Asymmetric nuclear matter in a parity doublet model with hidden local symmetry

名古屋大学　理学研究科
素粒子宇宙物理学専攻
クォークハドロン理論研究室
武田悠佑

- Parity doublet model
- Hidden local symmetry
- Numerical result
- Summary
- Future work

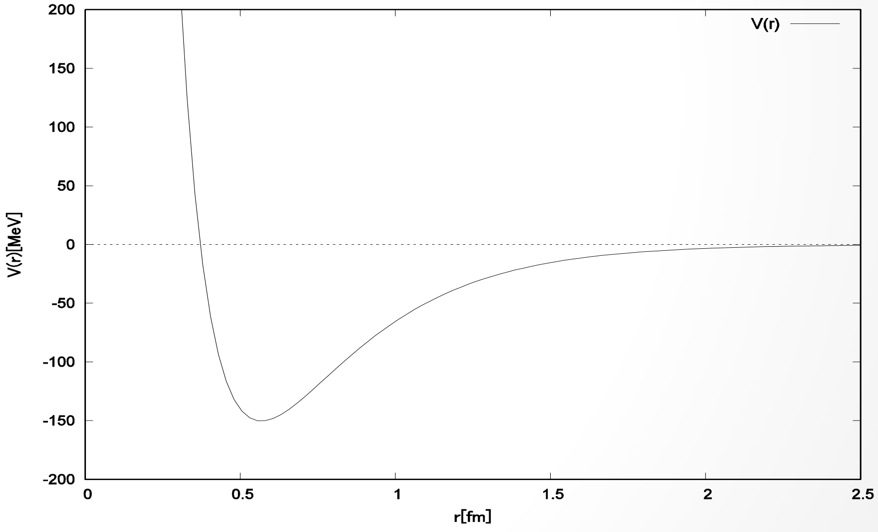
introduction

symmetricではσメソン ωメソン

asymmetricではρメソン

↓

有効理論



- Parity doublet model
- Hidden local symmetry
- Numerical result
- Summary
- Future work

Parity doublet

- doublet $$\psi = \begin{pmatrix} \psi_1 \\ \psi_2 \end{pmatrix}$$

$$\psi_i = (0, \frac{1}{2}) \oplus (\frac{1}{2}, 0)$$

- $SU(2)_R \times SU(2)_L$ Mirror asignment

$$\psi_{1r} \to g_R \psi_{1r} \quad , \quad \psi_{1l} \to g_L \psi_{1l}$$

$$\psi_{2r} \to g_L \psi_{2r} \quad , \quad \psi_{2l} \to g_R \psi_{2l}$$

$$M \to g_L M g_R^\dagger$$

Lagrangian

$$\mathcal{L}_N = \bar{\psi}_{1r} i\gamma^\mu D_\mu \psi_{1r} + \bar{\psi}_{1l} i\gamma^\mu D_\mu \psi_{1l}$$

$$+ \bar{\psi}_{2r} i\gamma^\mu D_\mu \psi_{2r} + \bar{\psi}_{2l} i\gamma^\mu D_\mu \psi_{2l}$$

$$- m_0[\bar{\psi}_{1l}\psi_{2r} - \bar{\psi}_{1r}\psi_{2l} - \bar{\psi}_{2l}\psi_{1r} + \bar{\psi}_{2r}\psi_{1l}]$$

$$- g_1[\bar{\psi}_{1r} M^\dagger \psi_{1l} + \bar{\psi}_{1l} M \psi_{1r}]$$

$$- g_2[\bar{\psi}_{2r} M \psi_{2l} + \bar{\psi}_{1l} M^\dagger \psi_{2r}]$$

$$D_\mu \psi_{1r,2l} = (\partial_\mu - iR_\mu)\psi_{1r,2l}$$

$$D_\mu \psi_{1l,2r} = (\partial_\mu - iL_\mu)\psi_{1l,2r}$$

Mass term

Mass termを対角化

$$\mathcal{L}_{mass} = -\begin{pmatrix}\bar{\psi}_1 & \bar{\psi}_2\end{pmatrix}\begin{pmatrix} g_1\sigma_0 & m_0\gamma_5 \\ -m_0\gamma_5 & g_2\sigma_0 \end{pmatrix}\begin{pmatrix}\psi_1 \\ \psi_2\end{pmatrix}$$

$$= -\begin{pmatrix}\bar{N}_+ & \bar{N}_-\end{pmatrix}\begin{pmatrix} m_+ & 0 \\ 0 & m_- \end{pmatrix}\begin{pmatrix}N_+ \\ N_-\end{pmatrix}$$

