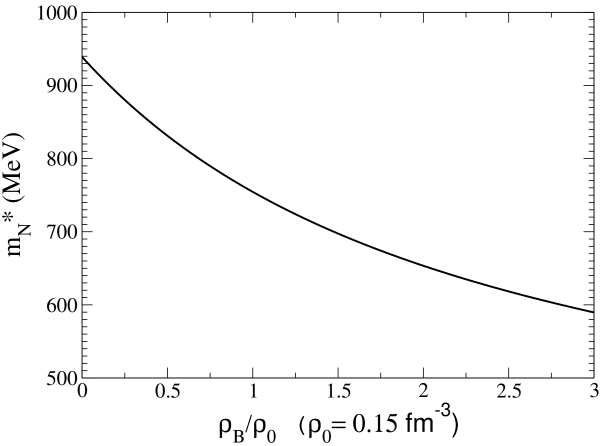
Table: Current quark mass values (inputs), quark-meson coupling constants and the bag constant B_p, obtained with the inputs: free nucleon bag radius $R_N = 0.8$ fm, empirical values $E^{\rm tot}/A - m_N = -15.7$ MeV ($m_N = 939$ MeV) at the saturation density $\rho_0 = 0.15$ fm^{-3}, and the symmetry energy, 35 MeV.

$m_{u,d}$	5 MeV	g_σ^q	5.69
m_s	250 MeV	g_ω^q	2.72
m_c	1270 MeV	g_ρ^q	9.33
m_b	4200 MeV	$B_p^{1/4}$	170 MeV

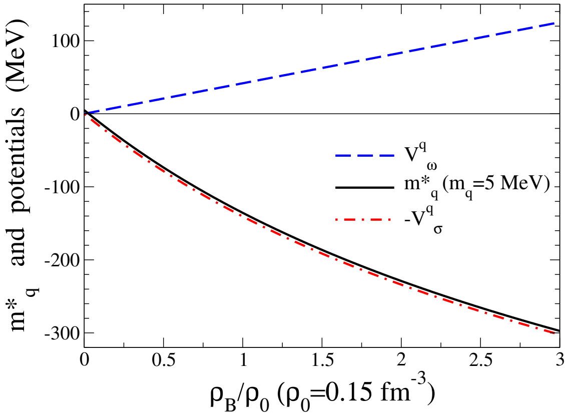
Results: Quark Meson Coupling (Standard)



- Symmetric Nuclear Matter - Binding Energy per Nucleon
- m_q = 5 MeV, K = 279.3 MeV

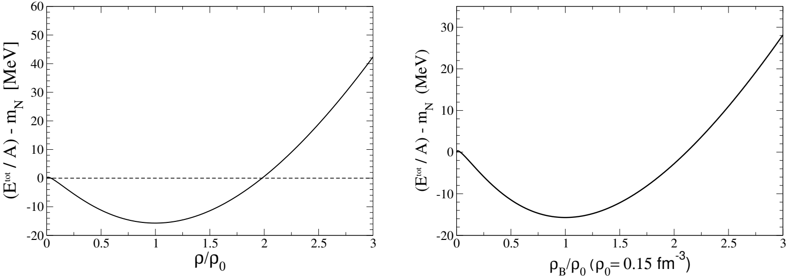


- **Nucleon effective mass: $m_q = 5$ MeV**

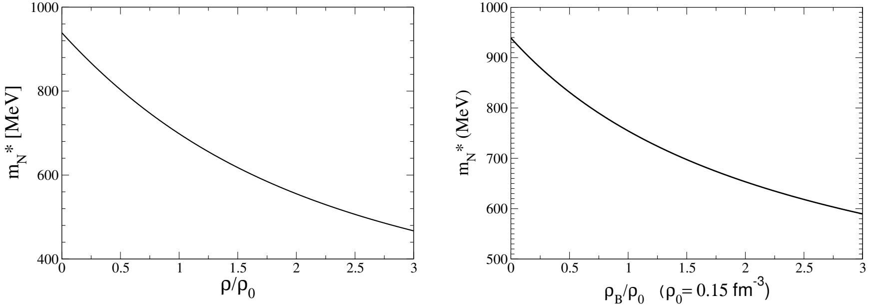


- Effective mass of constituent quarks: $m_q = 5$ MeV
- All the light-quarks in any hadrons feel the same potentials !!

Comparison of Energy/nucleon



- Symmetric Nuclear Matter - Binding Energy per Nucleon (scale !!)
- LF pion model (left): $m_q = 220$ MeV, $K = 320.9$ MeV
- Standard QMC (right): $m_q = 5$ MeV, $K = 279.3$, MeV

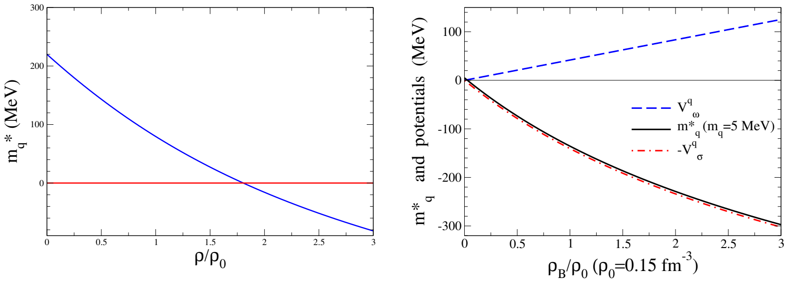


Nucleon effective mass

•**LF pion model** **(left: $m_q = 220 MeV$)**

•**Standard QMC** **(right: $m_q = 5 MeV$)**

LF pion model and Standard QMC: m_q^* (potentials)