Mass固有値

$$m_\pm = \frac{1}{2}(\sqrt{(g_1+g_2)^2+4m_0^2} \pm (g_1-g_2)\sigma_0)$$

Mixing angle

$$\tan 2\theta = \frac{2m_0}{(g_1+g_2)\sigma_0}$$

- Parity doublet model
- Hidden local symmetry
- Numerical result
- Summary
- Future work

Hidden local symmetry

ベクトル場をゲージ粒子として導入

$$SU(2)_L \times SU(2)_R \times SU(2)_{HLS} \times U(1)_{HLS} \to SU(2)_V$$

メソン場をパラメトライズ　$M = \sigma \xi_L^\dagger \xi_R = \sigma U$

変換性　$\xi_{L,R} \to h_\omega h_\rho \xi_{L,R} g_{L,R}^\dagger$

ユニタリゲージ

$$\xi_R = \xi_L^\dagger = \exp(i\pi^a T^a / f_\pi)$$

Maurer-Cartan one form

$$\alpha_\perp^\mu = \frac{1}{2i}[D^\mu \xi_R \xi_R^\dagger - D^\mu \xi_L \xi_L^\dagger]$$

$$\alpha_\parallel^\mu = \frac{1}{2i}[D^\mu \xi_R \xi_R^\dagger + D^\mu \xi_L \xi_L^\dagger]$$

$$D^\mu \xi_R = \partial^\mu \xi_R + i g_\rho \rho^\mu \xi_R + i \frac{g_\omega}{2} \omega^\mu \xi_R + i \xi_R R^\mu$$

$$D^\mu \xi_L = \partial^\mu \xi_L + i g_\rho \rho^\mu \xi_L + i \frac{g_\omega}{2} \omega^\mu \xi_L + i \xi_L L^\mu$$

変換性

$$\omega_\mu \to h_\omega \omega_\mu h_\omega^\dagger + \frac{i}{g_\omega}\partial_\mu h_\omega h_\omega^\dagger$$

$$\rho_\mu \to h_\rho \rho_\mu h_\rho^\dagger + \frac{i}{g_\rho}\partial_\mu h_\rho h_\rho^\dagger$$

$$\alpha_{\perp,\|} \to h_\omega h_\rho \alpha_{\perp,\|} h_\rho^\dagger h_\omega^\dagger$$

Lagrangian ： 核子

$$
\begin{aligned}
\mathcal{L}_{int} = & - a_{\rho NN}[\bar{\psi}_{1l}\gamma^\mu \xi_L^\dagger \alpha_{\parallel\mu}\xi_L \psi_{1l} \\
& \qquad + \bar{\psi}_{1r}\gamma^\mu \xi_R^\dagger \alpha_{\parallel\mu}\xi_R \psi_{1r}] \\
& - a_{\rho NN}[\bar{\psi}_{2l}\gamma^\mu \xi_R^\dagger \alpha_{\parallel\mu}\xi_R \psi_{2l} \\
& \qquad + \bar{\psi}_{2r}\gamma^\mu \xi_L^\dagger \alpha_{\parallel\mu}\xi_L \psi_{2r}] \\
& - a_{0NN} tr[\alpha_{\parallel\mu}](\bar{\psi}_{1r}\gamma^\mu \psi_{1r} + \bar{\psi}_{1l}\gamma^\mu \psi_{1l} \\
& \qquad + \bar{\psi}_{2r}\gamma^\mu \psi_{2r} + \bar{\psi}_{2l}\gamma^\mu \psi_{2l})
\end{aligned}
$$

Lagrangian : メソン

$$\mathcal{L}_M = \frac{1}{2}\partial^\mu\sigma\partial_\mu\sigma + \sigma^2 tr[\alpha_{\perp\mu}\alpha_\perp^\mu]$$

$$- V_\sigma - V_{SB} + \frac{m_\rho^2}{g_\rho^2} tr[\alpha_{\parallel\mu}\alpha_\parallel^\mu]$$

$$+ (\frac{m_\omega^2}{2g_\omega^2} - \frac{m_\rho^2}{2g_\rho^2}) tr[\alpha_{\parallel\mu}] tr[\alpha_{\parallel\mu}]$$

$$V_\sigma = -\frac{1}{2}\bar{\mu}^2\sigma^2 + \frac{1}{4}\lambda\sigma^4 - \frac{1}{6}\lambda_6\sigma^6$$

$$V_{SB} = -\frac{1}{4}\bar{m}\epsilon\sigma tr[U + U^\dagger]$$

- Parity doublet
- Hidden local symmetry
- Numerical result
- Summary
- Future work

In put

positive parity mass	m_+	939
negative parity mass	m_-	1535
omega meson mass	m_ω	783
rho meson mass	m_ρ	776
decay constant	f_π	93
pion mass	m_π	140

$$\rho_B(\mu_B = 923\mathrm{MeV}) = 0.16\mathrm{fm}^{-3}$$

$$\left[\frac{E}{A} - m_+\right]_{\rho_B=0.16} = -16\mathrm{MeV}$$

$$K = 9\rho_B \frac{\partial \mu_B}{\partial \rho_B}\Big|_{\rho_B=0.16} = 240\mathrm{MeV}$$

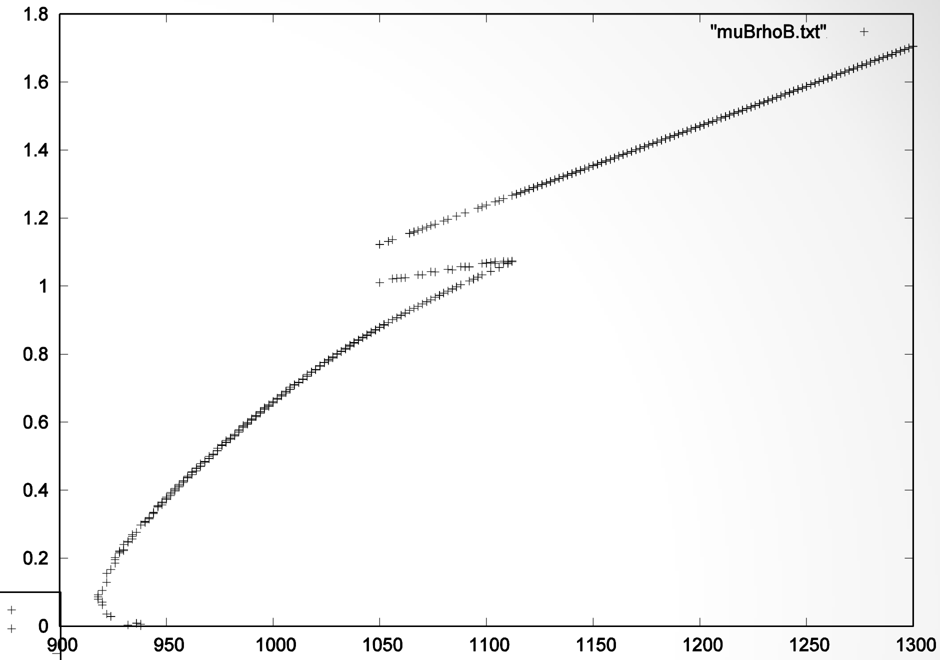
$$E_{sym} = \frac{1}{2!}\frac{\partial^2(E/A)}{\partial \delta^2} = 31\mathrm{MeV}$$