- Effective mass of constituent quarks, up and down
- LF pion model: $m_q = 220$ MeV (left)
- Standard QMC $m_q = 5$ MeV (right)

Standard QMC, π, ρ in LF model parameters comparison

- **Motivation:** The present model works well (Symmetric Vertex)!

m_q(MeV)	$g_\sigma^2/4\pi$	$g_\omega^2/4\pi$	m_N^*	K	Z_N	$B^{1/4}$(MeV)
5	5.39	5.30	754.6	279.3	3.295	170
220	6.40	7.57	698.6	320.9	4.327	148
430	8.73	11.93	565.25	361.4	5.497	69.75

- **Refs. LF π, ρ model:**

J.P.B.C. de Melo, KT et al.,
LF π model ($m_q = 220$ MeV): Phys.Rev. C90 (2014) no.3, 035201;
Phys.Lett. B766 (2017) 125;
Few Body Syst. 58 (2017) no.2, 85
LF ρ model ($m_q = 430$ MeV): Few Body Syst. 58 (2017) no.2, 82;
arXiv:1802.06096 [hep-ph], Phys. Lett. B 788 (2019) 137

QMC: Hadron masses in medium (Remind again!)

$x = (t, \vec{r})$ ($|\vec{r}| \leq$ bag radius) , $V^q_\sigma = g^q_\sigma \sigma$

$$\left[i\gamma \cdot \partial_x - (m_q - V^q_\sigma) \mp \gamma^0 \left(V^q_\omega + \frac{1}{2} V^q_\rho\right)\right] \begin{pmatrix} \psi_u(x) \\ \psi_{\bar{u}}(x) \end{pmatrix} = 0$$

$$\left[i\gamma \cdot \partial_x - (m_q - V^q_\sigma) \mp \gamma^0 \left(V^q_\omega - \frac{1}{2} V^q_\rho\right)\right] \begin{pmatrix} \psi_d(x) \\ \psi_{\bar{d}}(x) \end{pmatrix} = 0$$

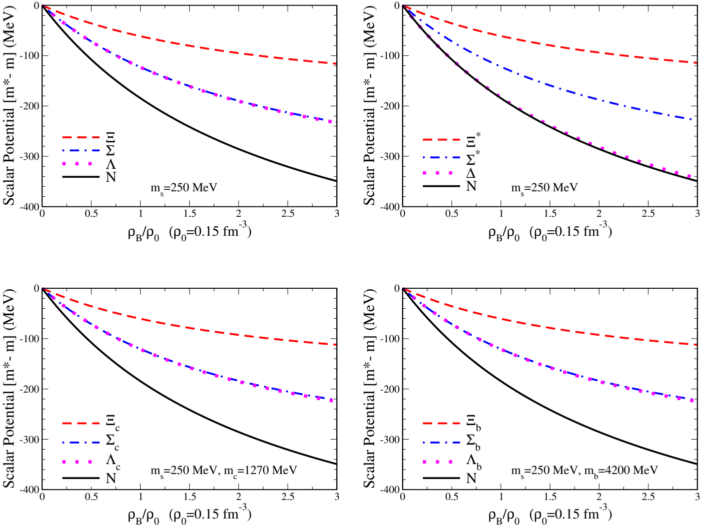
$$[i\gamma \cdot \partial_x - m_Q]\,\psi_Q(x) \;(\text{or } \psi_{\overline{Q}}(x)) = 0$$

$$m^*_h = \sum_{j=q,\bar{q},Q\overline{Q}} \frac{n_j \Omega^*_j - z_h}{R^*_h} + \frac{4}{3}\pi R^{*3}_h B, \quad \left.\frac{dm^*_h}{dR_h}\right|_{R_h = R^*_h} = 0$$

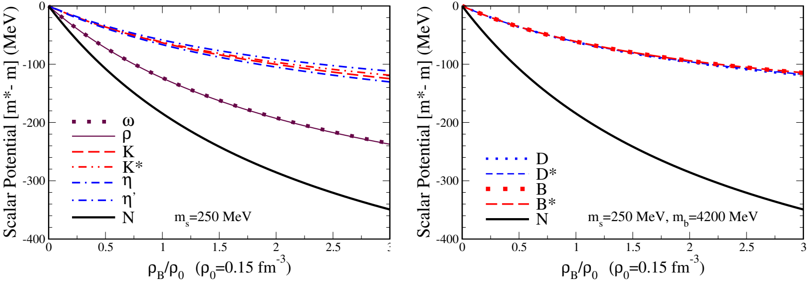
$$\Omega^*_q = \Omega^*_{\bar{q}} = [x^2_q + (R^*_h m^*_q)^2]^{1/2}, \text{with } m^*_q = m_q - g^q_\sigma \sigma$$

$$\Omega^*_Q = \Omega^*_{\overline{Q}} = [x^2_Q + (R^*_h m_Q)^2]^{1/2} \quad (Q = s, c, b)$$

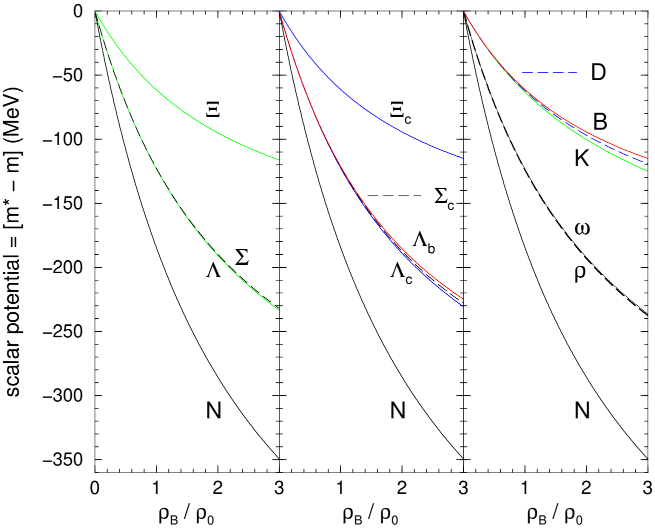
Baryon Scalar potential $[m_B^* - m_B]$



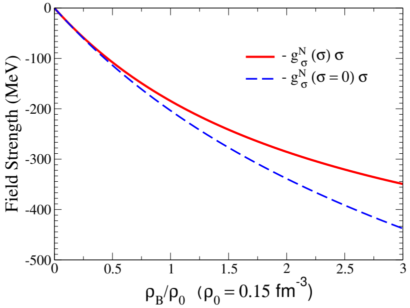
Meson Scalar potential $[m^*_M - m_M]$

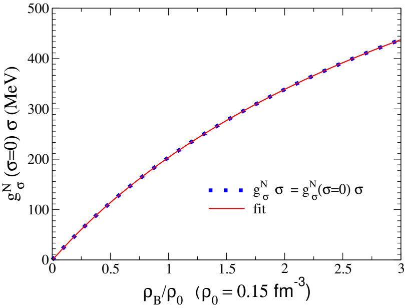


Scalar potential: $m^*_{B,M} - m_{B,M}$



Scalar field σ and fit





$$x = (\rho_B/\rho_0)$$

$$(g_\sigma^N\sigma)(x) = 1.60828 - 23.9107\sqrt{x} + 350.631\,x - 144.309\,x\sqrt{x} + 19.4750\,x^2 \;\; (x > 0, [x > 0.001])$$

$$(g_\sigma^N\sigma)(x) = 0 \;\; (x = 0)$$

$M^*_{B,M}$: Parametrizations

$$
\begin{aligned}
m_B^* &\simeq m_B - \frac{n_q}{3} g_\sigma^N \left[1 - \frac{a_B}{2}(g_\sigma^N \sigma)\right] \sigma, \\
&= m_B - \frac{n_q}{3} \left[(g_\sigma^N \sigma) - \frac{a_B}{2}(g_\sigma^N \sigma)^2\right], \\
&\quad (B = N, \Lambda, \Sigma, \Xi, \Delta, \Sigma^*, \Xi^*, \Lambda_c, \Sigma_c, \Xi_c, \Lambda_b, \Sigma_b, \Xi_b).
\end{aligned}
$$

$$
\begin{aligned}
m_M^* &\simeq m_M - \frac{n_q^M}{3} g_\sigma^N \left[1 - \frac{a_M}{2}(g_\sigma^N \sigma)\right] \sigma, \\
&= m_M - \frac{n_q^M}{3} \left[(g_\sigma^N \sigma) - \frac{a_M}{2}(g_\sigma^N \sigma)^2\right],
\end{aligned}
$$

$$(M = \omega, \rho, K, K^*, \eta, \eta', D, D^*, B, B^*, \text{ with } n_q^M \to 1 \text{ for } \eta \text{ and } \eta').$$

Vector Potentials: Parametrizations

$x = \rho_B/\rho_0$ ($\rho_0 = 0.15$ fm^{-3})

$$\begin{aligned} V^B_\omega(x) &= b_B\, x, \\ V^q_\omega(x) &= = 41.77\, x \\ V^h_\omega(x) &= V^h_\omega = (n_q - n_{\bar{q}}) V^q_\omega = (n_q - n_{\bar{q}}) \times 41.77\, x \\ V^K_\omega(x) &\simeq 1.96 \times 41.77\, x \end{aligned}$$

(baryon octet $\rightarrow$ Pauli potentials)

$y \equiv \rho_3/\rho_0 = (\rho_p - \rho_n)/\rho_0$, isospin-third component of h, I^h_3,

$$I^h_3 V^h_\rho(y) = I^h_3 \times 84.61\, y$$

Parameters

Table: **Effective mass slope parameter $a_{B,M}$, and b_B.**
$([m^*_\Sigma - m_\Sigma] + V^\Sigma_v \simeq +30$ MeV at ρ_0.)