Parameter fitting

m_0	500	600	700	800
g_1	8.96	8.43	7.76	6.94
g_2	15.4	14.8	14.2	13.4
$g_{\omega NN}$	5.39	5.36	5.37	5.38
$g_{\rho NN}$	6.04	6.03	6.02	6.02
$\bar{\mu}$[MeV]	1020	832	613	348
λ	232	156	85.0	27.0
λ_6	110	73.3	39.3	11.43

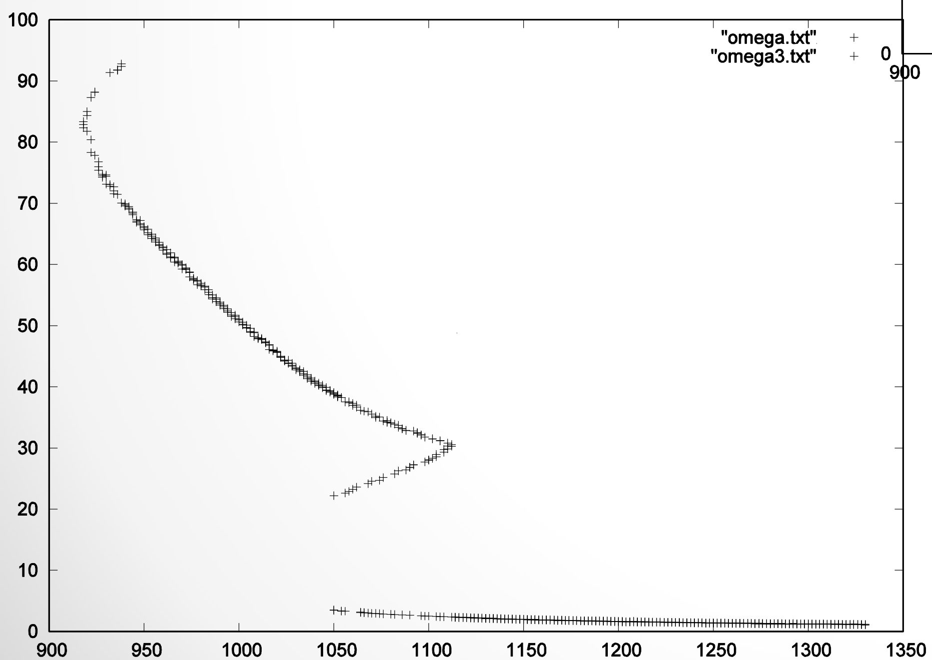
$$T = 0$$

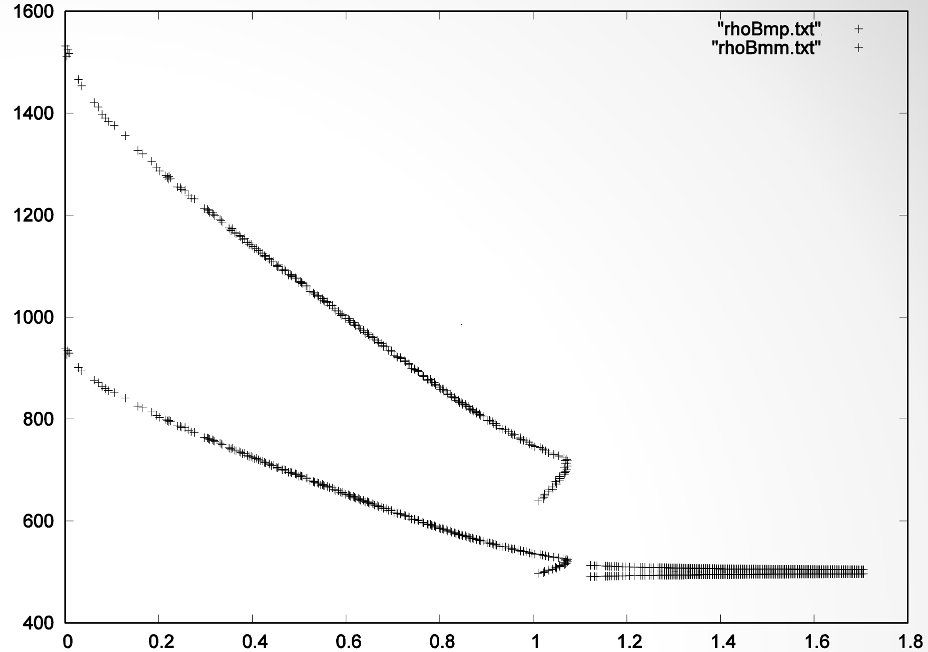
$$\mu_I = 0$$



$$\mu_B - \rho_B$$