a_B	$\times 10^{-4}$ MeV^{-1}	a_B	$\times 10^{-4}$ MeV^{-1}	a_B	$\times 10^{-4}$ MeV^{-1}	a_B	$\times 10^{-4}$ MeV^{-1}
a_N	9.15	a_Δ	10.08	—	—	—	—
a_Λ	9.35	—	—	a_{Λ_c}	9.90	a_{Λ_b}	10.78
a_Σ	9.59	a_{Σ^*}	10.15	a_{Σ_c}	10.34	a_{Σ_b}	11.22
a_Ξ	9.52	a_{Ξ^*}	10.15	a_{Ξ_c}	9.99	a_{Ξ_b}	10.83
b_B	MeV	b_B	MeV	b_B	MeV	b_B	MeV
b_N	125.30	b_Δ	125.30	—	—	—	—
b_Λ	92.57	—	—	b_{Λ_c}	83.54	b_{Λ_b}	83.54
b_Σ	100.12	b_{Σ^*}	83.54	b_{Σ_c}	83.54	b_{Σ_b}	83.54
$\tilde{b}_\Sigma$	152.42						
b_Ξ	46.29	b_{Ξ^*}	41.77	b_{Ξ_c}	41.77	b_{Ξ_b}	41.77
a_M	$\times 10^{-4}$ MeV^{-1}	a_M	$\times 10^{-4}$ MeV^{-1}	a_M	$\times 10^{-4}$ MeV^{-1}	a_M	$\times 10^{-4}$ MeV^{-1}
a_ω	8.73	a_K	6.66	a_D	8.61	a_B	9.92
a_ρ	8.70	a_{K^*}	8.60	a_{D^*}	9.09	a_{B^*}	10.04
—	—	$a_\eta(n^\eta_q \to 1)$	7.03	—	—	—	—
—	—	$a_{\eta'}(n^{\eta'}_q \to 1)$	8.81	—	—	—	—

Magnetic Moment $B(q_1, q_2, q_3)$

$$\mu_B = \frac{1}{3}(2\mu_1 + 2\mu_2 - \mu_3) \quad (B \neq \Lambda, \Lambda_{c,b} \neq \text{decuplet}),$$

$$\mu_B = \mu_3 \quad (B = \Lambda, \Lambda_{c,b}, \Xi_{c,b}),$$

$$\mu_B = \mu_1 + \mu_2 + \mu_3 \quad (B = \text{decuplet})$$

$$\mu_q \equiv e_q \eta_q$$

$$\equiv e_q \left[(N_q^B)^2 \int_0^{R_B} dr\, r^2 \frac{2r}{3} j_0(x_q r/R_B) \beta_q^B j_1(x_q r/R_B) \right]$$

$$|\mu_{\Sigma^0\Lambda}| = |\mu_{\Sigma_c^+\Lambda_c^+}| = |\mu_{\Sigma_b\Lambda_b}| = \frac{1}{\sqrt{3}}|\mu_u - \mu_d| \equiv \frac{1}{\sqrt{3}}|e_u\tilde{\eta}_u - e_d\tilde{\eta}_d|$$

$$\tilde{\eta}_q \equiv (N_q^{B'} N_q^B) \int_0^{\min(R_{B'},R_B)} dr\, r^2 \frac{r}{3}$$

$$\times \left[j_0(x'_q r/R_{B'})\, \beta_q^B j_1(x_q r/R_B) + \beta_q^{B'} j_1(x'_q r/R_{B'})\, j_0(x_q r/R_B) \right]$$

Free-space values: 1

Table: Free-space baryon magnetic moments by various models.

$B(q_1, q_2, q_3)$	Set I	Set II	[1, 2]	[3]	[4]	[5]	[6]	[7]	[8, 9]	[10]
$p(uud)$	1.535	1.535	2.56	—	—	—	2.8732	2.886	2.3	3.04
$n(ddu)$	-1.023	-1.023	-1.93	—	—	—	-1.9154	-1.924	-1.3	-1.84
$\Lambda(uds)$	-0.429	-0.500	-0.55	—	—	—	-0.5512	-0.580	-0.40	-0.70
$\Sigma^+(uus)$	1.557	1.628	2.60	—	—	—	2.7377	2.758	1.9	2.87
$\Sigma^0(uds)$	0.499	0.535	-1.48	—	—	—	0.8222	0.834	0.54	0.76
$\Sigma^-(dds)$	-0.560	-0.559	-1.26	—	—	—	-1.0932	-1.089	-0.87	-1.48
$\Xi^0(ssu)$	-0.929	-1.068	-1.32	—	—	—	-1.3734	-1.414	-0.95	-1.37
$\Xi^-(ssd)$	-0.405	-0.509	-0.57	—	—	—	-0.4157	-0.452	-0.41	-0.82
$\Delta^{++}(uuu)$	3.341	3.341	5.267	—	—	—	—	—	4.91	5.24
$\Delta^+(uud)$	1.671	1.671	2.430	—	—	—	—	—	2.46	0.97
$\Delta^0(udd)$	0	0	-0.408	—	—	—	—	—	0.00	-0.035
$\Delta^-(ddd)$	-1.671	-1.671	-3.245	—	—	—	—	—	-2.46	-2.98
$\Sigma^{*+}(uus)$	1.781	1.767	3.208	—	—	—	—	—	2.55	1.27
$\Sigma^{*0}(uds)$	0.102	0.040	0.188	—	—	—	—	—	0.27	0.33
$\Sigma^{*-}(dds)$	-1.577	-1.687	-2.105	—	—	—	—	—	-2.02	-1.88
$\Xi^{*0}(ssu)$	0.203	0.083	0.508	—	—	—	—	—	0.46	0.16
$\Xi^{*-}(ssd)$	-1.473	-1.686	-1.805	—	—	—	—	—	-1.68	-0.62

Free-space values: 2

Table: Free-space baryon magnetic moments (in nuclear magneton).

$B(q_1, q_2, q_3)$	Set I	Set II	[1, 2]	[3]	[4]	[5]	[6]	[7]	[8, 9]	[10]
$\Lambda_c^+(udc)$	0.423	0.423	—	—	0.42	0.385	0.341	0.352	—	—
$\Sigma_c^{++}(uuc)$	1.378	1.378	—	2.4	1.76	2.279	2.44	2.448	—	—
$\Sigma_c^+(udc)$	0.238	0.238	—	0.5	0.36	0.501	0.525	0.524	—	—
$\Sigma_c^0(ddc)$	-0.903	-0.903	—	-1.5	-1.04	-1.015	-1.391	-1.400	—	—
$\Xi_c^+(usc)$	0.424	0.426	—	0.8	0.41	0.711	0.796	0.779	—	—
$\Xi_c^0(dsc)$	0.424	0.426	—	-1.2	0.39	-0.966	-1.12	-1.145	—	—
$\Lambda_b^0(udb)$	-0.073	-0.074	—	—	-0.06	-0.064	—	—	—	—
$\Sigma_b^+(uub)$	1.675	1.681	—	2.4	2.07	2.229	2.575	2.586	—	—
$\Sigma_b^0(udb)$	0.437	0.439	—	0.6	0.53	0.592	0.659	0.662	—	—
$\Sigma_b^-(ddb)$	-0.801	-0.804	—	-1.3	-1.01	-1.047	-1.256	-1.261	—	—
$\Xi_b^0(usb)$	-0.073	-0.074	—	0.7	-0.06	0.766	0.93	0.917	—	—
$\Xi_b^-(dsb)$	-0.073	-0.074	—	-1.2	-0.06	-0.902	-0.985	-1.006	—	—

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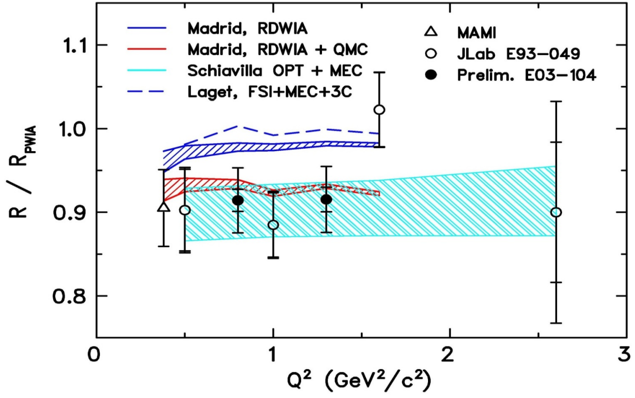
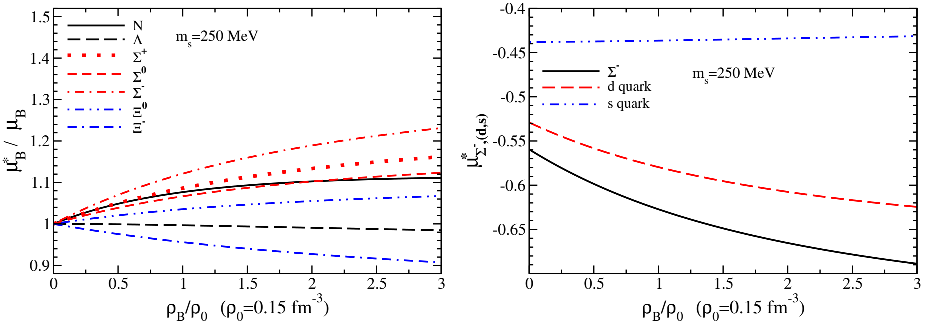
$$R = (p'_x / p'_z) = (G_E^p / G_M^p) : {}^4He / {}^1H$$

S. Malace, M. Paolone and S. Strauch, arXiv:0807.2251 [nucl-ex]

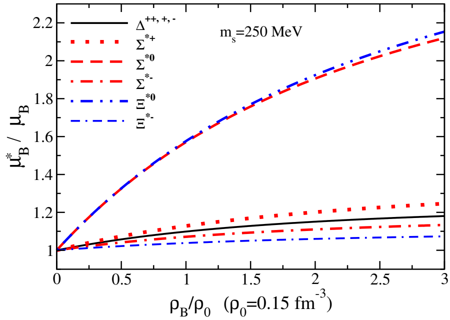
S. Strauch *et al.*, *Phys. Rev. Lett.* ***91, 052301 (2003)***