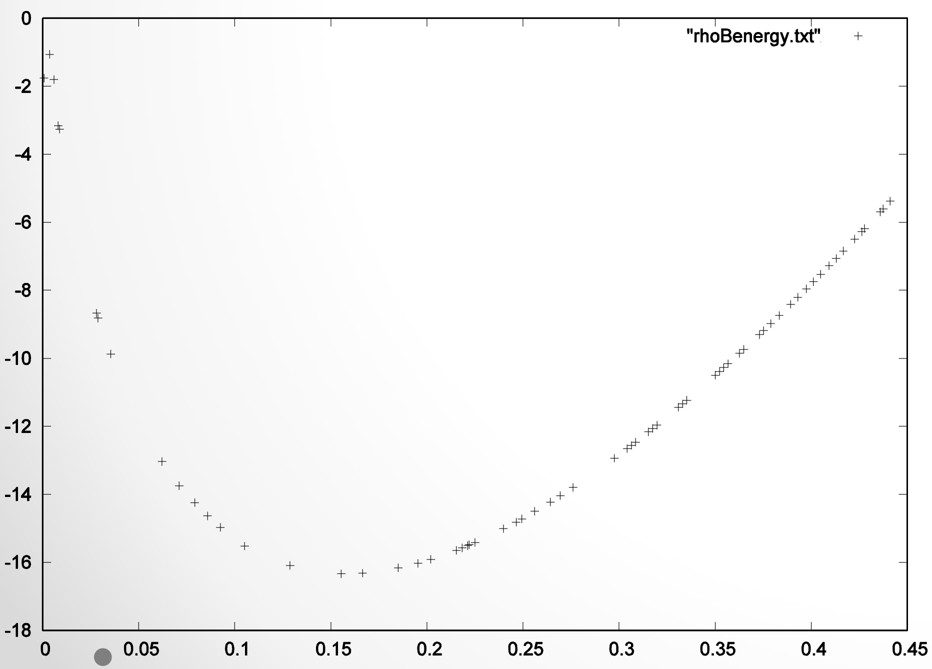
$$\mu_B - \sigma_0$$



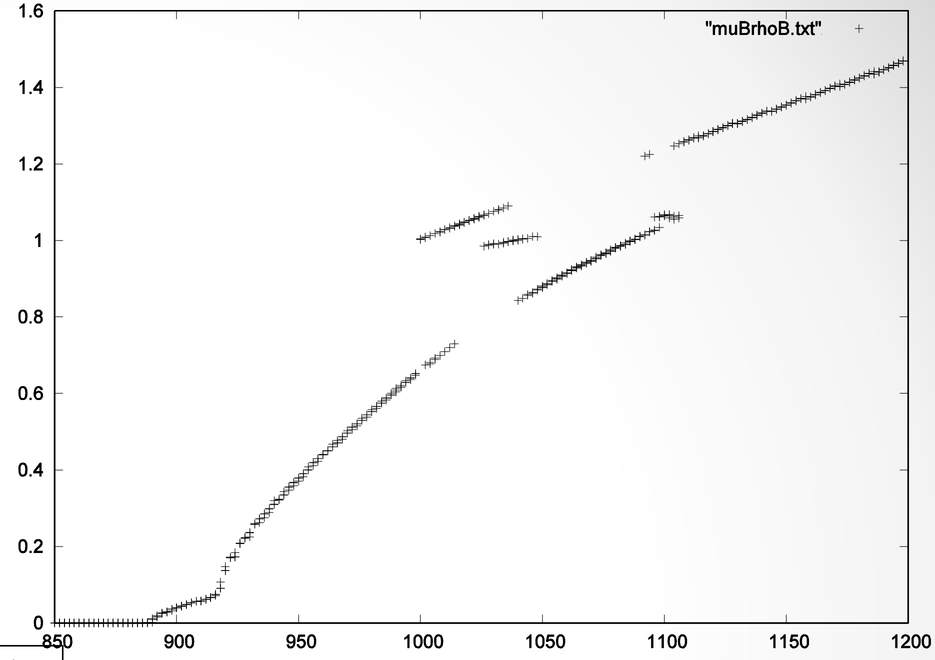


$\rho_B - mass$

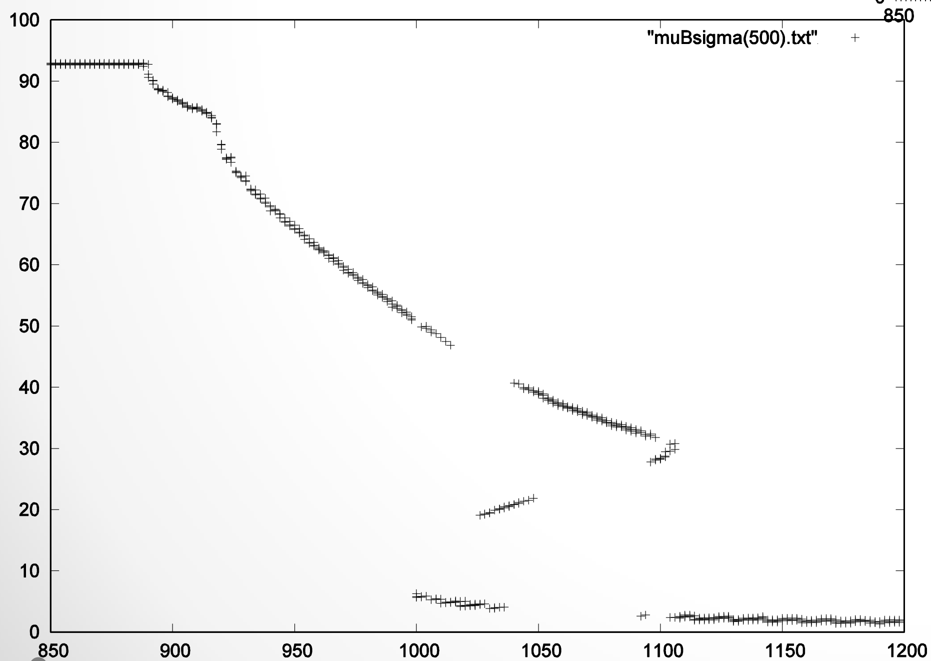
$\rho_B - \mathrm{energy}$



$\mu_I = 100\mathrm{MeV}$



$\mu_B - \sigma_0$

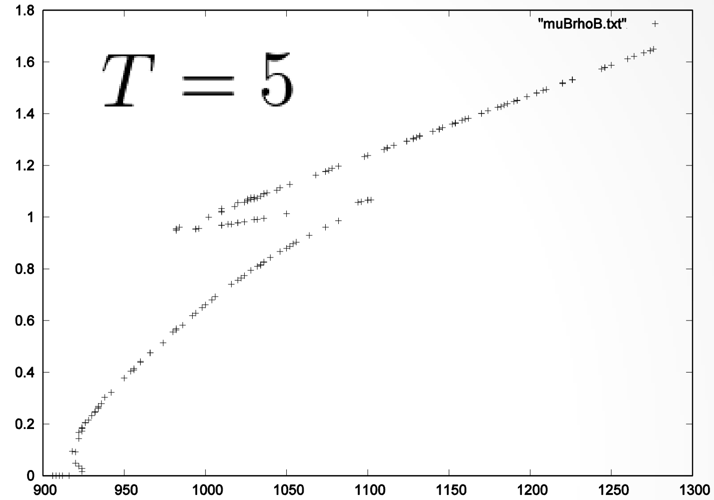


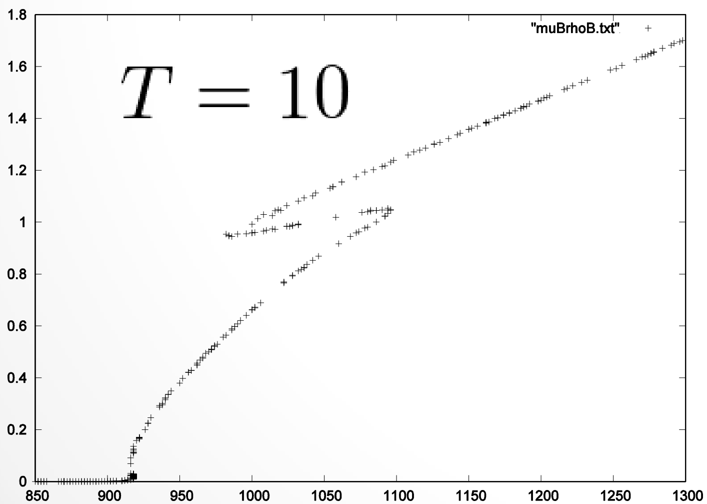
$\mu_B - \rho_B$