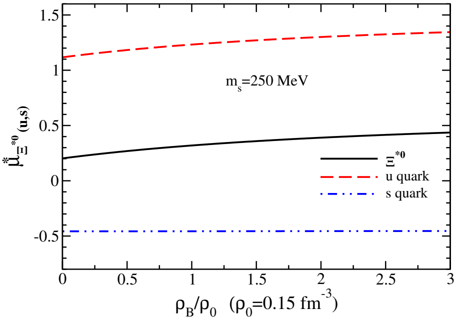


Octet Baryons

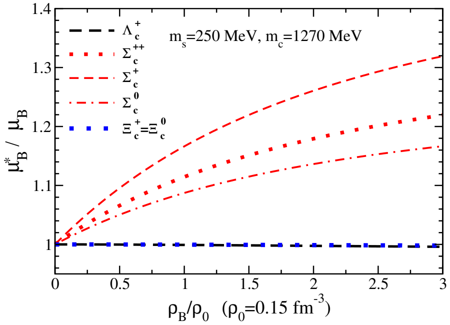


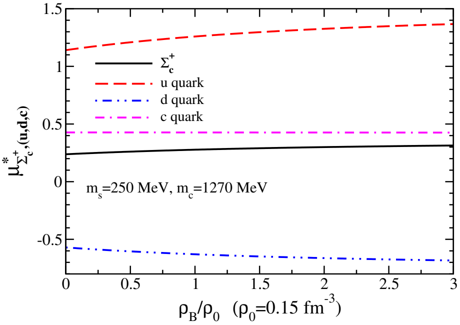
Decuplet Baryons



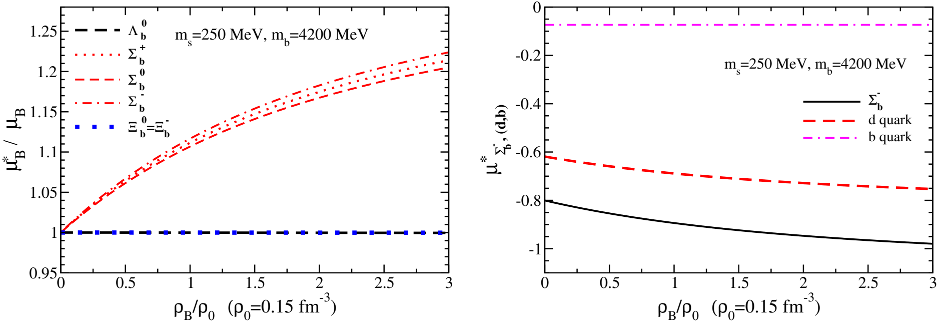


Charm Baryons





Bottom Baryons



Summary, Perspective

- In-medium magnetic moments of the Octet, Decuplet, low-lying Strange, Charm, Bottom baryons
(new: effective masses of Decuplet baryons)

- Density dependent parametrizations: $m^*_{B,M}$ and $V^{B,M}_{\omega,\rho}$
$\Longrightarrow$ Easier to use, applications
$\Longrightarrow$ Axial-vector coupling constants in medium
$\Longrightarrow$ Meson cloud effects: CBM-like approach in medium

- How to make connections with Experiments???

- Other interesting applications ??!! Suggestions ??!!

Thank You Very Much !!!

References:

In-medium magnetic moments $\rightarrow$ Submitted to PTEP
(arXiv article has not yet been revised!!)
(Heavy Baryons):
K. Tsushima
Phys. Rev. D 99, 014026 (2019)

Quarkonia-nuclear bindings (QMC model brief summary):
G. Krein, A. W. Thomas, K. Tsushima
Prog. Part. Nucl. Phys. 100, 161 (2018)

QMC model summary:
K. Saito, K. Tsushima and A. W. Thomas
Prog. Part. Nucl. Phys. 58, 1 (2007)

In-medium properties of the low-lying Strange, Charm, Bottom baryons (backup)

- Effective masses (Σ_b, Ξ_b !!)
- In-medium bag radii
- In-medium bag eigenfrequencies
- Scalar and vector (plus Pauli) potentials
- Excitation (total) energies (Σ_b, Ξ_b !!)

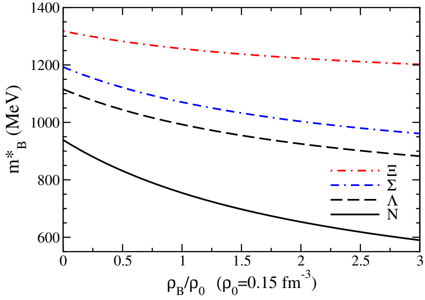
In vacuum (inputs)