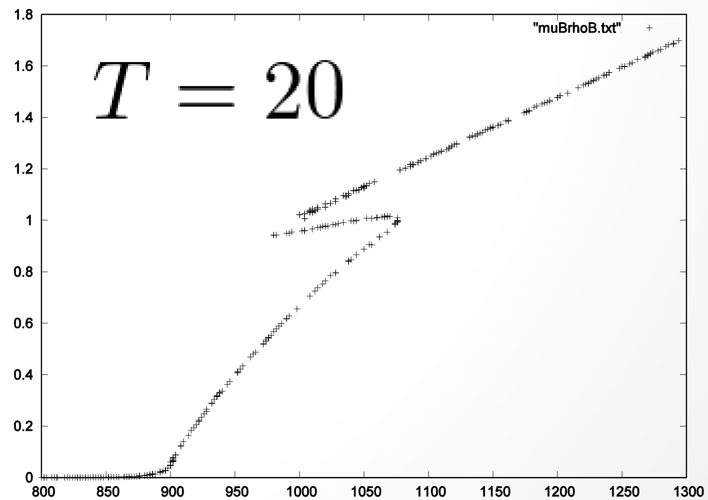
Finite temperature

$$\mu_B - \rho_B$$

$$\mu_I = 0$$







summary

σの6点相互作用を加えることでchiral invariant massが500MeVでも標準原子核の性質を再現

T=0で、対称核物質の場合

気液相転移 ： 1次

chiral相転移 ： 1次

（有限温度で2次になる）

非対称核物質の場合($\mu_I = 100\mathrm{MeV}$)

気液相転移 ： 2次

chiral相転移 ： 1次

Future work

- Parity doublet modelでデルタ粒子を扱う

$$\psi^{\mu} \approx (1, \frac{1}{2}) \oplus (\frac{1}{2}, 1)$$

$$m_{\pm}^{\Delta} = \sqrt{(a+b)^2\sigma^2 + m_0} \mp (a-b)\sigma$$

$$m_{\pm}^{N^*} = \frac{1}{2}\sqrt{(a+b)^2\sigma^2 + m_0} \pm \frac{1}{2}(a-b)\sigma$$

input $m_{+}^{\Delta} = 1232$

$m_{-}^{\Delta} = 1700$

- $g_{\Delta\Delta\omega}$ の見積もり
- $g_{\Delta N\pi}$ の見積もり
- デルタのプロパゲータを $N-\pi$ の 1loopのself energyを入れて計算しスペクトル関数を見る
- 物理量のm_0依存性を見る