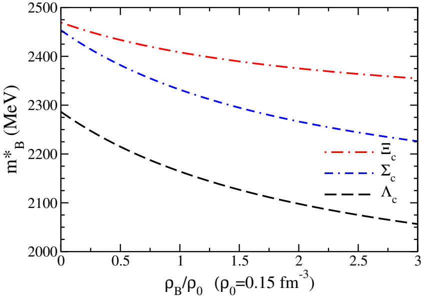
$B(q_1, q_2, q_3)$	z_B	m_B	R_B	x_1	x_2	x_3
$N(qqq)$	3.295	939.0	0.800	2.052	2.052	2.052
$\Lambda(uds)$	3.131	1115.7	0.806	2.053	2.053	2.402
$\Sigma(qqs)$	2.810	1193.1	0.827	2.053	2.053	2.409
$\Xi(qss)$	2.860	1318.1	0.820	2.053	2.406	2.406
$\Omega(sss)$	1.930	1672.5	0.869	2.422	2.422	2.422
$\Lambda_c(udc)$	1.642	2286.5	0.854	2.053	2.053	2.879
$\Sigma_c(qqc)$	0.903	2453.5	0.892	2.054	2.054	2.889
$\Xi_c(qsc)$	1.445	2469.4	0.860	2.053	2.419	2.880
$\Omega_c(ssc)$	1.057	2695.2	0.876	2.424	2.424	2.884
$\Lambda_b(udb)$	-0.622	5619.6	0.930	2.054	2.054	3.063
$\Sigma_b(qqb)$	-1.554	5813.4	0.968	2.054	2.054	3.066
$\Xi_b(qsb)$	-0.785	5793.2	0.933	2.054	2.441	3.063
$\Omega_b(ssb)$	-1.327	6046.1	0.951	2.446	2.446	3.065

In medium at $\rho_0 = 0.15\,\mathrm{fm}^3$

$B(q_1, q_2, q_3)$	m_B^*	R_B^*	x_1^*	x_2^*	x_3^*
$N(qqq)$	754.5	0.786	1.724	1.724	1.724
$\Lambda(uds)$	992.7	0.803	1.716	1.716	2.401
$\Sigma(qqs)$	1070.4	0.824	1.705	1.705	2.408
$\Xi(qss)$	1256.7	0.818	1.708	2.406	2.406
$\Omega(sss)$	—	—	—	—	—
$\Lambda_c(udc)$	2164.2	0.851	1.691	1.691	2.878
$\Sigma_c(qqc)$	2331.8	0.889	1.671	1.671	2.888
$\Xi_c(qsc)$	2408.3	0.859	1.687	2.418	2.880
$\Omega_c(ssc)$	—	—	—	—	—
$\Lambda_b(udb)$	5498.5	0.927	1.651	1.651	3.063
$\Sigma_b(qqb)$	5692.8	0.966	1.630	1.630	3.066
$\Xi_b(qsb)$	5732.7	0.931	1.649	2.440	3.063
$\Omega_b(ssb)$	—	—	—	—	—

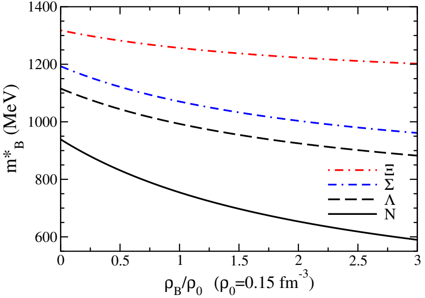
Effective masses:
Strange (left), Charm (right) baryons

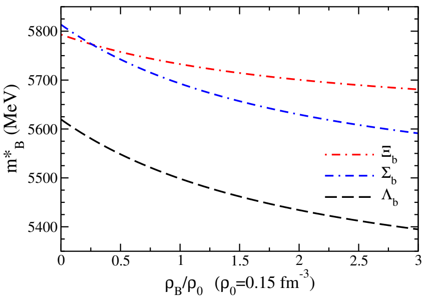




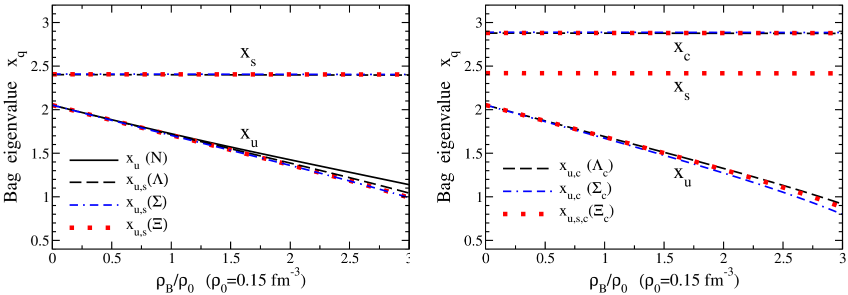
Effective masses:

Strange (left), Bottom (right) baryons

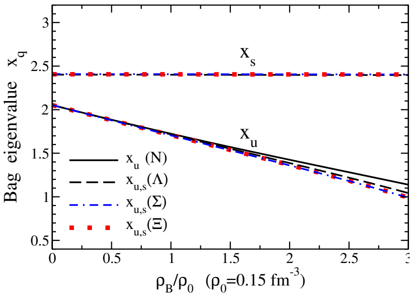


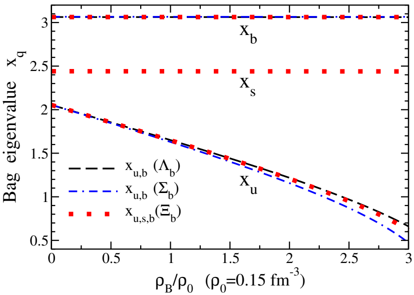


Bag eigenfrequencies:
Strange (left), Charm (right) baryons

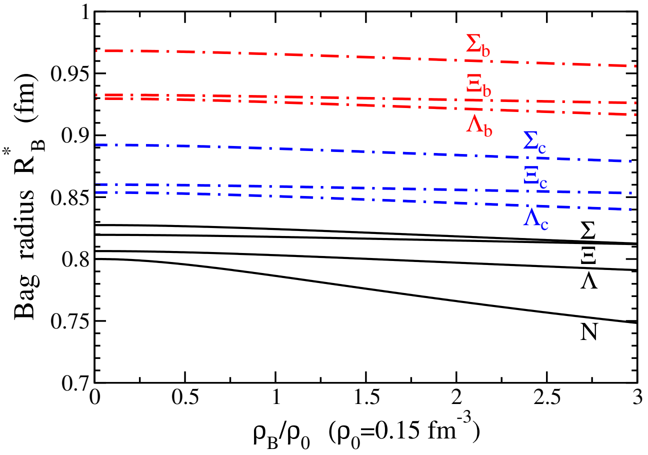


Bag eigenfrequencies: Strange (left), Bottom (right) baryons

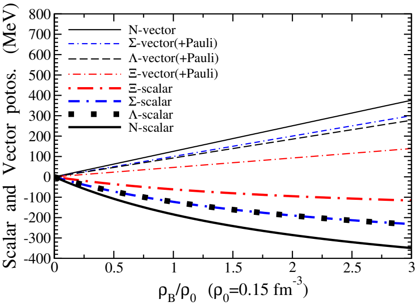


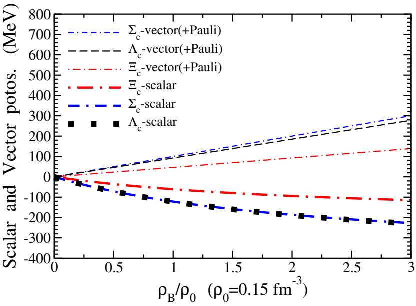


Bag radii: Strange, Charm, Bottom baryons

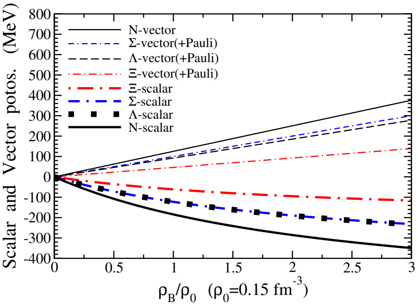


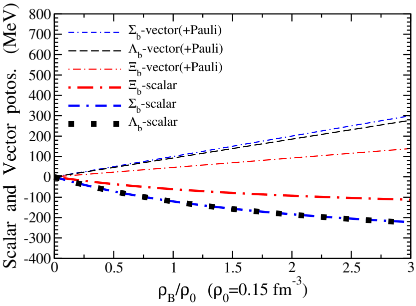
Scalar and (Vector+Pauli) potentials: Strange (left), Charm (right) baryons



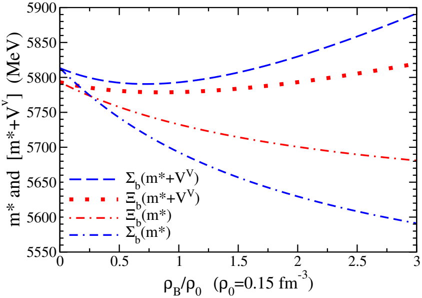


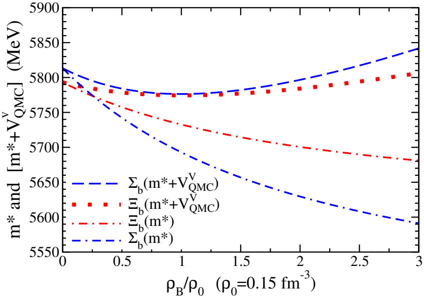
Scalar and (Vector+Pauli) potentials: Strange (left), Bottom (right) baryons





Excitation energies (scalar + vector pots.): Σ_b, Ξ_b
Vector + “Pauli” (left), Vector (right)





Summary, Perspective (backup)

•QMC model: In-medium properties of the low-lying Strange, Charm, Bottom baryons (completed) effective masses, bag radii, bag eigenfrequencies, (two different) vector potentials, excitation (total) energies

⟹• Σ_b, Ξ_b baryon effective masses!! excitation energies !!!

⟹• EM FFs., Weak-interaction FFs. for heavy baryons in medium
⟹•in the near future !!

⟹• Heavy ion collisions involving heavy baryons!!!

⟹•Other interesting applications ??!! Your Suggestions !!!

References:

In-medium properties of the low-lying strange, charm, and bottom baryons in the quark-meson coupling model (Heavy Baryons):
K. Tsushima
Phys. Rev. D 99, 014026 (2019)

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